**From:** Ex. 6 Personal Privacy (PP) cy (PP)
**To:** Shea, Valois
**Subject:** Comments on Dewey-Burdock Project Draft Permits and Draft Aquifer Exemption
**Date:** Monday, June 19, 2017 8:08:37 PM
**Attachments:** EPA Comments on Dewey-Burdock Draft Permits 6-17.docx

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Valois --

Here are my full comments.

Let me know if you have any questions.

Ex. 6 Personal Privacy (PP)

June 19, 2017

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Dear Ms. Shea:

This letter provides comments from Clean Water Alliance on the EPA's draft Underground Injection Control permits for the proposed Dewey-Burdock uranium project, as well as the associated proposed aquifer exemption. We oppose the EPA's proposed issuance of permits and an exemption for the following reasons.

There are a number of problems with the EPA's documents and with the process surrounding the draft permits and draft exemption. The items we have identified as key issues are explained below. The first part of the comments will discuss the problems with EPA documents. We will then turn to the EPA process and omissions. Then we'll discuss environmental justice and National Historic Preservation Act issues. And finally, we'll consider other types of issues.

## DOCUMENT ISSUES

A glaring problem with the EPA's documents on the proposed project is that large portions of the documents used to support the EPA's draft permits are based on other permits that do not exist or that were prepared inadequately. For example, the EPA's documents defer repeatedly to the NRC's SEIS for the Dewey-Burdock project. This document echoed Powertech/Azarga's submissions in all important respects, rather than the NRC taking a hard look at the situation. The EPA documents also refer repeatedly to the requirements of a state NPDES permit that has not even been applied for. And they refer frequently to a state Large Scale Mine Permit and a state Groundwater Discharge Permit (GDP) that have just barely begun the hearing process, are on hold, and are far from issuance.

To rely on non-existent regulatory instruments and what are essentially the applicant's documents for large portions of the permitting documents indicates both problems with the regulatory process and a lack of analysis of the proposed mine, deep disposal wells, and aquifer exemption. These non-existent "permits" are relied upon for major aspects of the proposed mine and associated facilities. For example, the GDP and NPDES permits are relied upon for statements that the land waste disposal option will be safe and that there will be no contamination. This runs counter to the research on this topic, which indicates a build-up of highly-toxic selenium at a similar site. And then the EPA signs off on Powertech's proposal to grow crops on the land disposal sites without any analysis of the safety of this practice for wildlife, domesticated animals, or humans. This is a problem.



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Similarly, the EPA relies upon an "NPDES permit" that hasn't even been applied for to discuss the Emergency Preparedness Program and Environmental Management Plan that are the basis of its discussion of impacts from spills and leaks, worker safety, and other topics. The agency concludes "Because the project site will be reclaimed and released for unrestricted use," there won't be impacts to land use. It's a long way from a non-existent "permit" to full reclamation twenty years down the line. This use of speculative information should not be allowed as part of the application, cumulative effects, draft permit, or aquifer exemption documents.

Some other examples of the reliance upon non-existent "permits" for key aspects of the Cumulative Effects analysis can be found pages 36, 39, 51, 53, 54, 55 (3 times!), 60, 61, 67, 71, 72 (3 times!), 74, 75 (3 times!), 79, 83, 88, 96, 109, 125, 132, 137, 138, 139, 140, 142, and 143. Until if and when the suggested permits are issued, information based on non-permits should be omitted from the EPA's documents. A realistic, complete EPA analysis should be done.

Perhaps the most important problem in the EPA's documents has to do with the confinement of mining fluids in the Class III wells areas. This goes to the heart of the safety of the project, and to the heart of the future of the region. There are real doubts whether the mining fluids can be contained at the proposed mine site. As Dr. Hannan LaGarry's research shows, there are around 7,500 old boreholes on the site, not the lower numbers put forward by the EPA or the company. This number comes from Dr. LaGarry's direct observation of Powertech's records (For further information, his e-mail address is Ex. 6 Personal Privacy (PP). Even the lower numbers indicate that it is unlikely that all old boreholes can be found and properly plugged. And the Class III draft permit is based on information that does not extend 1.2 miles outside the proposed project boundary (p. 36). Additional analysis is needed.

In addition, research by Boggs and Jenkins ("Analysis of Aquifer Tests Conducted at the Proposed Burdock Uranium Mine Site: Burdock, South Dakota," 1980) indicated leakage across the Fuson shale between the Lakota and Fall River formations in the Burdock area; this is one of the TVA papers. The Class III Fact Sheet notes the connection between the Chilson and Fall River formations in the Dewey area, which was from the other TVA test done in the early 1980s. This found the Chilson member of the Lakota formation to be "exceptionally permeable," as quoted by Dr. Perry Rahn (2014. "Permeability of the Inyan Kara Group in the Black Hills Area and its relevance to a proposed in-situ leach uranium mine" in the *Proceedings of the South Dakota Academy of Science*). Rahn, is Professor Emeritus at the South Dakota School of Mines and the acknowledged expert in matters related to hydrology in the southern Black Hills.

The EPA also notes that the Powertech pump test in the Dewey area was not only done differently, but that the TVA test was done at a pumping rate 16 times higher than the company test. This makes it look as though the company didn't want to do much that might show a connection between formations in the Dewey area. A more comparable update of the Dewey study is needed.

Research by Wicks, Dean, and Kulander ("Regional tectonics and fracture patterns in the Fall River Formation (Lower Cretaceous) around the Black Hills foreland uplift, western South Dakota and northeastern Wyoming." 2000) indicated that the Fall River formation is

"pervasively fractured" along the western edge of the Black Hills. The opinions of Dr. Robert Moran and Dr. Hannan LaGarry, which are included in the NRC proceedings and Exhibits, also indicate that fractures, faults, breccia pipes, and other geological characteristics of the project area, have not been adequately researched. The Class III Fact Sheet says that there are 64 drinking water, irrigation, and livestock wells in or within 1.2 miles of the mine boundary. To families on the ground, the situation is high-stakes, and this is not a game. It is critical that the geology of the area be fully understood – preferably before draft permits were issued – but certainly before any further steps are taken.

Research by Tank (1958. "Clay Mineralogy of Morrison Formation, Black Hills area, Wyoming and South Dakota," *Bulletin of the American Association of Petroleum Geologists"*), which may be the only focused research on the Morrison formation in the Dewey-Burdock area, indicates that the formation's thickness varies widely and that there is a "marked difference" between the formation's composition in Edgemont and seven miles north of Edgemont. The draft permits' heavy reliance on the Morrison formation as a confining layer should be re-considered, as the reality may not support the assumptions used in writing the draft permits. Making the Morrison Formation look thick in graphics and accepting the company's word for its permeability is not enough (Class III Draft Permit, p. 20; p. 23).

Given the information that is available, and given the importance of this particular issue, it is irresponsible to conclude that mining fluids could be contained based on limited scientific information, weak analysis, and company documents. It is up to the EPA to get or create accurate, substantial, third-party and peer-reviewed information and to analyze it thoroughly before granting draft permits and aquifer exemptions.

Otten and Hall of the U. S. Geological Survey are among those who have observed that "To date, no remediation of an ISR operation in the United States has successfully returned the aquifer to baseline conditions" ("In-situ recovery uranium mining in the United States: Overview of production and remediation issues" at http://www-pub.iaea.org/mtcd/meetings/PDFplus/2009/cn175/URAM2009/Session%204/08_56_Otton_USA.pdf ). Bill Von Till of the NRC issued similar sentiments when he said in August 2010 "to date, restoration to background water quality for all constituents has proven to be not practically achievable at licensed NRC IS[L] sites" (credited in another source to EIS for Moore Ranch ISR project, WY., p. B-36).

This is important partly because, typically, when companies can't restore water to baseline conditions or to the standards set by the NRC, the NRC simply raises the amount of contamination allowed. At some point, the restoration water "fits" those raised standards, and the mine's water is declared "restored." This is unacceptable for the NRC, and it would be unacceptable for the EPA. The EPA must retain its baseline permit limits through a true restoration process. It is also important that standards are set at a true "baseline," which is the original condition of the project area's water prior to uranium drilling or mining.

Given these experiences in the real, on-the-ground world of ISL mining at modern mines in the United States, the presumptions of companies who propose this type of mining – and the brave statements by regulating agencies -- must be approached with abundant caution. If no U.S. ISL

mine has ever returned the water to baseline and if restoration to background has proven not achievable, what makes the EPA believe that this unprecedented task will be accomplished at Dewey-Burdock? This question must be addressed explicitly and analyzed thoroughly as a result of a full NEPA process, if the EPA decides to push forward rather than deny the permits and exemption.

Another document issue is located in the Class III Fact Sheet (p. 108). The EPA, following Section 2.2.2 of *The Unified Guide*, described performance standards that Powertech must follow in its statistical analysis of groundwater monitoring data. One of the standards is that, when using a tolerance interval or prediction interval, that interval must be "protective of human health and the environment." The EPA should know that the science as to what is "protective" when it comes to in situ leach uranium mining is in dispute. There is very little science on the subject, and some of what has been done was completed with improper or inadequate methodology or was paid for by the uranium industry. Before any further steps are taken in working with this process, additional research needs to be completed.

These are some of the general problems with the EPA documents on the proposed project. Others will become apparent as we move into process issues and omissions.

PROCESS ISSUES

The basic process issue in this case has been the failure of the EPA to adhere to the NEPA process. While the NRC has attempted to follow that process for the possession of nuclear materials, its actions have not adequately covered a variety of issues that are under the EPA's purview, particularly water issues. The EPA needs to complete its own NEPA process.

The applicant's project has also changed in important respects between the time the NRC began considering it and the time the EPA began considering it. Examples include:

- NRC documents consider the use of 4,000 gallons of water per minute for the mining and reclamation process. The EPA applications consider the use of 9,000 gpm, more than twice as much water.
- This project was originally described as involving 1,500 injection, recovery, and monitoring wells. By the time the EPA issued its draft permits, this had grown to 4,000 wells, nearly three times more wells.
- The projected bleed rates have varied over time, from .5% of the water used to 17% of the water used. In addition, the reverse osmosis process makes at least 30% of the water put through the RO process into waste, and this is not fully considered in the EPA documents. This seriously weakens all the assumptions and calculations on water use in the Class III draft permit and in the Draft Cumulative Effects Analysis.
- Documents prepared by Petrotek for Powertech/Azarga set subsurface water movement rates at 6 to 7 feet per year (without offering peer-reviewed sources). NRC documents set the transmissivity rate in the Fall River formation at 255 $ft.^2$ per day and in the Lakota formation at 150 $ft.^2$ per day. Dr. Perry Rahn's 2014 article, mentioned above, concluded that the average ground water velocity for the Lakota and Fall River formations in the

Dewey-Burdock area was 66.1 ft./year. But, he said, groundwater velocity in the Inyan Kara Aquifers at the Dewey-Burdock site might be as much as 5,480 feet per year – over a mile -- which "might indicate fast groundwater movement through very permeable units or through fractures," although he considered this number "very high." The draft permits omit this critical information that could have very real impacts on wells that are downgradient of the proposed mine site. This issue is critically important, and further independent studies should be done before any permit is issued.

- Powertech talked about the possibility of doing open pit mining at the NRC hearings, and this possibility is not raised in the EPA documents.

These changes in the parameters of the proposed project go to the heart of the information that informs the process in this case. The NRC and the EPA have had different projects submitted to them. The processes are not functional equivalents, and consideration of both projects would not be redundant – it would be sensible. The EPA should begin a thorough NEPA process to assess the project as it is currently proposed.

As part of any new or continued process, the EPA should consider more than one alternative action. Although there are places where more than one alternative is considered for a minor action, the major actions only offer one alternative – giving the company a Class III permit, a Class V permit, and an aquifer exemption.

The agency must also rely on its own work, not just the information provided by Powertech, for critical information such as the "maximum volume of liquid wastes injected into the deep injection wells during aquifer restoration" (Cumulative Effects, p. 76). This number is central to the discussion of the Class V wells and should be determined independently of the applicant. If this number is wrong, so are all the assumptions and mitigation measures offered in the draft permits and other project documents.

The EPA must also do thorough tribal consultation. The existing documents indicate that this process has barely begun, and yet draft permits have been issued. This makes a mockery of the consultation process, which should be completed well before draft permits are issued, so that the resulting information can be analyzed. The EPA must halt all further action until mutually-satisfactory, government-to-government consultation is completed. All cultural and historical properties must be identified by Lakota experts, who should be paid if they so desire, and given complete protection.

Another process issue is that EPA has gone through all sorts of contortions in its Fact Sheet on the Class V application in an attempt to define what is clearly a Class I well as a Class V well. The disposal would clearly take place above a USDW, the Madison formation, which is a large aquifer of broad use in the Black Hills. It is used by, among others, Edgemont and Rapid City. The EPA justifies its labeling of Class I wells as Class V wells by treating them as Class I wells for construction and monitoring purposes and by requiring the company to treat the injectate until it is "at or below radioactive waste standards" (Class V Draft Area Permit Fact Sheet, p. 8). The fear of many people in the area, as expressed in the public hearings, is that this is not sufficient, and our water would become irretrievably contaminated.



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The other glaring process issue is that the EPA has rushed the process, creating draft permits and exemption without going through the proper rule-making process. This is the first time that the EPA has issued draft permits for Class III wells for an ISL uranium mine. It seemed to be in a hurry to do so. There has been extensive discussion of the process with the applicant and the uranium industry, resulting in a procedure, guidance, and draft documents. The draft permit and draft aquifer exemption documents often mimic others, including documents from the applicant, rather than creating a thoughtful analysis of the situation. (See Document Issues). However, there has been no public process on the de facto regulations created and used to craft the draft permits and draft exemption – no public notice, no public hearings, no analysis of public input. This violates the Administrative Procedure Act (APA), as well as the spirit of American government.

If allowed to stand, the entire process would fail to fully consider the project, provide adequate public input, leave western South Dakota with contaminated water, set a bad precedent for future proposed projects, and violate the APA. Process issues are not, however, the only shortcomings of the draft documents for the Dewey-Burdock project. There are also notable omissions.

## OMISSIONS

Moving to omissions, there is no analysis – or even discussion – of whether it is possible to treat the quantity of water being used by this project to the required standards. If it is not – and if the process is not closely monitored – water will be permanently contaminated. There is no analysis or discussion of whether it is possible to treat the water quickly enough to keep up with the injection rate proposed by this project. And there is no analysis or discussion of the reverse osmosis facilities, their location(s) in the project area, or the impacts they would bring. This includes the fact that at least 30% of the water put through the RO process typically becomes waste water. The Class V Fact Sheet uses the number 30% (p. 50), but RO operations can create four gallons of waste water for every 1 gallon of treated water. This waste is commonly called "brine," although the waste water in this project would be radioactive and full of heavy metals and would require further treatment before being disposed of as 11e waste.

There is also the question of whether RO treatment of all this water can be done economically, given the price of uranium (currently only $19.25 per pound of yellowcake) and other project costs. A responsible agency would include a full discussion of the RO process and its impacts on the environment, waste treatment, bonding requirements, and the feasibility of the project. It would also provide numerous examples of places in which this operation has proceeded successfully at the flow rates and with the contaminants proposed by the company.

We contend that, if the RO process and the actual costs of full aquifer restoration were considered, this project would not be feasible economically, technically, or environmentally. The history of the uranium industry includes abandonment of almost 200 mines and prospects in the southern Black Hills and over 3,000 in the Upper Missouri River basin, plus thousands more in the Southwest. Given this history, the applicant should be forced to provide an economic analysis using current uranium prices that shows that this project is feasible before they are given permits or an exemption. They should also provide a copy of a contract with a buyer for the



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uranium that would be produced at the mine. Even at a modern ISL mine, the Smith Ranch-Highlands mine in Wyoming, aquifer restoration took place for 10 years, and the water quality was about the same as when mining ended, according to a Violation issued by the Wyoming Department of Environmental Quality. Part of the reason appeared to be cost. This situation should not be allowed to happen again. A detailed analysis that includes strict, regular, on-site regulatory enforcement must be an important part of the permitting and exemption process.

The EPA wrongly leaves the completion of key tests until after a permit would be issued. These omissions include:

- wellfield delineation drilling,
- establishment of current water baselines,
- identification of faults,
- tests of the integrity of the confining zones,
- identification of leakage in the Fuson confining zone,
- how to deal with a 10" leaking TVA well,
- information on unsaturated groundwater flow (this should be done in real life, not using a model that can be easily manipulated),
- collecting drill cores to determine the characteristics of down-gradient aquifers' geochemistry,
- measurement of confining zone thickness,
- all of the work leading up to and including the Authorization Data Package Reports (Class III Fact Sheet, pp. 70-71),
- radiological impacts analysis (independent of Powertech analysis),
- demonstration of the effectiveness of vertical and horizonal monitoring systems,
- identifying and creating a contract for disposal for 11e wastes and solid wastes,
- the establishment of down-gradient compliance boundary wells (these should not be moved in case of an excursion, but should be maintained at their original locations), and
- pump tests.

It appears that additional drilling in the alluvial deposits to determine whether there is upwelling groundwater should also be done before further regulatory action is taken. The "several" drillholes suggested in the Class III Fact Sheet seems inadequate, but the number of drill holes is not specified (p. 39).

None of this information will be subject to public review or comment, and key information would become available only after permits have been granted. This turns the regulatory process on its head. All testing should be done, subject to professional review, public review and comment, before any draft permit or exemption is issued.

As part of this process, note that current conditions do not provide an adequate or accurate "baseline." All baseline measurements (ground and surface water, air, soil, sediment, etc.) should be defined as the original condition of the project area, before drilling and mining.

One of the questions that is raised by the public that is not answered in the EPA documents is whether there is any uranium left to mine in the project area, which was mined extensively in the

1950s – 1970s. Before the project goes any further, the company should be required to prove that there is the amount of ore present that it claims by providing information under close supervision by a knowledgeable regulator selected by the EPA. As stated above, this should occur before any final permit is issued. If the company balks at this requirement, it should be inferred that it is not committed to the project as designed, that it knows there is less uranium present than it has claimed, and/or that it expects the expenses of this activity to make the project unprofitable.

Moving to the nature of the ISL uranium industry, the Fact Sheets and Cumulative Effects documents do not discuss the uranium industry's record in relation to problems with the ISL process at other sites. This minimizes the many problems that the ISL industry has experienced and, thus, the potential problems from the Dewey-Burdock project. This makes the portions of the draft permit dealing with excursions and leaks inadequate, as well as sections about mitigation and reclamation.

For example, the Crow Butte ISL mine near Crawford, NE., has had 85 license violations and reportable incidents. These range from excursions to leaks and spills to wells failing integrity tests. One leak at this site was not found or dealt with for over two years, which makes a mockery of the EPA's great faith in gauges, sensors, alarms, and other hardware to identify leaks and related system problems.

If EPA staff look over the information about ISL mines and regulation at http://www.wise-uranium.org/umopusa.html (WISE Uranium, "Issues at Operating Uranium Mines and Mills – USA," last updated April 19, 2017), it quickly becomes clear that excursions are "normal," as the former CEO of Powertech said in a public forum in Colorado, and that leaks of both pipelines and ponds are common. This indicates that both surface and ground water are at risk.

This source also documents the movement of mining fluid beyond the mine boundary at the Kingsville Dome ISL mine in Texas (Rice. 2013. "Excursions of Mining Solution at the Kingsville Dome In-Situ Leach Uranium Mine." *Austin Geological Society Bulletin)* and the Highland Uranium Project in Wyoming. A summary of this type of information can also be found at Daniel Simmons-Ritchie, "Troubled history" in the *Rapid City Journal*. September 23, 2013. A history of these issues in the northern Plains region can be found in Jarding. 2011. Uranium Activities' Impacts on Lakota Territory, *Indigenous Policy Journal.*

The EPA omits important issues from its Draft Cumulative Effects Analysis. Three that are glaring are the potential for mining wastes to be transported from other areas to Dewey-Burdock Class V wells, the presence of other uranium companies in the Black Hills, and the potential for uranium mining to expand onto Powertech/Azarga's contiguous claims on the Wyoming side of the state line (the Dewey Terrace project) and to the east on National Forest Service land. It's important to consider climate change, but it's also important to consider cumulative impacts that are on or adjacent to the proposed mine site.

According to communication you had with Fall River County Commissioner Joe Allen on March 24, 2017, the current draft Class V permit would allow other ISL uranium mines to send wastes for disposal at the Dewey-Burdock site. These wastes could arrive without documentation or



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information on the origin of the wastes. First of all, wastes should not be brought to the Dewey-Burdock site from other sites under any conditions. This adds transportation risks to the scenario and makes our area a dumping ground. It is our position that pertinent South Dakota Statutes forbid this, and consideration and analysis of these laws should be part of the draft permit review process.

Second, if outside wastes are allowed to be brought to Dewey-Burdock, then their chemical composition, location of origin, mine of origin, company of origin, and other pertinent information should be required to be reviewed by EPA before transportation to Dewey-Burdock begins. This information should also be public, so people know what is arriving in our area. Testing should be required upon arrival to insure that the waste meets Class V water quality standards. All of this should have been part of the draft permits and Cumulative Effects Analysis. This is another example of why the current analysis is grossly incomplete.

As for other companies, there are 11 uranium companies that have expressed an interest in the Black Hills, and one – Peninsula Minerals – recently started an ISL mine on the northwestern edge of the Hills in Wyoming. If the Dewey-Burdock project is not abandoned and if Powertech acquires all the needed permits (at least 10 at last count, including the Clean Air Act permit), then this would be the first ISL mine in South Dakota. If Powertech is allowed to move forward – especially on such flimsy permitting documents – a precedent would be set. We do not want to open South Dakota to a stampede of ISL uranium mining companies, for all the reasons discussed in this document. However, for the EPA's documents to be complete, the existing Black Hills mine and the potential for a much larger number of ISL uranium mines must be fully considered. This need is even greater for the Class V draft permit, which might allow wastes from other mines to be injected into ground water in the Dewey-Burdock area.

And as for the third item, Powertech has claims to the east of the current project boundary, and it has contiguous claims just across the border in Wyoming. This is very clearly a topic that should be considered under any discussion of cumulative effects. According to our research, the company has approximately 744 federal claims in Wyoming, with the majority being across the border from the Dewey-Burdock project area.

Another important omission is that the draft permits beg the question of who is going to do on-the-ground regulation of the proposed mine and deep disposal wells. In 2011, the State of South Dakota suspended its ability to regulate in situ leach uranium mining, so it has no authority to do that regulation at this time. The NRC has two inspectors based in Texas, who visit ISL mines once or twice a year. There is no indication that their regulation can be complete or happen often enough to catch problems.

This is tremendously important. The draft permits include some very critical actions, such as testing the Minnelusa Aquifer to determine its water quality before deciding whether the company can proceed with deep disposal wells. This is a high-stakes test that would impact the future of the southwestern Black Hills. First, the water quality test should have been done under EPA's direct supervision before a draft permit was issued. If the Minnelusa's water turned out to be appropriate for drinking water, the time and expense of creating the application and the Class

V draft permit would have been avoided – as would have the stress on people in the area who use and rely on the aquifer.

Second, if the permit is issued, the testing of the Minnelusa aquifer's water should be done under EPA's direct supervision, rather than allowing the company to do a test in the areas of its choice using equipment it supervises, sending the sample to the lab of its choice, and expecting the people who use the Minnelusa Aquifer in the southern Black Hills to believe the results.

Similarly, the following must be done under the direct supervision of a knowledgeable regulator:

- pre-mining water quality testing in the proposed mining area,
- testing designed to determine the likelihood of down-gradient excursions,
- information underlying decisions about what holes and wells should be plugged,
- mitigation of air quality impacts,
- pump tests,
- well construction,
- reports on and handling of vehicle accidents involving hazardous or radioactive contaminants,
- groundwater level measurements,
- injection fluid characteristics,
- post-restoration monitoring,
- determination of the corrective response that must be taken when an excursion happens (this is currently left to the regulated company),
- well plugging and abandonment,
- analysis of radiological issues,
- disposal of hazardous wastes,
- regulation of a variety of soil issues (Section 7.0 of Draft Cumulative Effects Analysis),
- programs to minimize the impacts to land use,
- fugitive dust control, and
- all measurements related to the presence, monitoring, and impacts of excursions, and of attempts to measure or cure excursions.

Note that Raymond H. Johnson, the lead author of the two articles that are the basis for the section related to down-gradient excursions in the Class III Fact Sheet (p. 62), appeared as a speaker at an event hosted by Powertech that was designed to promote the Dewey-Burdock project. He worked for the USGS at the time, which gave the audience the impression that the USGS was promoting the project, according to people who were there. This occurred in Hot Springs and in Custer in the Spring of 2013. I note that he was also in communication with EPA staff on this project. He then went to work for a firm that serves the uranium industry. While the "revolving door" phenomenon is not uncommon as people move from government to the private sector – and sometimes back again – the impartiality of Mr. Johnson's research has been questioned by some people in the Black Hills. For more information, see http://www.argusleader.com/story/news/2015/03/07/ex-federal-scientist-center-uranium-fight/24581135/

On the topic of drilling, the Class V Fact Sheet says that the draft permit allows the company to "drill deeper in order to evaluate deeper sandstone units within the Minnelusa" (p. 15) and to drill to the Precambrian basement when drilling Well 1 (p. 41).[i] These processes should not be allowed. The Madison aquifer is directly below the Minnelusa aquifer, and the upper portion of the Madison aquifer is porous, containing many caves, fractures, and solution openings (Class V Fact Sheet, p. 18; USGS. 2002. *Atlas of Water Resources in the Black Hills Area, South Dakota,* pp. 24-25). If the company was careless or drilled just a bit too far, here would be no separation between the aquifers and potentially no containment of materials pumped into the deep disposal wells, and a major drinking water aquifer could be contaminated.

We do not want a repeat of what happened at Wasta, SD, about 50 miles east of Rapid City. There, a drill bit and 150' section of equipment broke off when a driller was looking for oil. Groundwater can be exposed, creating a possible link between the Minnelusa and Inyan Kara formations, and plugging the resulting hole may be impossible. The State's bond was wildly inadequate (*Rapid City Journal*, January 23, 2017 and March 17, 2017). We are not willing to take a risk that something similar could happen as a result of the proposed Dewey-Burdock project.

The EPA also omits information in its discussion of seismic factors in the Class V Fact Sheet. It states that it is "not aware" of a seismic event causing an injection well to contaminate a USDW or of studies done to determine whether such contamination has occurred (p. 54). It then lists states that have been studied on this issue. The list omits states with injection wells that have been linked – at least in the media -- to seismic incidents, including Oklahoma, North Dakota, and Pennsylvania. The EPA may be "not aware" of some of the research, but it should be held to a higher standard and required to do the relevant research before omitting important information.

We also searched the Class V Fact Sheet looking for a thorough discussion of the seismic characteristics of the proposed mining and injection area. The presence of faults in the immediate area is mentioned (pp. 22-23), but their potential impacts are never analyzed. Similarly in the Class III Fact Sheet, the mechanisms by which Fall River formation water comes up through the Dewey fault is never analyzed (p. 45).

At the end of the Class V Fact Sheet and the Draft Cumulative Effects Analysis, the EPA indicates that the Endangered Species Act will be complied with, but gives no information on how it intends to do this. When will this be done? What species will be considered? Who will do the analysis (not the company)? This should already have been completed before draft permits were issued.

The EPA mentions the presence of a short-horned lizard, which is rare and protected in South Dakota, in the proposed project area. After stating that the species is "important in some tribal cultures," it offers the solution "Once construction activities begin at the site, the EPA expects that the [sic] any short-horned lizards that were in the area will seek less disturbed locations." This is pure conjecture, without any back-up information on the size or habits of the lizards. Are they territorial, or is it species-appropriate for them to move? Are they large enough to move fast enough to out-run a bulldozer or pick-up truck? Or are they, in reality, unprotected?



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This and similar information must be provided and backed by scientific research at the Dewey-Burdock site for this and other species. Animals should not simply be expected to move out of a site that's over 10,000 acres in a systematic and comprehensive process. And the EPA then expects them to just move back in after mining is complete – as if the same animals will be alive and remember their former homes after as many as 20 years. This is beyond unacceptable in the direction of ludicrous – and is certainly unacceptable.

Species other than animals are not considered in this discussion. Plants cannot simply move off the site. Some of them are important to tribal practices and customs, such as medicinal plants and timpsila (prairie turnips). Full scientific information should be gathered, and full analysis must be done, for non-animal species. Species that are important to the long-term residents of the area -- the Lakota, Cheyenne, and other native nations – require special protection. There is already information on protection of some species in project documents that could serve as a base for part of this analysis. However, a full and independent analysis is also needed.

This analysis would include close consideration of the opinion of the South Dakota Department of Game, Fish and Parks. This opinion was stated in an October 17, 2008, letter written by Stan Michals. Michals said that exploratory activity should not take place on some parts of the project area between February and August (inclusive) due to the presence of a bald eagle nest (a state-protected bird) and a redtail hawk nest. Mining, deep disposal wells, land application, and reclamation, which are more long-lasting and disruptive than exploration, should clearly also not take place during those seven months of the year in raptor nesting and other protected areas.

The sturgeon chub must be included in the discussion of wildlife concerns. It is present in the Cheyenne River and may be threatened or endangered in areas downstream from the proposed mine. Additional silt, heavy metals, and radioactive materials would be potential threats.

Also missing from the Class III Fact Sheet is a reasonably believable analysis of the concerns surrounding abandoned uranium mines in the project area. Any discussion of a factual basis for this analysis would be reassuring. Instead, the document just asserts the number of old mines and their conditions. There are two drilling logs indicating the geological location for the two larger open-pit mines (where it is obvious), but for the other abandoned mines, their condition is simply asserted. Early uranium mining in the southern Black Hills was a "mom and pop" enterprise, and detailed records were not kept. Small abandoned mines or prospects could have escaped being recorded. One partial solutions is to allow Dr. LaGarry a longer period of time in which to look over the drilling logs; his time was quite limited when he was given access to Powertech's records under an order from the NRC administrative judges.

There is one statement in the Class III Fact Sheet that created more questions than it answers. This is the statement that "Groundwater pumped to the surface during the pump tests will not be injected back into the subsurface" (p. 59). The obvious question, of course, is what will be done with this waste water? Will it be allowed to run into the ground and/or the creeks? What will its quality be? Is this waste water included in the calculations of the amount of water consumed during the project? At a minimum, the answers to these questions should be included in the discussion.

One omission is simply the failure to provide a very important definition in the section of the Class III Fact Sheet related to mechanical integrity. This is the statement that internal mechanical integrity and external mechanical integrity will both be confirmed if "There is no significant" leak or fluid movement. The document needs to provide a clear, measurable definition of "significant" in each case.

Another problem that has been common in the mine area and that is omitted from the EPA's discussion is wildfires. There have been at least three large wildfires in the area in the last five years. The Crow Butte ISL mine – only about 65 miles from Dewey-Burdock -- was evacuated in 2012 due to a wildfire. The impacts on water, air, and land could be enormous, if a building containing nuclear materials, wellfields, or storage ponds were impacted by a wildfire. The discussion of cumulative effects must include a thorough discussion of how this type of problem would be dealt with to protect the land, air, and water.

The next omission is that the treatment of radiological wastes from the drying cycle at the Central Processing Plant is not specified. The Cumulative Effects Analysis says that "off-gases generated during the drying cycle will be filtered through a baghouse" (p. 86), and it also mentions a "sock filter" (p. 87). However, the document does not give any information on where or how the wastes in the filters/baghouse would be disposed. It is assumed that these wastes will be radioactive, so should probably be 11e wastes. But readers (and the company) should not have to guess about such things. This situation should be the subject of comprehensive analysis, and the entire waste cycle should be specified clearly. There is also no discussion of potential accidents during processing (which have occurred) or the remediation or mitigation that might be needed as a result.

Much of the mitigation sections appears to be vague, incomplete, or based on stock language picked from other documents, such as the discussion of soil impacts mitigation on page 78-79 of the Cumulative Effects Analysis. The mitigation sections of EPA documents should offer a complete and detailed analysis of the required mitigation that is site specific at the Dewey-Burdock location.

To top it off, the EPA makes use of the Draft Cumulative Effects Analysis difficult, as the document has neither a Table of Contents nor an Index. In the future – and before further action is taken on the proposed mine, Class V wells, and aquifer exemption -- we hope that the EPA will rectify this and the other omissions.

## ENVIRONMENTAL JUSTICE AND NATIONAL HISTORIC PRESERVATION ACT ISSUES

The issues involving the EPA's DRAFT Environmental Justice (EJ) Analysis and its National Historic Preservation Act (NHPA) report are linked and will be discussed briefly in this section.

The primary shortcoming of the DRAFT Environmental Justice Analysis is its limitation to a 20-mile radius. While it is true that Edgemont qualifies for impacted status, the 20-mile limitation effectively eliminates people who live downstream and on the Lakota reservations and who are

impacted by the destruction of treaty, historical, and cultural sites. Note that both EJ and NHPA analysis should have been completed as part of a full tribal government-to-government consultation before the draft permits or aquifer exemption were released. There has, at this point, already been a violation of trust by the EPA that will be difficult or impossible to remedy.

As part of its regulatory process, the EPA should require that old uranium mines in the Dewey-Burdock area be analyzed for potential Superfund status. This is critical not only to the people and animals who live in the area, but also for the company's employees. A uranium company should not be able to tell the federal government to "take a hike" when it controls known contaminated land through leases. Old mines that pollute the water and sediment for miles downstream with radioactivity and heavy metals should not be ignored, especially when area populations have well-documented increases in cancer and lowered life expectancy – both of which can be linked to higher levels of radioactivity. And whether or not the old mines reach Superfund status, they should be cleaned up before any new uranium mining is allowed.

The EJ analysis includes Table 12, which purports to list "Additional State and Federal Permits Powertech is required to obtain" (p. 24). This Table is misleading in several ways that make it look like the company faces few hurdles. First, the table does not include the Clean Air Act permit that the EPA says is required. Second, it does not indicate the current status of either the state water appropriation permits or the state Groundwater Discharge Plan. These permits have not just been "recommended for approval"; they have been put on hold for several years. And third, the NRC's Source Material License is under appeal in federal court, and this is not mentioned.

The EPA also states conclusions about the mining process and its outcomes that are not supported by experience or science in the EJ analysis. This is discussed elsewhere in these comments.

The EJ analysis mentions that the public in the White Mesa mill area, where the company wants to take its 11e wastes, is 49% American Indian and Native Alaskan. After making this statement, the agency fails to do an EJ analysis of that site, simply saying that the Dewey-Burdock waste would be a small percentage of the waste at the site. This begs the question – What are the impacts of the mill on the nearly half of the population of the area that should be protected under EJ guidelines? There should at least be a reference to a complete analysis of this issue and, if one doesn't exist yet, it should be done as part of the Dewey-Burdock process and before further action is taken by the EPA.

Turning to the NHPA document, EPA should not rely on the NRC's section 106 review and consultation. That process is grossly incomplete. A section 106 review should, of course, have been completed before draft permits or a draft aquifer exemption were issued. At this point, the EPA should conduct its own review to insure that different viewpoints are brought to bear on the situation and to insure that thorough work is done by the federal agencies that are involved in the Dewey-Burdock project.

The NHPA document also indicates that tribal consultation is in its infancy. Tribal leaders from the two reservations that are most likely to experience impacts from the Dewey-Burdock project,

the Oglala Sioux Tribe and the Cheyenne River Sioux Tribe, have not yet started consultation. Yet draft permits and a draft aquifer exemption have already been issued. This is a travesty, and it's difficult to see how the EPA can rectify the situation.

OTHER ISSUES

In addition to problems with documents, omission and process, there are statements that we simply disagree with in the EPA's project documents. First, the Class III Fact Sheet states, "There is no limit in the Class III Area Permit as to how many injection and production wells Powertech may construct" (p. 14). There certainly should be a limit, and that limit should be conservative and set by the regulator, i.e., the EPA. This should be corrected.

Another issue is that, because the EPA documents downplay the amount of water that would be consumed by this project, the cumulative impacts do not adequately consider the proposed project's use of large amounts of water. As a result, the EPA also does not adequately consider the actual drawdown of water or the long-term impacts that this water use could have on the environment and economy of the southwestern Black Hills. The southern Black Hills is a semi-arid area that will need all its ground water in the future. This need will grow with climate change and with the ongoing depletion of the High Plains (Ogallala) aquifer a bit to the south.

A third major problem is the admission that injectate from the Class V wells will mingle with Madison aquifer water and come to the surface 20 miles away. While the EPA says this will happen "on the scale of 10,000 years" in its Cumulative Effects Analysis, remember that the calculations of water movement underground at the Dewey-Burdock site vary widely. The information offered by Powertech's contractor suggests that water movement is many times slower than independent estimates. Also, there are other wells into the Minnelusa and Madison aquifers to the south and east, over the 20-mile span between the project site and Cascade Springs. This admission should negate the entire Class V application and send Powertech back to Canada, China, and the Cayman Islands.

The sections on ground water use in the Draft Cumulative Effects Analysis rely overly-much on the opinion of one person, the former South Dakota State Engineer. Other people should be consulted.

Next, the various types of ponds should not be built where there are old drillholes. Best practices should be followed for all ponds to avoid leakage either through the bottom or through flooding. This includes at least the following: thick, high-quality double liners, clay liners, leak detection systems, procedures for frequent checking of leak detection systems, and the maintenance of substantial empty space in the ponds to accommodate flood events.

It is not wise to build ponds in the 500-year floodplain, especially given the increase in flooding incidents in the area, and this practice should be proscribed. Similarly, the design of sediment control structures should protect from events larger than a 5-year, 24-hour precipitation event – especially because the mine and the ponds will be present for up to twenty years. This is a set-up for four spills from the ponds! This also goes to the EPA's finding that surface water impacts



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"should be minimal." They will not be minimal if a flood washes out sediment structures or over-tops a pond containing hazardous materials even once.

The statement that "radon-222 itself has very little radiological impact on human health or the environment" (p. 85, Cumulative Effects Analysis) runs counter to what can probably be called common knowledge. It certainly runs counter to the EPA's website on the topic: https://www.epa.gov/radon/health-risk-radon The UIC Program needs to go back to the drawing board and do a comprehensive, science-based analysis of this issue.

Along the same line, in its discussion of the Central Processing Plant, the Cumulative Effects Analysis says both that "ventilations systems will exhaust outside the building" and that there will be "open doorways" on processing buildings (p. 86). One would hope that, for the safety of workers, the open doorways are nowhere near the exhausts. This should be specified by the EPA, and potential employees should be fully informed of the situation.

Section 3.3.1 of the Cumulative Effects Analysis (p. 19) is vague on key aspects of the impacts that will occur to ground water quality in the ore zone. The second-to-last sentence of this section say that the company "will monitor groundwater using standard industry practices." This is repeated in the section on post-restoration monitoring (p. 22). These standard practices, of course, have been associated with all sorts of problems, including the ongoing failure to return even one ISL mine's water to baseline. The EPA can do better.

Similarly, the section ends with a statement that the EPA "concludes that impacts to ore zone water…should be minimal." How is "minimal" defined? Is it what the EPA will allow? Is it minimal to the company? Or is it minimal to the impacted communities? This term should receive better explanation.

We also disagree with the statement in Section 3.3.2.1, in which the EPA says that an excursion can be left as is, if it is not corrected within 60 days; instead, the company can increase its financial assurance obligation in a manner that is suitable to the NRC (p. 21). This is not acceptable.

In addition, the EPA should not rely on the NRC's analysis, recommendations, or regulations. The processes by the two agencies should be independent, so that the proposed mine, disposal wells, and aquifer exemption receive the benefits of the expertise and different regulatory focuses of both agencies.

Next, deep disposal well integrity should be tested at least once per year, not as infrequently as every 5 years, as EPA suggests in the Class V Fact Sheet (p. 56). And injectate should be monitored and analyzed regularly, as the characteristics of wellfields will differ, and as the functioning of the RO system may also vary in effectiveness. Records should be maintained until at least five years after the end of the project, in case problems develop over time, not for as little as three years, as the Fact Sheet suggests (p. 59).

Similarly, EPA calculations indicate that "the pressure within the Minnelusa injection zone resulting from injection activity is **not** [bold in original] below the critical pressure needed to

move fluids out of the Minnelusa injection zone into the Madison Formation" (p. 28). The EPA correctly requires the company to recalculate in light of this fact, but must also hold firm if the resulting injection rates are even near the critical pressure, with the potential result that the permit would not be granted. Again, it is critical to protect the Madison aquifer, and the nature of the upper portion of that aquifer is particularly concerning due to the presence of rapid water movement.

In addition, all boreholes and old uranium mines on the full project area should be plugged and reclaimed before any further mining is allowed. Not only does this protect the water, soil, and air of the area, but it also protects workers who would be exposed to the old, open mines. Abandoned open pit uranium mines spread contamination through the water, sediment, and air, as shown by research done by Dr. James Stone of the South Dakota School of Mines and Technology and others.[ii] The old mines must be reclaimed, and the soil, air, and water must be tested to insure that it is safe before allowing any new uranium mining to go forward.

As mentioned above, modeling is a weak alternative to on-the-ground testing. The EPA should certainly not rely exclusively on models for any decision or requirement in the case of such a complex, controversial project – especially models developed by or for Powertech. There should be independent analysis of any information currently left to modeling. As the EPA notes in the Cumulative Effects Analysis, "there is inherent uncertainty in the results" (p. 108) when modeling is involved.

There should also be clarification of the length of time that the proposed Dewey-Burdock project would be active. This goes directly to the potential impacts of the project. The estimate in the State Mining Permit Application is seven to 20 years of uranium recovery, maybe more, with the Central Processing Plant likely to operate longer. The Class III draft permit is for the "operating life of the facility" (p. 7). At 14 wellfields, each operating for two years, this could be as long as 28 years, if the company ran them consecutively. There is also the potential for the company to expand the project to include its contiguous claims to either the east or west of the current project area. There's a difference between regulating a project that lasts seven years and regulating a project that lasts over 20 years. As stated repeatedly, the draft permits and Cumulative Effects Analysis should discuss the full range of potential impacts and scenarios.

There are two statements in the Class III Fact Sheet that apparently involve the EPA being prescient. Especially given the critical topics that these statements are about, they should, instead, be made factual. The first is that "the Lower Chilson is expected to provide adequate confinement…." (p. 66), and the second is that "The distance between the Chilson Sandstone potentiometric surface and the targeted ore zone…is expected be [sic] adequate to allow the drawdown required…." (pp. 68-69). These statements should be proved, not "expected" into existence.

There is also a question about the rate of pumping of water during the mining process. In Section 5.2.1 of the Draft Cumulative Effects Analysis, the text says that the "header piping [would be] designed to accommodate injection and production flow rates of 2,000 gpm…." (p. 56). On the next page, the document says that there would be 100 wells per header house. The schedule for the project indicates that as many as five wellfields will be active at one time. As

each wellfield is likely to have more than 100 wells, these numbers add up to more than the 8,500 gpm that the company has asked to use in its more recent documents. This situation needs to be carefully researched and analyzed before any further action is taken on the proposed project.

A final issue is the demonstration of financial responsibility by the company, which the Class III Fact Sheet says should be done through a surety bond "or other adequate assurance" (p. 129). The only assurance that should be accepted is an adequate surety bond. The value of the company, if there is any, should not be used to demonstrate financial responsibility.

The definition of an "adequate" surety bond is critical. As noted above, in western South Dakota and elsewhere, it has been common historically for uranium and other mining companies to be unable to fund full restoration after mining, to go bankrupt, and to leave the burden for taxpayers – if restoration was even technically feasible.

In the case of in situ leach uranium mining, the Wyoming Department of Environmental Quality (DEQ) raised the bonds at the Highland and Smith Ranch ISL mines from $38,416,500 to $80,000,000, after it discovered that restoration attempts were not having any effect. In its March 10, 2008, Notice of Violation, the DEQ indicated that the real cost of restoration would be "on the order of $150 million." Regulators of other ISL projects should heed the Wyoming experience and insure that bonds for all activities that are associated with this technology are adequate, especially since full restoration has never happened. It is our position, based on the history of the uranium industry, that uranium mining cannot be done safely.

This is especially important because Powertech has already admitted that its restoration could be incomplete. In a 2014 "Restoration Action Plan" submitted to the NRC, the company said that "elevated concentrations above the restoration criteria may remain in the production zone following restoration," which the company called "hot spots." The company suggests that, after further study, the "hot spots" could be ignored and the "well field be declared restored." This is unacceptable, and the EPA should explicitly prohibit this practice.

We support the conclusion of EPA's statutory analysis that the Dewey-Burdock mine is subject to the Clean Air Act and subpart W. If the project goes forward, we request that public education sessions and public comment periods be held as part of the subpart W regulatory process.

The citizens of the area that would be most impacted by this project spoke loudly and clearly at the hearings in April and May. As many as 700 people attended the hearings. 212 people spoke (omitting duplicates in Valentine and Rapid City, but counting duplicates in Hot Springs and Edgemont). Of those 212 people, only 15 (7%) supported the proposal to mine uranium in the Black Hills and in our water supplies. The vast majority – 93% -- opposed the project. In a democracy, the will of the people counts.

The EPA should act consistently with the voices of the vast majority of the people at the hearings, rather than approving a project that is poorly considered, ill-advised, full of gaps, and

dangerous to the health, the economy, the cultural resources, and the environment of the Black Hills.

Clean Water Alliance respectfully requests that the EPA halt the permitting processes for the proposed Dewey-Burdock project by denying the permits and the exemption.

Sincerely,

**Ex. 6 Personal Privacy (PP)**

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**Ex. 6 Personal Privacy (PP)**

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[i] Note that if these drilling activities are actually allowed to proceed, there should be a provision that makes the resulting information public.

[ii] Onyeukwu, Kyrian. 2007. *Assessment of Wind- and Soil-Related Hazards Associates with Abandoned Uranium Mines in the North Cave Hills, Harding County, South Dakota*. Master's Thesis, S.D. School of Mines and Technology; Stone, James, and Larry Stetler. 2008. Environmental Impacts from the North Cave Hills Abandoned Uranium Mines, South Dakota. *Uranium, Mining and Hydrogeology;* Tuombe, Emmanuel. 2008. *Surface water and sediment investigation concerning abandoned uranium mines in the South Cave Hills, North Cave Hills, and Flint Buttes region, Harding County, South Dakota*. Master's Thesis, S.D. School of Mines and Technology; Albertus-Benham, Hannah. 2009. *Surface water and sediment investigation concerning abandoned uranium mines within the Slim Buttes region, Harding County, South Dakota*. Master's Thesis, S.D. School of Mines and Technology; Stone, James, Larry Stetler, and Albrecht Schwalm. 2007. *Final Report: North Cave Hills Abandoned Uranium Mines Impact Investigation*. Prepared for U.S. Department of Agriculture: Forest Service-Region I, Missoula, MT. at https://www.fs.usda.gov/Internet/FSE_DOCUMENTS/stelprd3834131.pdf; Sharma, Rohit, and James Stone. 2013. Chemical composition of bottom sediments within black hills region reservoirs of South Dakota and Wyoming. *Environmental Earth Sciences.*



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# Regional tectonics and fracture patterns in the Fall River Formation (Lower Cretaceous) around the Black Hills foreland uplift, western South Dakota and northeastern Wyoming

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**Abstract:** The Fall River Formation around the Black Hills uplift is pervasively fractured by layer-perpendicular joints. Systematic joints in the formation maintain consistent orientations over large areas and are commonly abutted by later-formed fractures, resulting in an orthogonal pattern. There are two major systematic sets, trending northeast and northwest, and one minor set trending north–south. The first two sets define two major fracture domains in the study area. The northwest joint set occupies a southern domain where it is the sole systematic fracture set. The northeast joint set is pervasively established throughout the northern domain, where northwest and north–south fracture sets are also developed in well-defined sectors. There is no genetic or spatial relationship between joint sets and local Laramide monoclines or folds of the region. Instead, the stratigraphic record indicates that joint development originated early in the lithification history of Fall River sandstones. Jointing occurred in response to local and regional extensional stresses that pervaded the northern and southern domains as a result of recurrent movement on basement faults that parallel the regional lineament system and surface structural zones throughout the region. Major uplift of the Black Hills and local fold development during Laramide time merely resulted in passive rotation of the early formed systematic and non-systematic joints.

## Statement of problem

Preliminary field work and aerial photograph reconnaissance revealed a pervasive network of joints throughout the Fall River Formation (Lower Cretaceous) outcrop belt around the Black Hills in northeastern Wyoming and western South Dakota. The major objectives of this study were to establish the joint patterns present in sandstones of this formation (Fig. 1) and to determine whether these joints are controlled by this Laramide uplift, its smaller associated folds or deep-seated basement fracture zones that are expressed by a regional lineament system. Systematic jointing in the Fall River Formation of the Black Hills was first documented by N. H. Darton (1904). He described the 'rude columnar appearance' of its massive sandstone cliffs near Newcastle, Wyoming (Fig. 1). Later, Gott *et al.* (1974) attributed changes in horizontal compressive stress directions for different joint trends in the southwestern part of the present investigated area. Other authors, including Bergendahl *et al.* (1961) and Brobst & Epstein (1963), have commented on the prominent fractures present in the Fall River but have no definite conclusions regarding their overall mode of origin and spatial relationship to regional or local structure. Overall, the patterns and structural significance of Fall River Formation joints have not been extensively studied by previous workers. The Fall River Formation was chosen for this study because of its areal extent and the comprehensive stratigraphic study by Gott *et al.* (1974). More recent work by Willis *et al.* (1995) has further defined the architecture of this formation in the southwestern Black Hills.

### *Methods of investigation*

The upper Fall River Formation was chosen for this study because it consists primarily of a 10–40-foot (3–12.2-m) thick massive sandstone unit, and caps many hogbacks and divides throughout the Black Hills region. Where this unit was absent or concealed, the middle Fall River Formation was used. One hundred and forty stations were established and 7214 joint attitudes were measured.

At each station joint strike was measured, or taken from aerial photographs in inaccessible areas (Fig. 2). All joints examined had an overall perpendicular relationship to bedding. In nearly all circumstances it was possible to distinguish

*From*: Cosgrove, J. W. & Ameen, M. S. (eds). *Forced Folds and Fractures*. Geological Society, London, Special Publications, **169**, 145–165. 1-86239-060-6/00/$15.00 © The Geological Society of London 2000.

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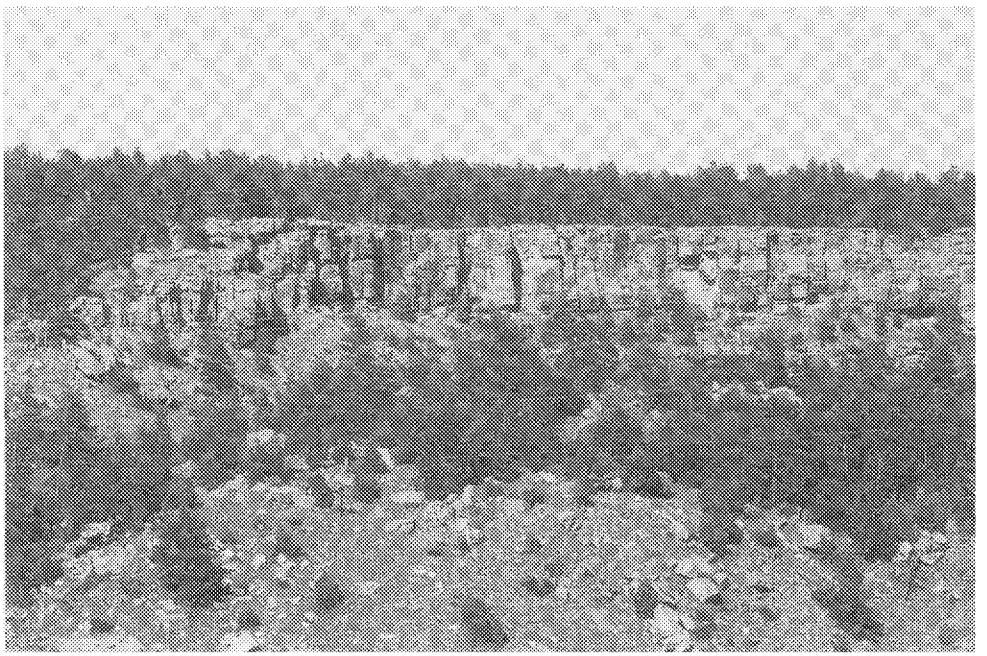

**Fig. 1.** Sandstone outcrop 2 miles (3.2 km) east of Newcastle, Wyoming on the crest of the Black Hills monocline. Systematic joints are perpendicular to the cliff face. Distance is 825 feet (252 m) along the cliff face.

**Fig. 2.** Aerial photograph of systematic (N30°W, i.e. 330°) and non-systematic joints in Fall River sandstone. Location is 7 miles (11.3 km) northeast of Edgemont, South Dakota, between Chilson anticline and Sheep Canyon monocline.

systematic from non-systematic joints based on the terminology of Hodgson (1961). Irregular, curved joints were not measured because no consistent bearing is maintained, and they may represent effects of stress relief rather than tectonic events. Details of other joint features such as abutting relationships, surface morphology (i.e. hackle plumes), mineralization and continuity of the joint faces also were recorded.

Inclined bedding was rotated to horizontal on a Schmidt net to place the joints in a vertical position. Mean bearings of systematic and non-systematic joints are shown as lines in Fig. 3. Where consistent joint trends exist throughout the Fall River outcrop belt, these areas are represented by composite rose diagrams (Fig. 4). All data and diagrams were then analyzed for consistency of regional joint trends, as well as geometric relationships of fractures to folds and surface structural zones. The latter are defined by faults and changes in fold traces and are expressed by major lineaments.

## Black Hills; geological setting and structure

The Black Hills is a Precambrian-cored anticline that rises out of the Great Plains of western

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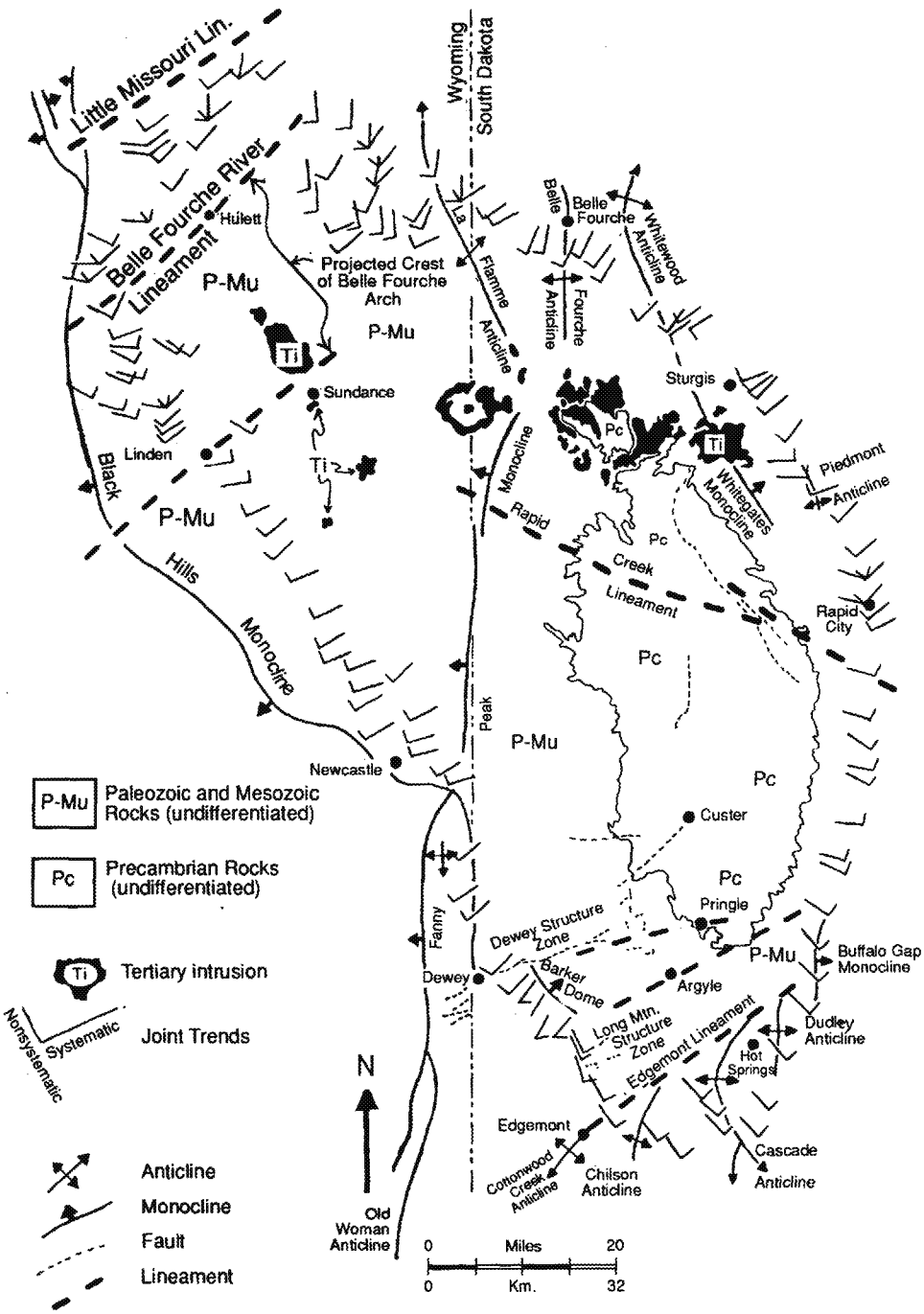


**Fig. 3.** Diagram showing systematic (long lines) and non-systematic (short lines) joints in the Fall River Formation around the Black Hills. Major lineaments are shown as heavy dashed lines. The northeastern projection of the crest of the Belle Fourche Arch is shown between the arrows in the northwestern Hills. Geological sources for the map are: Darton (1901, 1902, 1904, 1905*a b*), Darton & Smith (1904), Darton & O'Hara (1907, 1909), Darton & Paige (1925), Shapiro (1971), Gott *et al.* (1974), Wicks (1979), Lisenbee (1985), DeWitt *et al.* (1989).

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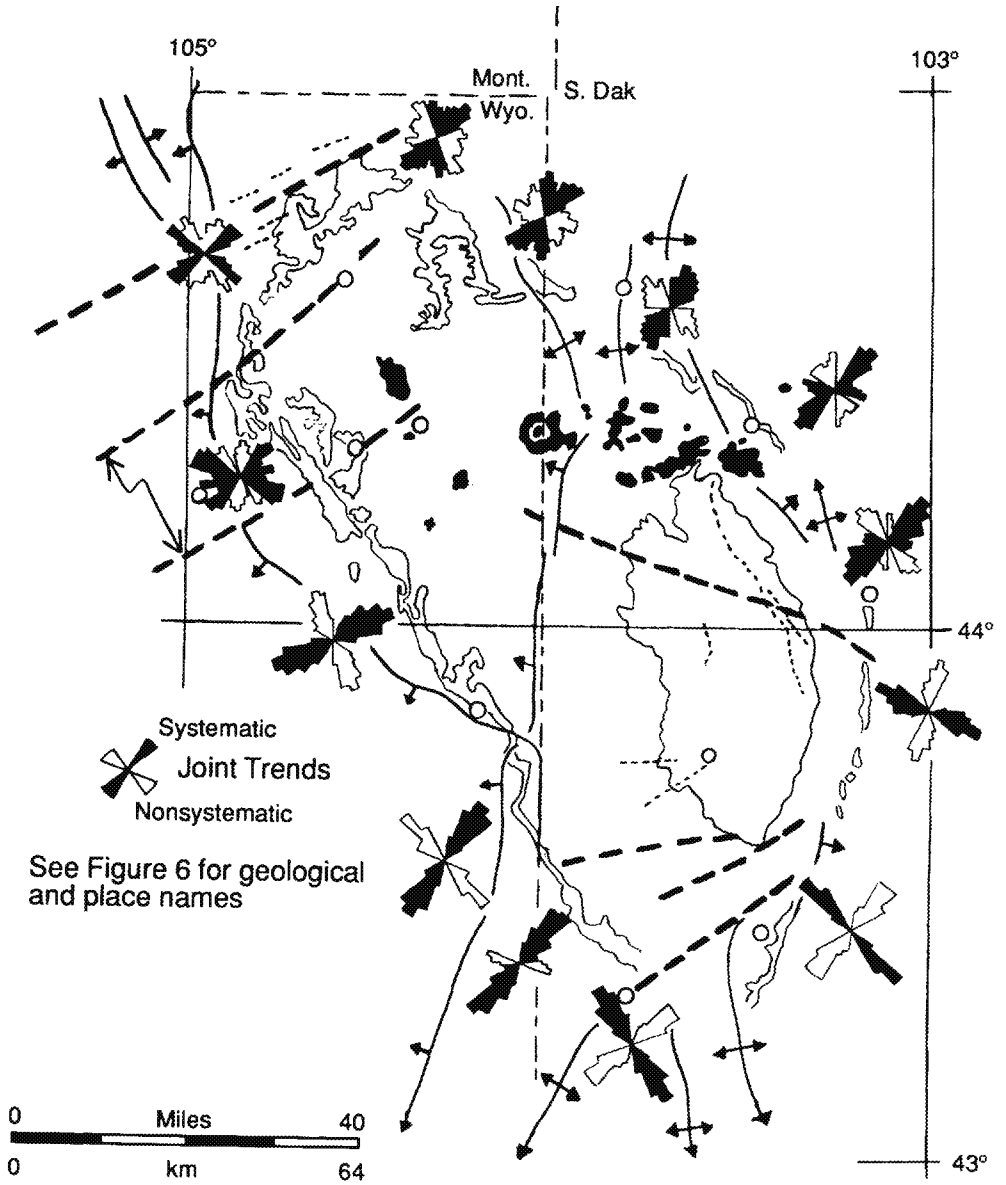


**Fig. 4.** Diagram of composite joint trends in relation to major structures of the Black Hills. Major lineaments shown as heavy dashed lines. Projected crest of the Belle Fourche Arch is shown between the arrows in the northwestern Hills. (Refer to Fig. 6 for abbreviations of towns; diagram from Lisenbee 1978; courtesy Geological Society of America.)

South Dakota and eastern Wyoming (Fig. 5). It is best described as a doubly plunging fold with a curvilinear axis striking generally north to northwest. The uplift is 180 miles (290 km) long, 68 miles (110 km) wide and formed during the Laramide orogeny. The Black Hills is the easternmost foreland uplift of the Rocky Mountain region. It is flanked by the Powder River basin to the west, the Williston basin to the northeast and is an extension of the Chadron Arch, which lies to the southeast. The structure continues to the northwest where it merges with the Miles City Arch in southeastern Montana. To the southwest, the Hartville Uplift connects

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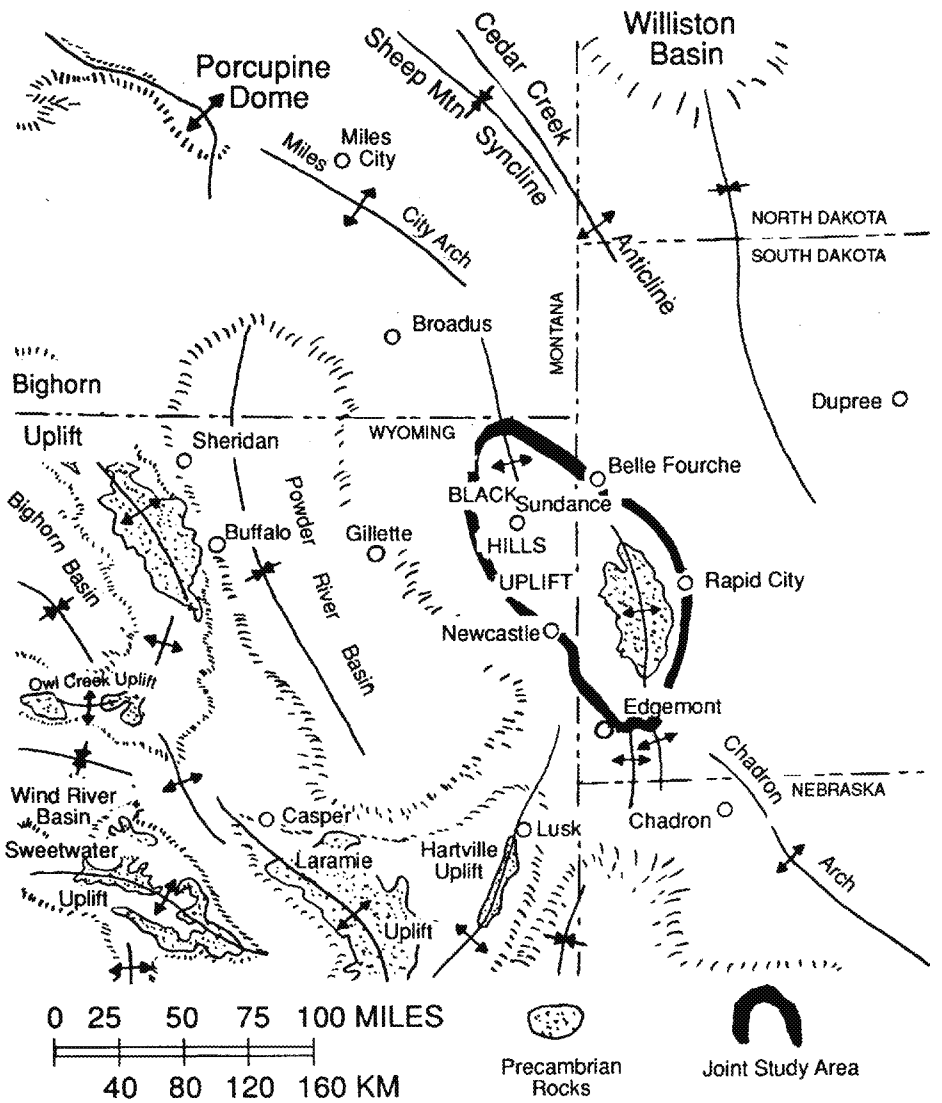


**Fig. 5.** Generalized map of the Black Hills uplift in relation to other regional structural features. The dark pattern shows the area of the Fall River Formation outcrop. The stippled pattern represents the Precambrian core of the foreland uplifts.

with the southwest margin of the uplift across a structural saddle (Lisenbee & DeWitt 1993).

Lisenbee (1978, 1985, 1988), DeWitt *et al.* (1989) and Lisenbee & DeWitt (1993) have comprehensively discussed the individual structures associated with the Black Hills. The gross structure of the uplift consists of two large Precambrian basement blocks which are separated by a N–S rending fold and fault zone defined as the Fanny Peak lineament along the South Dakota–Wyoming border (Noble 1952) (Fig. 6). The eastern (i.e. South Dakota) block is structurally higher and basement rock is exposed. Recent geophysical studies by Robbins (1994) suggest that the western (i.e. Wyoming) block is segmented into a third major block along NE–SW-trending magnetic and gravity anomalies across northeastern Wyoming and southeastern Montana, presenting an abrupt discontinuity in the northwestern Hills, rather than the usual depiction of northwestward plunge of the Precambrian surface into the Miles City Arch. The

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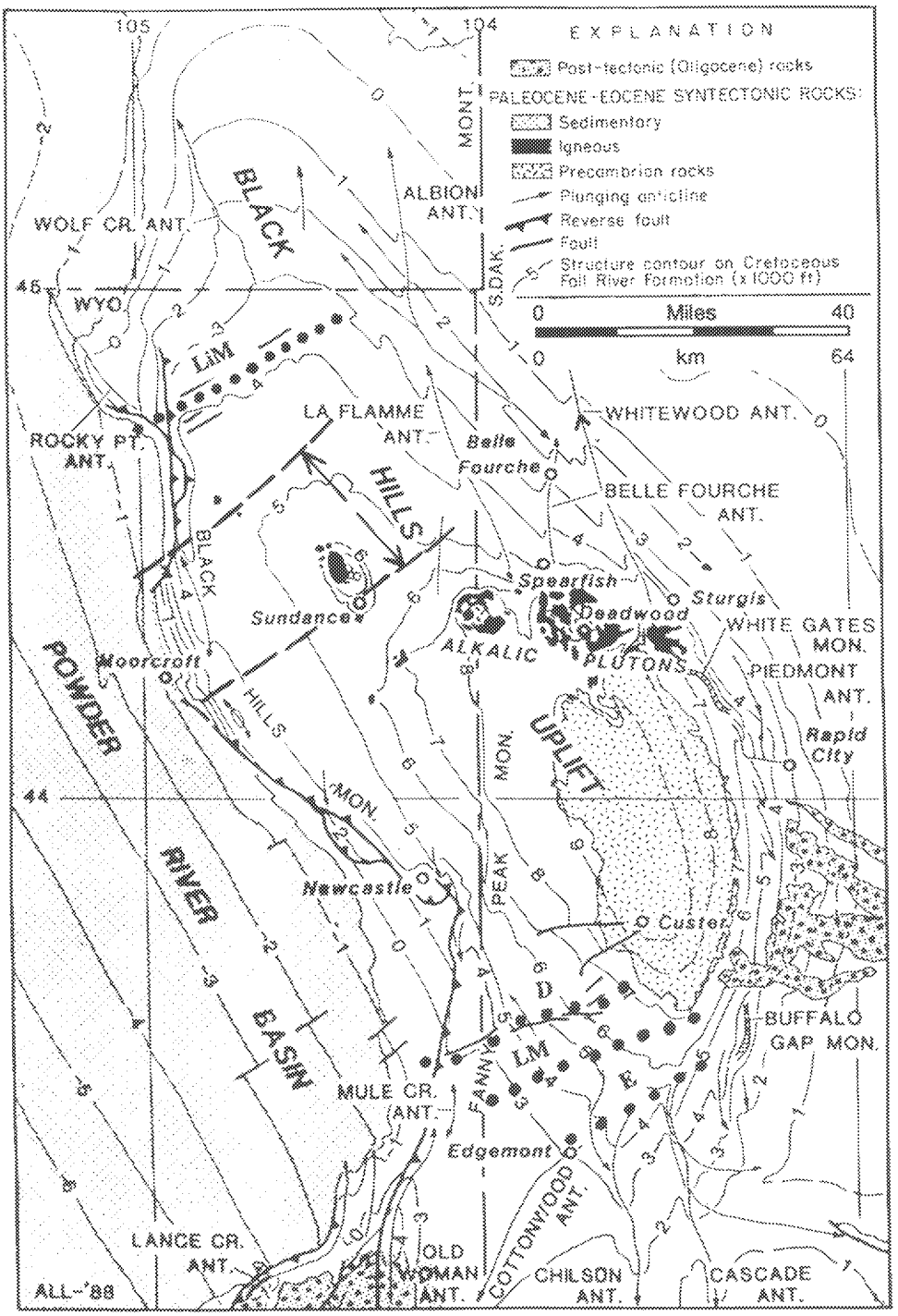


**Fig. 6.** Tectonic map of the Black Hills uplift and eastern Powder River basin (revised from Lisenbee 1988, courtesy of the Wyoming Geological Survey and Wyoming Geological Association). Little Missouri (LiM), Dewey (D), Long Mountain (LM) and Edgemont (E) structural zones shown by dotted lines. Projection of the crest of the Belle Fourche Arch shown between the arrows in the northwestern Hills.

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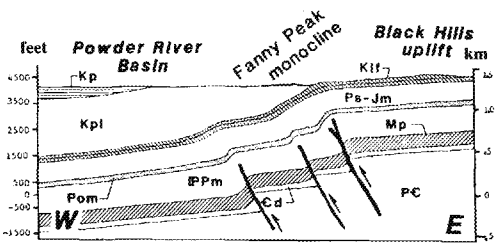


**Fig. 7.** West–east cross-section between the Powder River basin and the Black Hills uplift across the Fanny Peak monocline just south of Newcastle, Wyoming. (Figure from Lisenbee & DeWitt 1993; courtesy of the Wyoming Geological Survey.) Kp – upper part of the Pierre Shale; Kpl – lower part of the Pierre Shale; Klf – Lakota and Fall River Formations; Ps-Jm – Spearfish, Sundance and Morrison Formations; Pom – Opeche Shale and Minnekahta Limestone; PPm Minnelusa Formation; Mp – Pahasapa Limestone; P€ – Precambrian rocks, undifferentiated.

two Precambrian blocks are bounded by two regionally prominent folds, the Fanny Peak monocline along the western border of the South Dakota block and the Black Hills monocline along the western border of the Wyoming block (Fig. 6). Horizontal strata occupy the tops of the blocks and abruptly dip into monoclines at their margins. Locally, folds, ramps and terraces are developed, with interpreted faults often passing into surface asymmetrical folds.

The Fanny Peak monocline forms the southwest boundary between the Black Hills and the Powder River Basin, and extends along the length of the Fanny Peak lineament to the Hartville Uplift. The beds on the monocline are draped over the eastern block creating local monoclines, anticlines and terraces, as shown in Fig. 7. Figure 8 shows part of the lineament east of Newcastle, Wyoming. Figure 9 illustrates the interpreted structure beneath the surface.

The Black Hills monocline is the boundary between the Black Hills and the Powder River Basin in the west and northwest sectors of the study area. This fold begins where it intersects with the Fanny Peak monocline at Newcastle and extends from there to the Montana border. Numerous folds and terraces are developed along the extent of this feature.

Three structural zones transect the southwestern Black Hills in an east of northeast direction. The Dewey and Long Mountain zones consist of sets of NE-trending normal faults in the region (Figs 3 and 6). The Edgemont zone is defined by the termination of several folds. Collectively, the Dewey–Long Mountain–Edgemont structural zones constitute a major lineament zone across the southern Hills.

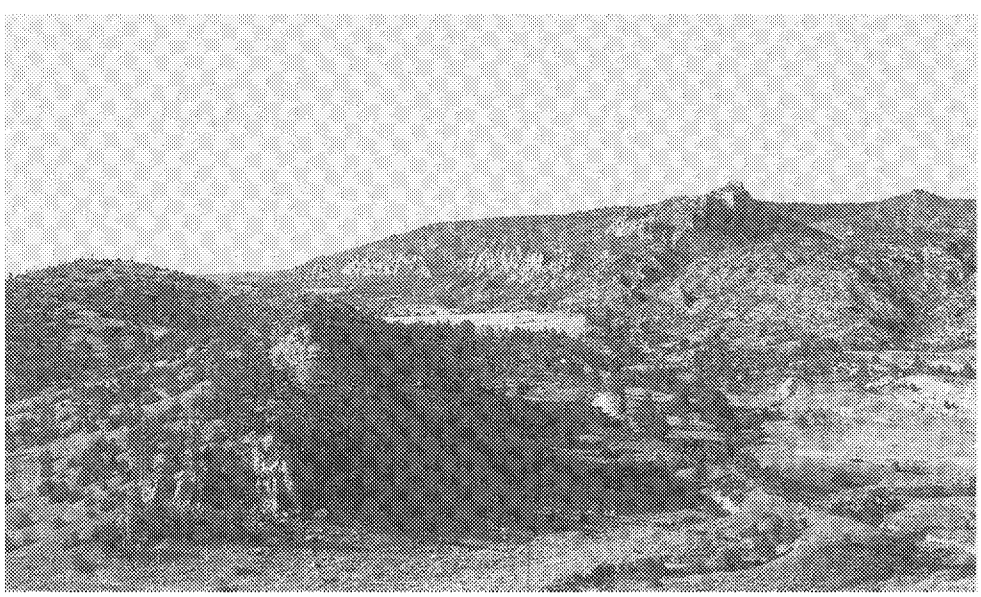

**Fig. 8.** Northeast view of Fanny Peak lineament from Route 16 north of LAK Ranch, 6 miles (9.7 km) east-southeast of Newcastle, Wyoming. Fall River Formation is the low hogback in the lower left portion of the photograph. Near-vertical monocline flatirons in the central part of the photograph become horizontal at Fanny Peak in the upper right.

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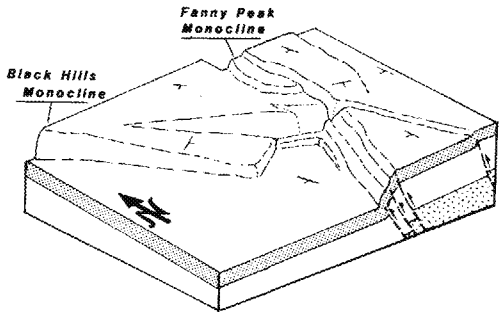


**Fig. 9.** Generalized block diagram showing the relationship of surface structures to basement faulting at the junction between the Black Hills monocline and Fanny Peak monocline near Newcastle, Wyoming. (Diagram from Lisenbee & DeWitt 1993; courtesy of the Wyoming Geological Survey.) The west border of the diagram is approximately 9 miles (14.5 km) in length.

The eastern flank of the Black Hills uplift has dips ranging from 20° to near vertical. The monocline along the eastern flank is locally interrupted by interpreted faults which die out upward into smaller-scale asymmetrical folds.

The northern Black Hills is characterized by sandstone plateaus and several N-plunging folds, such as the Belle Fourche, La Flamme and Albion anticlines. North of Belle Fourche, South Dakota, NW-trending folds cross the La Flamme and Albion anticline trend. The Little Missouri fracture zone also crosses the extreme northwestern Black Hills just north of Devils Tower, Wyoming. This N55E° (055°) trending structural zone is marked by numerous normal faults and folds subparallel to this zone, as well as the terminations of several NW-striking folds. Also of significance in the northern Hills is a group of Eocene plutons which are exposed in a linear trend extending southeastward from Missouri Buttes in eastern Wyoming to the vicinity of Sturgis in western South Dakota.

## Regional tectonic model

A variety of plate tectonics models have been advanced to account for the complex array of uplifts in the Rocky Mountain foreland. Consideration of these is beyond the scope of this paper, although a familiar theme has been the concept of foreland uplift in response to shallow subduction of the east Pacific plate beneath the North American plate (Lowell 1974; Dickenson & Snyder 1978; Jordan & Allmendinger 1986).

The role of basement deformation remains controversial and may involve the effects of basement folding (Snoke 1993) and reactivation of low-dipping, deep-seated Precambrian basement faults (Brown 1988, 1993), which may originate from a detachment at the brittle–ductile transition zone in the middle crust (Schmidt *et al.* 1985; Kulik & Schmidt 1988). Seismic evidence for thrust faults beneath many Laramide uplifts (Berg 1962; Smithson *et al.* 1978, 1979; Brewer *et al.* 1982; Allmendinger *et al.* 1982, 1983; Johnson & Smithson 1985) has weakened the case for the once prevalent view that these structures developed over deep-seated vertical faults and do not require crustal compression and shortening (Prucha *et al.* 1965; Stearns 1971).

## Structural evolution of the Black Hills

The Black Hills uplift began during Early Palaeocene and movement continued through Late Palaeocene–Early Eocene (Lisenbee & DeWitt 1993; Dutton 1995). It may represent one of the last Laramide uplifts to form, inasmuch as some foreland folds to the west developed earlier than the Black Hills (Brown 1988). We favour the model of Lisenbee & Dewitt (1993), first suggested by DeWitt *et al.* (1986), which attributes Black Hills uplift to a deep-seated, east-dipping reverse fault which terminates near the basement surface under the western Hills (DeWitt *et al.* 1989) and separates Precambrian rocks of Proterozoic age on the east from Archean rocks on the west.

Several lines of evidence support this interpretation. First is the coincidence of the overall configuration of the Fanny Peak and Black Hills monoclines with the boundary between Precambrian terrains. Secondly, magnetic and gravity anomalies (Kleinkopf & Redden 1975; Robbins 1994) show highs coincident with the postulated eastern upthrown block. Additional evidence is given by the fact that almost all monoclines and anticlines of the western and southern Black Hills have steep limbs facing west and many folds show a paired relationship (DeWitt *et al.* 1986), with the easternmost fold being the anticline and the western fold the syncline.

Large-scale wrench faulting has been postulated for significant control on Laramide structural evolution by various workers, including Sales (1968) and Stone (1969, 1970, 1975). Although extensive surface structural alignments and geophysical lineaments suggest major areal variations in buried Precambrian rock types, limited evidence exists in the Black Hills for significant strike-slip

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faulting during Laramide time. As pointed out by Lisenbee and DeWitt (1993), there is no substantial evidence for strike-slip faulting in the Black Hills.

## Fall river formation

### *Stratigraphy*

The Fall River Formation (Fig. 10) is the uppermost member of the Inyan Kara Group (Lower Cretaceous) and is primarily composed of sandstone with some interbedded siltstone and mudstone. Fall River thickness throughout the Black Hills is highly variable and ranges from 10–200 feet (3–61 m) in thickness. A typical outcrop is characterized by massive fluvial sandstones underlain by interbedded siltstone and mudstone. For purposes of the present study the formation is considered as three units (Waage 1959; Gott, *et al.* 1974).

- Upper unit – massive fluvial sandstone, similar to that in the middle unit. Underlain by interbeds of sandstone and mudstone, grading laterally into variegated mudstone.
- Middle unit – massive fluvial sandstone underlain by interbedded sandstone and mudstone.
- Lower unit – thin interbeds of sandstone, siltstone and some mudstone.

This sequence varies locally as well as regionally. At some localities, the sandstone–mudstone interbeds are absent and the fluvial sandstone of the upper unit rests directly on the massive sandstone of the middle unit. For consistency, the upper unit was used for joint measurements, except where absent or concealed at a few locations. There, joints from the sandstones of the middle unit were measured.

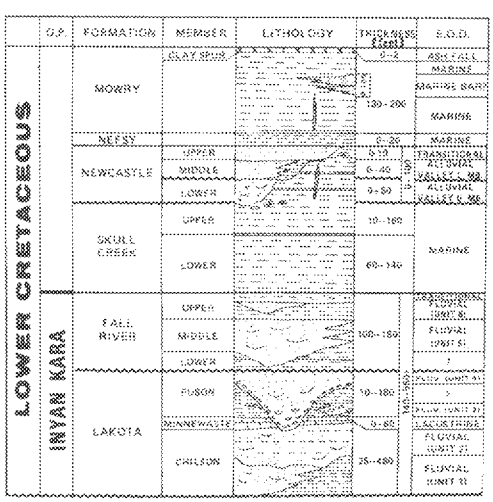


**Fig. 10.** Generalized stratigraphic section for Lower Cretaceous formations (Fig. from Weimer *et al.* 1982; courtesy of the Colorado School of Mines Press.)

### *Joints*

All exposures of Fall River Formation sandstones are pervasively fractured (Fig. 11). Joints are perpendicular to bedding, even in steeply inclined strata. Joint spacing ranged from 4 inches to 50 feet (0.1–15.2 m), with fractures penetrating strata with bedding partings from 1 inch to 50 feet (0.025–15.2 m) in thickness. The fractures in the massive sandstone are large and continuous, had typical spacings of 5 feet (1.5 m) or more and penetrated the entire thickness of the bed (Fig. 1). Joint spacing in thin-bedded units was typically from 1 inch to 5 feet (0.025–1.5 m).

Joint faces commonly present a morphology that is useful in ascertaining mode of origin and particular aspects of fracture propagation. The most common feature is the joint plume, which is discussed at length by Kulander *et al.* (1979) and Pollard & Aydin (1988). The present study was mainly concerned simply with the presence or absence of the plume as a means to determine whether or not the fracture formed as an extension joint.

Fracture plumes were present on virtually all Fall River Formation sandstone joint faces and verify an extensional origin. The joint surfaces show no evidence of horizontal slickensides. There is no offset on joints. The joints are orthogonal systems and show no evidence for a conjugate shear origin.

It is likely that stress relief played a role in fracture development, as it commonly the case with vertical bedrock faces of natural or man-made origin. This possibility exists with regard to the joint exposures on Fall River cliff faces. Commonly, undercutting by erosion causes bedrock to break off toward the unconfined face, with joint initiation at the base of the undercut exposure, resulting in a bottom origin and ensuing upward joint propagation. However, joints originating by this process are more typically curviplanar and show no tendency to fit the local, or regional, fracture pattern. In view of the fact that the joints in the present study have pervasive, planar faces that fit the regional pattern, it is concluded that they are of tectonic origin.

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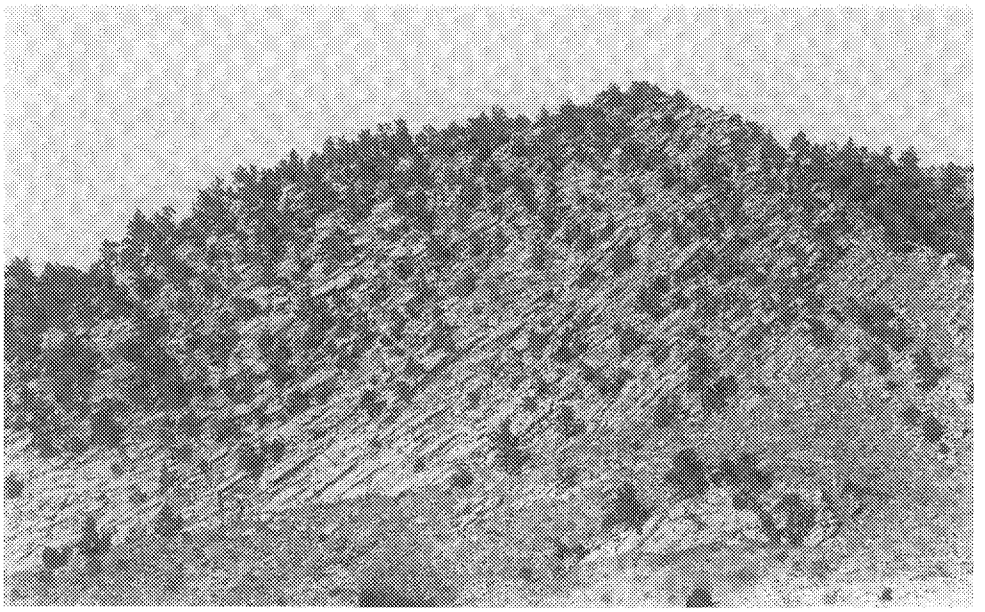

**Fig. 11.** Photograph of the west flank of the Cascade anticline 7 miles (11.3 km) south-southwest of Hot Springs, South Dakota. View is perpendicular to strike and the strata dip 60° towards the viewer. Systematic joints trend from upper right to lower left, oblique to strike. Non-systematic joints are orthogonal to systematics. All joints are perpendicular to bedding and were rotated with folding. The distance is 600 feet (183 m) along the base of the figure.

## Fracture domains

Systematic joint sets and associated non-systematic sets often occur in distinct domains. The word domain, as used here, is synonymous with the term 'fracture field' of Hobbs (1911). A fracture domain consists of a regional, uniform, systematic fracture set or sets, with associated non-systematic joints which are pervasive in a rock unit within the boundaries of a particular region. Fracture domain boundaries mark the zone where a regional fracture trend changes or a new set begins. Domain boundaries may be gradational or abrupt and several joint sets can occur within the same domain. In other regions of the Rocky Mountains joint domains are well demonstrated by Kelley & Clinton (1960) and Hodgson (1961, 1965) in the Colorado Plateau.

Fractures in Fall River sandstone are not randomly oriented. Systematic and abutting non-systematic joint sets maintain consistent orientations throughout large areas. The fractures in the investigated area can be separated into distinct southern and northern domains (Fig. 12). Each domain has at least one consistent orthogonal system. In the northern domain three systems of systematic and non-systematic joints are present. The domains defined by the fracture sets in the study area are evident in Figs 3, 4 and 12.

### *Southern domain*

The eastern end of the NW-trending Rapid Creek lineament (Pan 1978) serves as an approximate boundary between the northern and southern domains on the eastern flank of the Black Hills (Fig. 13). Here the systematic joint set strikes N75°W (285°) and parallels the boundary lineament. The strike of the systematic joint set shows a gradual shift to N30°W (330°) as the domain continues southwestward around the Fall River outcrop belt to the Long Mountain structure zone, which is the southern limit of the domain boundary on the southwestern flank of the Black Hills.

The joint set in the southern domain is consistent and well defined. These joints were easily identified at every outcrop and showed little variance from field station to field station, or from adjacent aerial photographs.

### *Northern domain*

The northern domain includes the remainder of the Fall River outcrop belt. This domain contains three distinct systematic fracture sets (Figs 3 and 4). The major set, designated set I, trends N30°E–N75°E (030°–075°) and is

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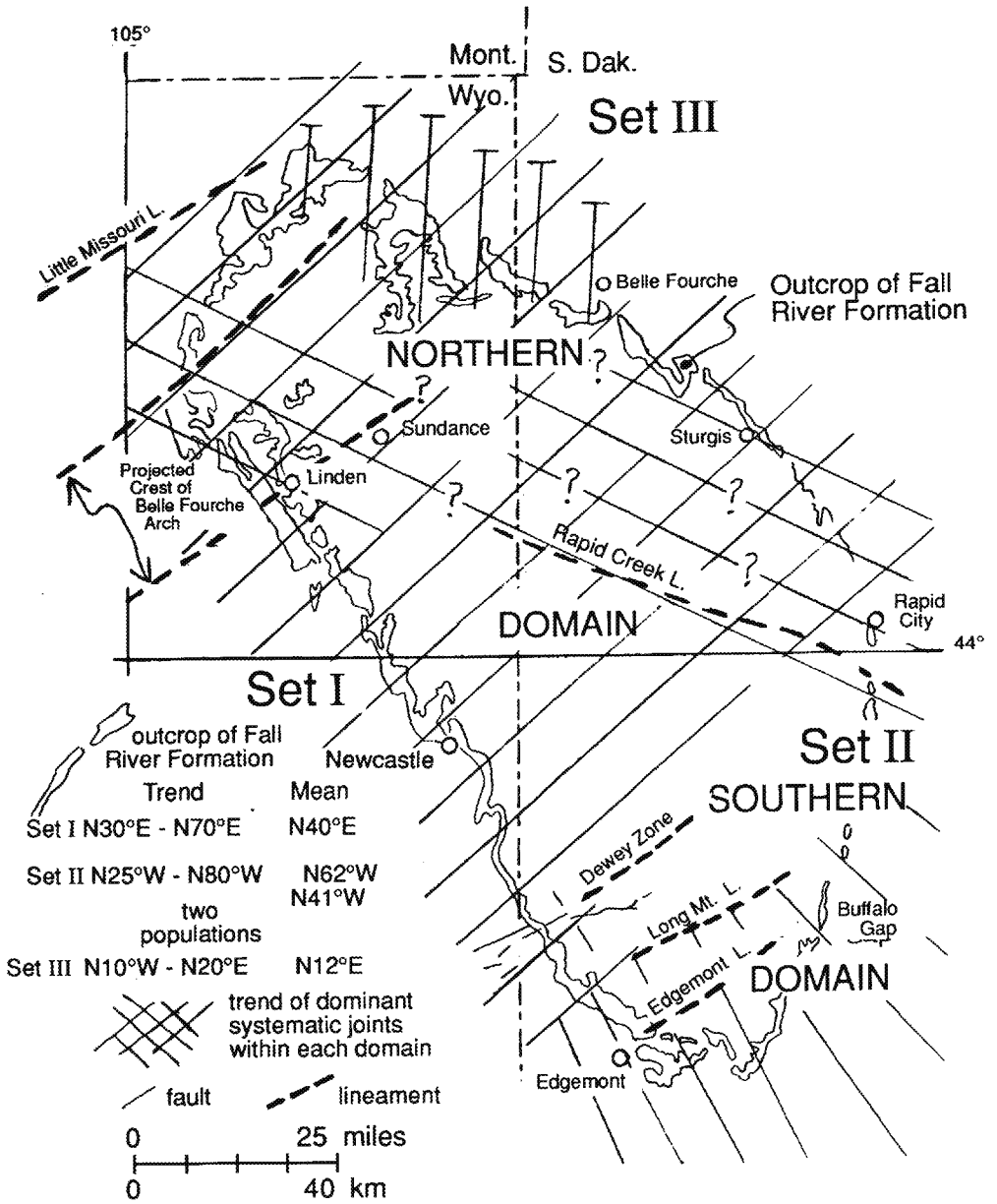


**Fig. 12.** Diagram showing the major joint domain boundary and systematic fracture trends around the Black Hills, extended where the Fall River Formation is absent. The projected crest of the Belle Fourche Arch is shown between the arrows in the northwestern Hills. (Refer to Fig. 3 for some abbreviations of towns.)

continuous throughout the northern domain. Set II, N50°W–N90°W (310°–270°) coincides with some of the systematic fractures of the southern domain. This set crosses the domain boundary on the eastern flank and is only present northward to the vicinity of Sturgis. On the northwestern flank, this set appears nearly along the line of extension of the Rapid Creek lineament to the Little Missouri structure zone. Set III trends N10°W–N20°E (350°–020°) and occurs only in the extreme northern Black Hills.

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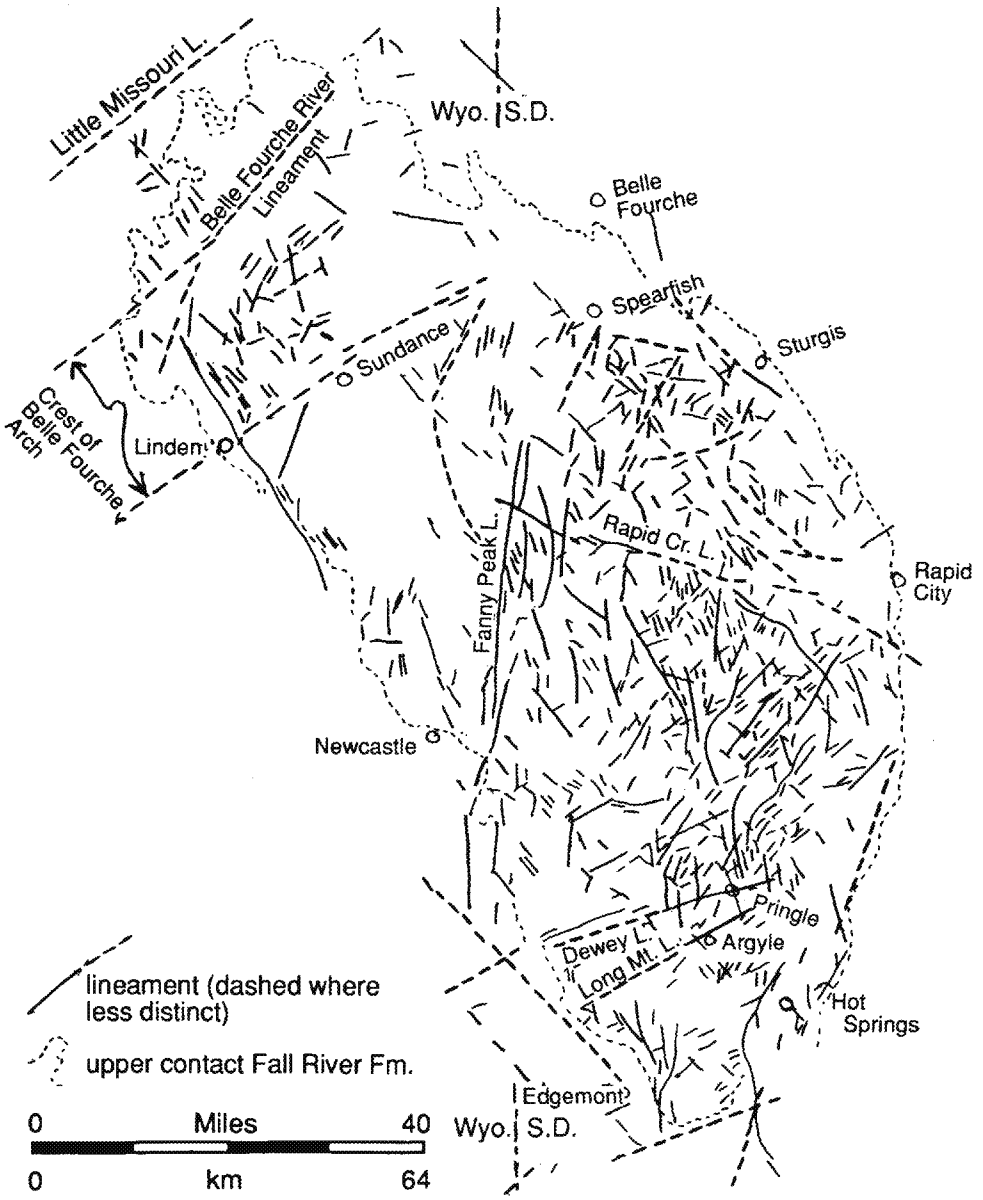


**Fig. 13.** Lineament map of the Black Hills area (modified from Pan 1978). The projected crest of the Belle Fourche Arch is shown by arrows in the northwestern Hills.

*Domain boundaries*

The domain boundary is well defined at the southwestern end by the Long Mountain structure zone and at the eastern end by the southeastern termination of the Rapid Creek lineament. Along the Long Mountain structure zone stations on both sides of the boundary confirm the abrupt change in systematic fracture orientation. There are no stations on either side of the boundary that contain both sets.

At the northeastern end of the domain boundary both set I and II joints are present north of the boundary. The NE-trending joints are most pervasive and the northwest joint set is secondary. The domain boundary is expressed further

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into the Black Hills then the Fall River outcrop belt, as shown by fracture-controlled cave passages in Mississippian Pahasapa (i.e. Madison) carbonates (Bakalowicz *et al.* 1987; Peter *et al.* 1991).

## Development of Fall River joints

Joint readings were obtained in the Fall River Formation on every major and local flexure around the Black Hills. After bedding was restored to horizontal, comparison of joint trends (Figs 3 and 4) with fold axial traces reveals that the fracture orientations remain constant, although the structural trends of many of these flexures vary considerably (Fig. 3). Clearly the joints formed prior to development of these folds and were merely rotated during later folding.

Figures 3 and 4 give the suggestion of radial systematic joint trends around the Black Hills, a configuration characteristic of domal uplifts. However, this interpretation is not supported when the overall joint pattern is considered. In the southern Hills a 90° difference in trends exists between set I and set II, requiring the principal extension direction to change abruptly along the major domain boundary that crosses the southern Black Hills. Additional difficulties arise with this interpretation because of the prevalence and consistency of set I trends around the western and northern parts of the uplift that do not fit a radial pattern. Finally, it has been shown by Lisenbee (1978, 1985), DeWitt *et al.* (1989) and Lisenbee & DeWitt (1993) that the folds around the Black Hills were initiated during the uplift. Fractures pre-date development of these flexures and do not fit an overall radial pattern around the Hills. Lateral compression has been invoked by Gott *et al.* (1974) to account for jointing in the Inyan Kara Group of the western and southern Black Hills. They proposed that the change in joint trends across the Long Mountain structural zone, which is the major domain boundary of this paper, resulted from a change in an overall northeastern–southwestern compression north of Long Mountain zone, to southeastern–northwestern compression south of this zone.

The work of Gries (1983, 1990), Gries *et al.* (1993) and Chapin & Cather (1981, 1983) has also suggested changes in regional compression from a southwesterly to northwesterly direction during the evolution of the Rocky Mountain foreland, which would require NE-trending systematic joints (set I) of the northern domain to form first with cessation of development of this set along the abrupt line of the major domain boundary. Northwest-trending set II systematic joints would then have to form later, principally in the southern domain. Set II joints do continue along the eastern flank of the Black Hills and along the northern hills in a broad band through the northern domain, but with an overall change in strike from approximately N40°W to N60°W (320°–300°) from the southern to northern domains. Several problems exist with this two-fold timing of regional lateral compression in systematic joint formation. The change in trend of set II joints from the southern to northern domains would require a major change in regional compression direction and would not account for the complete absence of set II joints in the western hills from Linden, Wyoming, to the Long Mountain structural zone in south Dakota, a distance of some 75 miles (121 km). An additional difficulty occurs in the northern hills where another systematic set emerges trending approximately N12°E (012°). Finally, proprietary seismic data reveal a N-trending, E-dipping Precambrian basement thrust fault that underlies the Old Woman anticline of the same trend well past the major domain boundary in the southern hills. Approximately east–west compression would have to account for the development of the Old Woman anticline, as well as the simultaneous development of sets I and II, even though the systematics trend at 90° different orientations. Regional compression may be a possibility for the Black Hills uplift and some peripheral structures but cannot account for the joint patterns, which have been shown to be of pre-fold origin.

The pattern and chronology of Fall River joint development requires an explanation unrelated to domal uplift, formation of local flexures or regional compression. A possible, but speculative, interpretation lies in the major structural zones and lineament systems that cross and border the Black Hills. The lineament systems (Figs 3, 4, 13, 14 and 15) were interpreted primarily from Landsat imagery and isopach maps by several workers. Lineaments of western South Dakota (exclusive of the Black Hills) were interpreted by Shurr (1978). Lineaments across the Black Hills structure were taken from the lineament map by Pan (1978), (Fig. 13). Papers by Thomas (1974) and Brown (1978) provided lineament data for southern Montana and northeastern Wyoming, respectively. The lineaments interpreted by Brown (1978), to some extend overlap those of Pan (1978).

Shurr (1978, 1979), Shurr & Rice (1986), and Shurr *et al.* (1989*a*, 1994) have shown from isopach and structure contour maps that this

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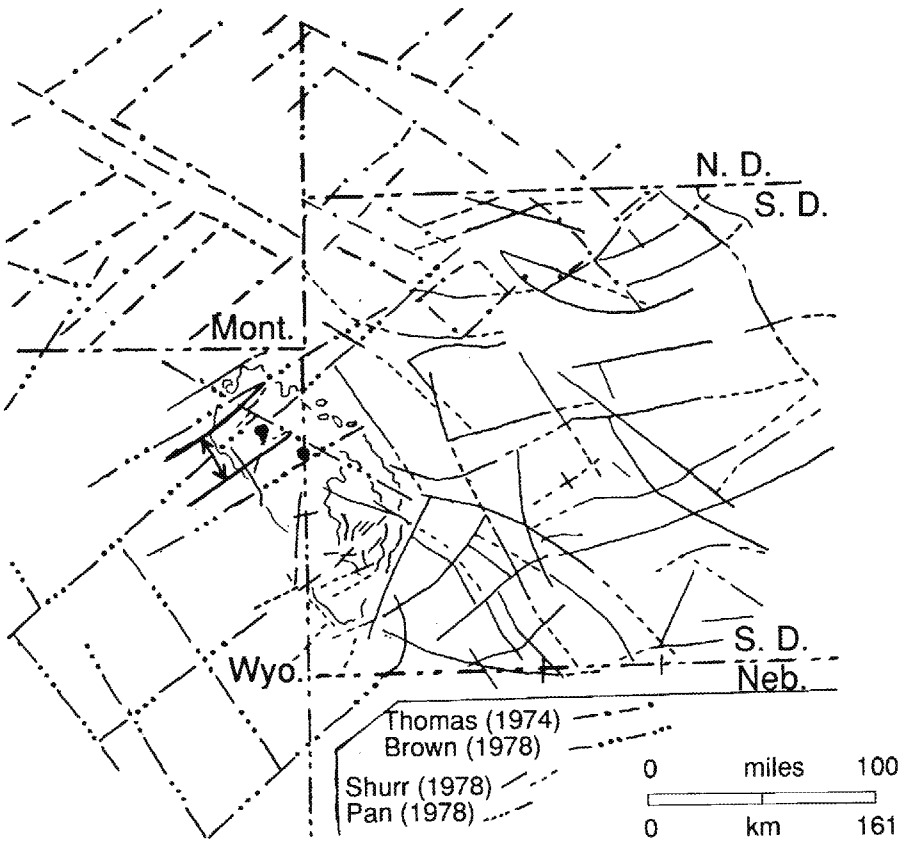


**Fig. 14.** Lineament map of the Black Hills and surrounding area. Data from Thomas (1974), Shurr (1978) and Brown (1978); Black Hills, Pan (1978). The projected crest of the Belle Fourche Arch is shown between the arrows in the northwestern Hills.

lineament system was established well before the Laramide orogeny affected the Black Hills. Shurr (1981), Shurr (1984), Shurr *et al.* (1989*a*, *b*, 1994), Shurr & Gay (1992), Shurr & Rice (1986) have documented the inter-relationship of basement block geometry and large-scale lineaments on palaeotectonism, subtle structures and the stratigraphic record in the western and northwestern midcontinent area adjacent to the Black Hills.

Slack (1981) (Fig. 15) has shown the dominance of NE-trending lineaments across the Powder River basin and well into the Black Hills uplift. He suggests that zones of subtle movement along basement faults throughout Phanerozoic time have defined the lineament system. Marrs & Raines (1984) (Fig. 15) also show pronounced NE-trending lineaments throughout the Powder River basin, but also a strong northwest trend. North of the Black Hills in the Williston basin, numerous workers, including Thomas (1974) and Gerhard *et al.* (1982) have shown NE- and NW-trending regional lineaments and have discussed the role of recurrent movement of basement faults on sedimentation, and development of folds in the sedimentary cover.

There are several examples of the correlation between systematic joints, changes in joint trends and structurally defined lineament zones (Figs 3, 6, 13, 14 and 15). The most prominent example is the Dewey–Long Mountain–Edgemont zone in the southern Hills, which, collectively, suggest a line of deep-seated fundamental weakness in the crust with the same trend as the Colorado lineament (Warner 1978) to the south in Colorado, and the Cheyenne belt in southeastern Wyoming. The Cheyenne belt marks a distinct change between Precambrian rocks of Archean and Proterozoic age, a NE-trending boundary that extends into the southern Black Hills (Lisenbee & DeWitt 1993) (Fig. 16).

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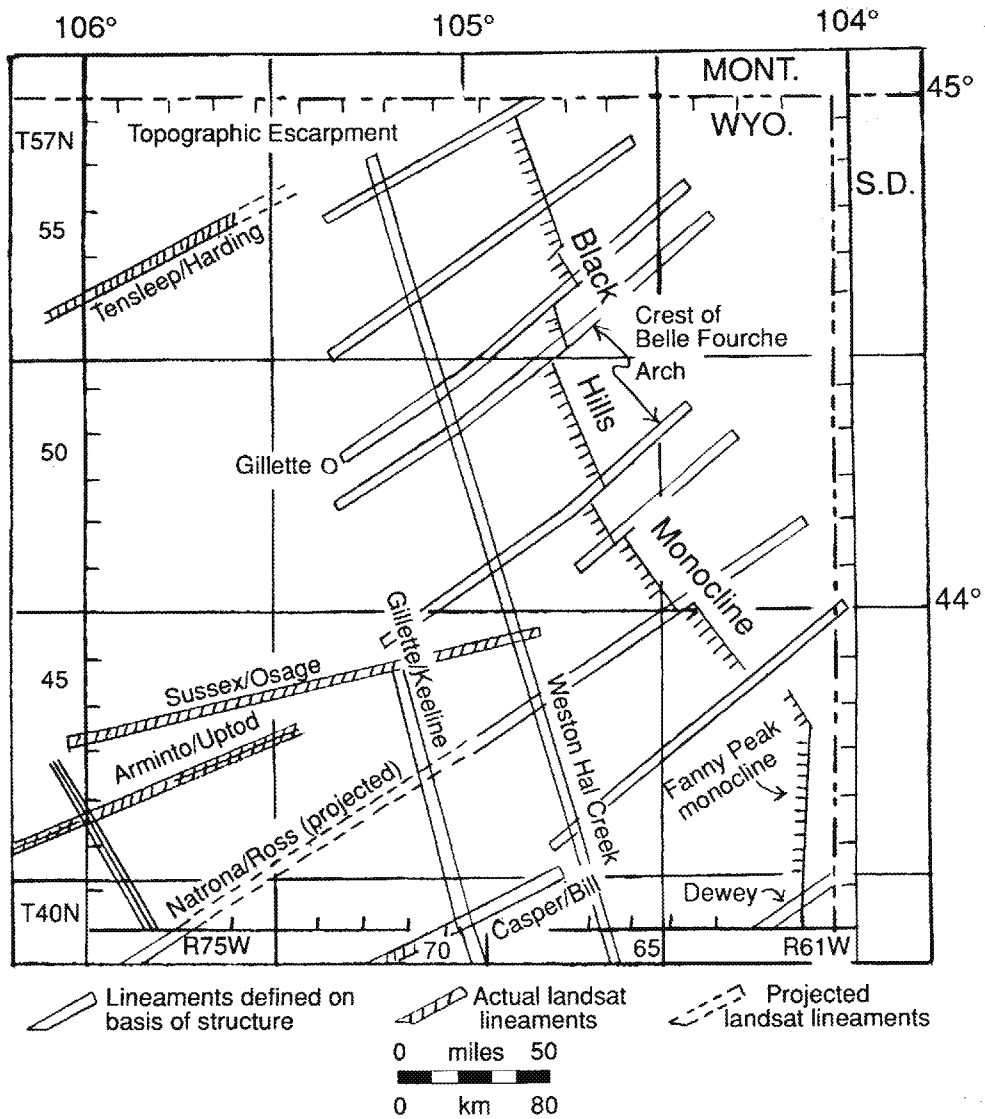


**Fig. 15.** Lineaments across the Powder River basin into the Black Hills. (Diagram modified from Slack (1981) and Marrs & Raines (1984); courtesy of the American Association of Petroleum Geologists.)

Also significant is the northwesterly alignment of Tertiary intrusions, faults in Precambrian rock and the Rapid Creek lineament across the Black Hills. In addition, in the northwestern Hills, the Little Missouri structure zone and the pronounced northeasterly trend of the Belle Fourche River are matched by Landsat lineaments. In this same area the Belle Fourche Arch of Slack (1981) is well defined along its northern border by a major lineament.

Figures 13–15 show that the dominant lineament trends across the Black Hills are in a northeasterly direction. Slack (1981) (Fig. 15) has projected NE-trending lineaments from the Powder River basin into the northwestern Black Hills, and shows the Little Missouri structural zone and the Belle Fourche River zone (i.e. Rozet lineament) to be positioned on the northern limb of the Belle Fourche Arch, a subtle NE-trending basement high during much of Cretaceous time. Dolson *et al.* (1991) have shown the presence of this arch as a major drainage divide in the northern Black Hills during the time of Muddy deposition (i.e. upper Lower

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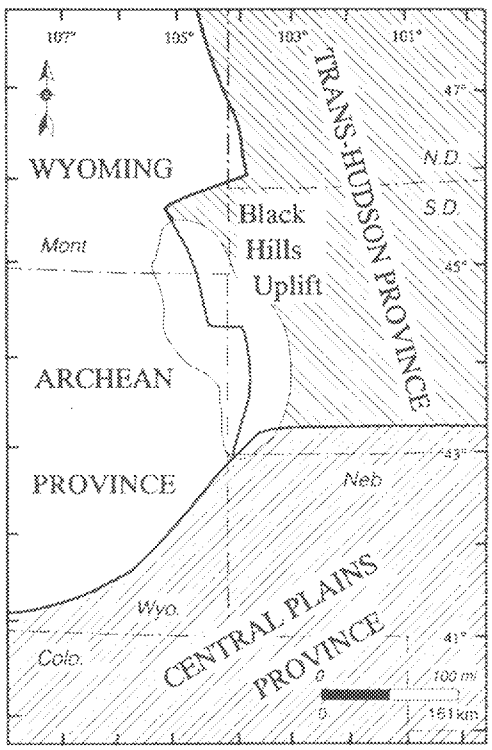


**Fig. 16.** Map showing the generalized boundary between Precambrian terrain in the Black Hills and the surrounding region. Younger Proterozoic rocks to the east and south shown with diagonal patterns. Older Archean rocks of Wyoming Province are shown in white. (Diagram from Lisenbee & DeWitt 1993; courtesy of the Wyoming Geological Survey).

Cretaceous). The lineaments north of the crest of the arch are interpreted to represent the surface expressions of deep-seated faults that were consistently down-thrown to the northwest during Cretaceous time. The most pervasive and consistently formed first-formed joints there are of set I. Southeast of the arch, a series of lineaments of similar trend extend into the Black Hills and have also been interpreted to bound NE-trending basement blocks, that were repeatedly down-faulted to the southeast towards the southern Black Hills. Set I joints are also the most pervasive and consistently first formed there. The eastern projection of the Belle Fourche Arch to a location northwest of Belle Fourche shows a dominance of set III joints, but with some variance about the overall N12°E (012°) mean. Jointing here may have an early association with similarly oriented basement faults that were later reactivated to form the numerous N–S- to NNW-trending anticlines in the extreme northern hills. The Nesson and Cedar Creek anticlines in the Williston basin of North Dakota and Montana, respectively, have been shown by Gerhard *et al.* (1982) to be bounded by basement faults that were periodically reactivated during Palaeozoic and Mesozoic time.

Geophysical anomalies shown by Robbins (1994) make a convincing argument for a segmented Precambrian basement in the northern and northwestern Black Hills. Magnetic and gravity trends are well developed and have the same directions as all three systematic joint sets in the region.

Jointing apparently occurred early in the depositional history of the Fall River Formation, resulting in widespread extension joints. The mechanism shown by Slack (1981) for the evolution of the Belle Fourche Arch across the northern hills and the numerous NE-trending lineaments across the Powder River basin into the uplift provides a plausible explanation for the dominant NE-trending joint set (set I) throughout the Black Hills. Under this scenario, faulting parallel to NE-trending lineaments occurred shortly after Fall River deposition, exerting extensional stresses to the northwest and southeast of the Belle Fourche Arch. Set I fractures formed as extension joints parallel to basement-controlled structural zones, now expressed as lineaments (Fig. 15) Slack (1981) and numerous other authors, including Emme & Weimer (1981), Weimer *et al.* (1982), Anna (1983), Moore (1983), Tillman & Martinsen (1983), Wheeler & Gustason (1987), Bryan & Petta (1988), Gustason *et al.* (1988), Weimer *et al.* (1988), Reinhold & Harwerth (1989), Rice & Keighin (1989), Forster & Horne (1994) and Way *et al.* (1995), have shown the effect of recurrent basement fault movements on depositional patterns in the Powder River basin. Recurrent movement on basement faults, in general, throughout sedimentary depositional history in the Rocky Mountain foreland and mid-continent area is a familiar theme and has been shown by Sonnenberg and Weimer (1982), Anderson *et al.* (1983), Clement (1983), Weimer (1984, 1992), Lindsay *et al.* (1988), Weimer & Sonnenberg (1989), Freisatz (1990), Rice *et al.* (1990), Von Den Bold *et al.* (1991), May *et al.* (1992) and other workers to affect and control changes in facies and stratigraphic thickness.

The most compelling support for NE-trending extensional jointing in the northern domain is given by Weimer *et al.* (1982) in a comprehensive treatment of depositional patterns of Lower Cretaceous formations in the southeastern Powder River basin and adjacent to the surface outcrop of the Fall River. They have shown that

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recurrent movement of basement fault blocks during Early Cretaceous time created subtle topographic highs and lows that influenced sedimentation. In the northern joint domain palaeotopographic highs and lows exactly parallel the trends of set I joints to the position of the Long Mountain structure zone and suggest that Fall River jointing occurred before deposition of the Newcastle Formation (Lower Cretaceous). Around the southern Hills Gott *et al.* (1974) have shown that Early Cretaceous Fall River drainage was dominantly to the northwest and that this palaeodrainage was diverted to the northeast and northwest at the Long Mountain and Dewey structural zones. Variable total thickness of the Lower Cretaceous Inyan Kara Group, and individual fluvial sandstone units (Gott *et al.* 1974), indicates that sections of present anticlines such as Dudley, Cascade, Chilson and Sheep Canyon probably had slight topographic relief along north to northwest trends during Early Cretaceous time. Major structural relief now present along the Dudley, Cascade, Chilson and Sheep Canyon folds was inherited from later Laramide deformation. The authors feel that set II NW-trending joints also formed before Newcastle deposition and parallel to similarly trending extensional faults that were active during Early Cretaceous time. Although Gott *et al.* (1974) have indicated that the area south of the Dewey and Long Mountains zones experienced relative down-faulting, it is felt that this faulting occurred in differential fashion along NW-trending blocks, yielding the NW-trending systematic joints of set II.

In the northern Black Hills a similar picture may exist for joints of set III (N12°E). East–west extension associated with movement on N–S- and NNW-trending basement faults may have initiated joint formation during Early Cretaceous time, with major folds such as the Belle Fourche and Laflamme anticlines forming during Laramide deformation along the same lines of basement weakness. The existence of N–S- and NNW-trending basement faults associated with the Nesson and Cedar Creek anticlines in the Williston Basin to the north (Gerhard *et al.* 1982) makes basement faulting a plausible explanation for the development of set III joints in the northern Hills.

The consistent and pervasive northeast trend of set I joints is interrupted by the broad northwesterly belt of joints across the northern domain parallel to the Rapid Creek lineament. These joints are positioned on the crest of the Belle Fourche Arch on the northwestern edge of the hills and extend to just south of Sturgis on the eastern limb of the uplift. Their timing is secondary on the northwestern and eastern flank of the hills, indicating that they formed after set I joints in both areas. Their overall N75–80°W (285°–280°) trend indicates that they may represent a different joint set than those in the southern domain. They do not appear to have any association with fault-related Early Cretaceous palaeohighs and palaeolows and sedimentation patterns as do sets I and II throughout much of the Black Hills. They may represent minor north-northeast to south-southwest extension that postdated the development of the Belle Fourche Arch and associated NE-trending lineaments and basement faults.

## Summary

Sandstones of the Fall River Formation are pervasively jointed throughout this outcrop belt around the Black Hills uplift, with systematic fractures maintaining consistent orientations over large areas. Two major systematic joint sets (I and II) are present, with a sharp boundary between these sets in the southern hills along the NE-trending Long Mountain structure zone. This feature separates NE-striking systematics (set I) of the northern domain from NW-trending dominant joints (set II) of the southern domain. A third systematic joint (set III) is locally present across the northern hills and trends north-northeast.

The stratigraphic record reveals that the Black Hills uplift was initiated late in the Laramide orogeny in Early Palaeocene time, with continued movements until Late Palaeocene–Early Eocene. Uplift is interpreted to have been effected along an east-dipping master thrust fault in the upper crust which may have been localized, in part, by the boundary between Precambrian age Archean rocks to the west and Proteozoic rocks to the east. This fault is interpreted to penetrate into, or near, the Palaeozoic-Precambrian interface at the position of the Fanny Peak and Black Hills monoclines along the western border of the Hills. The numerous monoclines and anticlines around the periphery of the uplift are interpreted to be drape-type folds, formed above steeply dipping Laramide reverse faults, that originated in basement rocks along pre-existing weakness lines inherited from Precambrian time, and were periodically reactivated as extensional faults throughout Palaeozoic and Mesozoic time prior to the Laramide orogeny.

Jointing in the Fall River Formation was not associated with the domal uplift of the Black Hills, and was in no way related to Laramide regional compressive stresses or extensional

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effects along the local and regional cover folds in the Fall River around the uplift. Joint development originated early in the lithification history of Fall River sandstones, most probably in late Early Cretaceous time prior to Newcastle deposition. Jointing occurred in response to local and regional extensional stresses that pervaded the northern and southern domains as a result of recurrent movements on basement faults that parallel the regional lineament system and surface structural zones throughout the Black Hills and surrounding region.

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| In the Matter of | ) | |
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| POWERTECH (USA) INC., | ) | Docket No. 40-9075-MLA |
| | ) | |
| (Dewey-Burdock In Situ Uranium Recovery Facility) | ) | |

**DECLARATION OF DR. ROBERT E. MORAN**

I, Dr. Robert E. Moran, do hereby swear that the following is true to the best of my knowledge:

**Professional Qualifications and Introduction**

1. I am a hydrogeologist/geochemist with more than 38 years of domestic and international experience in conducting and managing water quality, geochemical, and hydrogeologic work for private investors, industrial clients, tribal and citizens groups, NGO's, law firms, and governmental agencies at all levels. Much of this technical expertise involves the quality and geochemistry of natural and contaminated waters and sediments as related to mining, nuclear fuel cycle sites, industrial development, geothermal resources, hazardous wastes, and water supply development. Much of this experience has involved uranium mining, processing, and related environmental impacts. I have significant experience in the application of remote sensing to natural resource issues, development of resource policy, and litigation support. I have often taught courses to technical and general audiences, and have given expert testimony on numerous occasions. Countries worked in include: Australia, Greece, Mali, Senegal, Guinea, Gambia, Ghana, South Africa, Iraqi Kurdistan, Oman, Pakistan, Kazakhstan, Kyrgyzstan,



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Mongolia, Romania, Russia (Buryatia), Papua New Guinea, Argentina, Bolivia, Chile, Colombia, Guatemala, Honduras, Mexico, Peru, El Salvador, Canada, Great Britain, United States.

2. My services have been contracted to supply comments on the Powertech (USA) Inc. Dewey-Burdock (D-B) In Situ Recovery NRC License Application for the express purpose of aiding the Oglala Sioux Tribe, and others, in the drafting of contentions to be submitted to the NRC. My CV is attached.

**Literature Reviewed**

3. In addition to my professional experience, the opinions and comments that follow are based on review of all, or significant portions of the following documents:

Powertech Application for NRC Uranium Recovery License, Dewey-Burdock Project, Feb. 2009:

- Technical Report (TR)
- Environmental report (ER)
- Supplement to Application, Aug. 2009

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**Summary of Comments.**

4. As discussed in detail below, the Powertech application is technically deficient and not well organized. The application fails to include and analyze sufficient data to justify the conclusions asserted that the proposed mine will protect water quality, the environment, and human health. In particular, the application is deficient with respect to the baseline ground water, surface water, and hydrogeological characterizations. These aspects are critical to providing a defensible demonstration that mining fluids and mobilized constituents can be contained within the mine production zone and that impacted ground water can be restored to acceptable standards. The application fails to provide an adequate presentation of the potential impacts associated with waste disposal from the proposed mining operations, whether disposal by deep well injection or surface land application. Lastly, the application neglects to provide sufficient discussion of financial assurance calculations or amounts, a critical component for protection of natural and human resources.

**Specific Comments**

**Powertech's Application is Technically-deficient and Disorganized**

5. Powertech D-B Application is so disorganized and technically-deficient that it does not comply with the terms of NUREG-1569 and other relevant NRC regulations and should be revised. The various portions of the D-B Application total almost 6000 pages and are composed of:

- Technical Report (TR)-- 3103 pages;



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- Environmental Report (ER)-- 2615 pages;
- Supplement to Application-- 66 pages.

The relevant information, if compiled in a direct, transparent manner using predominantly maps, tables and graphs, could easily have been summarized in 150 pages for the main volume. Instead, the Application is so duplicative and poorly-organized that it makes informed review by both the regulators and general public largely impossible. The Table of Contents for both the TR and ER provide no page numbers for the masses of information presented in the Appendices. The Appendices, in places, seem to have been thrown together with little or no logic to the organization. The authors of the main portions of the ER and TR, whoever they are, have made the review process unnecessarily convoluted, for both the NRC and the public. To that point, for numerous sections of the Application, it is not possible to discern whose opinions are being stated – Powertech's, one of their consultants, or some other source.

6. What follows in paragraphs (6-10) are a few examples of the disorganized nature of these documents: For both the ER and TR, the tables of contents present basic titles, but no page numbers for the thousands of pages of appendices. As it is the Appendices that contain much of the corroborating data, such careless organization makes document review and substantiation of claims written in the text unnecessarily difficult. The headings of the appendices, figures, and tables often are far too vague to be useful. For example, regarding ER Append. 3.4-A, the title simply says: WELL LOCATION DATA. This is an inadequate presentation and several questions are evident. Data complied by whom? When was the data compiled? For what types of wells (domestic? agricultural?)? Are those wells still in use? Are those wells monitored?



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7. There are several other similar examples. One title says: Wells in Dewey-Burdock Database. Was this database originally compiled by Powertech? TVA?

8. Surface water sites discussed on pg. 2-192 through 2-194 of the TR have no specific names; they are simply labeled BVC01, BVC04, CHR01, CHR05. The field data for these sites are not integrated with the lab data from the same samples.

9. Application documents fail to provide summary tables and figures where they are most necessary. For example, the ER, pg. 3-39-40 provides no summary of the wells discussed, their uses, water-bearing units / formations, etc.; such tables should be included in the text where the discussions are taking place.

10. Water-related discussions / data are scattered throughout the ER and present inconsistent findings. For example, a reviewer (NRC or public) of water-related issues must search through the following sections:

3.4 Affected Environment [WQ and Q discussions not integrated];

4.6 Potential WR Impacts

6.1.8 GW Sampling

6.2 Physiocehmical GW Monitoring

7.4.3 Potential GW Impacts

8.1 Summary of Env. Consequences

Appendices:

3.3A, D

3.4A, B, C, D, E

3.5I

6.1B, C, D, E, F, G



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Given the need for the applicant to submit supplemental information, these deficiencies should have been resolved at that time.

**An Independent Review of the Application Is Necessary**

11. Given the inherent conflict of interest in having the Application preparation directed, partially-prepared, and paid for by the project proponent, some independent party needs to take a more assertive oversight role, including in oversight of actual monitoring methods in the field. This is especially evident in the biased decisions made throughout these Application documents regarding baseline water quality and quantity decisions, as discussed below.

**Water Use: The D-B Project will use and contaminate tremendous volumes of ground water**

12. The D-B project area is semi-arid, having an average yearly precipitation of about 12 to 13 inches. While the application documents fail to report yearly evapotranspiration (ET), estimates of ET are roughly 70 inches per year, about 5 times the yearly precipitation (ER, pg. 3-176 and 177; Fig. 3.6-27). Because the project is presently expected to operate for between 7 and 20 years, it will require the use of tremendous volumes of local ground water.

13. Unfortunately, the Application documents present conflicting estimates of the volumes of water actually needed to operate the project. The ER, pg. 4-25, section 4.6.2.7.2 Water Requirements for the Proposed Action Facilities states:

"Water requirements of the CPP and other facilities are estimated to have a maximum requirement of **65 gpm**. As this requirement is relatively large, it is expected that most of this water will be derived from a water supply well in the Madison formation. Some of this water may be withdrawn from the Inyan Kara formation, but if so, it will not occur in



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a fashion to affect any well field operations."

While the last sentence is totally unclear as to specific details, the greater problem comes on reading ER pg. 8-2 (Table 8.1-1), which states that ground water consumption will be **320 gpm.** Aside from the obvious lack of consistency, both of the estimates translate into massive amounts of ground water when considered over the full life of the project.

The water usage data for the conflicting water usage numbers referenced in the Application result in total water consumption over the life of the project as follows:

**65 gpm = 34.2 Million gpy (gals / yr).**

**After 7 yrs = 239,148,000 gallons, or 239.15 Million gals.**

**After 17 yrs = 580,788,000 gals or 580.8 Million gals.**

**320 gpm = 168.2 Million gpy (gals. / yr).**

**After 7 yrs = 1,177,344,000 = 1.2 Billion gallons**

**After 17 years = 2,859,264,000 gallons = 2.86 Billion gallons.**

14. The TR, pg. 2-181, also says water requirements will be 65 gpm, but the subsequent discussion (pg. 2-181 and 2-182) indicates great uncertainty. These inconsistencies need to be rectified to enable effective public and NRC staff review. Clearly, both of these estimates indicate that vast quantities of ground water will be extracted from these aquifers over the long-term, and it seems overly-optimistic to simply state that no significant impacts will occur. At a minimum, Powertech should be required to construct a credible project water balance and to more seriously investigate the potential that such large-volume water use might impact local / regional ground water levels. At present, I see no evidence that the Application contains a reliable compilation of baseline water



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level data for the surrounding domestic and agricultural wells (see discussion below). Without such reliable, summarized data, there will be no viable method to demonstrate that ground water levels (and related pumping costs) have not been impacted by project-related activities.

15. The public must assume that Powertech will pay no cost for the actual water (the commodity) used during operations---while numerous other users do. The specifics of this issue should be addressed by Powertech in writing.

**Baseline Water Quality**

16. The Powertech Application fails to define pre-operational baseline water quality and quantity—both in the ore zones and peripheral zones, both vertically and horizontally. Without adequate baseline water quality data (both ground water and surface water), there is no reasonable method for either the public or the NRC to evaluate the success or failure of either fluid containment or aquifer restoration. The Powertech Application documents repeatedly attempt to convey the impression that the D-B ground water quality is already degraded, rather than compile statistically-defensible data from both the ore zones and non-mineralized zones. This approach contradicts NRC guidance, which requires that pre-mining baseline conditions be defined before licensing (NRC, 2003, pg. 2-24).

17. Clearly the Powertech ground water baseline data should include, as a minimum, the chemical constituents listed in Table 2.7.3.1 of the NRC's Standard Review Plan (NRC, 2003, pg. 2-25). It seems only logical that the actual list of baseline constituents should be based on analyses of pregnant solutions resulting from leach testing of the D-B ores and lixiviants—not on theoretical assumptions about what might be the chemical



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composition.

18. Frequently, uranium roll-front ores will also mobilize significant concentrations of additional constituents, such as antimony, lithium, and strontium (Moran, 1976). In addition, it is common to detect elevated concentrations of aluminum, sometimes as the result of well-drilling and completion techniques. Thus, it is recommended that these constituents be included in routine determinations of baseline water quality. In fact, standard lab analytical scans, such as ICP (inductively-coupled plasma spectroscopy) routinely report all (or most) of these metals and metalloids at the same cost. It should be noted that almost all of these constituents were included in the data in Appendix 3.4-C of the ER. I suggest that ammonia determinations be included to preclude future disputes regarding impacts (ammonia may enter the aquifer via numerous agricultural or industrial activities) along with ion balances, to assist in evaluating the reliability of the analytical data (Hem, 1985).

19. Section 2.7 of NRC (2003) is unclear whether applicants shall provide water quality data from unfiltered (Total concentrations) or 0.45-micrometer-filtered samples ("dissolved"). Much of the D-B data in the Application Appendices include both. It is recommended that unfiltered samples be collected and analyzed, as a minimum, for baseline ground water evaluation. These provide more *conservative* characterization of the ground waters, and waters used in rural areas (human and livestock consumption from wells; other agricultural uses; irrigation; fisheries) are not filtered. Furthermore, contaminants carried in particulate form are ingested by humans and other organisms when consuming unfiltered waters. These particles / colloids are dissolved by the extreme biochemical conditions found in the guts of such organisms, mobilizing the contaminants



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into the blood and other tissues. In addition, many trace constituents are mobile in ground waters as colloidal particles (McCarthy, 1989; Ramsey, 2000), which would be removed by filtration, generating unreasonably-low concentrations.

20. The D-B baseline data should include statistical comparisons of the field and lab determinations of pH, and S.C. for the same samples. See section….below for further discussion.

21. The D-B project area has been historically mined and thousands of exploration holes have been drilled within the properties. Hence, it is imperative that high-quality baseline data be supplied to evaluate the actual extent of past impacts to water resources, and the success of future containment or aquifer restoration.

22. No coordinated, statistically-sound data set for **all** Baseline Water Quality data (both surface and ground water) is presented in these documents—as is required in NUREG--1569. For example, on pg. 2-14 and 2-15 of the Technical Report (TR), Sect. 2.2.3.2.2., Powertech states: "At the project site, baseline groundwater sampling was conducted in general (sic) accordance with NRC Regulatory Guide 4.14 (NRC, 1980). ... A summary of the results and methods for the groundwater quality monitoring program, as well as the historical TVA data, is presented in Section 2.7." However, when the reader goes to TR Section 2.7, there are no tables that actually statistically summarize complete baseline field and lab water quality data for the complete data sets—both historic and recent. Instead, for ground waters, Powertech presents statistics for field data from individual wells or selected aquifers, but fails to statistically-summarize the laboratory data and leaves out the historic TVA data. Powertech then states (TR, pg. 2-203): "Complete groundwater quality data results are available in Appendix 2.7-G." However, on TR, pg.



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2-205 (Sect. 2.7.3.2.2.2, Results for Laboratory Parameters) Powertech then states: "Summary statistics for baseline monitoring program laboratory samples are contained in Appendices 2.7-H and 2.7-I. Appendix 2.7-H gives statistics for all groundwater constituents detected at or above PQL by constituent." Thus, it appears that Powertech has not included "qualified values," that is data reported as "less than" some concentration. By deleting the "less than" values, Powertech has severely biased the data set, rendering it useless as a reliable source for evaluating baseline conditions.

23. Furthermore, Powertech states (TR, pg. 2-217-218) that they have arbitrarily selected some analyses from the voluminous historic TVA data, but the reviewer is never allowed to see a statistical summary of the total original data set. Portions of the relevant data are scattered throughout the Appendices of the various documents, and disingenuously organized to leave out all baseline data that had concentrations reported below the detection limits (i.e. "less than" values). Obviously, this approach biases the data. Powertech must statistically summarize all historic water quality data and all recently collected data in separate tables, including all "less than values." Both historic and recent baseline data should be segregated by water-bearing unit. Even should averaging of water quality data over a portion of the aquifer be acceptable, the methodology employed in the Application of discounting relevant data points is untenable.

24. To further confuse the baseline issues, Powertech's Supplement to the Application (August 2009) states on pg. 3-3: "A minimum of eight baseline water quality wells will be installed in the ore zone in the planned well field area." Thus it appears that the Applicant intends that the massive amounts of water quality data (historic and recent) presented in both the TR and ER (Environmental Report) will not actually be used to



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determine baseline. More importantly, it is unclear whether Powertech has baseline (pre-operational) ground water quality data that describes the **non-ore zone regions of the relevant aquifers.** It is imperative that baseline data for the non-ore zone ground waters be collected and summarized separate from those of the ore zones. Lastly, the Application should already contain a statistically-reliable database of baseline ground water quality data from all known wells within at least a one-kilometer radius of the project boundary.

**Surface Water Quality Baseline Data: Application fails to include statistically-reliable summaries of detailed data.**

25. The D-B Application casually dismisses the possibility of any significant impacts to surface water resources [ER, Pg. 4-14: 4.6 Potential Water Resource Impacts.] Page 4-16 of the ER states: "ISL operations do not involve the consumption of surface waters. Nor do the operations proposed require a long- term discharge to surface waters. For these reasons, no significant impacts to surface water quantity and use are anticipated."

26. On ER, pg. 4-16 (Section 4.6.1.2 Potential Surface Water Impacts from Operations) it further states: "Potential impacts from accidental spills or permitted temporary discharge to surface water may include the release of process materials into the environment or a release or spill from the operation or well field (e.g., handling of fuels, lubricant, oily wastes, chemical wastes, sanitary wastes, herbicides, and pesticides). Surface water monitoring and spill response procedures will limit the impact of potential spills to surficial aquifers."

These statements are far too simplistic and self-serving. They fail to mention that all such operations generate short-term discharges to surface waters, as a minimum. More importantly, the Application fails to provide a summarized, statistically-reliable surface



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water quality baseline database. As such, there will be no defensible method for verifying whether impacts to surface water quality have or have not occurred.

27. ER pg. 4-16 also states: "Most ISL operations extract slightly more groundwater than they re-inject into the uranium bearing formation. ***The groundwater extracted from the formation could result in a depletion of flow in nearby streams and springs if the ore-bearing aquifer is hydraulically connected to such features.*** However, because most, if not all ISL operations are expected to occur where the ore- bearing aquifers are confined, local depletion of streams and springs is unlikely, and potential impacts would be anticipated to be SMALL (NUREG-1910, 2008)."

28. As stated above, there is ample evidence to suggest that portions of the impacted water-bearing zones are, in fact, in hydraulic connection with each other and are also likely to be hydraulically-connected with local surface waters, springs, and seeps, especially when **long-term operating conditions** are considered. More importantly, Powertech has failed to provide a reliable baseline spring and seep survey. Hence there would be no way to verify whether future impacts were the result of the D-B operations. The Application provides no support for such statements. Thus, it is imperative that reliable surface water quality baseline data be made public and that a viable seep and spring survey be performed, prior to the issuance of any licenses.

**The presence of high-quality ground waters within the D-B Project boundary have not been adequately defined.**

29. Much of the Application discussion concerning ground water quality seems focused on showing that the site waters are already contaminated. This would not be surprising given the presence of the uranium mineralization and the past mining and exploration activities---all of which would have caused increased concentrations of numerous



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chemical constituents above true pre-mining baseline. However, based on statements made in the ER, pg 1-16, Powertech has not adequately defined whether zones peripheral to the D-B ore-bearing geologic formations and bounding formations (above and below) also contain zones of high-quality, possibly potable ground water. Such zones should already have been defined as part of the Application documents.

**The Application documents fail to present an adequate database and summary of Baseline Ground Water Levels, both within the project boundary or outside.**

30. ER, pg. 4-18: states that "Background water levels will be monitored in regional wells." Such monitoring of water levels should already have been completed for numerous episodes over at least a one-year period prior to issuance of any permits. The Application also fails to provide a map and detailed program describing which wells will be included in such water-level monitoring.

31. Rather than presenting actual water level data, the Application (ER, pg. 4-21 through 4-23: Drawdown Estimates) attempts to substitute predictions of future water levels, all of which are based on unrealistic, theoretical assumptions. The public and regulators need to see actual baseline water-level data.

32. Also, the public and regulators should note the great range of uncertainty the ER presents for predictions of water level declines after 8 years of continuous pumping:

- at the nearest domestic well in the Fall River Aquifer, located 15,075 feet from the approximate center of pumping is **9.9 to 42.8 feet** (Pg 4-23);
- at the nearest domestic well in the **Lakota Aquifer**, located 10,915 feet from the approximate center of pumping is **4.9 to 12.6 feet.**

With such uncertainty, it is quite possible that some neighboring wells will be negatively impacted.



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**A Baseline Spring and Seep Survey is not presented in the Application.**

33. The Application ER, pg 3-58 states that the region surrounding the D-B project contains numerous springs in both the Madison and Minnelusa formations. Baseline surveys of springs and seeps are crucial in studies where large volumes of ground water are to be extracted. The flows of such seeps and springs often decline or stop after large-scale, long-term ground water extraction begins, especially in arid or semi-arid regions, such as the D-B area. If such impacts begin to occur, disputes will arise as to the possible roles of the project water extraction and overall climate change, for example. Hence, it is imperative that such a survey be performed prior to issuance of any licenses, and such a survey should include, as a minimum:

-locate and survey all springs and seeps within some reasonable radius of the project boundary;

-measure and record flow / discharge quarterly for at least one year prior to issuance of any licenses;

-during all field episodes, make field measurements of in-situ pH, water temperature, and S.C.(specific conductance) and collect samples for laboratory analysis. Samples should be analyzed for the same list of constituents noted in the Baseline water Quality comments above. Spring and seep water quality data should be interpreted as representative of local ground water quality (Freeze and Cherry, 1979; Hem, 1985).

**Chemical Analyses (Detailed) of Ores, Pregnant Leach Solutions, Liquid Wastes are not presented in the Application.**

34. The Application fails to provide actual, detailed chemical analyses (numerous) of representative pregnant leach solutions (ore reacted with lixiviant), both before and after undergoing ion exchange treatment. Such data would routinely include both in-situ



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measurements of fluid temperature, pH, specific conductance, possibly D.O. (dissolved oxygen) and Eh (redox). Similar representative, detailed data should also have been included for the detailed chemical composition of liquid wastes to be disposed of via deep-well injection or land application.

35. Because most mining projects at a similar stage of advancement have already conducted extensive laboratory testing and prepared Feasibility Studies to present to potential investors, such detailed chemical composition data would be available. It is not sufficient to present theoretical / expected chemical compositions, as has been done on ER, pg. 4-83. Smith & Assoc. (2005), pg. 5, reports that TVA, one of the previous mineral right holders, had a "pre-mine feasibility study" prepared, probably in the late 1970's or 1980's. If TVA had obtained such detailed data in earlier decades, certainly Powertech would have / should have also. Clearly some information in Feasibility Studies is considered proprietary, but detailed chemical composition data on the pregnant solutions and liquids / wastes described above should be included in any complete Application.

**The D-B water-bearing units are hydrogeologically interconnected.**

36. The application presents overly-optimistic conclusions about the isolation of the ore-bearing zones, aquifers, and the lack of fluid excursions that will occur, both vertically and horizontally. Powertech's description and evaluation of possible water-related impacts [ER pg. 8-2 (Table 8.1-1)] are unreasonably optimistic. It is unlikely that the process waters can be contained within the project boundaries given the following sources of the evidence.



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37. The D-B uranium deposits occur in subsurface, fluvial channel, sandstone deposits in the Lakota and Fall River formations (Smith, 2005). These sandstones inter-finger with finer-grained silts and shales, often associated with lignites and coals, which form the typical lithologic sequences often seen in classic sedimentary uranium deposits (Abitz, 2005; Gott, 1974; Henry, 1982; Galloway, 1982; Henry, 1980; Harshman, 1972).

38. Hydraulically, such sedimentary packages typically allow ground waters to flow between the inter-fingering facies, both vertically and horizontally, when the coarser-grained sediments are stressed by long-term pumping. The hydraulic inter-connections are verified by conducting long-term aquifer tests integrated with sequential water quality sampling and in-situ measurement of field parameters (Henry, 1982; Galloway, 1982; Moran, R.E.—hydrogeochemical research activities, U.S.G.S., Water Resources Div., 1973—1978).

39. Thus, ore-bearing sandstones in typical sedimentary packages associated with roll-front uranium deposits do not routinely behave as hydraulically-isolated bodies. Numerous specific lines of evidence from the D-B Application documents indicate that the project sediments possess various pathways for the migration of water and contaminants from the ore zones into neighboring sediments, both vertically and laterally. For example, thousands of exploration boreholes have been drilled since the 1950's at the D-B site (Smith, 2005; TR, ER), many of which were not correctly plugged and abandoned (TR, Pg. 2-157; Append. 2.7-B, sub-Appendix D, pg. 1484; TR, Append. 2.6-A, pg. 972-1111). In addition, several sources (Smith, 2005, pg. 9; ER, pg. 3-106) report that the area contains historic shallow mine workings, both open pits and short tunnels that would provide additional flow pathways.



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40. There are numerous old and existing water wells and old oil test wells in the D-B area, many with rusty and leaky casings, often unplugged or partially-plugged, drilled through several formations which act as potential pathways for flow between water-bearing units (ER, pg.3-40; TR, Append. 2.2-A, pg. 740-779; 2.2-B, especially pg. 864-902).

41. The TR, pg. 2-153-154, states that hydraulic connections between local D-B aquifers often result because confining units thin or are absent in many areas (ER, pg.3-56-57). In addition, Gott (1974) and others have mentioned the presence of breccia / evaporite pipes (collapse structures), which create vertical permeability pathways between aquifers. Gott (1974, pg. 27-29) and others discuss the common presence of faults and joints throughout the region, which could easily act as flow pathways.

42. Vertical and lateral hydraulic connectivity between the ore zones and the neighboring facies / formations are also indicated by the aquifer test results conducted in both 1979 and 2008 (ER, pg.3-56-57; TR, pg. 2-170 & 2-180, for example; TR Append. 2.7-B, Knight-Piesold Pumping Test Report, pg. 1290).

43. It seems obvious that the aquifer testing already performed demonstrates leakage between the various formations / facies bounding the ore zone. However, it seems equally likely that longer-duration aquifer tests conducted at even higher pumping rates would demonstrate even more clearly the leaky nature of these site sediments.

44. Repeatedly throughout the Application, Powertech states that the project will bleed 0.5 to 3% of leachate to maintain a cone of depression, which will prevent flow of leachate outwards (i.e. ER, pg. 1-14). Rather than supporting this allegation with long-term, technical data from other operating sites, Powertech has inserted a public relations



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statement from the mining industries' lobbying group, the National Mining Association (NMA, 2007).

45. D-B Application Supplement, pg. 5-5 describes an aquifer exemption boundary, which acts as an additional buffer zone outside the monitor well rings **"to provide protection to adjacent water from the excursions that occur in the normal course of operations."** Page 5-6 of the Supplement further states that the aquifer exemption boundary is proposed to be up to 1200 ft. outside the monitor well ring, and **would be considered the point of regulatory compliance. Apparently simply pumping to create an inward flow direction is not adequate to control "excursions."** It appears this aquifer exemption boundary is actually an expanded ground water sacrifice zone.

**Potential hydrogeologic pathways to nearby wells have not been adequately investigated and documented.**

46. The discussion above presents ample evidence that the D-B area sediments contain numerous possible subsurface pathways for project leach fluids to migrate vertically between water-bearing units and outside the project boundaries. Unfortunately, as noted above, Powertech has not adequately defined the baseline water levels or water quality conditions of neighboring wells within a 1 to 2 mile radius of the D-B project. In addition, the TR, pg. 2-180, states that no public data are available on the use of aquifers in Fall River or Custer counties. Such data should have been compiled by Powertech as part of the Application, and should be required before any licenses are given.

**Potential impacts to ground waters have been unrealistically minimized and inadequately characterized.**

47. Powertech has failed to provide adequate baseline data to demonstrate that portions of the ore-bearing zones do not contain high quality ground water. On pg. 4-18 of the ER



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they misleadingly state that all D-B ore zone ground water quality is degraded by natural mineralization processes. They have failed to provide the data to support this allegation and in many similar situations it is simply not true. Furthermore, many ground water-bearing zones in mineralized areas do not contain elevated concentrations of metals, non-metals, etc. until they have been exposed to air and bacteria---often as the result of previous mining or exploration drilling—as has occurred here. Even following exploration and mining activities, some portions of ore-bearing formations continue to contain high-quality ground water.

48. Hence, it is not defensible for Powertech to state, as they do in Sect. 4.6.2.2 (Potential Impacts of Production on Ore Zone Groundwater Quality) that: "Potential environmental impacts to groundwater are changes to water quality in well fields within the exempted aquifer. The impact, in and of itself, it is of limited significance, due to the fact that the groundwater quality is very poor prior to ISL operations; due to the presence naturally occurring radionuclides, heavy metals, and other constituents that exceed EPA and/or state drinking water limits. Accordingly, the exempted aquifer is not and can never serve as a USDW (HRI, 1997; NMA, 2007)." The citations provided here by Powertech do not pertain to the specific D-B situation and one, the NMA citation, is simply a routine public relations statement made by the industry's lobbying group.

49. The public relations statements continue on ER, pg 4-18, where they state: "Powertech (USA) has proposed to use gaseous oxygen and carbon dioxide lixiviant. The interaction of the lixiviant with the mineral constituents of the exempted ore zone results in a slight increase in trace elements and primary constituents of sulfate, chloride, cations and TDS above pre production levels. There is no introduction of non-naturally occurring



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constituents from the leach fluids into the ore body."

50. To support these unsubstantiated statements, Powertech needs to supply actual, detailed chemical analyses of the pregnant leach solutions (multiple analyses)--solutions resulting from the chemical interaction of the proposed lixiviant and the ore zone rocks. All responsible parties knowledgeable about ISL operations are aware that the introduction of these lixiviants drastically changes the local ground water chemistry, routinely producing significantly-elevated concentrations of many major and trace metals and metalloids, plus other constituents: i.e. arsenic, antimony, molybdenum, selenium, vanadium, uranium, strontium, iron, manganese, lead, lithium, nickel, chromium, sulfate, chloride, etc. It is a total "red-herring" to claim that: "There is no introduction of non-naturally occurring constituents….."

51. In addition, there is ample evidence in the technical and regulatory literature to show that the leached aquifers at most, if not all ISL operations, have never truly been restored to their pre-operational, baseline water quality.

**Land application is not an approved method of radioactive liquid waste disposal.**

52. Powertech has proposed that various liquid wastes may be disposed via land application. However, US EPA (2008) guidance states that such land application is not an approved method for disposal of such wastes. Equally importantly, Powertech has failed to supply detailed chemical analyses of these proposed wastes (see discussion above) to clarify the chemical nature of the materials being disposed.

53. It is ironic that the Supplement to the Application states on pg. 4-7 that irrigation pivots have been used to dispose of non-hazardous wastes via surface application " with no deleterious effect on the environment" at Hobson, Mount Lucas, and Highland. In



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2008, the operators of the Highland and Smith ISL mines in Wyoming were forced into a settlement agreement with the WY Dept. of Environ. Quality, because land application of liquid wastes containing elevated concentrations of selenium had contaminated soils. Part of the settlement agreement required the operators of Highland to immediately pay $8 million to accelerate reclamation activities and to increase their financial assurance bonds for these two sites to $80 million (WY DEQ, 2008). Furthermore, Faillace and others (1997) report that release of such waters will contaminate the soil at the land application areas. Radionuclides adsorbed by the soil will become a source term for radioactive release through wind erosion processes.

**Deep Well Injection of Liquid Wastes. The Application fails to provide necessary details on the chemical composition of the wastes and water treatment specifics.**

54. ER, Pg 4-21 (4.6.2.6 Potential Impacts of Groundwater Consumption During Operations and Restoration) states: "The majority of groundwater used in the ISL process will be treated and injected." However, no details are provided on the (actual) chemical composition of either the untreated or treated liquid wastes. Instead, ER, Pg 4-83 states: "The physical and chemical properties of the wastes will be similar to the estimated quality of wastes provided in **Table 4.15-1 for land application**. The process waters for deep well injection will meet the regulatory provisions in 10 CFR 20.2002 and be within the dose limits in 10 CFR 20.1301." Table 4.15-1 lacks many of the constituents for which water quality standards / criteria exist. Powertech should be required to provide actual, detailed analyses for such wastes.

55. In addition, the Application presents no details on the specific methods of water treatment that would be used prior to injection. As discussed above, such details are routinely known at this stage of a project.



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**Ground water sampling results presented in ER, section 6.1.8 (Groundwater Sampling, pg 6-62) should be combined and integrated with those in ER, Chapter 3.**

56. ER, pg 6-69 states: "A groundwater quality constituent list was developed based on NUREG-1569 groundwater parameters, NRC 4.14 parameters, and added parameters from a constituent-list review with SD DENR." It is recommended that the constituent list be expanded to include all constituents for which any water quality standards or use criteria exist.

57. Which specific personnel performed the actual field activities (sampling and measurement)? Do field sheets exist to demonstrate that samples were preserved in the field?

**The technical and regulatory literature amply documents the numerous failures to restore aquifer water quality at other ISL sites. Thus, it is reasonable to assume that portions of the D-B ground water surrounding the leached zones will have degraded water quality and may be unfit for future uses.**

59. Powertech repeatedly makes optimistic statements about aquifer restoration such as: "Powertech (USA) will restore GW in each depleted well field consistent with pre-operational or baseline WQ conditions……." ER, pg. 1-1. However, there is no demonstration as to other in-situ operations that have been able to do so. Indeed, the historical reality from other operating or closed ISL sites demonstrates an inability to restore to pre-operational or baseline WQ conditions for all constituents. (Otton, 2009; Hall, 2009).

**The Application fails to adequately describe the common names (in addition to commercial names) and quantities of chemicals, fuels and explosives to be used and stored per year at the D-B site.**

60. The ER, pg. 1-32, presents some information on the chemicals to be used, but no quantities are given. ER, pg. 1-34, Sect. 1.4.7.9 presents a very limited mention of the



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fuels to be used, but again no details on the quantities. All categories of chemicals, explosives, fuels, and any other potential environmental contaminants need to be summarized in a simple table including estimated quantities to be used per year. *Equally importantly, all categories of baseline monitoring should determine chemical constituents that will indicate the possible presence of these compounds (organic and inorganic) in the environment.*

**What Commercial Products will be Extracted?**

61. Does Powertech intend to produce only uranium yellowcake as a commercial product or will other products be generated? [Any molybdenum, selenium, etc. products anticipated?]

**Improper Technical Conclusions.**

62. The Application is inadequate in its attempt to demonstrate that the ground water quality data are of suitable quality, as on ER pg. 3-61, 62. Here they state that a comparison of field and lab pH and specific conductance data "are within reasonable limits." Despite the vagueness of the language, this statement / section demonstrates a failure to understand the basics of applied water quality. Ground water chemistry routinely changes between the time a water sample is lifted from a well--where field pH and S.C. measurements should be made immediately--and much later when investigated in a laboratory. Hence, it is inappropriate to argue that, for example, the highest measured field pH was 12.67 and it "was verified by the contracting laboratory which reported a pH of 12.4 in the sample" (p. 3-62). Of course the chemistry changed as the temperature and pressure of the sample changed, the sample de-gassed, and various chemical reactions occurred. However, the authors failed to comment on the significance of the actual



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reported pH of 12.67. In such a hydrogeologic setting, a site that had been previously drilled by thousands of exploration boreholes, and possibly previously mined, the logical conclusion is that such a pH represents evidence of some form of contamination -- possibly from the incorrect completion of a well with cement and / or bentonite grout, a spill of some alkaline chemicals, or from some past attempts to test the leachability of these ores using an alkaline lixiviant. The same is true for the insufficient discussion of the field versus lab specific conductance values at well 677, which were reported to be 12,220 μS/cm versus 11,000 μS/cm (pg. 3-62). The authors ignore the more reasonable conclusions that some form of contamination has occurred.

63. However, someone preparing the Powertech ER knows that water quality data should be summarized statistically, as is evidenced by the format of ER Table 3.4-4, for all Powertech field parameters. Unfortunately, the Powertech documents fail to summarize the *laboratory data* in the same fashion. Nowhere else in the body of the ER is a similarly-detailed, statistical summary of water quality data presented. Also, they fail to include the previous water quality data from the historic TVA and other data in these summaries. Worse, they have chosen to leave out of their water quality summaries all lab data that have *qualified values* -- that is, values reported as "less than" some concentration. This approach totally biases the various data sets, because it neglects to include all determinations that had very low concentrations.

**Compliance: The actual regulatory role of US EPA here is unclear.**

64. Application Supplement, pg. 5-6 states: "EPA Region 8 has stated that they want to limit the distance outside the monitor well ring to minimize potential environmental impact. There is an idea that if there is an excursion out to the aquifer exemption



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boundary, operations will be shut down." This description does not provide a sufficient description of the EPA's regulatory program. The application should define these specifics, including a full description of "the idea that if there is an excursion out to the aquifer exemption boundary, operations will be shut down."

**UCL Parameters should be approved by NRC.**

65. Application Supplement, pg. 5-6, Sect. 5.2.7 states: "Powertech management has always used Chlorides, Sulfate, and Uranium as Upper Control Limit (UCL) Parameters. Sometimes Total dissolved Solids is used." This statement seems disingenuous as Powertech has never operated an ISL mine. Once a reliable baseline ground water database has been approved (for the various zones described above, not simply the ore-bearing zone), the NRC should approve the constituents designated as UCL parameters.

**Powertech's proposed ALARA goal for limiting uranium concentrations in site soils**

66. The ER, Pg 4-80 states: "Powertech (USA) Uranium USA proposes an ALARA goal of limiting the natural uranium concentration in the top 15 cm soil layer to 150 pCi/g averaged over the impacted areas. Subsurface soil (greater than 15 cm) natural uranium concentrations should be limited to 230 pCi/g averaged over the impacted area based on chemical toxicity." NRC should make public its opinion on this proposed goal prior to the issuance of any licenses.

**Soil contamination (radiation and metals / metalloids) from past mining and exploration should be incorporated into determining baseline**

67. ER, pg. 6-13 (Monitoring Programs--Surface Mine Area) states: "In the surface mine area, the gamma-ray count rates ranged from 5,550 to 460,485 cpm and the median was 12,717 cpm. In general, clusters of higher readings are associated with un-reclaimed open pit uranium mines, waste rock, rocky outcrops, and drainages in the surface mine area."



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"It is clear that the surface mine area in the eastern quarter of the site exhibits radiological impacts from historic and/or current anthropogenic activities within the area. In addition, gamma-ray count rates in the anomalous north area also are clearly distinct from those in the wider main PAA. **The precise sources of the differences are not relevant in the context of this investigation since they are part of the baseline or background radiological characteristics of the site."**

68. The site is clearly contaminated from past activities, and no reclamation has been required. Powertech has a conflict of interest if allowed to determine which data are relevant here. The NRC should make public its opinions on these matters prior to issuance of any licenses.

**Baseline soil and stream sediment databases should include data for a broad suite of other chemical constituents (metals, organics, etc.) besides simply selected radiochemical constituents.**

69. The ER, pg 6-21and 22 (6.1.3 Soil Sampling) states: Soil samples were analyzed for radium-226 while two were also analyzed for natural uranium, thorium-230, and lead-210. Baseline soil data should include data for a many additional chemical constituents, especially those that are routinely considered to be potentially toxic at hazardous waste sites. Similar comments pertain to stream sediment samples, which are described on ER, pg 6-41.

**Financial Assurance.**

70. The NRC and the general public know several general facts about the usefulness of most company-generated financial assurance estimates:



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1-They generally are based on overly-optimistic assumptions about future water quality, thereby under-estimating costs. Kuipers (2000) conducted a survey of bonding practices at metal mines throughout the western U.S. and found that the bond amounts available were hundreds of millions of dollars below that necessary to conduct actual clean-ups. Many of the "problem" sites have been foreign-owned entities, especially those with their corporate headquarters and assets based in Canada.

2-Aquifer restoration at most, if not all previously-licensed and operated ISL sites fail to actually return ground water quality to baseline conditions [Hall (2009); Otton and Hall (2009);

3-Predictions of future aquifer restoration success made by the project proponents seldom use truly conservative assumptions. Calculation of financial assurance amounts made by representatives of the party that stands to profit from project licensing represent an extreme conflict of interest.

4-The technical literature is filled with documentation that quantitative predictions of future water quality at specific sites cannot be done reliably [Sarewitz, et. al. (2000); Moran (2000); Pilkey & Pilkey-Jarvis(2007); Kuipers & Maest (2006)], and the general failure to restore aquifers back to pre-operational baseline concentrations supports this. At an academic level, this approach must be totally rejected because it assumes one can make accurate and precise *deterministic* predictions.

71. For these reasons, the financial assurance calculations should be made by some independent party, not paid or directed by the project proponents. These calculations should also consider the actual reclamation and restoration costs incurred, long-term, from a statistical sampling of the previously-licensed ISL sites. Furthermore, these



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financial assurance amounts and mechanisms should be made public prior to award of any licenses.

72. To ensure protection of the general public, such financial assurance vehicles (bonds, etc.) should be made with the parent corporation, not simply the local operating entity.

Pursuant to 10 C.R.F. § 2.304(d) and 28 U.S.C. § 1746, I declare under penalty of perjury, that the foregoing is true and correct to the best of my knowledge and belief. Signed on the 4th day of April, 2010,

Robert E. Moran, PhD.



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UNITED STATES OF AMERICA
NUCLEAR REGULATORY COMMISSION

BEFORE THE ATOMIC SAFETY AND LICENSING BOARD

| | | |
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| In the Matter of | ) | |
| | ) | |
| POWERTECH (USA) INC., | ) | Docket No. 40-9075-MLA |
| | ) | ASLBP No. 10-898-02-MLA-BD01 |
| (Dewey-Burdock In Situ Uranium Recovery | ) | |
| Facility) | ) | |

**SECOND SUPPLEMENTAL DECLARATION OF DR. ROBERT E. MORAN**

I, Dr. Robert E. Moran, do hereby swear that the following is true to the best of my knowledge:

1. **Professional Qualifications and Introduction**

**Robert E. Moran, Ph.D.**
Michael-Moran Assoc., LLC
Water Quality/Hydrogeology/Geochemistry
Golden, Colorado, U.S.A.
remwater@gmail.com

I am a hydrogeologist and geochemist with more than 42 years of domestic and international experience in conducting and managing water quality, geochemical and hydrogeologic work for private investors, industrial clients, tribal and citizens groups, NGO's, law firms, and governmental agencies at all levels. Much of his technical expertise involves the quality and geochemistry of natural and contaminated waters and sediments as related to mining, nuclear fuel cycle sites, industrial development, geothermal resources, hazardous wastes, and water supply development. In addition, I have significant experience in the application of remote sensing to natural resource issues, development of resource policy, and litigation support. I have often taught courses to technical and general audiences, and has given expert testimony on numerous occasions. Countries worked in include: Australia, Greece, Bulgaria, Mali, Senegal, Guinea, Gambia, Ghana, South Africa, Iraqi Kurdistan, Oman, Pakistan, Kazakhstan, Kyrgyzstan, Mongolia, Romania, Russia (Buryatia), Papua New Guinea, Argentina, Bolivia, Chile, Colombia, Guatemala, Honduras, Mexico, Peru, El Salvador, Belgium, France, Canada, Great Britain, United States. My curricula vitae is attached.



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NRC Responses to Comments do not Address or Change Previous Opinions.

3. The Final SEIS contains almost no technically-substantive responses to my past comments (attached). They frequently avoid discussing technical details by stating that the approach taken in this SEIS complies with appropriate regulations---disregarding the real-world experiences from previously-operated sites. Furthermore, the Final SEIS contains no new data, either from Powertech sources, but more importantly from any independent sources. The conclusions presented in this Final SEIS are based almost entirely on data collected by Powertech or their consultants, and on summaries and interpretations presented by Powertech to the NRC. The responses provided in the FSEIS do not substantively change the assertions or conclusions put forward in my previous declarations.

Water Resources and Related Impacts.

4. These opinions focus predominantly on the water resources and related impacts within the proposed Dewey-Burdock (D-B) area. The D-B waters are natural resources presently used collectively by numerous parties (ranchers, municipalities, tribal groups, fish and wildlife, mineral and oil and gas developers, etc.). The actions proposed in the SEIS will result in negative impacts on water and additional costs for the general public that are clearly not renewable. These include:
   -allowing Powertech to use tremendous volumes of water, which will increase competition for this water with other users;
   -removal of ground waters from public use (exempted aquifer);
   -contaminate and degrade the quality of much of this water;
   -divert much of the water to deep aquifers where it will be unusable;
   -evaporate much local ground water into the air where it will not be usable locally;
   -these short-term actions are likely to render these ground waters unusable for future, long-term uses, many of which may not be anticipated until many years in the future.

5. The Final SEIS must, but does not, realistically anticipate what will be the true *long-term* uses of these waters---especially when many generations must be

considered. Thus, *truly conservative assumptions* should be employed—which is not the case in this Final SEIS.

SEIS Water-related Sections Predominantly Based on Information from Biased Parties.

6. It is my experience that the agency preparing the NEPA document is responsible for ensuring accurate data, , but almost all of the data and fundamental, technical opinions in the SEIS were taken directly from reports generated by the applicant or their consultants. Even where the applicant has presented controversial flow pathway interpretations (for example, that the D-B site contains no faults, fractures, collapse structures), the NRC has repeated these interpretations in the SEIS as accepted conclusions. The presence of such geologic structures has been described in other historical documents (i.e. TVA, 1979; Butz, et. al. 1980), yet the NRC chose not to address these well-respected scientific opinions in the SEIS.

The SEIS quotes *generic* sections from the GEIS, but the NRC staff then fail to provide independent interpretations of the site-specific (D-B) data and information.

7. For example, on SEIS p.4-60: "Consumptive water use during ISR operations could impact those who use local water from the production aquifer outside the exempted zone. This potential impact will lower water levels in nearby wells and reduce the yield of these wells. In addition, if the production zone is hydraulically connected to other aquifers above and/or below the production zone, consumptive use may impact the water levels in these overlying and underlying aquifers and reduce the yield in any nearby wells withdrawing water from these aquifers. (NRC, 2009a)".

8. Such generic statements are made throughout the SEIS, yet the NRC then proceeds to use the data and assumptions from Powertech to explain why such impacts are not likely to occur. This is a disingenuous use of GEIS language to imply future site-specific safety and minimal impacts at D-B. In my experience, independent verification of an applicant's site-specific data and analysis is conducted by the reviewing agency.

Many Unknowns.

9. The SEIS fails to provide verifiable, detailed information on quantities of water available in aquifers to be impacted, or on the interactions (hydraulic and chemical) between these aquifers when pumped long-term. The NRC has allowed the applicant to delay collection of such detailed data until after permit approval. As such, there is no reason to accept Powertech's optimistic claims about the volumes of water to be used, or the impacts to be generated. They simply have not performed adequate testing to provide detailed answers to these questions.

10. Additional fundamental water "unknowns" that are not answered in the SEIS, but which are delayed until after permit approval include:

**-Pre-mining "Baseline"** will be determined after permit approval. [SEIS, V.1, p. 2-37 (131). Throughout the SEIS it is confusingly and inconsistently called "**background".**
- **Aquifer clean-up criteria** will not be determined until after permit approval and could change (be weakened) depending on the applicant's ability to remediate the aquifer(s). [SEIS, V.1, p. 2-35 & 2-37(129-131)].
-**Detailed hydrogeologic characteristic** of aquifers and inter-beds, surface water-ground / water interactions, including long-term pump tests; to be performed and determined after permit approval (SEIS Section 2.1.1.1.2.3).
-**Long-term water level declines** during and after long-term pumping and operation. For example, what will be long-term water level declines in the Madison aquifer at Edgemont where Madison wells supply municipal water? No detailed testing data have been supplied in the SEIS. To be determined after permit approval.
-**Specific lithologic details** of site sediments. These details to be determined after permit approval (SEIS Section 2.1.1.1.2.3).
-**Detailed Operating Procedures**, such as whether the applicant will mine in partially-saturated, eastern zones of the Chilson; to be determined after receipt of permits.
-**Detailed Water Rights** / hydrogeologic studies necessary to determine that adequate **unappropriated** ground waters exist in the Madison or Inyan Kara. Such detailed studies have been conducted and **relevant South Dakota Water Rights permits have not been received.** To be done after receipt of NRC permits.
-**Methods of liquid waste disposal** to be employed. Will deep-well injection or land application methods, or some combination be employed, and what are the technical details. To be determined after permit approval.
-D**eep-well, underground injection (UIC) permits.** These issued by US EPA, but EPA has not commented on these issues or awarded the permits. To be determined after NRC permit approval. In order for EPA to reliably evaluate the UIC options, they must have access to the detailed hydrogeologic data and information mentioned above, but which will not be available until after NRC permit award.
**-Aquifer Exemption (Inyan Kara).** Must be approved by US EPA, but will not done before NRC permits are issued.
**-Detailed chemical compositions** of pregnant leach solutions, liquid waste solutions (to be disposed by deep-well injection or land application), solid wastes accumulating in land application facilities, etc. are unknown and not reported in the SEIS. Powertech has publicly-stated that they have completed at least one Feasibility Study, so all such detailed information must already be known.
**-Financial Assurance details and amounts.** All such details are unknown and should be public before the NRC license is approved. Financial Assurance calculations are presently handled by three separate federal and state agencies.

Since NRC predicts that water-related impacts will be SMALL, then the Financial Assurance dollar amounts are likely to be relatively SMALL. Thus, there will be little protection for the taxpayers in the event of unforeseen impacts or unexpected project closure.

-**Detailed Water-related Impacts**. Because *detailed*, site-specific geologic, hydrogeologic, and geochemical data are not presently available, it has not been possible to reliably evaluate future water-related impacts (i.e. specific volumes of water available from the Inyan Kara aquifers). Thus, the estimates of impacts [SMALL, MODERATE, LARGE] presented by the NRC in the SEIS are based on inadequate data. Clearly such impacts will only be determined after permit approval.

**-Historical Data on Aquifer Restoration at Other ISL Sites.** The NRC, both in the SEIS and in their responses to public comments, repeatedly cites the results they have compiled from three NRC-licensed ISL facilities (COGEMA's Irigary/Christensen Ranch facility, PRI's Smith Ranch/Highland Uranium Project facility, and Crow Butte Resources' Crow Butte facility) (NRC, 2009b). However, it is misleading to selectively cite the results from only three ISL operations when data from at least 30+ such ISL operations should have been compiled for comparison. All such data / information I have reviewed—in addition to the three cited by NRC-- also indicate an inability to return the ground water quality to preoperational baseline. While the NRC did not directly regulate many of these operations, surely the NRC could have obtained these data if they truly wanted to evaluate the success or failure of aquifer water quality restoration over numerous decades. As such, it is clear that no one has conducted a reliable, representative study to evaluate long-term effectiveness of aquifer restoration (of preoperational water quality) at the vast majority of operating and closed ISL sites—at least not one that is publicly-available.

11. Clearly, the post-restoration water quality within the exempted aquifers, for many chemical constituents at the three sites cited by the NRC, was not returned to preoperational conditions / concentrations. Thus, these exempted waters are lost to the public for numerous future uses without some form of additional, costly treatment.

<u>D-B Uranium ore zones are NOT hydraulically-isolated from other geologic units, other aquifers, or zones outside the project area.</u>

12. The NRC has disregarded the conclusions of numerous hydrogeologic experts (both Powertech-funded and independent experts) in stating the following (Final SEIS, Exec. Summary, p. xxxvi): "Alluvial aquifers are separated from production zone and surrounding aquifers by thick aquitards (confining units) and, therefore, are not hydraulically connected to production zone and surrounding aquifers."

13. This incorrect and overly-simplistic statement clearly contradicts expert opinions which state or infer that, long-term, all of the relevant D-B water-bearing zones are hydrogeologically-interconnected (i.e. Keene 1973; Gott, et. al., 1974; TVA,

1979; Butz, et. al., 1980; Smith, 2005; Boggs & Jenkins, 1980, Boggs, 1983, Bredehoeft et. al., 1983; Knight Piesold, 2008.

14. After reviewing the relevant data, reports and various combinations of satellite imagery, I also conclude that these relevant D-B water-bearing zones are hydrogeologically-interconnected, especially when subjected to long-term pumping.

15. Powertech's management and ground water experts have made inconsistent statements about whether the D-B confining units are leaky or not, varying between individual reports, deposition opinions and public hearing testimony. In this Final SEIS, Powertech (through the NRC authors) states that all of the relevant pumping tests indicated that the D-B sandstones behaved as leaky-confined aquifers (SEIS, p. 3-34). The consultants who conducted these pumping tests reported the same conclusions. Nevertheless, on SEIS, p. 3-36, it states:

    "Based on results of the numerical model, the applicant concluded that vertical leakage through the Fuson Shale is caused by *improperly installed wells or improperly abandoned boreholes."*

16. These inconsistencies make clear that Powertech has failed to define the detailed, long-term hydrogeologic characteristics and behavior of the relevant D-B aquifers and adjacent sediments.

17. It is not unusual for the inter-fingering sands, shales, etc. of sedimentary uranium deposits to be hydrogeologically interconnected, when pumped, long-term. In fact, it is the norm.

<u>Potential Groundwater-Flow Pathways at D-B.</u>

18. D-B sediments are hydrogeologically-interconnected by several potential pathways, which include:
    - -inter-fingering sediments;
    - -fractures and faults;
    - -breccia pipes and / or collapse structures;
    - -4000 to 6000 exploration boreholes (Bush, 2010, Update Technical Report, prepared for Powertech, states approximately 6000 drill holes are present at D-B);
    - -oil test wells.

19. **Drilling of hundreds and thousands of wells since the 1880s has caused drop in artesian pressure of the various sedimentary aquifers in the southern Black Hills areas** (Keene, 1968; Darton, 1909; Davis, Dyer &Powell, 1961). Therefore, many wells and boreholes that formerly flowed to the land surface no longer do so, but still contained water under pressure. Thus, contrary to the NRC and applicant comments in the SEIS, upward flowing waters in these

wells and boreholes can interconnect and mix between the various vertical water-bearing zones without showing any expression at the land surface.

[Keene (1968) p.24: Re. Fall River Fm: " Interview reports indicate that the yields from the Fall River sands have dropped within recent years. Part of this problem is probably due to incrustation.....However, some of this loss of head may result from the recent uranium exploration program. The author personally saw uranium test holes that were uncased, unplugged, and flowing at the surface. This practice is not only wasteful of water, but will ultimately lead to loss of pressure in the aquifer and possible contamination of the Fall River and Lakota aquifers."]

20. Powertech has repeatedly claimed, and apparently the NRC accepts, that no significant geologic structures are present at the D-B site, structures which could allow migration of water vertically or horizonally. Again, this claim is contradicted by numerous published reports, such as: Braddock,1963; Butz, et. al.,1980; Gott, et. al., 1974; Smith, 2005; TVA, 1979. In addition, review of several forms of D-B-area satellite imagery by myself and senior remote-sensing experts at Front Range Natural Resources, Ft. Collins, CO, shows clearly that this area is intersected by numerous faults and fractures. The imagery also shows evidence of circular geologic features at the land surface, indicating the presence of collapse structures.

Breccia Pipes / Solution or Collapse Features.

21. Numerous authors state that breccia pipes / collapse structures allow upward flow of ground waters from the Paleozoic formations to the Inyan Kara rocks at the southern margins of the Black Hills [Bowles, 1968; Braddock, 1963; Keene, 1973; Gott, et. al., 1974; TVA, 1979; Butz, et. al., 1980. Carter, et. al., 2003 state such recharge to the Inyan Kara may occur via such pathways.]

22. However, several Powertech reports and the Final SEIS argue that there is no evidence that breccia pipes or related collapse structures exist within the D-B property [i.e. NRC, 2014(Final SEIS); NRC, 2013 (March), Safety Evaluation Report, p.40; Clarification of Breccia Pipes, LSMPA, Append. 3.2-C. [Sept. 2012].

23. In Appendix 3.2-C of the Large Scale Mine Permit Application [Powertech 2012 (Sept.)] Powertech presents a map, Plate 2, which shows a red line that supposedly represents the area in which evidence of breccia pipes and collapse structures have been reported. This Plate was modified by Powertech from an original map in Gott, et. al., 1974, [U.S.G.S. Professional Paper 763], Plate 4. However, Powertech has misrepresented the data on the original U.S.G.S. map, neglecting to include several locations within the outcrop areas of the Inyan Kara rocks that were originally described as being "topographic depressions" or "structures of possible solution origin". Clearly the original U.S.G.S. authors mapped these areas within the Inyan Kara rocks—near the D-B project-- as probable locations of solution features, such as breccia pipes.

24. Similar circular, topographic features can be seen on modern, satellite imagery of the D-B site and surrounding areas. It is my opinion and that of senior remote-sensing experts at Front Range Natural Resources, Ft. Collins, CO, that these features likely represent solution / collapse structures.

25. Neither Powertech nor the NRC have presented any detailed interpretations of the D-B structural geology using high-quality satellite imagery. Until such studies have been performed, it is reasonable to assume that these circular features are potential pathways for upward migration of ground waters into the Inyan Kara sediments.

26. Instead of meaningfully addressing my opinions, or the cited literature confirming the complex hydrology of the project area, this SEIS continues to allow Powertech to delay conducting detailed hydrogeologic testing and determination of detailed aquifer cleanup standards until after the NRC has given project approval. Detailed hydrogeologic and water quality studies must be conducted **prior to** issuance of NRC / State permits. Otherwise, it is not possible for regulators or the public to reliably evaluate potential impacts and consequences to natural resources and the environment.

<u>The applicant will use and contaminate tremendous quantities of ground water.</u>

27. Because differing water use volumes are presented in different sections of the SEIS, and because of the numerous operational uncertainties, reliable estimates of D-B water use volumes are unclear. The SEIS confirms that there are known volumes of water the applicant has applied for from the State of South Dakota [SEIS, p. 4-54 & 4-55 (360-361)]:

28. Powertech has applied for water from the Inyan Kara: 274.2 ac-ft of water **annually** at a rate of 8500 gpm = 12,240,000 gpd (gallons per day) = **4.5 Billion gallons per year = 89.4 Billion gallons over 20 years.**

    Powertech has applied for water from the Madison: 888.8 ac-ft water annually at a maximum rate of 551 gpm = 793,440 gpd = 289,605,600 gallons per year **(289.6 Million gallons per year)** = **5.8 Billion gallons over 20 years**.

    If deep disposal wells prove feasible, up to about 160 gpm will be required from the Madison. At 160 gpm = 84 Million gallons per year
    20 years = 1.7 Billion gallons over 20 years.

29. Referring to the Inyan Kara waters, the SEIS states that consumptive use will be relatively small as only 2 percent of the water will be disposed of as liquid waste (assuming UIC option is accepted). However, this estimate clearly neglects the fact that much of the water from either aquifer will have been contaminated, and that the water undergoing land application will be lost via evaporation /

evapotranspiration. In either case, this water is no longer available for present or future uses within the exempted aquifer zone. Clearly, the SEIS under-estimates the volumes of water that are lost or contaminated through these processes.

30. Because disclosure and analysis of detailed hydrogeologic evaluations have been delayed until after NRC permit approval, it seems untenable to state that approval of the application "will not result in average annual withdrawals from the Inyan Kara aquifer that exceed the average annual recharge to the aquifer." Likewise, using such limited testing data and modeling results, any estimates of long-term water level drawdown in either the Madison or Inyan Kara are semi-quantitative, at best.

No Adequate, Detailed Water Balance Presented in SEIS.

31. In order to evaluate the adequacy of mine water-related data and water management practices, it is standard practice for EISs and similar mine environmental reports to include a detailed water balance. Such a balance includes measured data for all water inputs and outputs related to all mine operations and all sources of water that might influence these operations. Essentially any detailed ground water textbook describes the workings of such water balances (e.g. Freeze & Cherry,1979) and ICMM (2012) and Golder Assoc. (2011) represent two industry-sponsored studies that describe how water balances should be applied at mine operations.

32. On page 2-36 the SEIS (see Fig. 2.1-14) contains what the authors claim is a water balance, but it clearly is not. In fact, it is actually labeled as "Typical Project-Wide Flow Rates". This is not a water balance for the D-B site or D-B operations. It lacks basic components of a water balance, including detailed, measured data for volumes of water entering the system and losses (e.g. volumes of ground water available in the various aquifers, evaporation from land-application facilities, volumes under-going UIC injection, etc.), and *fails to calculate an actual balance.* Clearly a reliable water balance was not prepared and moreover, could not be prepared until the detailed testing has been completed.

33. Apparently this misleading figure was added to the SEIS because of past criticisms of the lack of water balance in the Draft SEIS. However, NRC has not cured the deficiency by including a flow rate figure, which lacks the basic components of a water balance.

Tens of Thousands of Pages.

34. As of the end of 2013, one of the South Dakota law firms representing various citizen's groups against Powertech stated they had already received roughly 70,000 pages of documents related to D-B issues. The two volumes of the Final SEIS add another 1310 pages. **Nevertheless, the Final SEIS authored by**

**Powertech and the NRC still fails to provide some of the most basic information necessary to answer fundamental questions relating to the D-B water resources and possible impacts to these resources.**

35. The original Draft Environmental Statement for the Edgemont Uranium Mine, prepared by the Tennessee Valley Authority (TVA, 1979) was only 208 pages in total.

Short-term versus Long-term Impacts.

36. The SEIS fails to consider true, long-term impacts from either the proposed D-B operations or regional CUMULATIVE impacts. On pg. 5-28 (596) of the SEIS it states: "The timeframe for the analysis is 2009 to 2030 (see Section 5.1.2 for the estimated operating life of the facility)." Clearly the SEIS fails to consider long-term impacts that are likely to occur, such as changes and increases in water demand.

Past Uranium Mining and Other Contamination.

37. The D-B region has been impacted by past mining and related activities, which were permitted by the AEC / NRC, and which have resulted in negative impacts to the local water resources and environment. Activities at the Black Hills Ordinance Depot (operational from 1942 through1967) have also impacted waters in this region. While limited remediation of surface facilities at portions of these two areas has occurred, no remediation of the historic water contamination has occurred at either site.

Inadequate Baseline Concept and Baseline Data.

38. Throughout the Final SEIS, the NRC fails to consider that past uranium exploration and mining activities have degraded the quality of much of the D-B-area ground and surface waters. The SEIS presents no baseline water quality data from prior to such activities, or as a minimum, from samples collected in the early periods of these mining activities. Instead, the NRC assumes that the degraded water quality represents "baseline", against which all proposed activities are to be judged. This regulatory approach is an indirect path towards approving increased degradation of the original D-B area water quality.

Fundamental Hydrogeologic Information Lacking.

39. In addition to using a "degraded" concept of baseline water quality, the NRC has failed to require Powertech to provide *detailed water-related* data and information ***prior to approval*** of this Final SEIS. Such detailed information is necessary to develop reliable conclusions about future impacts, and includes publication of the following categories of information:

-detailed hydrogeologic testing, including long-term aquifer testing, coupled with simultaneous water-quality sampling;
-*detailed* chemical compositions and volumes of all solid and liquid wastes and operating fluids, such as pregnant lixiviant solutions;
-specific aquifer restoration "clean-up standards / criteria (including ACLs—see Append. B);
-risk assessment studies of chemical constituents that will require an ACL;
-final selection of actual waste disposal methods to be employed;
-EPA aquifer exemption;
-detailed analyses and data relating to the specific Underground Injection Control (UIC) Well studies required by the US EPA. EPA approval of the UIC well permits should precede approval of the NRC license.
-specific details concerning the Financial Assurance measures that will be required of Powertech if the NRC permit is approved.

40. The Final SEIS states repeatedly, that the NRC will require Powertech to collect such detailed data / information **after** NRC license approval. Such information is needed to reliably evaluate risks, impacts, costs / benefits, etc. In my opinion, the delayed production of information until after licensing prevents disclosure and analysis of the environmental impacts, alternatives, and mitigation measures involved with the D-B project.

Price of Water.

41. The SEIS makes no mention of the price that the applicant will pay for the water used in the sum total of all operations, either consumptively or otherwise. Because all other users must pay some price for the water they use, the SEIS should include a table of comparative unit costs paid by various users (e.g. domestic, municipal, agricultural, industrial, etc.). Likewise, no price for water seems to have been included in the cost-benefit analyses presented in the SEIS, even for situations where water quality has been degraded.

Data all provided by the applicant.

42. Almost none of the relevant Application data were collected by financially-independent parties. Preparation of most of the documents was directed and paid for by the applicant. The "independent" federal agency with the most, long-term hydrogeologic experience in this region, the Rapid City USGS staff, have not been included as cooperating agencies in the preparation of the SEIS.

43. Some of the recent documents are largely authored by the applicant, not their consultants. In my experience, this is a signal of significant conflict of interest and the possibility that the consultants were unwilling and unable to give the applicant the desired answer. Many of the significant conclusions disregard unfavorable details and lack the analytical methods and rigor used by professional hydrogeologists and other water experts.

Historic ISL Water Data from U.S. Operations.

44. Review of actual, detailed, historical data from operating and closed ISL sites is the best method for anticipating future problems and impacts. Such actual long-term, data provide much more reliable information on future impacts than do the typical, overly-optimistic computer simulations often presented in EISs. Some of these sites have operated since at least the early 1970s. Thus, considerable information / data must exist for all these sites. Despite the fact that the NRC has had a role in permitting such ISL operations for more than 40 years, no publicly-available, *detailed database* on aquifer restoration water quality (and quantity) data has been compiled, summarizing data from all, or the majority of such ISL sites. Some limited data summaries have been released [i.e. the present GEIS (US NRC, 2014); US EPA, 2011; Davis & Curtis, 2007; Hall, 2009; Darling, 2008; Sass, 2011]. Dr. Susan Hall, U.S.G.S., Lakewood, CO stated (Feb. 2014) that she expects to release a summary of the publicly-available ISL water quality data (pre-and post-remediation) sometime later in 2014. She also stated that long-term, historic ISL data are very limited.

45. Most importantly, the limited aquifer restoration data that are available provide ample evidence to show that the leached aquifers at most, if not all ISL operations, have never truly been restored to their pre-operational, baseline water quality.

    **Otton, J.K., & S. Hall, 2009, In-situ recovery uranium mining in the United States: Overview of production and remediation issues.** IAEA-CN-175/87
    *www-pub.iaea.org/mtcd/meetings/PDFplus/2009/.../08_56_Otton_USA.pdf*

    "To date, no remediation of an ISR operation in the United States has successfully returned the aquifer
    to baseline conditions."

    US EPA, 2007, TENORM, V.2, Append. III, P. AIII-10 last paragraph of section. "Finally, in situ leaching poses a problem from a restoration standpoint. Although there are multiple techniques to restore the mined aquifer to its preoperational state, in many cases the lixiviant can never be completely purged from the site. Attempts to bring the aquifer to a chemically reduced state cannot account for all types of contaminants, and the entire rehabilitation process is both expensive and time consuming."

46. Hence, summaries of water quality and hydrogeologic data from all operating or closed ISL sites within the U.S., together with interpretation of the impacts from these operations should be made publicly-available, prior to approval of the DB NRC license. Clearly some of these sites operated under State regulation, but it appears that the US NRC did not obtain and summarize the available information regarding actual performance of past and present ISL operations at similar sites, relying instead on generic information or no information at all.

Injection of wastes into major aquifers like Deadwood & Minnelusa.

47. Carter, et. al. (2003) p.11(electronic)
**"The major bedrock aquifers are the Deadwood, Madison, Minnelusa, Minnekahta, and Inyan Kara aquifers."**

GDP, P. 99: The Fall River Formation, along with the Chilson Member of the Lakota Formation, are the principal sources of water in the vicinity of the project area for domestic, livestock, and agricultural uses. These same formations are the host rocks for uranium mineralization within the project area.

Disposal capacities for these aquifers are not disclosed. No justification given to allow contamination of Madison waters via mixing / dilution by contaminated ISL process waters. [Madison Application, p. 6-7(electr.)]

Applicant's Performance in the Application process is flawed.

48. Despite the fact that the applicant has collected no new aquifer-testing or hydrogeologic information since their original Application, the applicant's "story" keeps changing with each new document and new deposition or hearing testimony. The applicant has presented a moving target of opinions [i.e. in early reports no leakage occurred between the Inyan Kara aquifers and the finer-grained, bounding sediments. Now, the applicant admits that leakage occurs between these units, but according to the applicant, this has no significant influence on operational details or project impacts]. Frequently the applicant's managers have been authors of the technical language which appears to "soften" the unfavorable conclusions of the original technical authors.

49. These sequential changes in the applicant's opinions based on the same, original test data came about only because of significant, costly opposition from the public and their experts (and not from changes required by the NRC or State). This pattern clearly demonstrates that the NRC should have required the applicant (or preferably, independent experts) to conduct the necessary *detailed,* long-term hydrogeologic testing and baseline sampling prior to issuance of the SEIS.

50. This raises the question as to whether other relevant applicant-generated or contracted water / hydrogeology-related reports exist, besides those listed in the various Applications and the SEIS. I would expect that other reports exist, as the reports listed in the Application and SEIS do not include the critical analysis and information I would expect to find in an unbiased inquiry.

Petrotek (2012) hydrogeologic model does not consider presence of faults, fractures, breccia pipes, or open boreholes, etc.

51. The predictions from such flow models are all based on the **simplifications and assumptions entered into the model.** At D-B, detailed, long-term testing has not been performed, so Petrotek lacked the detailed information necessary to reliably define many of the hydrogeologic processes. For example, many of the historic pump test data on hydraulic conductivity (vertical and horizontal) differ greatly from the data generated by lab testing of core. Thus the hydraulic conductivity inputs into this model are questionable, and any conclusions about leakage from one water-bearing unit to another are quite speculative. Also, the model assumes that no water flows vertically through some of the bounding geologic units (e.g. the underlying Morrison), but inadequate testing has been conducted to prove this. Likewise, several independent authors have argued that vertical flow does occur through the Morrison into the Inyan Kara. Inadequate data exist to reliably demonstrate the rates of recharge from the Graneros Group and surficial alluvium into the Inyan Kara, or the extent of other surface water-ground water relationships.

52. The simulations presented in Petrotek (2012) report are unable to reflect the complex inter-fingering of these sediments (facies changes, laterally and vertically), and assume that the Inyan Kara sediments are homogeneous sediments.

    Site boring data were used to calculate the tops and bottoms of formations---which were often inconsistent—but these borehole data failed to indicate whether the holes were functionally plugged or acted as conduits for vertical leakage. The statements (by the applicant and Petrotek) that some of the anomalous results are likely the result of leaking boreholes is simply a supposition, not based on actual data obtained from these wells and boreholes. Also, this explanation fails to explain the percentage of error that might be the result of cross-facies leakage, rather than communication through unplugged boreholes and wells.

    It is not reasonable to assume that where historic boreholes and wells have been functionally-plugged in the past, that these plugs remain stable forever. Numerous studies show this is simply untrue, and the various seals, surface casings, plugs, etc, begin to deteriorate after several years, leading to cross-communication between the water-bearing zones.

53. This flow model assumes that all ground water flow is via porous media and that no permeable faults, fractures or collapse structures act as flow pathways within the D-B property. In this model, even the Dewey Fault is considered a no-flow boundary (see below), despite the fact that Boggs (1983) presents conflicting statements about the Dewey Fault zone (p.12-13). Boggs states it is a barrier to flow, but also that upward recharge may occur at relatively low rates. Obviously detailed testing is needed to answer this question. More importantly, numerous

independent investigators have reported the presence of faults within the D-B area, contrary to the claims of the applicant. Additionally, significant information from independent remote-sensing indicate that faults do exist, and that surficial evidence of multiple, circular collapse structures are visible at the D-B site. Likewise, structural interpretations and production data from Cretaceous oil fields indicate that oil and gas have been generated from fractures within shales in these formations. These same Cretaceous formations exist within the D-B region, and it seems obvious that the entire package of D-B area Cretaceous sediments are fractured. **The Petrotek model assumes that none of these secondary geologic features transmit water, thus the flow rates are questionable, as would be the changes to water quality resulting from long-term dewatering of the various sand and shale formations.**

54. The model does include one simulation assuming the presence of **one** collapse structure at the D-B site, and assuming it transmits water vertically at 200 gpm. Evidence exists that several other vertical collapse structure pathways may exist, thus upward flows may be much greater than 200gpm. However, throughout the SEIS, the applicant and the NRC state that no evidence exists for and such collapse structures. Despite all of the evidence to the contrary, p. 4-61 of the SEIS P.4-61 states: "Because there is **no evidence for fast flow paths, such as fractures, in the ore-bearing aquifers,** NRC staff conclude that the cone of depression will be maintained during ISR operations."

55. Computer simulations only provide rough approximations of quantitative results---(flow volumes, not chemistry) even in simple, homogeneous, porous media. Often, when predicted results are compared to future, actual data, the results may be in error by hundreds of percent. One of the main goals of such model exercises is to promote a belief that someone can predict future impacts with real quantitative accuracy (Pilkey, 2007; Sarewitz, et. al. 2000)—which is often untrue. Where unreasonable assumptions and faulty evidence is used, the model cannot be relied upon to disclose impacts or to design monitoring and mitigation measures

56. Several examples of sections within Petrotek (2012) that support my analysis of the unreasonable assumptions and unreliable conclusions in the hydrogeologic modeling are provided below:

    -8: "The Morrison Formation beneath the Chilson is considered an aquitard for the region and is represented as a **no flow boundary in the model**. The Graneros Group is also considered an aquitard in the region but was included in the model to provide a reference point for water level elevations within the Fall River and Chilson aquifers relative to ground surface."

    -8: "The data within the Project Area are based on site borings. Outside of the Project area, geologic picks are largely based on available oil and gas well logs. The geologic dips of the surfaces are projected out to the model limits."

- 8: “Therefore, the assumption used in the development of the model is that there is no flow across the (Dewey) fault in either the Fall River or Chilson aquifers. The model domain north of the Dewey Fault system is simulated using the NFB condition.”

-11: “During model construction, there was difficulty in maintaining integrity between the various layers of the model. Based on projection of the available data, some of the layers intersected each other in space. This occurred primarily because the data sets were not entirely consistent,….”

-11: As previously noted, the Fuson ranges from 20 to 80 feet thick across the Project Area (Dewey- Burdock TR), therefore, **a simulated thickness of 45 feet** is a reasonable approximation for purposes of the model.

-12: “Because of the uncertainty in the discharge rates from the pumping and artesian wells, the calibration is considered to be more of a representative steady state than a true steady state calibration.”

-14: “The model was **unable to replicate drawdown in the Fall River** on the scale of what was observed during the test despite extensive efforts to do so. It is possible that the drawdown observed in the Fall River during the 495 gpm pumping test in the Chilson was the **result of improperly completed wells or exploration boreholes that provided a hydraulic connection between the two units.”**

-17: “In summary, changes to the conductance and head of the GHBs in the vicinity of Pass Creek do not appreciably alter the flux of the Fall River and Chilson aquifers across the Project Area, but do result in significant increases to the RSS, indicating a **generally poorer calibration**. **Increasing the recharge rate also changes the calibration substantially and causes large increases in the flux of both the Fall River and Chilson.** Decreasing the recharge has negligible effect on either flux or calibration.”

-18: “For purposes of this modeling effort, the Fall River and Chilson are not subdivided and are each simulated as a single layer within the model.”

-22: “Use of a numerical model can assist in this effort. However, real time monitoring of water levels during operations and adjustment of flow rates in response to water level changes provides the best engineering control to minimize wellfield interference.”

-26: “The calibrated numerical model developed for the Dewey-Burdock ISR Project was used to assess the potential hydraulic impacts of a hypothetical

breccia pipe release. **A breccia pipe release into the Fall River and or Chilson was simulated by placing an injection well into the model layers** representing those hydrostratigraphic units and running a steady state simulation. **A value of 200 gpm was selected for the simulations. Much higher flow rates have been documented at known breccia pipe locations.** Discharge rates much lower than 200 gpm would probably have minimal impact on ISR operations and could be controlled using engineering practices."

-26: "Because of the large change in the potentiometric surface, the occurrence of discharge from a breccia pipe into either the Fall River or Chilson should be observable with the existing monitor well network and **would definitely be noticed once a monitor ring has been installed around a proposed production unit**."

Surface Water Predictions of 100-year floodplains are likely merely semi-quantitative representations.

57. The September 2013 flood events in the Colorado Front Range and Blizzard in the Black Hills of South Dakota demonstrate the degree of error routinely encountered in such hydrologic predictive models. In both areas, actual flooding and snowfall exceeded not simply 100-year, but 500-year predictions for many of the affected areas.

Pursuant to 10 C.R.F. § 2.304(d) and 28 U.S.C. § 1746, I declare under penalty of perjury, that the foregoing is true and correct to the best of my knowledge and belief.

Signed on the 17th day of March, 2014,

Robert E. Moran, PhD.

UNITED STATES OF AMERICA
NUCLEAR REGULATORY COMMISSION

BEFORE THE ATOMIC SAFETY AND LICENSING BOARD

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| In the Matter of | ) | |
| | ) | |
| POWERTECH (USA) INC., | ) | Docket No. 40-9075-MLA |
| | ) | ASLBP No. 10-898-02-MLA-BD01 |
| (Dewey-Burdock In Situ Uranium Recovery Facility) | ) | |

**SUPPLEMENTAL DECLARATION OF DR. ROBERT E. MORAN**

I, Dr. Robert E. Moran, do hereby swear that the following is true to the best of my knowledge:

**Professional Qualifications and Introduction**

**Robert E. Moran, Ph.D.**
Michael-Moran Assoc., LLC
Water Quality/Hydrogeology/Geochemistry
Golden, Colorado, U.S.A.
remwater@gmail.com

1. I am a hydrogeologist and geochemist with more than 40 years of domestic and international experience in conducting and managing water quality, geochemical and hydrogeologic work for private investors, industrial clients, tribal and citizens groups, NGO's, law firms, and governmental agencies at all levels. Much of his technical expertise involves the quality and geochemistry of natural and contaminated waters and sediments as related to mining, nuclear fuel cycle sites, industrial development, geothermal resources, hazardous wastes, and water supply development. In addition, I have significant experience in the application of remote sensing to natural resource issues, development of resource policy, and litigation support. I have often taught courses to technical and general audiences, and has given expert testimony on numerous occasions. Countries worked in include: Australia, Greece, Bulgaria, Mali, Senegal, Guinea, Gambia, Ghana, South Africa, Iraqi Kurdistan, Oman, Pakistan, Kazakhstan, Kyrgyzstan, Mongolia, Romania, Russia (Buryatia), Papua New Guinea, Argentina, Bolivia, Chile, Colombia, Guatemala, Honduras, Mexico, Peru, El Salvador, Belgium, France, Canada, Great Britain, United States.



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**Literature Reviewed**

2. In addition to my professional experience, the opinions and comments that follow are based on review of all, or significant portions of the following documents:

Powertech Application for NRC Uranium Recovery License, Dewey-Burdock Project, Feb. 2009:

- Technical Report (TR)
- Environmental report (ER)
- Supplement to Application, Aug. 2009
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**Summary Comments**

3. These opinions focus predominantly on the water resources and related impacts within the proposed Dewey-Burdock (D-B) area. These waters are natural resources presently used collectively by numerous parties (ranchers, municipalities, tribal groups, fish and wildlife, mineral and oil and gas developers, etc.). However, the DSEIS must realistically anticipate what will be the true *long-term* uses of these waters---especially when many generations must be considered. Thus, *truly conservative assumptions* should be employed—which is not the case in this DSEIS.

4. Some of these waters are already contaminated by past uranium exploration and mining, with little or no remediation required by any regulatory agency, which suggests a great deal about the future oversight. The D-B site contains numerous old uranium workings (shallow open-pit and underground), accumulations of various contaminated waste materials, 1000s of unplugged

boreholes, which likely provide hydraulic connections between various water-bearing units. To allow for a meaningful review, all available borehole information needs to be assembled and presented in a comprehensive manner.

5. Past exploration and mining activities have exposed the mineralized rocks to reactive surface waters and ground waters and bacteria, increasing the concentrations of numerous contaminating chemical constituents in local waters, soils, etc. *Nevertheless, some of the water-bearing units within and around the DB area will still contain high or relatively-uncontaminated waters, suitable for numerous other uses.* This pattern is the norm at typical metal mine locations worldwide, including uranium sites. The proposed D-B activities will increase the concentrations of such contaminants in some local ground waters, as a minimum. Thus, it is imperative that the specific locations and characteristics of these contaminated and uncontaminated waters be defined in a DSEIS available for public review and comment prior to publication of a FEIS and project approval.

6. The DSEIS gives the impression that all of the D-B-area waters (surface and ground) are already contaminated. However the DSEIS fails to supply the detailed data necessary to support that contention. Experience at similar sedimentary uranium sites indicates that significant quantities of uncontaminated ground water likely exist, and could be used for other livestock, agricultural, domestic, etc. uses. The NRC has failed to require Powertech to provide statistically-adequate, reliable, *preoperational* baseline data, either within the D-B project area, or in surrounding regions. Without adequate baseline data, the presently-uncontaminated waters could be become contaminated through ISL-related activities, but the public would have no way of discovering this impact.

7. The DSEIS fails to provide basic information necessary to reliably evaluate future, LONGTERM impacts. If the D-B-area resources had been evaluated in a truly detailed, interdisciplinary, scientific manner, the DSEIS would have collected and summarized the most fundamental technical information relating to water resources, such as:

- a detailed inventory of all present water users within a radius of at least 2 miles of the proposed D-B boundaries. Such an inventory would include statistically-valid, preoperational data on well yields, water levels, detailed water quality;
- a detailed, statistically-valid summary of BASELINE data for water quality and quantity from the relevant water-bearing units, *based on pre-operational data*. These would already include evaluation of hydrogeologic characteristics for all of the relevant water-bearing units based on actual, long-term aquifer / pump testing data. Such baseline data would also incorporate all relevant data collected prior to Powertech's involvement, including data collected during the 1950s to the present (including, for example, TVA data).

- detailed data on the presence and condition of all subsurface borings (exploration holes, oil and gas holes, etc.)
- a detailed spring and seep survey, which would have included statistically-reliable (and seasonally-meaningful) measurement of field parameters and yields, detailed water quality---all based on preoperational data.
- all such actual data / information could easily be summarized in the form of maps, tables, and graphs, without resorting to thousands of pages of disorganized text, which has been the approach taken by Powertech and the NRC.

8. In addition, a technically-reliable study of the D-B area would have summarized the detailed data and long-term impacts from the numerous actual, operating and closed ISL sites (throughout the USA and other countries), to gain insight on actual results and impacts obtained from a *population* of sites. It is technically-meaningless to make deterministic predictions about such impacts at a *single* site, especially a site to be operated by a company that has never operated another ISL mine.

9. Impact evaluation (by NRC, PT and consultants) in this DSEIS fails to follow accepted approaches used in the wider scientific community. The DSEIS fails to use reliable scientific investigation to assess or compare known impacts at *populations* of other operating and closed ISL sites. Most importantly, it is not possible to reliably-rank future D-B impacts [SMALL, MODERATE, LARGE] when the NRC and public lack reliable baseline data to use as a measure of change. Such approaches would not be acceptable in most technical, scientific (academic-research) publications.

10. The data and information described above are required for an analysis in a DSEIS prior to FEIS or license approval. Otherwise reliable evaluations of future impacts cannot be made. In addition, without such data, it will be largely impossible to hold the operators responsible for future, unremediated impacts.

## Specific Comments

**The DSEIS has been publicly-released at a period specifically inconvenient for public review.**

11. By releasing the DSEIS over the winter holiday season, NRC has obviously made review and commenting on these documents more difficult and precluded the public from making a useful site visit to verify data and claims made in the DSEIS.

**The DSEIS comprises thousands of pages of convoluted, poorly-organized and inadequately-summarized material.**

**12.** The various D-B documents submitted to the NRC encompass more than **14,512 pages**, yet fail to adequately present the most basic data (see below). For example:
--the 2009 Application was almost 6000 pages;
 [Technical Report (TR)-- 3103 pages; Environmental Report (ER)-- 2615 pages;
Supplement to Application-- 66 pages.]
--the 2011 Powertech submittal totaled roughly 5000 pages;
--the present DEIS (Vols. 1 & 2) comprises 858 pg., which is only part of the GEIS;
--the GEIS, to which much of the DSEIS refers comprises 3512 pages.

13. The relevant D-B information, if compiled in a direct, transparent manner using predominantly maps, tables and graphs, could easily have been summarized in 150 pages for the DSEIS. Instead, the DSEIS is so duplicative and poorly-organized that it makes informed review by both the regulators and general public unnecessarily convoluted.

**The DSEIS fails to adequately respond to the weaknesses and written criticisms of the Powertech Application.**

14. The Powertech Application submittals (2009, 2011) were prepared by Powertech and its consultants, based largely on data collected by these same parties. While the DSEIS states that it was prepared by the NRC [and the CNWRA (Center for Nuclear Waste Regulatory Analyses)], it appears that it is based entirely on these same Powertech data, with no new water-related data added since the application. Clearly most of the DSEIS opinions are also based on the technical opinions of Powertech and their consultants.

15. Also, the DSEIS fails to adequately respond or address most of my written Opinions made regarding the D-B Application, which were submitted to the NRC in April 2010 (Moran Declaration, April 2010).

**The DSEIS is Technically-deficient, lacking fundamental data that are needed to reliably evaluate likely impacts to the D-B-area water resources and related environment.**

16. The DSEIS admits that important water quality data collection and aquifer testing will only be conducted after license issuance (e.g. DSEIS p. 2-16, 7-8, 7-14, 7-17).

17. Such data are needed *now*, as part of any useful EIS and certainly prior to issuance of an operating permit. These data include: reliable preoperational

baseline data on water quality and quantity / yields of all relevant surface and ground waters; specific data on the total water volumes to be used by all D-B operations; detailed data on hydrogeologic characteristics of all relevant geologic units; detailed evaluations of the hydraulic interconnections between the uranium production zones and the other relevant water-bearing and confining units; data on the detailed chemical compositions of barren and pregnant solutions, evaporation pond waters, etc.; a detailed inventory of all water users within at least a 2 mile distance of the D-B project boundaries.
Details on these categories are discussed below.

**Concerns Expressed by Other Federal and State Agencies not Addressed**

18. The DSEIS mentions on p. 1-15 and 16 that several other Federal and State agencies have expressed concerns regarding impacts to Water Resources, etc. from the proposed D-B project, but fails to discuss or address in any detail these criticisms. This omission gives the false impression that the present comments (for the Oglala Sioux) are made in isolation from those of these other regulatory agencies.

19. A brief review of the coordination conducted with other agencies reveals the following points of concern with respect to these agencies:

- Coordination with BLM: South Dakota BLM field office:
provided NRC staff with information on **oil and gas leases** in the proposed project area. DSEIS, P1-16. Additionally, BLM staff expressed **concerns related to water quality and hydrology, land use, and cumulative effects.**

-Coordination with U.S. Army Corps of Engineers:
USACE documented the presence of 20 wetlands within the project area and determined that 4 were jurisdictional waters; these are Beaver Creek, an unnamed tributary to Beaver Creek, Pass Creek, and an unnamed tributary to Pass Creek (Powertech, 2009b, Appendix 3.5–H).

-Coordination with USFS:
it expressed concerns that construction and operational activities could impact the nearby Black Hills National Forest and Buffalo Gap National Grasslands. USFS staff noted a concern about the cumulative groundwater effects of the project on the USFS-managed aquatic recreation areas of Cascade Springs and Keith Park Springs. USFS also expressed concerns about potential effects the project could have on Craven Canyon, known to have traditional cultural significance to Native American tribes.

-Coordination with USGS: With respect to the proposed Dewey-Burdock ISR Project, USGS staff expressed a concern that **contaminated groundwater** may travel from the project area and discharge into Beaver Creek within the proposed

project area and the Cheyenne River south of the proposed project area [via groundwater or surface water].

-Coordination With South Dakota Department of Environment and Natural Resources expressed concerns regarding:
(i) the adequacy of subsurface characterization, (ii) groundwater flow rates within and in the vicinity of the project area, (iii) potential complications in hydrology caused by past exploratory drill holes, (iv) potential hydrologic connection of production zones and abandoned onsite surface mines, and (v) the effectiveness of confining layers in isolating ore-bearing aquifers. NRC and SDDENR staffs also discussed the applicant's Class III UIC permit application (Powertech, 2010) and the water appropriation and waste management permitting processes for the proposed project. Potential risks to wildlife from wastewater surface impoundments associated with the proposed project were also discussed. SDDENR would coordinate with SDGFP to mitigate the potential effects of surface impoundments on wildlife; mitigation measures discussed included the use of netting and fencing to protect wildlife and implementing protocols to assess the effects of wastewater constituents on wildlife.

-Coordination with S.D. Game, Fish and Parks:
focused primarily on threatened or potentially threatened and endangered species (e.g., the plains topminnow, sage-grouse, and black-footed ferret) and species of local concern (e.g., raptors). SDGFP expressed a **major concern: the potential effects on birds flying through the proposed project area and drinking at exposed wastewater evaporation ponds**. SDGFP suggested two measures to mitigate effects on bird populations: (i) **testing** to determine the **toxicity of constituents in the evaporation ponds** and (ii) using **netting and fencing to restrict wildlife access to exposed ponds**. SDGFP also noted the **need for testing and monitoring of soils** at the proposed site to **identify any buildup of salts and metals** that could result from proposed land application of **treated wastewater**.

**Water Use: The D-B Project will use and contaminate tremendous volumes of ground water. How much water will be used throughout the life of the proposed DB operation?**

20. The D-B project area is semi-arid, having an average yearly precipitation of about 12.4 inches, and the range of evaporation for the So. Dakota-WY-Nebraska uranium region is between 40 and 50 inches (NRC GEIS 2009). Thus evaporation is roughly 3 to 4 times the yearly precipitation (ER, pg. 3-176 and 177; Fig. 3.6-27). Because the project is presently expected to operate for between 7 and 20 years, it will require the use of tremendous volumes of local ground water, and will result in losses of significantly greater quantities of water via evaporation.



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21. Unfortunately, the DSEIS fails to provide reliable estimates for the volumes and sources of water to be used (consumptive and non-consumptive uses) during all stages of the proposed operation. Actual, detailed data on amounts of water required for operations are not presented (e.g. ISL operations, human consumption, dust suppression, evaporation from disposal ponds, waste disposal, etc.). In mining hydrogeologic studies, such data would routinely be included in a detailed Water Balance.

22. No detailed Water Balance is provided in the DSEIS. Instead the DSEIS provides imprecise, conflicting information on the volumes of water to be used throughout the various sections of the DSEIS (e.g. p.2-15, 2-34, 4-57-59, etc.).

23. Powertech calculates that the sustainable pumping rate from the Inyan Kara Group / Aquifer is about 40 gpm for the life of the project (DSEIS p. 4-59). However, the NRC / Powertech state that the operational requirements for the Burdock CPP alone would require a sustained pumping rate of 65 gpm (at DSEIS p. 4-59). Powertech has applied to the SDDENR for permits to extract water from the Madison Aquifer. Thus, it is presently unclear which aquifer will be the source for long-term, operational phase water. If the permits for using Madison Aquifer waters are denied, additional sources (besides Inyan Kara) would be required.

24. The applicant estimates the wellfield production bleed would be approximately **0.5 to 3.0 percent** of the **production flow rate,** yielding a wellfield production bleed rate between 20 gpm and 120 gpm (DSEIS, P. 2-34).

25. Powertech estimates that approximately 52.6 million gallons of ground water would be required for the Construction phase alone (DSEIS p.5-30). **No data are provided for the volumes of ground water required for the other phases, throughout the life of the project.**

26. Clearly, the DSEIS fails to reveal reliable long-term water use data for all phases of the entire project. Greater uncertainty is shown when one reads the water use data originally presented in the 2009 Powertech Application, ER pg. 8-2 (Table 8.1-1), which states that **ground water consumption will be 320 gpm.**

27. Because no Water Balance is presented, it is unclear how much of this volume is recycled, re-injected as waste in other formations, etc. In addition, one must assume that quality of much of the recycled and re-injected water would be degraded as compared to any reliable preoperational baseline data.

28. Aside from the obvious lack of consistency, the estimates (above) translate into massive amounts of ground water when considered over the full life of the project. Using two of the estimated ground water use rates stated above, total water consumption over the life of the project can be estimated as follows:

**65 gpm = 34.2 Million gpy (gals / yr).**

**After 7 yrs = 239,148,000 gallons, or 239.15 Million gallons.**
**After 17 yrs = 580,788,000 gals or 580.8 Million gallons.**

**320 gpm = 168.2 Million gpy (gals. / yr).**
**After 7 yrs = 1,177,344,000 = 1.2 Billion gallons**
**After 17 years = 2,859,264,000 gallons = 2.86 Billion gallons.**

29. Clearly, this range of estimates indicates that vast quantities of ground water will be extracted from these aquifers over the long-term. At a minimum, Powertech should be required to construct a credible project water balance and to more seriously investigate the potential that such large-volume water use might impact local / regional ground water levels and well yields.

30. At present, I see no evidence that the Application contains a reliable compilation of *baseline water level and pumping-rate data for the surrounding domestic and stock wells (see discussion below).* Without such reliable, summarized data, there will be no viable method to demonstrate that ground water levels (and related pumping costs) have not been impacted by project-related activities.

31. The public must assume that Powertech will pay no cost for the actual water (the commodity) used during operations---while numerous other users do. The specifics of this issue should be addressed by Powertech in writing.

32. Despite the central role of water in the operation of the project, water use, availability, depletion, and consumption are not seriously analyzed through a water balance investigation, or other similar technique. This analysis is critical to understanding the anticipated impacts during project review and for monitoring actual water impacts should this project actually begin using and consuming groundwater.

**Hydrogeologic Performance of the Water-bearing and Other Geologic Units.**

33. The DSEIS fails to provide detailed, site-specific information / data on the hydrogeologic characteristics of the relevant D-B water-bearing and other bounding geologic units, including the mineralized zones. Such data must be obtained by performing and interpreting *long-term*, aquifer test data. The DSEIS admits that such long-term, detailed testing will not be performed until after the NRC license is issued (e.g. DSEIS at 2-17, 7-11).

34. The hydrogeologic data presented in the DSEIS are **inadequate** to reliably portray and predict the following:
-the baseline, detailed directions of ground water flow in the relevant water-bearing units;

-the extent of long-term hydraulic connections between the various geologic units, both within the project area and outside;
-the horizontal / regional extent of water level declines (and impacts on pumping rates) outside the project boundaries;
-the degree to which ground water withdrawals may impact local surface waters;
-the operator's ability to contain the migration of contaminants;
-the operator's ability to restore aquifer water quality to baseline / acceptable conditions.

35. Such inadequate hydrogeologic data also mean that any ground water flow simulations based on these data are likely to provide highly imprecise and unreliable predictions (e.g. SEIS, P.2-16, L 30-37).

36. In addition, such inadequate hydrogeologic data, coupled with the lack of reliable baseline water quality data (see below), render the NRC staff predictions about impacts (both incremental and Cumulative) to water resources *largely meaningless* (e.g. the Executive Summary and Section 5.0). For example, despite failing to define the extent (areal, vertical) and specific, detailed chemical compositions of past contamination, the NRC staff predicts that Cumulative Impacts to *Surface Waters and Wetlands* will be MODERATE TO LARGE (p.5-17), but that the D-B project will have a SMALL incremental impact on surface waters and wetlands when added to all other past and present impacts (p. 5-30). *Given the lack of detailed baseline data (hydrogeologic and water quality) such conclusions sound more like public relations statements than science.*

**Impacts from Long-term Pumping of Ground Waters.**
**Radius of Impacts / Influence. (modified from Moran Declaration, 2010)**

37. The DSEIS presents no specific hydrogeologic information on the anticipated declines in water levels at domestic and stock wells outside the D-B project. Despite lacking adequate, long-term aquifer test data, the Powertech ER (2009) presented *predictions* of **water level declines** after 8 years of continuous pumping:
- **9.9 to 42.8 feet** at the nearest domestic well in the Fall River Aquifer, located 15,075 feet [**about 2.9 mi**.] from the approximate center of pumping (ER pg 4-23);
- **4.9 to 12.6 feet** at the nearest domestic well in the **Lakota Aquifer,** located 10,915 feet [**about 2.07 mi.**] from the approximate center of pumping.

38. With such uncertainty, it is quite possible that some neighboring wells will be negatively impacted (water level declines / reduced pumping rates). These data interpretations indicate that domestic and stock, etc. wells should be inventoried and monitored out to at least 2 miles from the D-B boundary.

**The D-B water-bearing units are hydrogeologically interconnected.**

39. The DSEIS avoids discussing definitively the likely hydraulic interconnections between the various D-B water-bearing units. The 2009 Powertech Application does discuss these issues, but presents overly-optimistic conclusions about the isolation of the ore- bearing zones, aquifers, and the lack of fluid excursions that will occur, both vertically and horizontally. Powertech's description and evaluation of possible water-related impacts [2009 Application, ER pg. 8-2 (Table 8.1-1)] are unreasonably optimistic. It is unlikely that the process waters can be contained within the project boundaries given the following pathways that connect the project area with surrounding aquifers: 1) sedimentary formations; 2) geologic fractures, 3) exploration boreholes, 4) mine workings, 5), other anthropogenic fractures and borings.

40. The D-B uranium deposits occur in subsurface, fluvial channel, sandstone deposits in the Lakota and Fall River formations (Smith, 2005). These sandstones *inter-finger* with finer-grained silts and shales, often associated with lignites and coals, which form the typical lithologic sequences often seen in classic sedimentary uranium deposits (Abitz, 2005; Gott, 1974; Henry, 1982; Galloway, 1982; Henry, 1980; Harshman, 1972).

41. Hydraulically, such sedimentary packages typically allow ground waters to flow between the inter-fingering facies, both vertically and horizontally, when the coarser- grained sediments are *stressed by long-term pumping*. The hydraulic inter-connections are verified by conducting ***long-term aquifer tests integrated with sequential water quality sampling and in-situ measurement of field parameters*** (Henry, 1982; Galloway, 1982; Moran, R.E.—hydrogeochemical research activities, U.S.G.S., Water Resources Div., 1973—1978). *The hydraulic interconnections of such inter-fingering facies has been well known for decades within the petroleum industry research groups (e.g. Fisher, et. al.,1969).*

42. Thus, ore-bearing sandstones in typical sedimentary packages associated with roll- front uranium deposits do *not routinely behave as hydraulically-isolated bodies.* Numerous specific lines of evidence from the 2009 D-B Application documents indicate that the project sediments possess various pathways for the migration of water and contaminants from the ore zones into neighboring sediments, both vertically and laterally. For example, thousands of exploration boreholes have been drilled since the 1950's at the D-B site (Smith, 2005; TR, ER), many of which were not correctly plugged and abandoned (TR, Pg. 2-157; Append. 2.7-B, sub-Appendix D, pg. 1484; TR, Append. 2.6- A, pg. 972-1111). In addition, several sources (Smith, 2005, pg. 9; ER, pg. 3-106) report that the area contains historic shallow mine workings, both open pits and short tunnels that would provide additional flow pathways.

43. There are numerous old and existing water wells and old oil test wells in the D-B area, many with rusty and leaky casings, often unplugged or partially-plugged, drilled through several formations which act as potential pathways for

flow between water- bearing units (ER, pg.3-40; TR, Append. 2.2-A, pg. 740-779; 2.2-B, especially pg. 864- 902).

44. The 2009 Application, TR, pg. 2-153-154, states that hydraulic connections between local D-B aquifers often result because confining units are thin or are absent in many areas (ER, pg.3-56-57). In addition, Gott (1974) and others have mentioned the presence of breccia / evaporite pipes (collapse structures), which create vertical permeability pathways between aquifers. Gott (1974, pg. 27-29) and others discuss the common presence of faults and joints throughout the region, which could easily act as flow pathways. The DSEIS states that detailed geologic mapping conducted by Powertech found no indication of such breccia pipes (p. 3-32), but the document fails to state that a detailed examination of all the subsurface data was searched for the presence of such breccia pipes.

45. Vertical and lateral hydraulic connectivity between the ore zones and the neighboring facies / formations are also indicated by the aquifer test results conducted in both 1979 and 2008 (ER, pg.3-56-57; TR, pg. 2-170 & 2-180, for example; TR Append. 2.7-B, Knight-Piesold Pumping Test Report, pg. 1290).

46. The DSEIS fails to assess the forgoing conditions, or likely impacts associated with these conditions in any scientifically meaningful way, nor does it consider that geologic materials with geologic / hydraulic characteristics similar to the D-B target formations frequently yield both water and oil and gas from ***geologic fractures***. A classic example is the Florence oil field in Colorado, which has been producing continuously from fractures in the Cretaceous Pierre Formation since 1862, making it the second oldest producing field in the U.S. [http://ghostdepot.com/rg/library/magazine/florence%20oil.htm ].

47. The Pierre Formation exists in the Black Hills region and lies stratigraphically above the Inyan Kara Group, the target formations at D-B (Tourtelot, 1962; DSEIS p.3-14). Thus, it is likely that several of the geologic units in the D-B area can also transmit fluids via fracture pathways. This indicates that future computer simulations of D-B ground water flow and leach field performance should be capable of modeling fracture flow characteristics.

48. The aquifer testing already performed *demonstrates leakage between the various formations / facies bounding the ore zone. However, it seems equally likely that longer-duration aquifer tests conducted at even higher pumping rates would demonstrate even more clearly the leaky nature of these site sediments.*

**Potential hydrogeologic pathways to nearby wells have not been adequately investigated and documented.**

49. The discussion above presents ample evidence that the D-B area sediments contain numerous possible subsurface pathways for project leach fluids to migrate vertically between water-bearing units and outside the project

boundaries. Unfortunately, as noted above, Powertech has not adequately defined the baseline water levels or water quality conditions of neighboring wells within a 2-mile radius of the D-B project. In addition, the 2009 Application, TR pg. 2-180, states that no public data are available on the use of aquifers in Fall River or Custer counties. Such data should have been compiled by Powertech as part of the DSEIS and Application, and should be required before any licenses are given.

**Toxic and Hazardous Substances to be Used at D-B.**

50. The following chemicals are proposed to be used / stored at D-B (DSEIS, p.4-19):
"The applicant proposes to store, use, and receive shipments of the following chemicals: sodium chloride (NaCl), sodium carbonate (NaHCO3), sodium hydroxide (NaOH), hydrochloric acid (HCl), hydrogen peroxide (H2O2), carbon dioxide (CO2), oxygen (O2), anhydrous ammonia (NH3), diesel fuel, gasoline, and bottled gases (Powertech, 2009b)."

51. All these chemicals are likely stored / used in concentrations that would qualify them as toxic or hazardous substances. Releases of such chemicals can contaminate local soils and waters. Despite the proposed use of these chemicals, the proposed water quality (surface and ground waters) and soils monitoring does include constituents adequate to demonstrate the presence of several of these chemicals, especially the fuels / organic compounds (see below).

**Chemical Analyses (Detailed) of Ores, Pregnant Leach Solutions, Liquid Wastes are not presented in the DSEIS.**

52. The DSEIS fails to provide actual, detailed chemical analyses (numerous) of representative pregnant leach solutions (ore reacted with lixiviant), both before and after undergoing ion exchange treatment. Such data would routinely include both in-situ measurements of fluid temperature, pH, specific conductance, possibly D.O. (dissolved oxygen) and Eh (redox). Similar representative, detailed data should also have been included for the detailed chemical composition of liquid wastes to be disposed of via deep-well injection, land application and evaporation.

53. Because most mining projects at a similar stage of advancement have already conducted extensive laboratory testing and prepared Feasibility Studies to present to potential investors, such detailed chemical composition data would be available. It is not sufficient to present theoretical / expected chemical compositions, as has been done in the 2009 Powertech ER, pg. 4-83. Smith & Assoc. (2005), pg. 5, reports that TVA, one of the previous mineral right holders, had a "pre-mine feasibility study" prepared, probably in the late 1970's or 1980's. If TVA had obtained such detailed data in earlier decades, certainly Powertech would have obtained the older Feasibility information and contracted to have an

updated Feasibility Study performed. Clearly some information in Feasibility Studies is considered proprietary, but detailed chemical composition data on the pregnant solutions and liquids / wastes described above should be analyzed and available to the public and included in any complete DSEIS.

**Characterization of Water Resources: Inadequately Described and Characterized.**

54. The DSEIS fails to clearly distinguish site surface waters, ground waters (including springs and seeps), wetlands, and waters flowing from boreholes. As all of these waters are ultimately interconnected, hydraulically, this prevents a clear understanding of future impacts to water resources. In several sections, the DSEIS actually confusingly describes ground waters as surface waters. For example, on p. 3-23, it discusses ground waters in abandoned mine pits as though they are surface waters. Page 3-23 states that there are *no known natural springs* within the proposed Dewey-Burdock ISR Project area, which does not mean that a detailed attempt to locate and characterize such springs was ever conducted. On p. 3-27-28, the DSEIS confusingly describes water flowing from an old well as the source of a wetland, when it is obviously not a natural wetland.

55. DSEIS page 3-20 contains a section disingenuously entitled "Artificial Penetrations", but which is strangely not included in the discussions pertaining to either Surface or Ground Waters. It states: "According to the environmental report, there are 4,000 exploration drill holes representing historic exploration activities (Powertech, 2009a). The applicant has drilled approximately 115 exploration holes, including 20 monitoring wells in the project area. While the applicant cannot confirm that all historic borings were properly plugged and abandoned, the applicant has made commitments to ensure that unplugged drill holes will not impact human health or the environment during operations (Powertech, 2009b, 2011). In the technical report (Powertech, 2009b), the applicant stated that little evidence of unplugged boreholes has been observed given infrared photography data. However, an infrared map of a portion of the Burdock area shows an alkali pond area (Powertech, 2011). The applicant states unplugged borings appear to explain the presence of this pond area. No other pond areas or springs appear in infrared photography data of the Dewey-Burdock site. There is no other evidence indicating that previously unplugged borings are current groundwater flow pathways (Powertech, 2011)."

56. This section makes several half-explained statements as though they are proven facts, and diverts from the likely hydraulic interconnections these boreholes have created between the site surface and ground waters. It implies that a careful study of the site using infra-red photography has been performed, when it is clear that a map of only a portion of the site was available. Despite this tortured language, there is no reason to dismiss the likelihood that many of the old boreholes are acting as conduits between the various water-bearing units, at least below the land surface. Strangely, the DSEIS describes the presence of

several water-filled mine pits (p. 3-23), yet they are not mentioned as being visible on the "infrared photography data of the Dewey-Burdock site". Clearly a more thorough investigation using infra-red photography and satellite imagery is called for.

**Baseline Water Quality**

57. The D-B project area has been historically mined and thousands of exploration holes have been drilled within the properties. Hence, it is imperative that high-quality baseline data be supplied to evaluate the actual extent of past impacts to water resources, and the success of future containment or aquifer restoration.

58. The DSEIS, like the Powertech Application, fails to define pre-operational baseline water quality and quantity—both in the ore zones and peripheral zones, both vertically and horizontally. Without adequate baseline water quality data (both ground water and surface water), there is no reasonable method for either the public or the NRC to evaluate the success or failure of either fluid containment or aquifer restoration. The DSEIS and Powertech Application documents repeatedly attempt to convey the impression that the D-B ground water quality is already degraded, rather than compile statistically-defensible data from both the ore zones and non-mineralized zones.

59. This approach contradicts NRC guidance, which requires that pre-mining baseline conditions be defined *before licensing* (NRC, 2003, pg. 2-24). Failing to define specific baseline conditions prior to license approval also contradicts NEPA regulations (Parsons, 2013, p.2).

60. Failing to define and quantify preoperational baseline is also scientifically unsupportable as it allows Powertech and the DSEIS to avoid discussing which specific water sources are contaminated by past uranium mining activities and which represent naturally-contaminated waters.

61. The DSEIS, Table 3.5-4 misleadingly presents what is entitled: Baseline Groundwater Samples with Values Exceeding the MCLs(p. 3-38). Firstly, this table and related discussion fail to make clear that many of these sites are contaminated by past, un-remediated uranium mining and processing. Secondly, the table leaves out most of the important baseline constituents a competent evaluation would have included. Thirdly, the table leaves out any values below the MCLs. Thus, this table does not represent baseline ground water quality. *Most importantly, the DSEIS does not contain tables of any of the detailed water quality data, baseline or otherwise.* Further, there is no data or analysis of the hydrogeological mechanisms by which the previous contamination occurred, spread, or was contained.

62. Clearly the DSEIS / Powertech ground water baseline data should include, *as a minimum,* the chemical constituents listed in Table 2.7.3.1 of the NRC's Standard Review Plan (NRC, 2003, pg. 2-25), and Table 7.3-1 of the DSEIS. In addition, baseline water quality monitoring (both ground and surface water) should be expanded to include nitrate, ammonia, aluminum, antimony, strontium, lithium, thallium, turbidity, scans for organic compounds, and / or total organic carbon, and be integrated with *in-situ* field measurements (temperature, pH, S.C. turbidity), water levels and well yields and / or flows.

63. It is only logical that the actual list of baseline constituents should be based on analyses of pregnant solutions resulting from leach testing of the D-B ores and lixiviants—not on theoretical assumptions about what might be the chemical compositions. Such pregnant solution analyses should be made public in the DSEIS prior to Application approval.

64. Frequently, uranium roll-front ores will also mobilize significant concentrations of additional constituents, such as antimony, lithium, and strontium (Moran, 1976). In addition, it is common to detect elevated concentrations of aluminum, sometimes as the result of well-drilling and completion techniques. Thus, it is recommended that these constituents be included in routine determinations of baseline water quality. In fact, standard lab analytical scans, such as ICP (inductively-coupled plasma spectroscopy) routinely report all (or most) of these metals and metalloids at the same cost. It should be noted that almost all of these constituents were included in the data in Appendix 3.4-C of the Powertech ER.

65. I suggest that nitrate and ammonia determinations be included to allow future analysis and determinations regarding impacts from agricultural or industrial sources (ammonia may enter the aquifer via numerous agricultural or industrial activities).

66. Section 2.7 of NRC (2003) is unclear whether applicants shall provide water quality data from unfiltered (Total concentrations) or 0.45-micrometer-filtered ("dissolved") samples. Table 7.3-1 of the DSEIS states that only dissolved constituents will be reported. Much of the D-B data in the Powertech Application Appendices includes both dissolved and Total determinations. It is recommended that unfiltered samples be collected and analyzed, as a minimum, for baseline ground water evaluation. These provide more *conservative* characterization of the ground waters, and waters used in rural areas (human and livestock consumption from wells; other agricultural uses; irrigation; fisheries) are not filtered. Furthermore, contaminants carried in particulate form are ingested by humans and other organisms when consuming unfiltered waters. These particles / colloids are dissolved by the extreme biochemical conditions found in the guts of such organisms, mobilizing the contaminants into the blood and other tissues. In addition, many trace constituents are mobile in ground waters as colloidal

particles (McCarthy, 1989; Ramsey, 2000), which would be removed by filtration, generating unreasonably-low concentrations.

67. Determination of "suspended" fractions is of little utility as there are no regulatory criteria or standards for suspended forms, and such data are subject to much greater error (from the combination of sampling and analytical errors) than are either simple filtered (Dissolved) or unfiltered (Total) determinations.

68. To ensure data quality, the D-B baseline data should include:
- statistical comparisons of the field and lab determinations of pH, and S.C. for the same samples;
- comparisons of Dissolved versus Total determinations from the same samples;
- ion balances, to assist in evaluating the reliability of the analytical data, with comparisons of TDS and S.C. (Hem, 1985).

69. No coordinated, statistically-sound data set for all Baseline Water Quality data (both surface and ground water) is presented in these documents—as is required in NUREG-- 1569. The DSEIS makes clear that baseline water quality will actually be established after operations begin (e.g. DSEIS p.7-13, 14: Projectwide GW monitoring ). The DSEIS fails to include reliable baseline water quality data for any of the categories of ground water or surface water.

70. The 2009 Powertech Application, carried forward in the DSEIS, include what it incorrectly calls baseline. For example, on pg. 2-14 and 2-15 of the Technical Report (TR), Sect. 2.2.3.2.2, Powertech states: "At the project site, baseline groundwater sampling was conducted in general (sic) accordance with NRC Regulatory Guide 4.14 (NRC, 1980). ... A summary of the results and methods for the groundwater quality monitoring program, as well as the historical TVA data, is presented in Section 2.7." However, when the reader goes to TR Section 2.7, there are no tables that actually statistically summarize complete baseline field and lab water quality data for the complete data sets—both historic and recent. Instead, for ground waters, Powertech presents statistics for field data from individual wells or selected aquifers, but fails to statistically-summarize the laboratory data and leaves out the historic TVA data. Powertech then states (TR, pg. 2-203): "Complete groundwater quality data results are available in Appendix 2.7-G." However, on TR, pg. 2-205 (Sect. 2.7.3.2.2.2, Results for Laboratory Parameters) Powertech then states: "Summary statistics for baseline monitoring program laboratory samples are contained in Appendices 2.7-H and 2.7-I. Appendix 2.7-H gives statistics for all groundwater constituents detected at or above PQL by constituent." Thus, it appears that Powertech has not included "qualified values," that is data reported as "less than" some concentration. By deleting the "less than" values, Powertech has severely biased the data set, rendering it useless as a reliable source for evaluating baseline conditions.

71. Furthermore, Powertech states (TR, pg. 2-217-218) that they have arbitrarily selected some analyses from the voluminous historic TVA data, but the reviewer is never allowed to see a statistical summary of the total original data set. This error is carried forward in the DSEIS. Portions of the relevant data are scattered throughout the Appendices of the various documents, and disingenuously organized to leave out all baseline data that had concentrations reported below the detection limits (i.e. "less than" values). Obviously, this approach biases the data. The NRC must require Powertech to statistically summarize all historic water quality data and all recently collected data in separate tables, including all "less than values." Both historic and recent baseline data should be segregated by water-bearing unit. Even should averaging of water quality data over a portion of the aquifer be acceptable, the methodology employed in the Application and DSEIS of discounting relevant data points is untenable.

72. To further confuse the baseline issues, Powertech's Supplement to the Application (August 2009) states on pg. 3-3: "A minimum of eight baseline water quality wells will be installed in the ore zone in the planned well field area." Thus it appears that the Applicant intends that the massive amounts of water quality data (historic and recent) presented in both the TR and ER (Environmental Report) will not actually be used to determine baseline. More importantly, it is unclear whether Powertech has true baseline (pre- operational) ground water quality data that describe the **non-ore zone regions of the relevant aquifers.** It is imperative that baseline data for the non-ore zone ground waters be collected and summarized separate from those of the ore zones – a review the DSEIS fails to conduct.

73. Any revision of the DSEIS should incorporate the comments made in Abitz (2009) regarding baseline characterization and data interpretation.

74. Lastly, the DSEIS should already contain a statistically-reliable database of baseline ground water quality data from all known wells within at least 2 miles of the DB boundary

**Confusion of Baseline and Background**

75. Table 7.3-1 of the DSEIS (p. 7-8 to 7-11), and the accompanying text confusingly and incorrectly use the terms "Background" and "Baseline" as having the same meaning. For many decades, "background" in geochemical / water quality literature has been defined as: "The normal abundance of an element in unmineralized earth materials is commonly referred to as background." (Rose, Hawkes & Webb, 1979, p. 30). Baseline in environmental studies has routinely been used to define a starting criterion, or yardstick, against which subsequent data are to be compared. Baseline has been used in this sense for many decades. In mining-related studies, the most common "baseline" is either pre-mining or preoperational conditions.

**The DSEIS fails to clearly and adequately describe the detailed methods employed for collecting water quality and water quantity data, for both surface and ground waters.**

76. Because the specific sampling and handling procedures can drastically change the results obtained when collecting water quality samples (both surface and ground water), it is imperative that the DSEIS include detailed descriptions of the various sampling, sample handling, preservation and shipment methods employed. Likewise, the DSEIS contains inadequate detail concerning the specific methods employed in collecting field water quality measurements and measurements of well yield, stream flow, etc.

77. For example, such details should provide information similar to those contained in the U.S.G.S. methods documents cited below:

[USGS] United States Geological Survey, variously dated, National field manual for the collection of water-quality data: U.S. Geological Survey Techniques of Water-Resources Investigations, book 9, chaps. A1-A9, available online at: http://pubs.water.usgs.gov/twri9A.

**Surface Water Quality Baseline Data: The DSEIS fails to adequately characterize these resources, or to include statistically- reliable summaries of detailed surface water data.**

78. Tables 3.5-1 and 3.5-2 (p.3-25-26) present totally incomplete and inadequate summaries of surface water quality. Most hydrogeologically-important chemical constituents are missing from these tables and they contain no indication of whether samples were field-filtered, or if the data are Total concentrations. (unfiltered samples).

79. The DSEIS contains no substantive discussion of the interactions between ground and surface waters, especially when the hydrogeologic system would be under pumping stress---as would be expected during the operating life of the D-B project. The DSEIS contains no detailed analysis or discussion of potential impacts to site surface waters due to ground water pumping, or potential spills and permitted discharges to surface waters. All such operations generate short-term impacts to surface waters, as a minimum.

80. The DSEIS no longer contains the questionable statements included in the 2009 application at ER pg. 4-16, which state: "Most ISL operations extract slightly more groundwater than they re-inject into the uranium bearing formation. ***The groundwater extracted from the formation could result in a depletion of flow in nearby streams and springs if the ore-bearing aquifer is hydraulically connected to such features.*** However, because most, if not all ISL operations are expected to occur where the ore- bearing aquifers are

confined, local depletion of streams and springs is unlikely, and potential impacts would be anticipated to be SMALL (NUREG-1910, 2008)." However, the DSEIS provides no detailed technical analysis to support the contention that surface waters will not be impacted because water-bearing units having confined aquifer conditions underlie much of the D-B site.

81. More importantly, the DSEIS and Application fail to provide a summarized, statistically-reliable surface water quality baseline database. As such, there will be no defensible method for verifying whether impacts to surface water quality have or have not occurred.

**A Baseline Spring and Seep Survey is not presented in the DSEIS.**

82. Disingenuously the DSEIS states that: "There are **no known natural springs** within the proposed Dewey-Burdock ISR Project area (Powertech, 2011). There is one area in the southwest corner of the Burdock area, known as the "alkali flats" or the "alkali area," where **groundwater is discharging** to the ground surface from the Fall River aquifer and Chilson aquifer (Chilson Member of the Lakota Formation) **through improperly plugged exploratory boreholes** (Powertech, 2011). Two springs are present along the Dewey Fault near the town of Dewey approximately 2 km [1.2 mi] northwest of the proposed project boundary (DSEIS p. 3-23)."

83. The DSEIS presents no information to indicate that either the NRC or Powertech have conducted an actual spring and seep survey. Such a survey would have included and characterized the springs along the Dewey Fault, and any others located within the D-B area and a reasonable perimeter, which should be at least 2-miles from the project boundary—given the results of the short-term pump test data in the 2009 Application.

84. The region surrounding the D-B project contains numerous springs in both the Madison and Minnelusa formations (DEIS p.3-32; Driscoll, et al., 2002). Baseline surveys of springs and seeps are crucial in studies where large volumes of ground water are to be extracted. The flows of such seeps and springs often decline or stop after large-scale, long-term ground water extraction begins, especially in arid or semi-arid regions, such as the D-B area. If such impacts begin to occur, disputes will arise as to the possible roles of the project water extraction and overall climate change, for example. Hence, it is imperative that such a survey be performed prior to issuance of any licenses, and such a survey should include, as a minimum:
-locate and survey all springs and seeps within some reasonable radius of the project boundary;
-measure and record flow / discharge quarterly for at least one year prior to issuance of any licenses;
-during all field episodes, make field measurements of in-situ pH, water temperature,

and S.C.(specific conductance) and collect samples for laboratory analysis.

Samples should be analyzed for the same list of constituents noted in the Baseline water Quality comments above. Spring and seep water quality data should be interpreted as representative of local ground water quality (Freeze and Cherry, 1979; Hem, 1985).

**The presence of high quality ground waters within the D-B Project boundary have not been adequately defined.**

85. Much of the DSEIS discussion concerning ground water quality seems focused on showing that the site waters are already contaminated. This would not be surprising given the presence of the uranium mineralization and the past mining and exploration activities---all of which would have caused increased concentrations of numerous chemical constituents above true pre-mining baseline. However, based on statements and data presented in the DSEIS, Powertech has not adequately defined whether zones peripheral to the D-B ore-bearing geologic formations and bounding formations (above and below) also contain zones of high-quality, possibly potable ground water. Such zones should already have been defined as part of the DSEIS and Application documents.

**Potential impacts to ground waters have been unrealistically minimized and inadequately characterized.**

86. The DSEIS fails to provide adequate baseline data to demonstrate that portions of the ore-bearing zones do not contain high quality ground water. In fact, it is clear that the NRC has relied on Powertech data that clearly are biased against revealing the extent of high quality ground waters. For example, Table 3.5-4 includes only water quality concentrations that exceed the MCLs (maximum contaminant levels), and discards all data having lower concentrations (p. 3-38). The discussion on p. 3-37 also is clearly intended to convey the message that most of the D-B area waters are already contaminated. A similar bias is presented in the DSEIS discussions of D-B area surface water quality (p.3-23, 25, 26, 27).

87. The DSEIS continues the unbalanced discussion of contaminated "baseline" that was presented in the 2009 Application. The ER (pg. 4-18) states that all D-B ore zone ground water quality is degraded by natural mineralization processes, but there are no data provided to support this allegation and in many similar situations it is simply not true. Furthermore, many ground water- bearing zones in mineralized areas do not contain elevated concentrations of metals, non- metals, etc. until they have been exposed to air and bacteria---often as the result of previous mining or exploration drilling—as has occurred here. Even following exploration and mining activities, some portions of ore-bearing formations continue to contain high-quality ground water.

88. Hence, it is not defensible for NRC and Powertech to state, as the company does in ER Sect. 4.6.2.2 (Potential Impacts of Production on Ore Zone Groundwater Quality) that: "Potential environmental impacts to groundwater are changes to water quality in well fields within the exempted aquifer. The impact, in and of itself, is of limited significance, due to the fact that the groundwater quality is very poor prior to ISL operations; due to the presence naturally occurring radionuclides, heavy metals, and other constituents that exceed EPA and/or state drinking water limits. Accordingly, the exempted aquifer is not and can never serve as a USDW (HRI, 1997; NMA, 2007)." The citations provided here by Powertech do not pertain to the specific D-B situation and one, the NMA citation, is simply a routine public relations statement made by the industry's lobbying group. The DSEIS inadequately addresses these issues.

89. The public relations statements continue on ER, pg 4-18, where they state: "Powertech (USA) has proposed to use gaseous oxygen and carbon dioxide lixiviant. The interaction of the lixiviant with the mineral constituents of the exempted ore zone results in a slight increase in trace elements and primary constituents of sulfate, chloride, cations and TDS above pre production levels. There is no introduction of non-naturally occurring constituents from the leach fluids into the ore body."

90. To support these unsubstantiated statements, Powertech needs to supply actual, detailed chemical analyses of the pregnant leach solutions (multiple analyses)--solutions resulting from the chemical interaction of the proposed lixiviant and the ore zone rocks. It is a basic purpose of an ISL operation to introduce these lixiviants to drastically change the local ground water chemistry, routinely producing significantly-elevated concentrations of many major and trace metals and metalloids, plus other constituents: i.e. arsenic, antimony, molybdenum, selenium, vanadium, uranium, strontium, iron, manganese, lead, lithium, nickel, chromium, sulfate, chloride, etc. It is a total "red-herring" to claim that: "There is no introduction of non- naturally occurring constituents....."

91. *In addition, there is ample evidence in the technical and regulatory literature to show that the leached aquifers at most, if not all ISL operations, have never truly been restored to their pre-operational, baseline water quality.*

**Ground Water Monitoring Methods are Inadequate to Reliably Define Past or Future Impacts. Domestic and Stock Wells.**

92. DSEIS p.7-13 and 14 (Project-wide GW monitoring), states that all domestic and stock wells within **2km** (1.2 mi.) of the project area will be sampled quarterly for a year to establish baseline water quality after operations begin [based on NRC, 1980, Regulatory Guide 4.14]. "All the preoperational groundwater samples will be analyzed for the constituents listed in Table 7.3-1."

93. The stated approach presents several *serious flaws*:

- if the samples are collected after operations begin, they cannot be considered true baseline;
- the list of constituents to be monitored is inadequate;
- The NRC Guidance Document cited is inappropriate: it refers only to uranium mills, not ISL operations, and deals only with radiological effluent.
- This Guidance Document does not define the radius to which domestic and stock, etc. wells should be monitored, for any type of uranium operation--ISL or mill. The authors have incorrectly applied the 2-Km distance as the Guidance speaks only with regard to tailings impoundments at conventional mills (section 2.13; p. 4.14-4).
- sampling of these wells *during operations* is proposed to be done *once per year*, which is totally inadequate to note changes in water quality or water level.

94. The definition of the area containing domestic and stock wells to be monitored needs to be expanded and defined more precisely. Because the DSEIS fails to show that Powertech has ever performed a detailed well inventory of all wells outside the proposed DB boundary, such an inventory is needed to evaluate present and future impacts as part of any acceptable EIS. A preliminary inventory should investigate and summarize the characteristics of all wells within at least 2 miles of the DB boundary. The inventory should plot the locations of all such wells on appropriate maps and summarize their uses; date drilled; completion characteristics, including depths; well yields; availability of water quality data. Once such an inventory is completed, all of these wells should be monitored for detailed water quality and water levels quarterly for a year, with all data summarized in a revised EIS.

**Baseline Water Quality Within Proposed Operation Areas.**

95. The DSEIS states (p. 7-8) that selected wells completed within the mineralized zones will be used to evaluate "baseline" water quality and they will then be converted into injection or production wells. Clearly the water quality in many of these zones is no longer true baseline due to all of the historical drilling / mining in many of these areas. These activities would have altered the original geochemical and bacteriological conditions, leading to significant changes in the water quality. In addition, if the "baseline" wells are converted to injection or production uses, these wells must be maintained, post-closure, to allow for long-term monitoring to evaluate the success or failure of aquifer restoration.

**Land application is not an approved method of radioactive liquid waste disposal.**

96. The DSEIS proposes that various liquid wastes may be disposed via land application. However, US EPA (2008) guidance states that land application is not an approved method for disposal of such wastes. Equally importantly, the DSEIS has failed to supply detailed chemical analyses of these proposed wastes (see discussion below) to clarify the chemical nature of the materials being disposed.



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97. Such detailed chemical composition data should be included in the DSEIS available for public comment and technical review prior to FEIS and license approval.

98. It is ironic that the Supplement to the 2009 Application erroneously states on pg. 4-7 that irrigation pivots have been used to dispose of non-hazardous wastes via surface application " with no deleterious effect on the environment" at Hobson, Mount Lucas, and Highland. In 2008, the operators of the Highland and Smith ISL mines in Wyoming were forced into a settlement agreement with the WY Dept. of Environ. Quality, because land application of liquid wastes containing elevated concentrations of selenium had contaminated soils. Part of the settlement agreement required the operators of Highland to immediately pay $8 million to accelerate reclamation activities and to increase their financial assurance bonds for these two sites to $80 million (WY DEQ, 2008). Furthermore, Faillace and others (1997) report that release of such waters will contaminate the soil at the land application areas. Radionuclides adsorbed by the soil will become a source term for radioactive release through wind erosion processes.

**Deep Well Injection of Liquid Wastes. The DSEIS fails to provide necessary details on the chemical composition of the wastes and water treatment specifics.**

99. At present, the public has not been told what specific measures will be used to dispose of D-B liquid wastes. One option mentioned is to dispose of such wastes via deep wells completed into the Minnelusa and / or Deadwood Formations (DSEIS p. 2-22). However, the public has no idea of the detailed chemical compositions of these liquid wastes. Detailed chemical analyses of these liquids should have been included in the DSEIS, including, as a minimum, all chemical constituents for which any category of environmental standard or criterion exists. These should include determinations of S.C., TDS, pH, all commonly-reported inorganics, trace elements, radiochemicals, and a detailed organic-constituent scan. Such data should be provided in the EIS for both treated and untreated liquid wastes.

100. While both the Minnelusa and Deadwood Formations are deep below the land surface, it is quite short-sighted to assume that these waters, once contaminated by the process wastes, could never generate negative impacts—especially if one considers the cumulative impact of the other industrial wastes that are or will be injected into these formations, long-term. Long-term scenarios should consider timeframes of at least 100s to 1000s of years in the future, when these deep waters may be required for other foreseeable domestic, agricultural, or industrial uses, and the economics of water are likely to be quite different than has been assumed in the GEIS (DSEIS p. 5-31). Thus, detailed water quality

analyses should be performed on these deep aquifer waters, both pre-injection and at various periods after injection is initiated.

**The technical and regulatory literature amply documents the numerous failures to restore aquifer water quality at other ISL sites. Thus, it is reasonable to assume that portions of the D-B ground water surrounding the leached zones will have degraded water quality and may be unfit for future uses.**

101. GEIS Section 2.5 described aquifer restoration activities within wellfields that *ensure water quality in surrounding aquifers would not be adversely affected by the uranium recovery operations* (DSEIS p. 2-35; NRC, 2009a). However, neither the DSEIS or the GEIS contain detailed discussions to demonstrate that the population of other in-situ operations have been able to do so. Indeed, the historical reality from other operating or closed ISL sites demonstrates an inability to restore to pre-operational or baseline WQ conditions for all constituents. (Otton, 2009; Hall, 2009).

**The public has no detailed information concerning the specific aquifer restoration standards / criteria that will actually be employed. The DSEIS presents no such specific aquifer clean-up standards / criteria.**

102. Because the DSEIS does not contain actual baseline data for D-B water resources, the DSEIS does not contain any such specific aquifer restoration standards / criteria. Instead, the DSEIS has the following convoluted, bureaucratic language (p.2-35):
"The primary goal of aquifer restoration is to return groundwater quality within the production zone of wellfields to the preoperational water quality conditions or to standards consistent with NRC requirements at 10 CFR Part 40, Appendix A, Criterion 5B(5) (Powertech, 2009b, 2011)."

103. The subsequent language makes clear to the reader that the public will not be told what the specific aquifer clean-up criteria will be until long after aquifer restoration has begun, and that the criteria are totally flexible.

"10 CFR Part 40, Appendix A, Criterion 5B(5) requires that groundwater quality in the exempted ore-bearing aquifer be restored to (i) a Commission-approved background (CAB) concentration; (ii) the maximum contaminant levels (MCLs) listed in 10 CFR Part 40, Appendix A, Table 5C, for constituents listed in Table 5C and if the background level of the constituents fall below the listed value; or (iii) an alternate concentration limit (ACL) established by the Commission, if the constituent background level and the values listed in Table 5C are not reasonably achievable. The ACL development is described in SEIS Appendix B. These groundwater quality standards would be implemented, as part of the aquifer restoration phase, to ensure public health and safety."

**Target Restoration Goals and UCL Parameters and standards should all be selected by the NRC and presented publicly in the EIS, prior to license approval.**

104. The DSEIS uses unnecessarily convoluted and inconsistent terms to describe aquifer restoration standards / criteria. Various parts of the DSEIS use the following terms (DSEIS p. 2-35):
Commission-approved background (CAB)
Maximum contaminant levels (MCLs)
Alternate concentration limit (ACL)
target restoration goals
lixiviant migration indicators (DSEIS p. 7-11)

105. It is impossible to discern whether or not the target restoration goals are the same as lixiviant migration indicators.

106. DSEIS p. 7-11 states: "The constituents and parameters selected as lixiviant migration indicators and for which UCLs will be set at the proposed Dewey-Burdock ISR Project are **chloride, conductivity, and total alkalinity** (Powertech, 2011)."

107. The 2009 Powertech Application Supplement, pg. 5-6, Sect. 5.2.7, states: "Powertech management has always used **Chlorides, Sulfate, and Uranium** as Upper Control Limit (UCL) Parameters. **Sometimes Total dissolved Solids** is used." This statement fails to provide necessary clarity, as Powertech has never operated an ISL mine.

108. The descriptions of proposed water quality monitoring (surface and ground waters) on pages DSEIS 7-4 through 7-15 are unclear and unnecessarily convoluted. Instead of the pages of unclear wording presented here, these details should have been summarized using tables to show: the specific sites / wells to be sampled; specific constituents & parameters; sampling frequency, reporting protocol and frequency.

109. The procedures describing how UCLs will be determined are inconsistent (p. 7-11, L 24-38). The UCLs named in the 2009 Application supplement and the DSEIS (2012) are different. How could the procedures used in both cases comply with NUREG-1569 (NRC 2003)? Furthermore, setting the UCLs at the mean concentration plus 5 standard deviations is excessively lax. It would be much more meaningful to present means plus the 95 percent confidence intervals.

110. Apparently only water level and UCL data (chloride, conductivity, and total alkalinity) will be reported to EPA, and only quarterly (DSEIS p. 7-11). Such reporting is totally inadequate in both frequency and constituents. In essence it

prevents the public and the EPA from understanding what is happening at the site.

111. The NRC has considerable experience with numerous operating and closed ISL / ISR operations. Clearly NRC, not the operator, should select the appropriate "target restoration goals". Yet, the DSEIS p. 2-35, L 37-38, states: "The applicant would establish target restoration goals [CAB concentrations per…….]." Selection of such target restoration goals and UCL parameters and standards should be done by the regulatory agency in the DSEIS to avoid possible conflicts of interest and reveal these foreseeable impacts at the earliest possible stages of project analysis.

112. *Such specific restoration goals and standards should be presented in the DSEIS for public review and comment prior to FEIS or license approval.*

**The SDEIS does not clearly define the various zones that are contemplated to contain, monitor, and control migration of lixiviant-mobilized groundwater and chemical constituents.**

113. D-B Application Supplement, pg. 5-5 describes an aquifer exemption boundary, which acts as an additional buffer zone outside the monitor well rings **"to provide protection to adjacent water from the excursions that occur in the normal course of operations."** Page 5-6 of the Supplement further states that the aquifer exemption boundary is proposed to be up to 1200 ft. outside the monitor well ring, and **would be considered the point of regulatory compliance. Apparently simply pumping to create an inward flow direction is not adequate to control "excursions."** It appears this aquifer exemption boundary is actually an expanded ground water sacrifice zone.

**Mitigation is Not Detailed In a Manner That Allows Any Meaningful Review**

114. The DSEIS portrays mitigation to account for impacts, but the mitigation consists only of proposals to make plans to restore groundwater in the future. There is no detail as to the effectiveness of these proposed mitigation measures, nor any analysis of whether any such plans have succeeded in the past.

115. The DSEIS provides for monitoring of restored groundwater aquifers for only 12 months. DSEIS, P. 2-37. However, there is no assessment as to whether 12 months is adequate. Aquifer restoration activities at numerous other ISL sites have failed to return aquifer water quality to baseline conditions following years of attempts at clean-up. Hence, at minimum, the NRC should conduct these effectiveness reviews and require that post-operational monitoring of D-B aquifer water quality continue until baseline conditions are attained.

**Financial Assurance**

116. DSEIS, p. 2-35 states that: "The applicant would also be required to provide financial sureties to cover the costs of both planned and delayed restoration programs, in accordance with 10 CFR Part 40, Appendix A, Criterion 9. NRC reviews financial sureties annually." Although a final decision on surety amounts will come at a later date, the revelation and analysis of the likely amount of surety must be revealed and analyzed in the DSEIS.

117. The NRC and the public know several general facts about the usefulness of most company-generated financial assurance estimates:

1-They generally are based on overly-optimistic assumptions about future water quality, thereby under-estimating costs. Kuipers (2000) conducted a survey of bonding practices at metal mines throughout the western U.S. and found that the bond amounts available were hundreds of millions of dollars below that necessary to conduct actual clean-ups. Many of the "problem" sites have been foreign-owned entities, especially those with their corporate headquarters and assets based in Canada.
2-Aquifer restoration at most, if not all previously-licensed and operated ISL sites has failed to actually return ground water quality to baseline conditions [Hall (2009); Otton and Hall (2009);
3-Predictions of future aquifer restoration success made by the project proponents seldom use truly conservative assumptions. Calculation of financial assurance amounts made by representatives of the party that stands to profit from project licensing represents an extreme conflict of interest.
4-The technical literature is filled with documentation that quantitative predictions of future water quality at *specific* sites cannot be done reliably [Sarewitz, et. al. (2000); Moran (2000); Pilkey & Pilkey-Jarvis(2007); Kuipers & Maest (2006)], and the general failure to restore aquifers back to pre-operational baseline concentrations supports this. This approach must be totally rejected because it assumes one can make accurate and precise *deterministic* predictions.

118. For these reasons, at least preliminary financial assurance calculations should be included in the DSEIS, preferably made by some independent party, not paid or directed by the project proponents. These calculations should also consider the actual reclamation and restoration costs incurred, long-term, from a statistical sampling of the previously-licensed ISL sites. Furthermore, these financial assurance amounts and mechanisms should be made public prior to award of any licenses.

119. To ensure protection of the general public, such financial assurance agreements (bonds, etc.) should be made with the parent corporation, not simply the local operating entity.



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Pursuant to 10 C.R.F. § 2.304(d) and 28 U.S.C. § 1746, I declare under penalty of perjury, that the foregoing is true and correct to the best of my knowledge and belief.

Signed on the 24th day of January, 2013,

Robert E. Moran, PhD.

Robert E. Moran, PhD.



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## EDUCATION

University of Texas, Austin: Ph.D., Geological Sciences, 1974
San Francisco State College: B.A., Zoology, 1966

## PROFESSIONAL HISTORY

Michael-Moran Associates, LLC, Partner, 2003 to present
Woodward-Clyde Consultants, Senior Consulting Geochemist, 1992 to 1996
Moran and Associates, President, 1983 to 1992; 1996 to 2003
Gibbs and Hill, Inc., Senior Hydrogeologist, 1981 to 1983
Envirologic Systems, Inc., Senior Hydrogeologist / Geochemist, 1980 to 1981
Tetra Tech Intl./ Sultanate of Oman, Senior Hydrogeologist, 1979 to 1980
Science Applications, Inc., Geochemist / Hydrologist, 1978 to 1979
U.S. Geological Survey, Water Resources Div., Hydrologist / Geochemist, 1972 to 1978
Texas Bureau of Economic Geology, Research Scientist Assistant, summers:1970 & 1971

## REPRESENTATIVE EXPERIENCE

Dr. Moran has more than 42 years of domestic and international experience in conducting and managing water quality, geochemical and hydrogeologic work for private investors, industrial clients, tribal and citizens groups, non-governmental organizations, law firms, and governmental agencies at all levels. His experience includes the following representative project assignments.

***2003 to Present: Michael-Moran Associates, LLC:***

- Contraloría General de la República & IKV Pax Christi, Bogota, Colombia. Provide assistance and training to the independent auditing arm of the Colombian government on mining & environmental audits and legislation.
- The Black Hills Wild Horse Sanctuary, and Bangs, McCullen, South Dakota. Expert opinions and testimony before State regulatory agencies regarding Large-Scale Mine and Water Use permits for the proposed Dewey-Burdock in-situ uranium operations.
- Sims Murray Ltd. and the Town of Florence, Arizona. Review of Town nuisance ordinance related to proposed in-situ mining and aquifer impacts. Expert opinions for litigation.
- Wild Salmon Center & World Wildlife Federation (Russia), Moscow, Russia. Elaboration and presentation of mining and water-related issues to members of Russian government, industry and the environmental communities.

- Citizens of Cañon City / Colorado Citizens Against Toxic Waste, Inc. (CCAT); Cañon City, Colorado. Technical assistance to citizen's group on hydrogeologic and geochemical issues related to contamination from disposal of radioactive, etc. materials at the Cotter uranium mill site.
- Environmental Defender Law Center and GRUFIDES (NGO), Cajamarca, Peru. Review of Environmental documents relating to the Conga Mine; site visit; report preparation.
- Roanoke River Basin Association; Virginia. Assistance on technical issues related to proposed uranium mine and processing facilities; presentations to public and regulators; participation in government planning meetings.
- Human Development Center "Tree of Life"; Bishkek, Kyrgyzstan. Review of operations at Kumtor Gold Mine using funds from Bankwatch, Kiev, Ukraine.
- Za Zemiata (Sofia) and the University Autonoma de Barcelona; Krumovgrad, Bulgaria. Review of the EIS for a proposed gold mine; municipal / public meeting presentations; prepare report using E.U. funds.
- Powder River Basin Resource Council; Oshoto, Wyoming.
  Review of Strata Energy NRC License Application to operate an in-situ leach uranium operation; provide technical opinions.
- Pro Patrimonio (the National Trust of Romania); Brussels, Belgium. Presentation to members of European Union Parliament regarding environmental aspects associated with the proposed Rosia Montana Mine, Romania.
- Trustees for Alaska. Prepared expert report on hydrogeologic and water quality impacts from exploration activities at the Pebble Mine site. Opinions prepared for litigation in Alaska Superior Court on behalf of *Nunamta Aulukestai, et. al. v. State of Alaska, et. al.* (Pebble Limited Partners); deposition and trial testimony.
- Bank Information Center and Earthworks, Washington, D.C. Report on hydrogeologic and geochemical impacts at the proposed Weda Bay, Indonesia, cobalt-nickel mine; delivered to Multilateral Investment Guarantee Agency.
- IKV Pax Christi (Netherlands), Bogota, Colombia. Prepare mining-environmental best practices report for presentation to Colombian Ministry of Environmental Affairs.
- Oglala Sioux Tribe, Western Mining Action Project, Gonzalez Law Firm, South Dakota. Review of Powertech License Application, EIS and provide expert opinions: Dewey-Burdock In Situ Uranium Project.
- Comisión de Gestión Integral de Aguas de Bolivia (Commission for the Integrated Management of Bolivian Waters) and Federación Regional Única de los Trabajadores Campesinos del Altiplano Sud (Regional Farmers Federation of the Southern Altiplano), Bolivia. Review of present mining activities and documents related to the San Cristobal Mine. Activities funded by the Municipality of Colcha K (Potosí, Bolivia), the Centro de Estudios de la Universidad de San Simón, Cochabamba, and Global Green Grants Fund.



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- Shute, Mihaly & Weinberger / San Diego State University Research Foundation. Review of hydrogeologic / environmental impacts associated with quarry construction near a university wildlife refuge.
- Sarah Vogel Law Firm, North Dakota. Litigation support and evaluation of environmental impacts resulting from a release of oilfield waters onto livestock lands and waters.
- IKV Pax Christi (Netherlands), Tolima, Colombia. Technical review of proposed La Colosa gold project (Anglo Gold Ashanti); interaction with regulators, civil society and company; prepare recommendations & report.
- Thompson Divide Coalition, Western Colorado. Technical assistance to a consortium of environmental groups in designing and conducting a baseline water sampling program in anticipation of gas drilling activities. Preparation of summary report.
- Global Green Grants / Nature's Own, Papua New Guinea. Prepare technical / policy papers on marine disposal of mining wastes.
- SAVIA, School of Ecological Thought / Comision Pastoral Paz y Ecologia, Guatemala. Presentations on ecological aspects of resource legislation to Guatemalan government ministries, high-level officials, and educational institutions. Conduct water quality training classes; assist with development of laboratory capabilities.
- Astrella & Rice, Colorado, U.S.A. Technical assistance in preparing litigation arguments for citizen lawsuit involving alleged drinking water contamination by oil and gas activities.
- Office of the Prime Minister, Iraqi Kurdistan. Development of information infrastructure and management training for numerous ministries in Northern Iraq; done in partnership with faculty of American University, Washington, D.C. Headed an audit team for the Regional Statistics Organization.
- Southwest Research and Information Center / Buryat Regional Organization on Baikal / Mongolia Nature Protection Coalition; Buryatia, Siberia, Russia and northern Mongolia. Technical information exchanges with local NGOs, government officials and mining company staffs.
- Rulison Citizens Group / Public Counsel of the Rockies. Colorado. Development of technical arguments and potential litigation support intended to define environmental issues related to gas development near the Rulison underground nuclear test site. Hearing testimony.
- The Nature Conservancy, Trout Unlimited, Alaska Conservation Foundation, Trustees for Alaska and Renewable Resources Coalition, Alaska. Presentations to public interest groups and development of technical issues and papers relating to construction of the Pebble copper-molybdenum-gold mine, proposed for operation above the largest sockeye salmon fishery in the world.
- Wild Salmon Center, Alaska. Technical evaluation of hydrogeological and chemical issues that may impact fisheries near the proposed Pebble Mine.



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- Miller, Axline & Sawyer / Meyers, Nave, Riback, Silver & Wilson / City of Grass Valley, California. Technical and litigation support in a suit alleging contamination by Newmont Mining Corporation; deposition testimony.
- Latin American Water Tribunal. San Salvador, El Salvador. Prepare presentations and conduct workshops on water and water quality. Funding: Heinrich Boll Foundation.
- Alburnus Maior, Rosia Montana, Romania. Evaluation of EIA and preparation of summary report on a proposed gold mine in Transylvania. Funded by the Staples Trust, U.K. and the Open Society Foundation, Romania.
- Asociacion de Desarrollo Social Santa Marta (ADES), El Salvador. Evaluate EIA and related documents, El Dorado Mine; technical presentation at national forum; prepare review report. Funded by DIAKONIA, Swedish Ecumenical Action.
- Alburnus Maior, Romania. Review documents and prepare comments related to development of proposed Rosia Montana Mine for a Romanian NGO.
- La Lumiere, Senegal and WACAM, Ghana. Conducted water quality training sessions for NGO and government staffs, as related to mining and other development activities. Funded by Oxfam America.
- ESRI (Environmental Systems Research Institute). Provide technical assistance to several Iraqi Ministries to define information management needs, deploy map-based systems (GIS), and establish a Middle East-based Center of Excellence to support these ministries. Performed in conjunction with NGA.
- Colectivo Madre Selva, Guatemala. Evaluation of Marlin Mine site, review of EIA and preparation of report; attendance at national and indigenous mining forums; conducted water quality training; review of CAO / IFC documents. Funded partly by Misereor, Catholic Bishops' Development Organization, Germany.

***1996 to 2003: Moran and Associates, Inc.:***

- International Union for Conservation of Nature and Natural Resources (IUCN, Switzerland). Review of the Mining and Metals Supplement of the Global Reporting Initiative (GRI).
- World Bank, Extractive Industry Review. Member of Advisory Group assisting WB in evaluating extractive industry practices; London, Lisbon.
- Nishnawbe Aski and other Ontario First Nation bands---Ontario, Canada. Review of environmental documents relating to Montcalm Mine, a proposed copper-nickel facility. Activities paid for by Falconbridge Limited.
- Kazakh Institute of Physics and Technology / ISTC---Almaty, Kazakhstan. Technical oversight of environmental program, evaluating migration of radionuclides at the Semipalatinsk Nuclear Test site.
- Greenpeace Argentina / Mineral Policy Center---Esquel, Argentina. Review of EIA (water, environ. issues) and conditions at proposed mine in Patagonia.



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- Oxfam America / Sahel Development Foundation: Syama Mine, Southern Mali. Review of environmental conditions and documents related to an IFC-funded gold mine (2003); conduct technical workshops and policy meetings with Mali government and press (2004).
- Kivalina Relocation Planning Committee---Alaska. Litigation support to Center on Race, Poverty & the Environment regarding water quality issues, Red Dog Mine. Deposition testimony.
- Asociation de Organismos No Gubernamentales—Santa Rosa de Copan, Honduras. Independent review of water / environmental issues at San Andres mine; funded by Dan Church Aid (Danish government and NGOs) and Christian Aid (English NGO).
- Oxfam America / Friends of the Earth Int'l. / Global Green Grants---Quellaveco, Peru. Independent review of mining, water and environmental issues at request of Asociacion Civil "Labor", Lima.
- Oxfam America / Mineral Policy Center / Environmental Mining Council of B. C.: Tambogrande, Peru. Independent review of mining water and environmental issues. Includes numerous public presentations to citizens and governmental groups, including members of the Peruvian Congress.
- New Mexico Environment Department---New Mexico. Review of cost estimates for water treatment systems for closure plans / bonding calculations, Chino and Tyrone Mines.
- International Institute for Environment and Development—London, U.K. Consultant to MMSD project on sustainable development / mining issues.
- Technical Chamber of Greece---Thrace, Greece. Technical assistance to advisory arm of the Greek government and citizens groups regarding gold mining / environmental issues.
- Malerah-Wahlabul Native Title Claimants / Friends of the Earth—Sydney, Australia. Review of water quality issues related to cyanide leach gold operations on aboriginal lands, and testimony at Land and Environment Court.
- Loeb Aron &Co.---London, U.K. Preparation of report evaluating the Baia Mare, Romania waste spill for an investment banking firm.
- Centro de Investigacion y Planificacion del Medio Ambiental (CIPMA) / World Resources Institute / International Development Research Centre---Chile. Evaluation of environmental costs associated with copper mining in Chile.
- Carl Duisberg Gesellschaft / Univ. of Witwatersrand / United Nations---South Africa. Training in cyanide and environmental technology assessment issues.
- Dogrib Nation / Pape and Salter---Yellowknife, Canada. Geochemical consulting and testimony regarding the proposed Diavik diamond mine.
- Soros Foundation Kyrgyzstan---Bishkek, Kyrgyzstan. Water quality instruction to regulators and NGOs regarding mining, sampling, laboratory procedures, and general environmental issues. Review laboratory.



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- General Chemical / Sierra Club---Piceance Basin, Colorado. Review of water quality, treatment, legal and policy issues regarding the proposed Yankee Gulch soda ash mine; hearing testimony.
- Sierra Club Legal Defense Fund / Okanogan Highlands Alliance----Crown Jewel Mine, Washington. Litigation support on water quality, geochemistry, treatment issues to groups opposing proposed gold operation; test case on federal mining law; deposition testimony.
- National Wildlife Federation---Carlota Mine, Arizona. Litigation support for challenge of EPA regarding water quality/ treatment issues at copper mine. Review of TMDL issues related to Pinto Creek for NWF and local citizens.
- International Rivers Network---Review of proposed dam project and associated mine water quality issues at the San Roque site, Philippines.
- Mineral Policy Center---Preparation of technical documents on the environmental behavior, analysis and toxicity of cyanides.
- Holnam Industries---Penrose, Colorado. Ground water quality/ geochemistry study for cement operation.
- World Resources Institute---mining water quality/ geochemistry assistance on Venezuelan forestry / mining environmental regulations, and environmental economics of copper mining practices, Chile.
- U.S. EPA / American Geological Services---French Gulch, Colo. Geochemical / treatment /remediation support at an abandoned mine site; negotiated Superfund issues.
- Stoel Rives / Richmond Hill Mine, So. Dakota. Review water quality treatment and geochemistry issues at a closed gold mine site with discharge violations.
- Nacho Nyak Dun First Nation / Pape and Salter—Yukon, Canada. Evaluation of proposed heap-leach gold mining facilities and practices for native group and barristers.

***1992—1996: Woodward-Clyde Consultants, Inc.***

-Molycorp / Unocal—Questa, New Mexico. Review of water quality, geochemical, & aquatic biology issues at a molybdenum mine / mill site.

-Minera Escondida Ltda.---Chile. Review of geochemical data for copper mine.

-Homestake Mining---Lead, South Dakota, U.S.A. Review of water quality and geochemical problems and waste rock storage and tailings stability issues.

-U.S. Bureau of Land Management / Summo Minerals—Lisbon Valley, Utah. Review of water quality and geochemistry, and assistance in preparation of an EIS at a proposed copper mining and recovery site.



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-Southern Peru Copper Corp.--Toquepala, Peru. Design and oversight of water quality, geochemistry, and remediation issues at an open-pit copper mine, mill, and waste facilities.

-Cortez Mining/ Placer Dome / U.S. Bureau of Land Management - Pipeline Project, Nevada. Review of water quality and geochemistry and preparation of EIS-related reports at this proposed open pit gold site.

-Kennecott Utah Copper. Interacted with the law firm of Bogle and Gates to assist an active metal mining company in defending against a CERCLA listing. Activities involved interpreting water quality/geochemical and other environmental data within the Hazardous Ranking System (HRS) context.

-ASARCO - Leadville, Colorado. Oversight of water quality and geochemical activities at a historic metal mining and processing site where the client is involved in CERCLA negotiations. Interaction with State and EPA representatives and legal staff.

-Cambior Minerals - Metates Mine, Mexico. Water quality and geochemistry evaluation of a new gold property.

-Fraser Stryker and the Lindsey Chemical Co. - Nebraska. Technical support to legal staff involved in negotiations regarding a Superfund industrial processing site.

-W.R. Grace - Motorwheel Site, Michigan. Technical assistance to Grace legal staff involved in CERCLA negotiations at a hazardous waste site.

-Zortman Mining Co. / U.S. Bureau of Land Management. Technical and management responsibilities for water resources and geochemistry tasks in preparation of revised EIS at a gold-cyanide leach site with existing acid drainage problems.

-Echo Bay Mining, Lamefoot Mine, Republic, Washington. Responsible for geochemistry and water quality aspects of a supplemental EIS at a new gold mine site. Development of monitoring, testing and remedial recommendations to the BLM.

-Angelina Farms, Louisiana. Technical support to legal staff of oil production companies accused of contaminating groundwaters with brines.

-Amax Gold / Haile Mining, South Carolina. Water quality consulting at a gold mining site with existing acid drainage problems.

-Chino Mines, New Mexico. Technical evaluation of water quality and geochemical issues associated with leaching operations at an operating copper facility.

***1983 to 1992: Moran and Associates, Inc.:***



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-Shea and Gardner / Rockwell--Rocky Flats Nuclear Plant, Colorado. Reviewed and evaluated geochemical studies; proposed future activities in preparation of potential environmental-criminal litigation.

-Saunders, Snyder, Ross and Dickson / American Water Development, Inc. - San Luis Valley, Colorado. Coordinated water quality and geochemistry activities in support of water rights litigation. Oversaw water quality sampling, evaluated water quality and remote sensing data, assisted attorneys in technical strategy development and opponents' depositions; supplied deposition testimony.

-Arnold and Porter / Keystone Ski Corporation - Keystone, Colorado. Designed water quality and geochemical sampling program for ski area expansion in a previously mined area. Evaluated data and proposed remediation activities.

-Advanced Sciences, Inc. / EG&G - Rocky Flats Nuclear Plant, Colorado. Evaluated existing water quality and geochemical sampling programs; prepared document on non-facility related sources of chemical constituents and background.

-City of Brighton - Brighton, Colorado. Evaluated existing surface and groundwater quality data and suggested remedial activities to deal with excessive manganese and dissolved organic concentrations. Provided testimony to City Council.

-Chadwick & Associates, Inc. / Newmont Mining - Telluride, Red Mountain, Colorado. Provided diverse water quality and geochemical consulting relating to remediation of acid mine drainage problems.

-Intergraph Corp. - Reston, Virginia. Assisted in technical development and marketing of a new environmental data management / GIS product.

-U.S. Forest Service - Salmon, Idaho. Geochemical / water quality consultant at the Beartrack mine site, a proposed cyanide-leach gold project.

-Earth Satellite Corporation / Navajo Nation / Patton, Boggs, and Blow - Window Rock, Arizona. Conducted a preliminary reconnaissance of water resources on the joint-use area of the Navajo/Hopi reservations using satellite imagery.

-Mission-Viejo / Morrison and Forester - Denver Basin, Colorado. Acted as a geochemical consultant in a groundwater rights dispute.

-Bunker Hill Corporation / Dames and Moore - Kellogg, Idaho. Reviewed field and laboratory water quality procedures at a CERCLA metal-mining and processing facility. Audited proposed laboratory.



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-Saunders, Snyder, Ross, and Dickson / Adolph Coors Company - Golden, Colorado. Water quality consultant; reviewed data from Central City/Blackhawk, CERCLA site, and determined potential impact to the Coors water treatment plant. Provided testimony at stream classification hearings, Colorado Water Quality Control Commission.

-Colorado Water Resources and Power Authority - San Luis Valley, Colorado. Conducted water quality/geochemical and Landsat evaluations of deep groundwater to aid in development decisions.

-Armstrong, Teasdale, Kramer, Vaughan, and Schlafly / Anschutz Corp.-- Fredricktown, Missouri. Supervised technical activities of a CERCLA / SARA-related lawsuit; acted as a technical liaison with attorneys and regulators; managed consultants; authored reports; deposition testimony.

-Holland and Hart / White and Jankowski / Weller, Friedrich, Ward and Andrew / Breckenridge Ski Corporation - Breckenridge, Colorado. Technical supervision of water quality-related issues in a private lawsuit against Breckenridge Ski Corporation. Managed sampling and data interpretation; interacted with attorneys on strategy and assisted at depositions; authored reports; expert witness.

-Dames and Moore / Hecla Mining Corporation - Leadville, Colorado. Acted as hydrogeological/geochemistry consultant to Hecla on a natural resources damage suit; interacted with attorneys at Davis, Graham and Stubbs.

-Dames and Moore / Davis, Graham and Stubbs - Eagle Mine, Colorado. Supervised water quality/hydrogeology activities in preparation of a legal defense of Gulf and Western Corporation versus the State of Colorado in a natural resources damage suit; supervised and participated in all sampling; QA activities and report preparation; interacted with attorneys and regulators; assisted at depositions; deposition testimony; testified before Colorado Water Quality Control Commission on appropriateness of proposed metals standards.

-Jacobs Engineering - Albuquerque, New Mexico. Prepared policy documents on water quality/geochemistry procedures associated with the Uranium Mill Tailings Remedial Actions Project (UMTRA).

-University of Wisconsin. Designed a proposed groundwater exploration program for Gambia, West Africa, in conjunction with Earth Satellite Corporation.

-Harza Engineering Company / University of Michigan - Senegal, Guinea, and Gambia, West Africa. Evaluated potential impacts of new dam construction within the Gambia River basin. Reviewed local hydrogeology, mining production and exploration data; interacted with local officials.



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-Engineering-Science, Inc. Faisalabad, Pakistan. Assisted in design of a well field for a groundwater supply in the central Punjab where high salinity and TDS were major problems; negotiated with local officials; prepared reports for Asian Development Bank.

***1981-1983: Gibbs & Hill, Inc.***

-Holme Roberts and Owen - Canon City, Colorado. Reviewed and interpreted existing hydrogeology and water quality data at the Cotter uranium mill and tailings; proposed future activities; interpreted background concepts, prepared position papers for attorneys in negotiations with State of Colorado.

-Earth Satellite Corporation - Sultanate of Oman. Conducted an interpretive study of regional groundwater potential in Oman, with the staff of Earth Satellite Corporation. Activities included interpretation of existing geology and Landsat imagery combined with conventional low altitude flight and ground reconnaissance. Prepared reports for government of Oman.

-Anschutz Mining Corporation - Fredericktown, Missouri. Managed water resource-related activities for environmental baseline studies at a proposed cobalt/ nickel mine. Designed sampling programs, oversaw sampling, data interpretation, and report preparation.

-Kemmerer Coal Company - Frontier, Wyoming. Managed and conducted hydrogeologic and water quality studies at a proposed open-pit coal mine. Supervised well installation, aquifer testing, sampling, report preparation; interacted with state regulators.

-Anaconda Copper Company - Rico, Colorado. Conducted an investigation of hydrology, water chemistry, and aquatic biology at a complex-ore mining district.

-Union Carbide Corporation - Uravan, Colorado. Managed and conducted a water quality monitoring program for a proposed uranium tailings disposal area and effluent evaporation basin. Assisted in design of geochemical testing program to evaluate potential leachate quality.

-Anschutz, Mining Corporation - Laredo, Texas. Managed and conducted an investigation of groundwater hydrology and soils geochemistry and associated hazardous wastes at a metal ore handling and reagent storage facility. Designed sampling protocol; prepared reports; negotiated with state regulators; interacted with attorneys at Baker, Botts.

-Snowmass Coal Company - Carbondale, Colorado. Managed and conducted hydrogeology investigation of an underground coal mine with steeply dipping seams.



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-Marline Uranium Corporation / Union Carbide Corporation - Danville, Virginia. Managed water resources portion of a baseline investigation at a proposed hard-rock uranium mine site. Oversaw well installation monitoring programs and dewatering investigations.

-Southern Pacific Petroleum - Means, Kentucky. Conducted baseline hydrogeological/geochemical investigations at a proposed oil shale mine and retort facility.

***1980-1981: Envirologic Systems, Inc.***

-Central Arizona Association of Governments - Globe/Miami, Arizona. Conducted study to determine hydrogeologic/geochemical impact of long-term copper mining and processing facility. Designed monitoring programs; interacted with federal, state, local and tribal officials; prepared numerous reports.

-United Nuclear - Homestake Partners - Milan, New Mexico. Conducted hydrogeological/geochemical evaluation of an existing monitoring program for a uranium milling and waste-disposal facility.

-Homestake Uranium - Marshall Pass, Colorado. Hydrogeological / geochemical evaluation of a proposed, hardrock, open-pit uranium mine.

***1979-1980: Sultanate of Oman / Tetra Tech International*** - Muscat, Oman. Member of Water Resources Council Staff, Sultanate of Oman, based in Muscat, Oman. The Water Resources Council was an inter-ministerial body intended to coordinate all water-related activities within the Sultanate. Duties involved planning and design of surface and groundwater projects (both exploration and utilization) for the Omani government; development of water resources policy for the government; hydrogeological field work on both exploration and resource characterization projects - aquifer testing, borehole geophysics, water quality sampling, hydrogeologic mapping; review of work performed (or planned) by other consultants to the government, published reports on water resources of Oman.

***1978-1979: Science Applications Inc.:***

-EG&G - Idaho National Engineering Laboratory, Idaho Falls, Idaho. Managed a hydrologic investigation of transuranic nuclide migration in groundwater. Contributed geochemical expertise to evaluation of waste isolation and transport modeling.

-Kerr-McGee Corporation - Grants, New Mexico. Conducted investigation into geochemistry of selenium associated with uranium mining/ milling.



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***1972—1978: U.S. Geological Survey Water Resources Division***; responsible for the design, management, and implementation of the following hydrogeological / geochemical studies:

-Metal-Mine Drainage - Colorado. Study of impacts of mining activities (metals, uranium, coal) on the quality of streams in all major Colorado mining districts.

-Selenium in Groundwater - Golden, Colorado. Hydrogeological / geochemical investigation of selenium, uranium and associated constituents at the margins of the Rocky Flats nuclear plant.

-Geothermal Resources - Colorado. Reconnaissance investigation of potential geothermal resources throughout Colorado.

-Underground Coal Mine Water Quality - Colorado. Evaluation of existing and potential water quality problems from underground coal mines.

-In Situ Uranium Leaching - Grover, Colorado. Study of geochemical and hydrologic processes associated with in situ uranium mining and reinjection of waste products.

-Alluvial Metal Transport - Telluride, Colorado. Investigation of metal (especially chromium) movement from tailings ponds into alluvium.

-Southwest Colorado Groundwater - Colorado. Study to determine availability and quality of groundwater in southwestern Colorado.

-Oil Shale Waters - Piceance Basin Colorado. Evaluation of disposal of saline groundwater discharged to the surface during oil shale development.

-Grace Coal Site - Axial Basin, Colorado. Hydrogeological / water quality study of proposed open-pit coal site.

***1970, 1971, Summers: Texas Bureau of Economic Geology.*** Evaluation of the aqueous geochemistry and biochemistry of Gulf Coastal sedimentary sulfur and uranium deposits and their relationships with hydrocarbons: interpretation of geologic and geophysical logs, water quality data.



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Moran, R.E. and D.A. Wentz, 1974. Effects of metal-mine drainage on water quality in selected areas of Colorado, 1972-1973. Colorado Water Conservation Board. Water Resources Circular No. 25, 250 pp.
http://co.water.usgs.gov/publications/pubsnonusgs.html
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Moran, R.E. and D.A. Wentz, 1974. Thermodynamic constraints on Metal Solubilities in a stream affected by mine drainage, Bonanza, Colorado. pp. 54-64,in *Water Resources Problems Related to Mining*. Hadley, R.F. and D.T. Snow (eds.). American Water Resources Association. Minneapolis, Minnesota. 236 pp.

Moran, R.E. and D.A. Wentz, 1974. Trace element content of a stream affected by metal-mine drainage, Bonanza, Colorado pp. 84-91 IN: International Symposium on Water-Rock Interaction Proc. Cadek, J. and T. Paces (eds.). Prague, Czechoslovakia. September 9-19, 1974. Geological Survey, Prague. 464 pp.

Moran, R.E., 1976. Geochemistry of Selenium in Groundwater near Golden, Jefferson County, Colorado. Abstracts with Programs, Geological Society of America. 1976 Annual Meeting. November 8-11, 1976. 8(6):1018.

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Moran, R.E. 1979. Available and Potential Water Resources of Oman. Submitted to Water Resources Council, Sultanate of Oman.

Moran, R.E. and J.V. Rouse, 1981. Procedures for Collection of Water Quality Samples and Data. Envirologic Systems, Inc. Denver, Colorado. 61 pp. Prepared for the Central Arizona Assoc. of Gov'ts.

Moran, R.E. 1984. Impacts of Proposed Mining and Hydrogeological Activities on Development within the Gambia River basin, Senegal, Guinea and Gambia. Submitted to Harza Engineering.

Moran, R.E. 1984. Preliminary Design Report, Groundwater Supply, Faislabad, Pakistan. Submitted to Engineering Science, Inc.



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Harlan, R.L. and R.E. Moran, 1986. Closure of Metal Mining Sites: Hydrologic, Environmental and Legal Issues. Abstracts from Society of Mining Engineers Meeting, September 7-10, 1986, St. Louis, Missouri.

HRS Water Consultants and R.E. Moran, 1987. San Luis Valley Confined Aquifer Study. Three reports prepared for the Colorado Water Resources and Power Development Authority. http://digital.library.colostate.edu/cdm4/document.php?CISOROOT=/cowaters&CISOPTR=4681&CISOSHOW=4379; http://digital.library.colostate.edu/cdm4/document.php?CISOROOT=/cowaters&CISOPTR=5539&CISOSHOW=4888

Straskraba, V. and R.E. Moran, 1990. Environmental Occurrence and Impacts of Arsenic at Gold Mining Sites in the Western United States: Proceedings, International Symposium on Acid Mine Water in Pyritic Environments, Lisbon, Portugal. September 16-19, 1990; *in* Mine Water and the Environment, Volume 9, Numbers 1-4 / March, 1990, Springer Berlin / Heidelberg; available at: http://www.imwa.info/bibliographie/09_14_181-191.pdf ; http://www.springerlink.com/content/m1721074878301j4/ [abstract].

Moran, R.E., 1990. Environmental Constituents in the Rocky Flats Area - Non-Facility Related Sources Pertinent to Water Quality. Prepared for Advanced Sciences Inc., December 10, 1990.

Patton, C.A., K.M. McGaffey, J.L. Ehrenzeller, R.E. Moran, and W.S. Eaton. "The Hazard Ranking System: Special Considerations for Mining Sites." Presented at the 8th Annual Regional Environmental Business & Management Conference & Expo, Denver, Colorado. October 1994.

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Moran, R.E. and S. Mernitz. "Acid Mine Drainage and Political Conflicts in the Third Party EIS: Water Resources at Risk." Amer. Instit. of Hydrology, editors Hotchkiss, W.R. et. al., p. RA-36, Minneapolis, Minnesota. 1995.

Davidson, R.R., Peter A. Stauffer, and R.E. Moran, Tailings Impoundment Design -- Striving for Balance, January 1996, *in* Tailings and Mine Waste '96; Proceedings of the Third International Conference on Tailings and Mine Waste, Colorado State University, Fort Collins, Colorado, p. 83-90, A.A. Balkema, Rotterdam.



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and at: http://www.mineralresourcesforum.org/technical/cyanide/cyanidem.htm
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Moran, R. E., 2000, Mining Environmental Impacts---Integrating an Economic Perspective (DRAFT): Centro De Investigacion Y Planificacion Del Medio Ambiente, Santiago, Chile: Internet Forum on Export Markets and the Environment [ *at*: http://www.cipma.cl/hyperforum/index.htm and http://www.idrc.ca/mpri/documents/cipmaart3.html and http://www.tei.or.th/pdfdoc/potash_021.pdf (draft), http://enrin.grida.no/case_studies/bor/docs/env-eff-cu-chile.pdf ]

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http://www.tierralimpia.net/docs/tambo-grande-informe.pdf

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UNITED STATES OF AMERICA
NUCLEAR REGULATORY COMMISSION

BEFORE THE ATOMIC SAFETY AND LICENSING BOARD

| | | |
|---|---|---|
| In the Matter of | ) | |
| | ) | |
| POWERTECH (USA) INC., | ) | Docket No. 40-9075-MLA |
| | ) | ASLBP No. 10-898-02-MLA-BD01 |
| (Dewey-Burdock In Situ Uranium Recovery | ) | |
| Facility) | ) | |

**SECOND SUPPLEMENTAL DECLARATION OF DR. ROBERT E. MORAN**

I, Dr. Robert E. Moran, do hereby swear that the following is true to the best of my knowledge:

1. **Professional Qualifications and Introduction**

**Robert E. Moran, Ph.D.**
Michael-Moran Assoc., LLC
Water Quality/Hydrogeology/Geochemistry
Golden, Colorado, U.S.A.
remwater@gmail.com

I am a hydrogeologist and geochemist with more than 42 years of domestic and international experience in conducting and managing water quality, geochemical and hydrogeologic work for private investors, industrial clients, tribal and citizens groups, NGO's, law firms, and governmental agencies at all levels. Much of his technical expertise involves the quality and geochemistry of natural and contaminated waters and sediments as related to mining, nuclear fuel cycle sites, industrial development, geothermal resources, hazardous wastes, and water supply development. In addition, I have significant experience in the application of remote sensing to natural resource issues, development of resource policy, and litigation support. I have often taught courses to technical and general audiences, and has given expert testimony on numerous occasions. Countries worked in include: Australia, Greece, Bulgaria, Mali, Senegal, Guinea, Gambia, Ghana, South Africa, Iraqi Kurdistan, Oman, Pakistan, Kazakhstan, Kyrgyzstan, Mongolia, Romania, Russia (Buryatia), Papua New Guinea, Argentina, Bolivia, Chile, Colombia, Guatemala, Honduras, Mexico, Peru, El Salvador, Belgium, France, Canada, Great Britain, United States. My curricula vitae is attached.



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Wyoming DEQ, 2008, Settlement Agreement with Power Resources / Cameco Resources, regarding Highland and Smith Ranch Uranium projects. http://deq.state.wy.us/out/downloads/LQ%20SA%204231-08.pdf

Yates, M.V., J. A. Brierley, C. L. Brierley, & Steven Follin, 1983, Effect of Microorganisms on In Situ Uranium Mining; APPLIED AND ENVIRONMENTAL MICROBIOLOGY, Vol. 46, No. 4, Oct. 1983, p. 779-784.

NRC Responses to Comments do not Address or Change Previous Opinions.

3. The Final SEIS contains almost no technically-substantive responses to my past comments (attached). They frequently avoid discussing technical details by stating that the approach taken in this SEIS complies with appropriate regulations---disregarding the real-world experiences from previously-operated sites. Furthermore, the Final SEIS contains no new data, either from Powertech sources, but more importantly from any independent sources. The conclusions presented in this Final SEIS are based almost entirely on data collected by Powertech or their consultants, and on summaries and interpretations presented by Powertech to the NRC. The responses provided in the FSEIS do not substantively change the assertions or conclusions put forward in my previous declarations.

Water Resources and Related Impacts.

4. These opinions focus predominantly on the water resources and related impacts within the proposed Dewey-Burdock (D-B) area. The D-B waters are natural resources presently used collectively by numerous parties (ranchers, municipalities, tribal groups, fish and wildlife, mineral and oil and gas developers, etc.). The actions proposed in the SEIS will result in negative impacts on water and additional costs for the general public that are clearly not renewable. These include:
   -allowing Powertech to use tremendous volumes of water, which will increase competition for this water with other users;
   -removal of ground waters from public use (exempted aquifer);
   -contaminate and degrade the quality of much of this water;
   -divert much of the water to deep aquifers where it will be unusable;
   -evaporate much local ground water into the air where it will not be usable locally;
   -these short-term actions are likely to render these ground waters unusable for future, long-term uses, many of which may not be anticipated until many years in the future.

5. The Final SEIS must, but does not, realistically anticipate what will be the true *long-term* uses of these waters---especially when many generations must be

considered. Thus, *truly conservative assumptions* should be employed—which is not the case in this Final SEIS.

SEIS Water-related Sections Predominantly Based on Information from Biased Parties.

6. It is my experience that the agency preparing the NEPA document is responsible for ensuring accurate data, , but almost all of the data and fundamental, technical opinions in the SEIS were taken directly from reports generated by the applicant or their consultants. Even where the applicant has presented controversial flow pathway interpretations (for example, that the D-B site contains no faults, fractures, collapse structures), the NRC has repeated these interpretations in the SEIS as accepted conclusions. The presence of such geologic structures has been described in other historical documents (i.e. TVA, 1979; Butz, et. al. 1980), yet the NRC chose not to address these well-respected scientific opinions in the SEIS.

The SEIS quotes *generic* sections from the GEIS, but the NRC staff then fail to provide independent interpretations of the site-specific (D-B) data and information.

7. For example, on SEIS p.4-60: "Consumptive water use during ISR operations could impact those who use local water from the production aquifer outside the exempted zone. This potential impact will lower water levels in nearby wells and reduce the yield of these wells. In addition, if the production zone is hydraulically connected to other aquifers above and/or below the production zone, consumptive use may impact the water levels in these overlying and underlying aquifers and reduce the yield in any nearby wells withdrawing water from these aquifers. (NRC, 2009a)".

8. Such generic statements are made throughout the SEIS, yet the NRC then proceeds to use the data and assumptions from Powertech to explain why such impacts are not likely to occur. This is a disingenuous use of GEIS language to imply future site-specific safety and minimal impacts at D-B. In my experience, independent verification of an applicant's site-specific data and analysis is conducted by the reviewing agency.

Many Unknowns.

9. The SEIS fails to provide verifiable, detailed information on quantities of water available in aquifers to be impacted, or on the interactions (hydraulic and chemical) between these aquifers when pumped long-term. The NRC has allowed the applicant to delay collection of such detailed data until after permit approval. As such, there is no reason to accept Powertech's optimistic claims about the volumes of water to be used, or the impacts to be generated. They simply have not performed adequate testing to provide detailed answers to these questions.

10. Additional fundamental water "unknowns" that are not answered in the SEIS, but which are delayed until after permit approval include:

**-Pre-mining "Baseline"** will be determined after permit approval. [SEIS, V.1, p. 2-37 (131). Throughout the SEIS it is confusingly and inconsistently called "**background".**
- **Aquifer clean-up criteria** will not be determined until after permit approval and could change (be weakened) depending on the applicant's ability to remediate the aquifer(s). [SEIS, V.1, p. 2-35 & 2-37(129-131)].
-**Detailed hydrogeologic characteristic** of aquifers and inter-beds, surface water-ground / water interactions, including long-term pump tests; to be performed and determined after permit approval (SEIS Section 2.1.1.1.2.3).
-**Long-term water level declines** during and after long-term pumping and operation. For example, what will be long-term water level declines in the Madison aquifer at Edgemont where Madison wells supply municipal water? No detailed testing data have been supplied in the SEIS. To be determined after permit approval.
-**Specific lithologic details** of site sediments. These details to be determined after permit approval (SEIS Section 2.1.1.1.2.3).
-**Detailed Operating Procedures**, such as whether the applicant will mine in partially-saturated, eastern zones of the Chilson; to be determined after receipt of permits.
-**Detailed Water Rights** / hydrogeologic studies necessary to determine that adequate **unappropriated** ground waters exist in the Madison or Inyan Kara. Such detailed studies have been conducted and **relevant South Dakota Water Rights permits have not been received.** To be done after receipt of NRC permits.
-**Methods of liquid waste disposal** to be employed. Will deep-well injection or land application methods, or some combination be employed, and what are the technical details. To be determined after permit approval.
-D**eep-well, underground injection (UIC) permits.** These issued by US EPA, but EPA has not commented on these issues or awarded the permits. To be determined after NRC permit approval. In order for EPA to reliably evaluate the UIC options, they must have access to the detailed hydrogeologic data and information mentioned above, but which will not be available until after NRC permit award.
**-Aquifer Exemption (Inyan Kara).** Must be approved by US EPA, but will not done before NRC permits are issued.
**-Detailed chemical compositions** of pregnant leach solutions, liquid waste solutions (to be disposed by deep-well injection or land application), solid wastes accumulating in land application facilities, etc. are unknown and not reported in the SEIS. Powertech has publicly-stated that they have completed at least one Feasibility Study, so all such detailed information must already be known.
**-Financial Assurance details and amounts.** All such details are unknown and should be public before the NRC license is approved. Financial Assurance calculations are presently handled by three separate federal and state agencies.

Since NRC predicts that water-related impacts will be SMALL, then the Financial Assurance dollar amounts are likely to be relatively SMALL. Thus, there will be little protection for the taxpayers in the event of unforeseen impacts or unexpected project closure.

-**Detailed Water-related Impacts**. Because *detailed*, site-specific geologic, hydrogeologic, and geochemical data are not presently available, it has not been possible to reliably evaluate future water-related impacts (i.e. specific volumes of water available from the Inyan Kara aquifers). Thus, the estimates of impacts [SMALL, MODERATE, LARGE] presented by the NRC in the SEIS are based on inadequate data. Clearly such impacts will only be determined after permit approval.

**-Historical Data on Aquifer Restoration at Other ISL Sites.** The NRC, both in the SEIS and in their responses to public comments, repeatedly cites the results they have compiled from three NRC-licensed ISL facilities (COGEMA's Irigary/Christensen Ranch facility, PRI's Smith Ranch/Highland Uranium Project facility, and Crow Butte Resources' Crow Butte facility) (NRC, 2009b). However, it is misleading to selectively cite the results from only three ISL operations when data from at least 30+ such ISL operations should have been compiled for comparison. All such data / information I have reviewed—in addition to the three cited by NRC-- also indicate an inability to return the ground water quality to preoperational baseline. While the NRC did not directly regulate many of these operations, surely the NRC could have obtained these data if they truly wanted to evaluate the success or failure of aquifer water quality restoration over numerous decades. As such, it is clear that no one has conducted a reliable, representative study to evaluate long-term effectiveness of aquifer restoration (of preoperational water quality) at the vast majority of operating and closed ISL sites—at least not one that is publicly-available.

11. Clearly, the post-restoration water quality within the exempted aquifers, for many chemical constituents at the three sites cited by the NRC, was not returned to preoperational conditions / concentrations. Thus, these exempted waters are lost to the public for numerous future uses without some form of additional, costly treatment.

<u>D-B Uranium ore zones are NOT hydraulically-isolated from other geologic units, other aquifers, or zones outside the project area.</u>

12. The NRC has disregarded the conclusions of numerous hydrogeologic experts (both Powertech-funded and independent experts) in stating the following (Final SEIS, Exec. Summary, p. xxxvi): "Alluvial aquifers are separated from production zone and surrounding aquifers by thick aquitards (confining units) and, therefore, are not hydraulically connected to production zone and surrounding aquifers."

13. This incorrect and overly-simplistic statement clearly contradicts expert opinions which state or infer that, long-term, all of the relevant D-B water-bearing zones are hydrogeologically-interconnected (i.e. Keene 1973; Gott, et. al., 1974; TVA,

1979; Butz, et. al., 1980; Smith, 2005; Boggs & Jenkins, 1980, Boggs, 1983, Bredehoeft et. al., 1983; Knight Piesold, 2008.

14. After reviewing the relevant data, reports and various combinations of satellite imagery, I also conclude that these relevant D-B water-bearing zones are hydrogeologically-interconnected, especially when subjected to long-term pumping.

15. Powertech's management and ground water experts have made inconsistent statements about whether the D-B confining units are leaky or not, varying between individual reports, deposition opinions and public hearing testimony. In this Final SEIS, Powertech (through the NRC authors) states that all of the relevant pumping tests indicated that the D-B sandstones behaved as leaky-confined aquifers (SEIS, p. 3-34). The consultants who conducted these pumping tests reported the same conclusions. Nevertheless, on SEIS, p. 3-36, it states:

    "Based on results of the numerical model, the applicant concluded that vertical leakage through the Fuson Shale is caused by *improperly installed wells or improperly abandoned boreholes."*

16. These inconsistencies make clear that Powertech has failed to define the detailed, long-term hydrogeologic characteristics and behavior of the relevant D-B aquifers and adjacent sediments.

17. It is not unusual for the inter-fingering sands, shales, etc. of sedimentary uranium deposits to be hydrogeologically interconnected, when pumped, long-term. In fact, it is the norm.

Potential Groundwater-Flow Pathways at D-B.

18. D-B sediments are hydrogeologically-interconnected by several potential pathways, which include:
    - -inter-fingering sediments;
    - -fractures and faults;
    - -breccia pipes and / or collapse structures;
    - -4000 to 6000 exploration boreholes (Bush, 2010, Update Technical Report, prepared for Powertech, states approximately 6000 drill holes are present at D-B);
    - -oil test wells.

19. **Drilling of hundreds and thousands of wells since the 1880s has caused drop in artesian pressure of the various sedimentary aquifers in the southern Black Hills areas** (Keene, 1968; Darton, 1909; Davis, Dyer &Powell, 1961). Therefore, many wells and boreholes that formerly flowed to the land surface no longer do so, but still contained water under pressure. Thus, contrary to the NRC and applicant comments in the SEIS, upward flowing waters in these

wells and boreholes can interconnect and mix between the various vertical water-bearing zones without showing any expression at the land surface.

[Keene (1968) p.24: Re. Fall River Fm: " Interview reports indicate that the yields from the Fall River sands have dropped within recent years. Part of this problem is probably due to incrustation ..However, some of this loss of head may result from the recent uranium exploration program. The author personally saw uranium test holes that were uncased, unplugged, and flowing at the surface. This practice is not only wasteful of water, but will ultimately lead to loss of pressure in the aquifer and possible contamination of the Fall River and Lakota aquifers."]

20. Powertech has repeatedly claimed, and apparently the NRC accepts, that no significant geologic structures are present at the D-B site, structures which could allow migration of water vertically or horizonally. Again, this claim is contradicted by numerous published reports, such as: Braddock,1963; Butz, et. al.,1980; Gott, et. al., 1974; Smith, 2005; TVA, 1979. In addition, review of several forms of D-B-area satellite imagery by myself and senior remote-sensing experts at Front Range Natural Resources, Ft. Collins, CO, shows clearly that this area is intersected by numerous faults and fractures. The imagery also shows evidence of circular geologic features at the land surface, indicating the presence of collapse structures.

Breccia Pipes / Solution or Collapse Features.

21. Numerous authors state that breccia pipes / collapse structures allow upward flow of ground waters from the Paleozoic formations to the Inyan Kara rocks at the southern margins of the Black Hills [Bowles, 1968; Braddock, 1963; Keene, 1973; Gott, et. al., 1974; TVA, 1979; Butz, et. al., 1980. Carter, et. al., 2003 state such recharge to the Inyan Kara may occur via such pathways.]

22. However, several Powertech reports and the Final SEIS argue that there is no evidence that breccia pipes or related collapse structures exist within the D-B property [i.e. NRC, 2014(Final SEIS); NRC, 2013 (March), Safety Evaluation Report, p.40; Clarification of Breccia Pipes, LSMPA, Append. 3.2-C. [Sept. 2012].

23. In Appendix 3.2-C of the Large Scale Mine Permit Application [Powertech 2012 (Sept.)] Powertech presents a map, Plate 2, which shows a red line that supposedly represents the area in which evidence of breccia pipes and collapse structures have been reported. This Plate was modified by Powertech from an original map in Gott, et. al., 1974, [U.S.G.S. Professional Paper 763], Plate 4. However, Powertech has misrepresented the data on the original U.S.G.S. map, neglecting to include several locations within the outcrop areas of the Inyan Kara rocks that were originally described as being "topographic depressions" or "structures of possible solution origin". Clearly the original U.S.G.S. authors mapped these areas within the Inyan Kara rocks—near the D-B project-- as probable locations of solution features, such as breccia pipes.

24. Similar circular, topographic features can be seen on modern, satellite imagery of the D-B site and surrounding areas. It is my opinion and that of senior remote-sensing experts at Front Range Natural Resources, Ft. Collins, CO, that these features likely represent solution / collapse structures.

25. Neither Powertech nor the NRC have presented any detailed interpretations of the D-B structural geology using high-quality satellite imagery. Until such studies have been performed, it is reasonable to assume that these circular features are potential pathways for upward migration of ground waters into the Inyan Kara sediments.

26. Instead of meaningfully addressing my opinions, or the cited literature confirming the complex hydrology of the project area, this SEIS continues to allow Powertech to delay conducting detailed hydrogeologic testing and determination of detailed aquifer cleanup standards until after the NRC has given project approval. Detailed hydrogeologic and water quality studies must be conducted **prior to** issuance of NRC / State permits. Otherwise, it is not possible for regulators or the public to reliably evaluate potential impacts and consequences to natural resources and the environment.

<u>The applicant will use and contaminate tremendous quantities of ground water.</u>

27. Because differing water use volumes are presented in different sections of the SEIS, and because of the numerous operational uncertainties, reliable estimates of D-B water use volumes are unclear. The SEIS confirms that there are known volumes of water the applicant has applied for from the State of South Dakota [SEIS, p. 4-54 & 4-55 (360-361)]:

28. Powertech has applied for water from the Inyan Kara: 274.2 ac-ft of water **annually** at a rate of 8500 gpm = 12,240,000 gpd (gallons per day) = **4.5 Billion gallons per year = 89.4 Billion gallons over 20 years.**

    Powertech has applied for water from the Madison: 888.8 ac-ft water annually at a maximum rate of 551 gpm = 793,440 gpd = 289,605,600 gallons per year **(289.6 Million gallons per year)** = **5.8 Billion gallons over 20 years**.

    If deep disposal wells prove feasible, up to about 160 gpm will be required from the Madison. At 160 gpm = 84 Million gallons per year
    20 years = 1.7 Billion gallons over 20 years.

29. Referring to the Inyan Kara waters, the SEIS states that consumptive use will be relatively small as only 2 percent of the water will be disposed of as liquid waste (assuming UIC option is accepted). However, this estimate clearly neglects the fact that much of the water from either aquifer will have been contaminated, and that the water undergoing land application will be lost via evaporation /

evapotranspiration. In either case, this water is no longer available for present or future uses within the exempted aquifer zone. Clearly, the SEIS under-estimates the volumes of water that are lost or contaminated through these processes.

30. Because disclosure and analysis of detailed hydrogeologic evaluations have been delayed until after NRC permit approval, it seems untenable to state that approval of the application "will not result in average annual withdrawals from the Inyan Kara aquifer that exceed the average annual recharge to the aquifer." Likewise, using such limited testing data and modeling results, any estimates of long-term water level drawdown in either the Madison or Inyan Kara are semi-quantitative, at best.

No Adequate, Detailed Water Balance Presented in SEIS.

31. In order to evaluate the adequacy of mine water-related data and water management practices, it is standard practice for EISs and similar mine environmental reports to include a detailed water balance. Such a balance includes measured data for all water inputs and outputs related to all mine operations and all sources of water that might influence these operations. Essentially any detailed ground water textbook describes the workings of such water balances (e.g. Freeze & Cherry,1979) and ICMM (2012) and Golder Assoc. (2011) represent two industry-sponsored studies that describe how water balances should be applied at mine operations.

32. On page 2-36 the SEIS (see Fig. 2.1-14) contains what the authors claim is a water balance, but it clearly is not. In fact, it is actually labeled as "Typical Project-Wide Flow Rates". This is not a water balance for the D-B site or D-B operations. It lacks basic components of a water balance, including detailed, measured data for volumes of water entering the system and losses (e.g. volumes of ground water available in the various aquifers, evaporation from land-application facilities, volumes under-going UIC injection, etc.), and *fails to calculate an actual balance.* Clearly a reliable water balance was not prepared and moreover, could not be prepared until the detailed testing has been completed.

33. Apparently this misleading figure was added to the SEIS because of past criticisms of the lack of water balance in the Draft SEIS. However, NRC has not cured the deficiency by including a flow rate figure, which lacks the basic components of a water balance.

Tens of Thousands of Pages.

34. As of the end of 2013, one of the South Dakota law firms representing various citizen's groups against Powertech stated they had already received roughly 70,000 pages of documents related to D-B issues. The two volumes of the Final SEIS add another 1310 pages. **Nevertheless, the Final SEIS authored by**

**Powertech and the NRC still fails to provide some of the most basic information necessary to answer fundamental questions relating to the D-B water resources and possible impacts to these resources.**

35. The original Draft Environmental Statement for the Edgemont Uranium Mine, prepared by the Tennessee Valley Authority (TVA, 1979) was only 208 pages in total.

Short-term versus Long-term Impacts.

36. The SEIS fails to consider true, long-term impacts from either the proposed D-B operations or regional CUMULATIVE impacts. On pg. 5-28 (596) of the SEIS it states: "The timeframe for the analysis is 2009 to 2030 (see Section 5.1.2 for the estimated operating life of the facility)." Clearly the SEIS fails to consider long-term impacts that are likely to occur, such as changes and increases in water demand.

Past Uranium Mining and Other Contamination.

37. The D-B region has been impacted by past mining and related activities, which were permitted by the AEC / NRC, and which have resulted in negative impacts to the local water resources and environment. Activities at the Black Hills Ordinance Depot (operational from 1942 through1967) have also impacted waters in this region. While limited remediation of surface facilities at portions of these two areas has occurred, no remediation of the historic water contamination has occurred at either site.

Inadequate Baseline Concept and Baseline Data.

38. Throughout the Final SEIS, the NRC fails to consider that past uranium exploration and mining activities have degraded the quality of much of the D-B-area ground and surface waters. The SEIS presents no baseline water quality data from prior to such activities, or as a minimum, from samples collected in the early periods of these mining activities. Instead, the NRC assumes that the degraded water quality represents "baseline", against which all proposed activities are to be judged. This regulatory approach is an indirect path towards approving increased degradation of the original D-B area water quality.

Fundamental Hydrogeologic Information Lacking.

39. In addition to using a "degraded" concept of baseline water quality, the NRC has failed to require Powertech to provide *detailed water-related* data and information ***prior to approval*** of this Final SEIS. Such detailed information is necessary to develop reliable conclusions about future impacts, and includes publication of the following categories of information:

-detailed hydrogeologic testing, including long-term aquifer testing, coupled with simultaneous water-quality sampling;
-*detailed* chemical compositions and volumes of all solid and liquid wastes and operating fluids, such as pregnant lixiviant solutions;
-specific aquifer restoration "clean-up standards / criteria (including ACLs—see Append. B);
-risk assessment studies of chemical constituents that will require an ACL;
-final selection of actual waste disposal methods to be employed;
-EPA aquifer exemption;
-detailed analyses and data relating to the specific Underground Injection Control (UIC) Well studies required by the US EPA. EPA approval of the UIC well permits should precede approval of the NRC license.
-specific details concerning the Financial Assurance measures that will be required of Powertech if the NRC permit is approved.

40. The Final SEIS states repeatedly, that the NRC will require Powertech to collect such detailed data / information **after** NRC license approval. Such information is needed to reliably evaluate risks, impacts, costs / benefits, etc. In my opinion, the delayed production of information until after licensing prevents disclosure and analysis of the environmental impacts, alternatives, and mitigation measures involved with the D-B project.

Price of Water.

41. The SEIS makes no mention of the price that the applicant will pay for the water used in the sum total of all operations, either consumptively or otherwise. Because all other users must pay some price for the water they use, the SEIS should include a table of comparative unit costs paid by various users (e.g. domestic, municipal, agricultural, industrial, etc.). Likewise, no price for water seems to have been included in the cost-benefit analyses presented in the SEIS, even for situations where water quality has been degraded.

Data all provided by the applicant.

42. Almost none of the relevant Application data were collected by financially-independent parties. Preparation of most of the documents was directed and paid for by the applicant. The "independent" federal agency with the most, long-term hydrogeologic experience in this region, the Rapid City USGS staff, have not been included as cooperating agencies in the preparation of the SEIS.

43. Some of the recent documents are largely authored by the applicant, not their consultants. In my experience, this is a signal of significant conflict of interest and the possibility that the consultants were unwilling and unable to give the applicant the desired answer. Many of the significant conclusions disregard unfavorable details and lack the analytical methods and rigor used by professional hydrogeologists and other water experts.

Historic ISL Water Data from U.S. Operations.

44. Review of actual, detailed, historical data from operating and closed ISL sites is the best method for anticipating future problems and impacts. Such actual long-term, data provide much more reliable information on future impacts than do the typical, overly-optimistic computer simulations often presented in EISs. Some of these sites have operated since at least the early 1970s. Thus, considerable information / data must exist for all these sites. Despite the fact that the NRC has had a role in permitting such ISL operations for more than 40 years, no publicly-available, *detailed database* on aquifer restoration water quality (and quantity) data has been compiled, summarizing data from all, or the majority of such ISL sites. Some limited data summaries have been released [i.e. the present GEIS (US NRC, 2014); US EPA, 2011; Davis & Curtis, 2007; Hall, 2009; Darling, 2008; Sass, 2011]. Dr. Susan Hall, U.S.G.S., Lakewood, CO stated (Feb. 2014) that she expects to release a summary of the publicly-available ISL water quality data (pre-and post-remediation) sometime later in 2014. She also stated that long-term, historic ISL data are very limited.

45. Most importantly, the limited aquifer restoration data that are available provide ample evidence to show that the leached aquifers at most, if not all ISL operations, have never truly been restored to their pre-operational, baseline water quality.

    **Otton, J.K., & S. Hall, 2009, In-situ recovery uranium mining in the United States: Overview of production and remediation issues.** IAEA-CN-175/87
    *www-pub.iaea.org/mtcd/meetings/PDFplus/2009/.../08_56_Otton_USA.pdf*

    "To date, no remediation of an ISR operation in the United States has successfully returned the aquifer
    to baseline conditions."

    US EPA, 2007, TENORM, V.2, Append. III, P. AIII-10 last paragraph of section. "Finally, in situ leaching poses a problem from a restoration standpoint. Although there are multiple techniques to restore the mined aquifer to its preoperational state, in many cases the lixiviant can never be completely purged from the site. Attempts to bring the aquifer to a chemically reduced state cannot account for all types of contaminants, and the entire rehabilitation process is both expensive and time consuming."

46. Hence, summaries of water quality and hydrogeologic data from all operating or closed ISL sites within the U.S., together with interpretation of the impacts from these operations should be made publicly-available, prior to approval of the DB NRC license. Clearly some of these sites operated under State regulation, but it appears that the US NRC did not obtain and summarize the available information regarding actual performance of past and present ISL operations at similar sites, relying instead on generic information or no information at all.

Injection of wastes into major aquifers like Deadwood & Minnelusa.

47. Carter, et. al. (2003) p.11(electronic)
**"The major bedrock aquifers are the Deadwood, Madison, Minnelusa, Minnekahta, and Inyan Kara aquifers."**

GDP, P. 99: The Fall River Formation, along with the Chilson Member of the Lakota Formation, are the principal sources of water in the vicinity of the project area for domestic, livestock, and agricultural uses. These same formations are the host rocks for uranium mineralization within the project area.

Disposal capacities for these aquifers are not disclosed. No justification given to allow contamination of Madison waters via mixing / dilution by contaminated ISL process waters. [Madison Application, p. 6-7(electr.)]

Applicant's Performance in the Application process is flawed.

48. Despite the fact that the applicant has collected no new aquifer-testing or hydrogeologic information since their original Application, the applicant's "story" keeps changing with each new document and new deposition or hearing testimony. The applicant has presented a moving target of opinions [i.e. in early reports no leakage occurred between the Inyan Kara aquifers and the finer-grained, bounding sediments. Now, the applicant admits that leakage occurs between these units, but according to the applicant, this has no significant influence on operational details or project impacts]. Frequently the applicant's managers have been authors of the technical language which appears to "soften" the unfavorable conclusions of the original technical authors.

49. These sequential changes in the applicant's opinions based on the same, original test data came about only because of significant, costly opposition from the public and their experts (and not from changes required by the NRC or State). This pattern clearly demonstrates that the NRC should have required the applicant (or preferably, independent experts) to conduct the necessary *detailed,* long-term hydrogeologic testing and baseline sampling prior to issuance of the SEIS.

50. This raises the question as to whether other relevant applicant-generated or contracted water / hydrogeology-related reports exist, besides those listed in the various Applications and the SEIS. I would expect that other reports exist, as the reports listed in the Application and SEIS do not include the critical analysis and information I would expect to find in an unbiased inquiry.

Petrotek (2012) hydrogeologic model does not consider presence of faults, fractures, breccia pipes, or open boreholes, etc.

51. The predictions from such flow models are all based on the **simplifications and assumptions entered into the model.** At D-B, detailed, long-term testing has not been performed, so Petrotek lacked the detailed information necessary to reliably define many of the hydrogeologic processes. For example, many of the historic pump test data on hydraulic conductivity (vertical and horizontal) differ greatly from the data generated by lab testing of core. Thus the hydraulic conductivity inputs into this model are questionable, and any conclusions about leakage from one water-bearing unit to another are quite speculative. Also, the model assumes that no water flows vertically through some of the bounding geologic units (e.g. the underlying Morrison), but inadequate testing has been conducted to prove this. Likewise, several independent authors have argued that vertical flow does occur through the Morrison into the Inyan Kara. Inadequate data exist to reliably demonstrate the rates of recharge from the Graneros Group and surficial alluvium into the Inyan Kara, or the extent of other surface water-ground water relationships.

52. The simulations presented in Petrotek (2012) report are unable to reflect the complex inter-fingering of these sediments (facies changes, laterally and vertically), and assume that the Inyan Kara sediments are homogeneous sediments.

    Site boring data were used to calculate the tops and bottoms of formations---which were often inconsistent—but these borehole data failed to indicate whether the holes were functionally plugged or acted as conduits for vertical leakage. The statements (by the applicant and Petrotek) that some of the anomalous results are likely the result of leaking boreholes is simply a supposition, not based on actual data obtained from these wells and boreholes. Also, this explanation fails to explain the percentage of error that might be the result of cross-facies leakage, rather than communication through unplugged boreholes and wells.

    It is not reasonable to assume that where historic boreholes and wells have been functionally-plugged in the past, that these plugs remain stable forever. Numerous studies show this is simply untrue, and the various seals, surface casings, plugs, etc, begin to deteriorate after several years, leading to cross-communication between the water-bearing zones.

53. This flow model assumes that all ground water flow is via porous media and that no permeable faults, fractures or collapse structures act as flow pathways within the D-B property. In this model, even the Dewey Fault is considered a no-flow boundary (see below), despite the fact that Boggs (1983) presents conflicting statements about the Dewey Fault zone (p.12-13). Boggs states it is a barrier to flow, but also that upward recharge may occur at relatively low rates. Obviously detailed testing is needed to answer this question. More importantly, numerous

independent investigators have reported the presence of faults within the D-B area, contrary to the claims of the applicant. Additionally, significant information from independent remote-sensing indicate that faults do exist, and that surficial evidence of multiple, circular collapse structures are visible at the D-B site. Likewise, structural interpretations and production data from Cretaceous oil fields indicate that oil and gas have been generated from fractures within shales in these formations. These same Cretaceous formations exist within the D-B region, and it seems obvious that the entire package of D-B area Cretaceous sediments are fractured. **The Petrotek model assumes that none of these secondary geologic features transmit water, thus the flow rates are questionable, as would be the changes to water quality resulting from long-term dewatering of the various sand and shale formations.**

54. The model does include one simulation assuming the presence of **one** collapse structure at the D-B site, and assuming it transmits water vertically at 200 gpm. Evidence exists that several other vertical collapse structure pathways may exist, thus upward flows may be much greater than 200gpm. However, throughout the SEIS, the applicant and the NRC state that no evidence exists for and such collapse structures. Despite all of the evidence to the contrary, p. 4-61 of the SEIS P.4-61 states: "Because there is **no evidence for fast flow paths, such as fractures, in the ore-bearing aquifers,** NRC staff conclude that the cone of depression will be maintained during ISR operations."

55. Computer simulations only provide rough approximations of quantitative results---(flow volumes, not chemistry) even in simple, homogeneous, porous media. Often, when predicted results are compared to future, actual data, the results may be in error by hundreds of percent. One of the main goals of such model exercises is to promote a belief that someone can predict future impacts with real quantitative accuracy (Pilkey, 2007; Sarewitz, et. al. 2000)—which is often untrue. Where unreasonable assumptions and faulty evidence is used, the model cannot be relied upon to disclose impacts or to design monitoring and mitigation measures

56. Several examples of sections within Petrotek (2012) that support my analysis of the unreasonable assumptions and unreliable conclusions in the hydrogeologic modeling are provided below:

    -8: "The Morrison Formation beneath the Chilson is considered an aquitard for the region and is represented as a **no flow boundary in the model**. The Graneros Group is also considered an aquitard in the region but was included in the model to provide a reference point for water level elevations within the Fall River and Chilson aquifers relative to ground surface."

    -8: "The data within the Project Area are based on site borings. Outside of the Project area, geologic picks are largely based on available oil and gas well logs. The geologic dips of the surfaces are projected out to the model limits."

- 8: "Therefore, the assumption used in the development of the model is that there is no flow across the (Dewey) fault in either the Fall River or Chilson aquifers. The model domain north of the Dewey Fault system is simulated using the NFB condition."

-11: "During model construction, there was difficulty in maintaining integrity between the various layers of the model. Based on projection of the available data, some of the layers intersected each other in space. This occurred primarily because the data sets were not entirely consistent, ."

-11: As previously noted, the Fuson ranges from 20 to 80 feet thick across the Project Area (Dewey- Burdock TR), therefore, **a simulated thickness of 45 feet** is a reasonable approximation for purposes of the model.

-12: "Because of the uncertainty in the discharge rates from the pumping and artesian wells, the calibration is considered to be more of a representative steady state than a true steady state calibration."

-14: "The model was **unable to replicate drawdown in the Fall River** on the scale of what was observed during the test despite extensive efforts to do so. It is possible that the drawdown observed in the Fall River during the 495 gpm pumping test in the Chilson was the **result of improperly completed wells or exploration boreholes that provided a hydraulic connection between the two units."**

-17: "In summary, changes to the conductance and head of the GHBs in the vicinity of Pass Creek do not appreciably alter the flux of the Fall River and Chilson aquifers across the Project Area, but do result in significant increases to the RSS, indicating a **generally poorer calibration**. **Increasing the recharge rate also changes the calibration substantially and causes large increases in the flux of both the Fall River and Chilson.** Decreasing the recharge has negligible effect on either flux or calibration."

-18: "For purposes of this modeling effort, the Fall River and Chilson are not subdivided and are each simulated as a single layer within the model."

-22: "Use of a numerical model can assist in this effort. However, real time monitoring of water levels during operations and adjustment of flow rates in response to water level changes provides the best engineering control to minimize wellfield interference."

-26: "The calibrated numerical model developed for the Dewey-Burdock ISR Project was used to assess the potential hydraulic impacts of a hypothetical

breccia pipe release. **A breccia pipe release into the Fall River and or Chilson was simulated by placing an injection well into the model layers** representing those hydrostratigraphic units and running a steady state simulation. **A value of 200 gpm was selected for the simulations. Much higher flow rates have been documented at known breccia pipe locations.** Discharge rates much lower than 200 gpm would probably have minimal impact on ISR operations and could be controlled using engineering practices."

-26: "Because of the large change in the potentiometric surface, the occurrence of discharge from a breccia pipe into either the Fall River or Chilson should be observable with the existing monitor well network and **would definitely be noticed once a monitor ring has been installed around a proposed production unit.**"

Surface Water Predictions of 100-year floodplains are likely merely semi-quantitative representations.

57. The September 2013 flood events in the Colorado Front Range and Blizzard in the Black Hills of South Dakota demonstrate the degree of error routinely encountered in such hydrologic predictive models. In both areas, actual flooding and snowfall exceeded not simply 100-year, but 500-year predictions for many of the affected areas.

Pursuant to 10 C.R.F. § 2.304(d) and 28 U.S.C. § 1746, I declare under penalty of perjury, that the foregoing is true and correct to the best of my knowledge and belief.

Signed on the 17th day of March, 2014,

Robert E. Moran, PhD.

UNITED STATES OF AMERICA
NUCLEAR REGULATORY COMMISSION

BEFORE THE ATOMIC SAFETY AND LICENSING BOARD

| | | |
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| In the Matter of | ) | |
| | ) | |
| POWERTECH (USA) INC., | ) | Docket No. 40-9075-MLA |
| | ) | ASLBP No. 10-898-02-MLA-BD01 |
| (Dewey-Burdock In Situ Uranium Recovery Facility) | ) | |

**OPENING WRITTEN TESTIMONY OF DR. ROBERT E. MORAN**

I, Dr. Robert E. Moran, do hereby swear that the following written testimony is true to the best of my knowledge:

## I. Basis for Testimony as an Expert in Hydrogeology

The opinions below are based on my review of the materials in the hearing record, including those materials referenced in my previous declarations and in the testimony below. My qualifications as an expert in hydrogeology and geochemistry are summarized in this testimony, and are set out more completely in the documents contained in the hearing record that detail my education, training, and experience. My curricula vitae is attached.

By way of summary, I earned my Ph.D. in, Geological Sciences from University of Texas, Austin in 1974 after earning my B.A. in Zoology from San Francisco State College in 1966. I am a hydrogeologist and geochemist with more than 42 years of domestic and international experience in conducting and managing water quality, geochemical and hydrogeologic work for private investors, industrial clients, tribal and citizens groups, NGO's, law firms, and governmental agencies at all levels. Much of my technical expertise involves the quality and geochemistry of natural and contaminated waters and sediments as related to mining, nuclear fuel cycle sites, industrial development, geothermal resources, hazardous wastes, and water supply development. In addition, I have significant experience in the application of remote sensing to natural issues, development of resource policy, and litigation support. I have often taught courses to technical and general audiences, and have given expert testimony on numerous occasions. Countries worked in include: Australia, Greece, Bulgaria, Mali, Senegal, Guinea, Gambia, Ghana, South Africa, Iraqi Kurdistan, Oman, Pakistan, Kazakhstan, Kyrgyzstan, Mongolia, Romania, Russia (Buryatia), Papua New Guinea, Argentina, Bolivia, Chile, Colombia, Guatemala, Honduras, Mexico, Peru, El Salvador, Belgium, France, Canada, Great Britain, United States.

Literature reviewed in preparation of my testimony includes:

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- Technical Report (TR)
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## II. **Contention 2: Baseline Characterizations are Inadequate**

### A. Past Uranium Mining and Other Contamination.

1. *Expert Opinion*: Analyis of impacts from past mining and other contamination are critical to assessing the baseline water quality and potenential impacts of future mining activity at the proposed site.

2. *Basis for Opinion*: The Dewey-Burdock region has been impacted by past mining and related activities, which were permitted by the AEC / NRC, and which have resulted in negative impacts to the local water resources and environment. Activities at the Black Hills Ordinance Depot (operational from 1942 through1967) have also impacted waters in this region. While limited remediation of surface facilities at portions of these two areas has occurred, no remediation of the historic water contamination has occurred at either site.

### B. Inadequate Baseline Concept and Baseline Data.

1. *Expert Opinion*: The Application and Final Supplemental Environmental Impact Statement (FSEIS) are inadequate to establish a hydrogeological baseline for the aquifers that would be impacted by the D-B Project.

2. *Basis for Opinion*: Both documents fail to analyze past uranium exploration and mining activities that have degraded the quality of much of the Dewey-Burdock area ground and surface waters. Neither the Application nor FSEIS presents baseline water quality data obtained prior to past mining activities and the contamination from the Black Hills Ordinance Depot. The Application and FSEIS do not address data from samples collected in the early periods of these mining activities.

Instead, the Powertech and NRC Staff assume that the degraded water quality represents "baseline", against which all proposed activities are to be judged. This approach is not scientifically justified as it improperly presents a degraded picture of the original Dewey-Burdock area water quality as a baseline.

C. Fundamental Hydrogeologic Information is Lacking.

1. *Expert Opinion*: The FSEIS and Application lack necessary scientifically-defensible hydrological and hydrogeological information.

2. *Basis for Opinion*: In addition to using a concept of baseline water quality that starts with a degraded aquifer, neither the FSEIS nor Application provides detailed water-related data and information.

Detailed information necessary to develop reliable and scientifically-defensible baseline analysis is not included in the FSEIS or Application. Additional information needed to demonstrate an adequate baseline methodology includes the following categories of information:

-detailed hydrogeologic testing, including long-term aquifer testing, coupled with simultaneous water-quality sampling;
-*detailed* chemical compositions and volumes of all solid and liquid wastes and operating fluids, such as pregnant lixiviant solutions;
-identification of chemical constituents that will be used for aquifer restoration and clean-up standards /criteria for each constituent);
-List of chemical constituents that are likely to require an ACL based on similar projects;
- actual waste disposal methods to be employed;
-detailed analyses and data relating to the specific Underground Injection Control (UIC) Well studies required by the US EPA. EPA approval of the UIC well permits; and,
-Additional structural geologic information, including faults, breccia pipe info., human-induced connectivity.

The Final SEIS states repeatedly that the NRC will require Powertech to collect such detailed data / information **after** NRC license approval, because the Application lacked such data.

The delayed production of this critical baseline information until after licensing is not scientifically defensible as it prevents establishment of a baseline on which to identify, disclose, and analyze the environmental impacts, alternatives, and mitigation measures involved with the Dewey-Burdock project proposal. A scientifically defensible monitoring and mitigation of an operating project is not possible based on the baseline data and analyses I have reviewed.

D. Data Provided Entirely by the Applicant is not an Accepted or Reliable Basis for Analysis.

1. *Expert Opinion*: Analytical results that rely entirely on data provided by the project proponent are not considered reliable by professional hydrogeologists and other water experts.

2. *Basis of Opinion*: Almost none of the relevant Application data, relied upon in the FSEIS, were collected by financially-independent parties. Preparation of most of the documents was directed and paid for by the applicant. The "independent" federal agency with the most, long-term hydrogeologic experience in this region, the Rapid City USGS staff, have not been included as cooperating agencies in the preparation of the FSEIS. Some relevant data collected by USGS was not included in the FSEIS analysis, as it was considered by NRC Staff to be preliminary. In order for the FSEIS to be scientifically acceptable, the available data should have be provided, interpreted, and included in the analysis, and any questions regarding its finality should be noted. Excluding available USGS data results in an unreliable analysis in the FSEIS.

Some of the recent documents provided to NRC Staff by the applicant are largely authored by the applicant, not their consultants. In my experience, this is a signal of significant conflict of interest and the possibility that the consultants were unwilling and unable to give the applicant the desired answer. Many of the significant conclusions in these filings disregard unfavorable details and lack the analytical methods and rigor used by professional hydrogeologists, geochemists, and other water experts. The employment of self-serving analytical methodology does not stand up to accepted scientific methods.

## III. Contention 3: The Targeted Production Zones are Unable to Contain Fluids

A. The Targeted Zones are not Hydraulically Isolated

1. *Expert Opinion*: Dewey-Burdock uranium ore zones are not hydraulically-isolated from other geologic units, other aquifers, or zones outside the project area.

2. *Basis for Opinion*: The NRC Staff has disregarded the conclusions of numerous hydrogeologic experts (both Powertech-funded and independent experts) in stating the following (Final SEIS, Exec. Summary, p. xxxvi): "Alluvial aquifers are separated from production zone and surrounding aquifers by thick aquitards (confining units) and, therefore, are not hydraulically connected to production zone and surrounding aquifers."

This incorrect and overly-simplistic statement clearly contradicts expert opinions which state or infer that, long-term, all of the relevant D-B water-bearing zones are hydrogeologically-interconnected (i.e. Keene 1973; Gott, et. al., 1974; TVA, 1979; Butz,

et. al., 1980; Smith, 2005; Boggs & Jenkins, 1980, Boggs, 1983, Bredehoeft et. al., 1983; Knight Piesold, 2008).

Upon conducting extensive pumping tests and monitoring, Boggs (1980) concluded: "The aquifer test results indicate that the Fuson member of the Lakota formation is a **leaky** aquitard separating the Fall River and Lakota aquifers. The hydraulic communication between the two aquifers observed during the tests is believed to be the result of (1) **general leakage through the primary pore space and naturally occurring joints and fractures of the Fuson shall,** and (2) direct connection of aquifers via numerous old unplugged exploratory boreholes." (Emphasis added). *Ibid*, p.31.

After reviewing the relevant data, reports and various combinations of satellite imagery, I also conclude that these relevant Dewey-Burdock water-bearing zones are hydrogeologically-interconnected, especially when subjected to long-term pumping as proposed by the Applicant.

Powertech's management and ground water experts have made inconsistent statements about whether the Dewey-Burdock confining units are leaky or not, varying between individual reports, deposition opinions and public hearing testimony. For example, in the Application and Final SEIS, Powertech and NRC Staff assert that all of the relevant pumping tests indicated that the Dewey-Burdock sandstones behaved as leaky-confined aquifers (SEIS, p. 3-34). The consultants who conducted these pumping tests reported the same conclusions. Nevertheless, the SEIS, p. 3-36, states:

"Based on results of the numerical model, the applicant concluded that vertical leakage through the Fuson Shale is caused by *improperly installed wells or improperly abandoned boreholes."*

It is not unusual for the inter-fingering sands, shales, etc. of sedimentary uranium deposits to be hydrogeologically-interconnected, when pumped, long-term. In fact, it is the norm.

Keene (1973) stated that the existence of improperly plugged uranium test holes has contributed to the drop in yields from flowing wells in the Fall River formation. "This practice is not only wasteful of water, "but will ultimately lead to loss of pressure in the aquifer and possible contamination of the Fall River and Lakota aquifers." Keene, p. 24. Neither the Applicant nor the Final SEIS addressed how the Applicant's proposed ISL mining operation will be affected the 1000s of pre-existing boreholes, many of which have never been plugged correctly.

B. Potential Groundwater-Flow Pathways

1. *Expert Opinion*: Potential groundwater-flow pathways in and near the project area are critical to analyzing the proposal and impacts from operations.

2. *Basis for Opinion*: Dewey-Burdock sediments are hydrogeologically interconnected by several potential pathways, which include:

-inter-fingering sediments;
-fractures and faults;
-breccia pipes and / or collapse structures;
-4000 to 6000 exploration boreholes (Bush, 2010, Update Technical Report, prepared for Powertech, states approximately 6000 drill holes are present at D-B);
-oil test wells.

Drilling of hundreds and thousands of wells since the 1880s has caused a drop in artesian pressure of the various sedimentary aquifers in the southern Black Hills areas (Darton, 1909; Davis, Dyer &Powell, 1961, Keene, 1973). Therefore, many wells and boreholes that formerly flowed to the land surface no longer do so, but still contain water under pressure. Thus, contrary to the FSEIS and Application materials, upward flowing waters in these wells and boreholes can interconnect and mix between the various vertical water-bearing zones without showing any expression at the land surface.

"Interview reports indicate that the yields from the Fall River sands have dropped within recent years. Part of this problem is probably due to incrustation.....However, some of this loss of head may result from the recent uranium exploration program. The author personally saw uranium test holes that were uncased, unplugged, and flowing at the surface. This practice is not only wasteful of water, but will ultimately lead to loss of pressure in the aquifer and possible contamination of the Fall River and Lakota aquifers." Keene (1973) p.24: Re. Fall River Fm:

These inconsistencies make clear that Powertech and NRC Staff have failed to define the detailed, long-term hydrogeologic characteristics and behavior of the relevant Dewey-Burdock aquifers and adjacent sediments. In my opinion, the lack of support for NRC Staff's conclusion renders its conclusion scientifically invalid.

C. <u>Significant Geological Structures Allow Migration</u>

1. *Expert Opinion*: The FSEIS and Application rely on the erroneous claim that no significant geologic structures are present at the D-B Project site that could allow migration of water vertically or horizontally.

2. *Basis for Opinion*: The no-migration premise of the FSEIS and Application is contradicted by numerous published reports, such as: Braddock,1963; Butz, et. al.,1980; Gott, et. al., 1974; Smith, 2005; TVA, 1979. Keene also concluded that the recharge of the Inyan Kara by the Minnelusa formation occurred in part through "fault zones. Keene, 1973, p. 1.

As Keene (1973) noted: "The determination of a recharge rate is extremely important in a study of ground-water conditions of a watershed..." *Ibid*, p.35. While the "usual" methods for obtaining such information "are costly, time consuming and involved

extensive pumping tests, infiltration tests and a relatively large amount of instrumentation…only by the determination of a recharge rate for a particular aquifer can realistic withdrawal rates be applied to preclude 'mining' of our groundwater resources…Determination of a recharge rate for the Fall River Formations would be extremely difficult….because of the contribution of water from the Minnelusa Formation along the faults in the area." *Ibid*, p. 35-36.

The existence of a "trench" in the potentiometric surface of the Fall River aquifer "where the Cheyenne River flows through Inyan Kara rocks…suggests that the Inyan Kara strata are contributing some water to the river…Residents living along the Cheyenne River report that the river will flow at Rocky Ford (T9S R4E) when the river at Edgemont and Hat Creek are dry." Keene (1973), p. 36. Rocky Ford (T9S R4E) is down stream from the D-B site. If the ground water in the Inyan Kara becomes contaminated Applicant's proposed ISL mining operation, such contamination could affect the water quality of the Cheyenne River at or around Rocky Ford. Rocky Ford is in the vicinity of the Black Hills Wild Horse Sanctuary. Thus, the surface waters that run through the Sanctuary's property could be directly impacted by the contamination of the Inyan Kara aquifer.

In addition, review of several forms of D-B-area satellite imagery by myself and senior remote-sensing experts at Front Range Natural Resources, Ft. Collins, CO, shows clearly that this area is intersected by numerous faults and fractures. The imagery also shows evidence of circular geologic features at the land surface, indicating the presence of collapse structures.

D. Breccia and Collapse Features are Present

1. *Expert Opinion:* Breccia pipes/solution or collapse features are present in the project area that are critical to analyzing the hydrological baseline and project impacts.

2. *Basis for Opinion*: Numerous authors state that breccia pipes / collapse structures allow upward flow of ground waters from the Paleozoic formations to the Inyan Kara rocks at the southern margins of the Black Hills [Bowles, 1968; Braddock, 1963; Keene, 1973; Gott, et. al., 1974; TVA, 1979; Butz, et. al., 1980. Carter, et. al., 2003; state such recharge to the Inyan Kara may occur via such pathways.] For example:

Keene cited Bowles 1968 "excellent study of groundwater movement within the Inyan Kara Group for southwestern South Dakota. In this study, Bowles suggests that water in the Lakota and Fall River Formations originates in the Minnelusa formation …then moves upward along the breccia pipes…Some pipes have been reported to have stoped upwards as much as 1300 feet into rocks of the Inyan Kara Group (Bowles, 1968). This allows recharge of the Lakota and Fall River Formations from artesian water rising from the Minnelusa Formation. Keene, p. 1, 31.

However, several Powertech reports and the Final SEIS argue that there is no evidence that breccia pipes or related collapse structures exist within the D-B property [i.e. NRC, 2014(Final SEIS); NRC, 2013 (March), Safety Evaluation Report, p.40; Clarification of Breccia Pipes, LSMPA, Append. 3.2-C. [Sept. 2012].

In Appendix 3.2-C of the Large Scale Mine Permit Application [Powertech 2012 (Sept.)] Powertech presents a map, Plate 2, which shows a red line that supposedly represents the area in which evidence of breccia pipes and collapse structures have been reported. This Plate was modified by Powertech from an original oversize plate in Gott, et. al., 1974, [U.S.G.S. Professional Paper 763], Plate 4. However, Powertech has misrepresented the data on the original U.S.G.S. map, neglecting to include several locations within the outcrop areas of the Inyan Kara rocks that were originally described as being "topographic depressions" or "structures of possible solution origin". Clearly the original U.S.G.S. authors mapped these areas within the Inyan Kara rocks—near the D-B project-- as probable locations of solution features, such as breccia pipes.

Similar circular, topographic features can be seen on modern, satellite imagery of the D-B site and surrounding areas. It is my opinion and that of senior remote-sensing experts at Front Range Natural Resources, Ft. Collins, CO, that these features likely represent solution / collapse structures.

Neither Powertech nor the NRC Staff have presented any detailed interpretations of the D-B structural geology using high-quality satellite imagery. Until such studies have been performed, it is reasonable to assume that these circular features are potential pathways for upward migration of ground waters into the Inyan Kara sediments.

E. <u>NRC Staff Deferred Analysis of Difficult Hydrological Controversies</u>

1. *Expert Opinion*: NRC Staff did not meaningfully consider my comments and opinions in preparing the FSEIS and issuing the License.

2. *Basis for Opinion*: Instead of meaningfully addressing my opinions, or the cited literature confirming the complex hydrology of the project area, this FSEIS and license allowed Powertech to delay conducting detailed hydrogeologic testing and determination of detailed aquifer cleanup standards until after the NRC has given project approval. Detailed hydrogeologic and water quality studies identified in my comments must be conducted in order to support scientifically credible identification, disclosure and analysis of the complex hydrogeological impacts and effects of the D-B proposal. By delaying the response to issues I raised until after the FSEIS and License issue, it is not possible for regulators, other hydrogeologists, or the public to reliably evaluate potential impacts and consequences to natural resources and the environment.

Based on my experience, the delayed analysis raises the question as to whether other relevant applicant-generated or contracted water / hydrogeology-related reports exist, besides those listed in the various Applications and the SEIS. I would expect that other reports do exist, as the reports listed in the Application and SEIS do not include the

critical analysis and information I would expect to find in a scientifically-defensible inquiry. In my opinion, NRC Staff has delayed a full and credible hydrogeological analysis until after the licensing decision, without providing a credible reason for its incomplete analysis.

F. The Petrotek (2012) Model is Unreliable and Biased

1. *Expert Opinion:* The Petrotek (2012) hydrogeologic model does not consider presence of faults, fractures, breccia pipes, or open boreholes, etc. identified by available data.

2. *Basis for Opinion*: The predictions from the Petrotek (2012) flow models are all based on the improper **simplifications and assumptions entered into the model.** At D-B, detailed, long-term testing has not been performed, so Petrotek lacked the detailed information necessary to reliably define many of the hydrogeologic processes. For example, many of the historic pump test data on hydraulic conductivity (vertical and horizontal) differ greatly from the data generated by lab testing of core. Thus the hydraulic conductivity inputs into this model are questionable, and any conclusions about leakage from one water-bearing unit to another are quite speculative. Also, the model assumes that no water flows vertically through some of the bounding geologic units (e.g. the underlying Morrison), but inadequate testing has been conducted to prove this. Likewise, several independent authors have argued that vertical flow does occur through the Morrison into the Inyan Kara. Inadequate data exist to reliably demonstrate the rates of recharge from the Graneros Group and surficial alluvium into the Inyan Kara, or the extent of other surface water-ground water relationships.

The simulations presented in Petrotek (2012) report are unable to reflect the complex inter-fingering of these sediments (facies changes, laterally and vertically), and assume that the Inyan Kara sediments are homogeneous sediments.

Site boring data were used to calculate the tops and bottoms of formations---which were often inconsistent—but these borehole data failed to indicate whether the holes were functionally plugged or acted as conduits for vertical leakage. The statements (by the applicant and Petrotek) that some of the anomalous results are likely the result of leaking boreholes is simply a supposition, not based on actual data obtained from these wells and boreholes. Also, this explanation fails to explain the percentage of error that might be the result of cross-facies leakage, rather than communication through unplugged boreholes and wells.

It is not reasonable for Petrotek (2012) to assume that where historic boreholes and wells have been functionally-plugged in the past, that these plugs remain stable forever. Numerous studies show this is simply untrue, and the various seals, surface casings, plugs, etc, begin to deteriorate after several years, leading to cross-communication between the water-bearing zones.

This flow model assumes that all ground water flow is via porous media and that no permeable faults, fractures or collapse structures act as flow pathways within the D-B property. In this model, even the Dewey Fault is considered a no-flow boundary (see below), despite the fact that Boggs (1983) presents conflicting statements about the Dewey Fault zone (p.12-13). Boggs states it is a barrier to flow, but also that upward recharge may occur at relatively low rates. Obviously detailed testing is needed to answer this question. More importantly, numerous independent investigators have reported the presence of faults within the D-B area, contrary to the claims of the applicant. Additionally, significant information from independent remote-sensing indicate that faults do exist, and that surficial evidence of multiple, circular collapse structures are visible at the D-B site. Likewise, structural interpretations and production data from Cretaceous oil fields indicate that oil and gas have been generated from fractures within shales in these formations. These same Cretaceous formations exist within the D-B region, and it seems obvious that the entire package of D-B area, Cretaceous sediments are fractured. **The Petrotek model wrongly assumes that none of these secondary geologic features transmit water, thus the flow rates are questionable, as would be the changes to water quality resulting from long-term dewatering of the various sand and shale formations.**

The Petrotek (2012) model includes one simulation assuming the presence of **one** collapse structure at the D-B site, and assuming it transmits water vertically at 200 gpm. Evidence exists that several other vertical collapse structure pathways may exist, thus upward flows may be much greater than 200 gpm. However, throughout the FSEIS, the NRC Staff state that no evidence exists for such collapse structures. Despite all of the evidence to the contrary, p. 4-61 of the SEIS P.4-61 states: "Because there is **no evidence for fast flow paths, such as fractures, in the ore-bearing aquifers,** NRC staff conclude that the cone of depression will be maintained during ISR operations."

Computer simulations only provide rough approximations of quantitative results---(flow volumes, not chemistry) even in simple, homogeneous, porous media. Often, when predicted results are compared to future, actual data, the results may be in error by hundreds of percent. One of the main goals of such model exercises is to promote a belief that someone can predict future impacts with real quantitative accuracy (Pilkey, 2007; Sarewitz, et. al. 2000)—which is often untrue. Where unreasonable assumptions and faulty evidence are used, the model cannot be relied upon to disclose impacts or to design monitoring and mitigation measures. Hydrogeological modelling based on uncertain data and assumptions is only useful when supported by numerous simulations based on a range of data and reasonable assumptions, including data and assumptions unfavorable to the project proponent. However, the modelling in the FSEIS does not consider my comments.

Several examples of sections within Petrotek (2012) support my opinion of the unreasonable assumptions and unreliable conclusions in the hydrogeologic modeling are provided:

-pg 8: "The Morrison Formation beneath the Chilson is considered an aquitard for the region and is represented as a **no flow boundary in the model**. The Graneros Group is also considered an aquitard in the region but was included in the model to provide a reference point for water level elevations within the Fall River and Chilson aquifers relative to ground surface."

-8: "The data within the Project Area are based on site borings. Outside of the Project area, geologic picks are largely based on available oil and gas well logs. The geologic dips of the surfaces are projected out to the model limits."

- 8: "Therefore, the assumption used in the development of the model is that there is no flow across the (Dewey) fault in either the Fall River or Chilson aquifers. The model domain north of the Dewey Fault system is simulated using the NFB condition."

-11: "During model construction, there was difficulty in maintaining integrity between the various layers of the model. Based on projection of the available data, some of the layers intersected each other in space. This occurred primarily because the data sets were not entirely consistent,…."

-11: As previously noted, the Fuson ranges from 20 to 80 feet thick across the Project Area (Dewey- Burdock TR), therefore, **a simulated thickness of 45 feet** is a reasonable approximation for purposes of the model.

-12: "Because of the uncertainty in the discharge rates from the pumping and artesian wells, the calibration is considered to be more of a representative steady state than a true steady state calibration."

-14: "The model was **unable to replicate drawdown in the Fall River** on the scale of what was observed during the test despite extensive efforts to do so. It is possible that the drawdown observed in the Fall River during the 495 gpm pumping test in the Chilson was the **result of improperly completed wells or exploration boreholes that provided a hydraulic connection between the two units."**

-17: "In summary, changes to the conductance and head of the GHBs in the vicinity of Pass Creek do not appreciably alter the flux of the Fall River and Chilson aquifers across the Project Area, but do result in significant increases to the RSS, indicating a **generally poorer calibration**. **Increasing the recharge rate also changes the calibration substantially and causes large increases in the flux of both the Fall River and Chilson.** Decreasing the recharge has negligible effect on either flux or calibration."

-18: "For purposes of this modeling effort, the Fall River and Chilson are not subdivided and are each simulated as a single layer within the model."

-22: "Use of a numerical model can assist in this effort. However, real time monitoring of water levels during operations and adjustment of flow rates in response to water level changes provides the best engineering control to minimize wellfield interference."

-26: "The calibrated numerical model developed for the Dewey-Burdock ISR Project was used to assess the potential hydraulic impacts of a hypothetical breccia pipe release. **A breccia pipe release into the Fall River and or Chilson was simulated by placing an injection well into the model layers** representing those hydrostratigraphic units and running a steady state simulation. **A value of 200 gpm was selected for the simulations. Much higher flow rates have been documented at known breccia pipe locations.** Discharge rates much lower than 200 gpm would probably have minimal impact on ISR operations and could be controlled using engineering practices."

-26: "Because of the large change in the potentiometric surface, the occurrence of discharge from a breccia pipe into either the Fall River or Chilson should be observable with the existing monitor well network and **would definitely be noticed once a monitor ring has been installed around a proposed production unit**."

## IV. Contention 4 –Failure to Adequately Analyze Ground Water Quantity Impacts

### A. Water Consumption

1. *Expert Opinion*: The applicant will use and contaminate tremendous quantities of ground water, thereby preventing / restricting the use of these waters by others.

2. *Basis of Opinion*: Because differing water use volumes are presented in different sections of the FSEIS, and because of the numerous operational uncertainties, reliable estimates of D-B water use volumes are unclear. The FSEIS confirms that there are known volumes of water the applicant has applied for from the State of South Dakota [SEIS, p. 4-54 & 4-55 (360-361)]:

> Powertech has applied for water from the Inyan Kara: 274.2 ac-ft of water **annually** at a rate of 8500 gpm = 12,240,000 gpd (gallons per day) = **4.5 Billion gallons per year = 89.4 Billion gallons over 20 years.**
>
> Powertech has applied for water from the Madison: 888.8 ac-ft water annually at a maximum rate of 551 gpm = 793,440 gpd = 289,605,600 gallons per year **(289.6 Million gallons per year) = 5.8 Billion gallons over 20 years**.

If deep disposal wells prove feasible, up to about 160 gpm will be required from the Madison. At 160 gpm = 84 Million gallons per year for 20 years = 1.7 Billion gallons over 20 years.

Referring to the Inyan Kara waters, the FSEIS states that consumptive use will be relatively small as only 2 percent of the water will be disposed of as liquid waste (assuming UIC option is accepted). However, this estimate clearly neglects the fact that much of the water from either aquifer will have been contaminated, and that the water undergoing land application will be lost via evaporation / evapotranspiration. In either case, this water is no longer available for present or future uses within the exempted aquifer zone. Clearly, the SEIS under-estimates the volumes of water that are lost or contaminated through these processes.

Because disclosure and analysis of detailed hydrogeologic evaluations have been delayed until after NRC permit approval, it is untenable to state that approval of the application "will not result in average annual withdrawals from the Inyan Kara aquifer that exceed the average annual recharge to the aquifer." Likewise, using such limited testing data and modeling results, any estimates of long-term water level drawdown in either the Madison or Inyan Kara are semi-quantitative, at best.

B. Water Balance

1. *Expert Opinion*: The FSEIS relied on an inadequate and unreliable analysis of water use, and failed to provide a water balance.

2. *Basis for Opinion*: In order to evaluate the adequacy of mine water-related data and water management practices, it is standard practice for EISs and similar mine environmental reports to include a detailed water balance. Such a balance includes measured data for all water inputs and outputs related to all mine operations and all sources of water that might influence these operations. Essentially, any detailed ground water textbook describes the workings of such water balances. Freeze & Cherry (1979) and ICMM (2012) and Golder Assoc. (2011) represent two industry-sponsored studies that describe how water balances should be applied at mine operations.

The water balance in the FSEIS did not follow these accepted methodologies. On page 2-36 the FSEIS (see Fig. 2.1-14) contains what the authors claim is a water balance, but it clearly is not. In fact, it is also labeled as "Typical Project-Wide Flow Rates," which more accurately describes what is contained in the FSEIS. The flow rates calculation is not a water balance for the D-B site or D-B operations. It lacks basic components of a water balance, including detailed, measured data for volumes of water entering the system and losses (e.g. volumes of ground water available in the various aquifers,

evaporation from land-application facilities, volumes under-going UIC injection, etc.), and *fails to calculate an actual balance*. In my opinion, a reliable water balance was not prepared and moreover, could not be prepared until the detailed testing described in my testimony has been completed.

Apparently, this misleading water balance figure was added to the FSEIS to deflect comments noting the lack of water balance in the Draft SEIS. However, NRC has not cured the deficiency by including a flow rate figure, which lacks the basic components of a water balance.

Pursuant to 10 C.F. R. §22.304(d) and 28 U.S.C. §1746, I declare under penalty of perjury, that the foregoing is true and correct to the best of my knowledge and belief.

Signed on the 20th day of June, 2014

Robert E. Moran

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## EDUCATION

University of Texas, Austin: Ph.D., Geological Sciences, 1974
San Francisco State College: B.A., Zoology, 1966

## PROFESSIONAL HISTORY

Michael-Moran Associates, LLC, Partner, 2003 to present
Woodward-Clyde Consultants, Senior Consulting Geochemist, 1992 to 1996
Moran and Associates, President, 1983 to 1992; 1996 to 2003
Gibbs and Hill, Inc., Senior Hydrogeologist, 1981 to 1983
Envirologic Systems, Inc., Senior Hydrogeologist / Geochemist, 1980 to 1981
Tetra Tech Intl./ Sultanate of Oman, Senior Hydrogeologist, 1979 to 1980
Science Applications, Inc., Geochemist / Hydrologist, 1978 to 1979
U.S. Geological Survey, Water Resources Div., Hydrologist / Geochemist, 1972 to 1978
Texas Bureau of Economic Geology, Research Scientist Assistant, summers:1970 & 1971

## REPRESENTATIVE EXPERIENCE

Dr. Moran has more than 42 years of domestic and international experience in conducting and managing water quality, geochemical and hydrogeologic work for private investors, industrial clients, tribal and citizens groups, non-governmental organizations, law firms, and governmental agencies at all levels. His experience includes the following representative project assignments.

### *2003 to Present: Michael-Moran Associates, LLC:*

- Contraloría General de la República & IKV Pax Christi, Bogota, Colombia. Provide assistance and training to the independent auditing arm of the Colombian government on mining & environmental audits and legislation.
- The Black Hills Wild Horse Sanctuary, and Bangs, McCullen, South Dakota. Expert opinions and testimony before State regulatory agencies regarding Large-Scale Mine and Water Use permits for the proposed Dewey-Burdock in-situ uranium operations.
- Sims Murray Ltd. and the Town of Florence, Arizona. Review of Town nuisance ordinance related to proposed in-situ mining and aquifer impacts. Expert opinions for litigation.
- Wild Salmon Center & World Wildlife Federation (Russia), Moscow, Russia. Elaboration and presentation of mining and water-related issues to members of Russian government, industry and the environmental communities.

- Citizens of Cañon City / Colorado Citizens Against Toxic Waste, Inc. (CCAT); Cañon City, Colorado. Technical assistance to citizen's group on hydrogeologic and geochemical issues related to contamination from disposal of radioactive, etc. materials at the Cotter uranium mill site.
- Environmental Defender Law Center and GRUFIDES (NGO), Cajamarca, Peru. Review of Environmental documents relating to the Conga Mine; site visit; report preparation.
- Roanoke River Basin Association; Virginia. Assistance on technical issues related to proposed uranium mine and processing facilities; presentations to public and regulators; participation in government planning meetings.
- Human Development Center "Tree of Life"; Bishkek, Kyrgyzstan. Review of operations at Kumtor Gold Mine using funds from Bankwatch, Kiev, Ukraine.
- Za Zemiata (Sofia) and the University Autonoma de Barcelona; Krumovgrad, Bulgaria. Review of the EIS for a proposed gold mine; municipal / public meeting presentations; prepare report using E.U. funds.
- Powder River Basin Resource Council; Oshoto, Wyoming.
  Review of Strata Energy NRC License Application to operate an in-situ leach uranium operation; provide technical opinions.
- Pro Patrimonio (the National Trust of Romania); Brussels, Belgium. Presentation to members of European Union Parliament regarding environmental aspects associated with the proposed Rosia Montana Mine, Romania.
- Trustees for Alaska. Prepared expert report on hydrogeologic and water quality impacts from exploration activities at the Pebble Mine site. Opinions prepared for litigation in Alaska Superior Court on behalf of *Nunamta Aulukestai, et. al. v. State of Alaska, et. al.* (Pebble Limited Partners); deposition and trial testimony.
- Bank Information Center and Earthworks, Washington, D.C. Report on hydrogeologic and geochemical impacts at the proposed Weda Bay, Indonesia, cobalt-nickel mine; delivered to Multilateral Investment Guarantee Agency.
- IKV Pax Christi (Netherlands), Bogota, Colombia. Prepare mining-environmental best practices report for presentation to Colombian Ministry of Environmental Affairs.
- Oglala Sioux Tribe, Western Mining Action Project, Gonzalez Law Firm, South Dakota. Review of Powertech License Application, EIS and provide expert opinions: Dewey-Burdock In Situ Uranium Project.
- Comisión de Gestión Integral de Aguas de Bolivia (Commission for the Integrated Management of Bolivian Waters) and Federación Regional Única de los Trabajadores Campesinos del Altiplano Sud (Regional Farmers Federation of the Southern Altiplano), Bolivia. Review of present mining activities and documents related to the San Cristobal Mine. Activities funded by the Municipality of Colcha K (Potosí, Bolivia), the Centro de Estudios de la Universidad de San Simón, Cochabamba, and Global Green Grants Fund.

- Shute, Mihaly & Weinberger / San Diego State University Research Foundation. Review of hydrogeologic / environmental impacts associated with quarry construction near a university wildlife refuge.
- Sarah Vogel Law Firm, North Dakota. Litigation support and evaluation of environmental impacts resulting from a release of oilfield waters onto livestock lands and waters.
- IKV Pax Christi (Netherlands), Tolima, Colombia. Technical review of proposed La Colosa gold project (Anglo Gold Ashanti); interaction with regulators, civil society and company; prepare recommendations & report.
- Thompson Divide Coalition, Western Colorado. Technical assistance to a consortium of environmental groups in designing and conducting a baseline water sampling program in anticipation of gas drilling activities. Preparation of summary report.
- Global Green Grants / Nature's Own, Papua New Guinea. Prepare technical / policy papers on marine disposal of mining wastes.
- SAVIA, School of Ecological Thought / Comision Pastoral Paz y Ecologia, Guatemala. Presentations on ecological aspects of resource legislation to Guatemalan government ministries, high-level officials, and educational institutions. Conduct water quality training classes; assist with development of laboratory capabilities.
- Astrella & Rice, Colorado, U.S.A. Technical assistance in preparing litigation arguments for citizen lawsuit involving alleged drinking water contamination by oil and gas activities.
- Office of the Prime Minister, Iraqi Kurdistan. Development of information infrastructure and management training for numerous ministries in Northern Iraq; done in partnership with faculty of American University, Washington, D.C. Headed an audit team for the Regional Statistics Organization.
- Southwest Research and Information Center / Buryat Regional Organization on Baikal / Mongolia Nature Protection Coalition; Buryatia, Siberia, Russia and northern Mongolia. Technical information exchanges with local NGOs, government officials and mining company staffs.
- Rulison Citizens Group / Public Counsel of the Rockies. Colorado. Development of technical arguments and potential litigation support intended to define environmental issues related to gas development near the Rulison underground nuclear test site. Hearing testimony.
- The Nature Conservancy, Trout Unlimited, Alaska Conservation Foundation, Trustees for Alaska and Renewable Resources Coalition, Alaska. Presentations to public interest groups and development of technical issues and papers relating to construction of the Pebble copper-molybdenum-gold mine, proposed for operation above the largest sockeye salmon fishery in the world.
- Wild Salmon Center, Alaska. Technical evaluation of hydrogeological and chemical issues that may impact fisheries near the proposed Pebble Mine.

- Miller, Axline & Sawyer / Meyers, Nave, Riback, Silver & Wilson / City of Grass Valley, California. Technical and litigation support in a suit alleging contamination by Newmont Mining Corporation; deposition testimony.
- Latin American Water Tribunal. San Salvador, El Salvador. Prepare presentations and conduct workshops on water and water quality. Funding: Heinrich Boll Foundation.
- Alburnus Maior, Rosia Montana, Romania. Evaluation of EIA and preparation of summary report on a proposed gold mine in Transylvania. Funded by the Staples Trust, U.K. and the Open Society Foundation, Romania.
- Asociacion de Desarrollo Social Santa Marta (ADES), El Salvador. Evaluate EIA and related documents, El Dorado Mine; technical presentation at national forum; prepare review report. Funded by DIAKONIA, Swedish Ecumenical Action.
- Alburnus Maior, Romania. Review documents and prepare comments related to development of proposed Rosia Montana Mine for a Romanian NGO.
- La Lumiere, Senegal and WACAM, Ghana. Conducted water quality training sessions for NGO and government staffs, as related to mining and other development activities. Funded by Oxfam America.
- ESRI (Environmental Systems Research Institute). Provide technical assistance to several Iraqi Ministries to define information management needs, deploy map-based systems (GIS), and establish a Middle East-based Center of Excellence to support these ministries. Performed in conjunction with NGA.
- Colectivo Madre Selva, Guatemala. Evaluation of Marlin Mine site, review of EIA and preparation of report; attendance at national and indigenous mining forums; conducted water quality training; review of CAO / IFC documents. Funded partly by Misereor, Catholic Bishops' Development Organization, Germany.

***1996 to 2003: Moran and Associates, Inc.:***

- International Union for Conservation of Nature and Natural Resources (IUCN, Switzerland). Review of the Mining and Metals Supplement of the Global Reporting Initiative (GRI).
- World Bank, Extractive Industry Review. Member of Advisory Group assisting WB in evaluating extractive industry practices; London, Lisbon.
- Nishnawbe Aski and other Ontario First Nation bands---Ontario, Canada. Review of environmental documents relating to Montcalm Mine, a proposed copper-nickel facility. Activities paid for by Falconbridge Limited.
- Kazakh Institute of Physics and Technology / ISTC---Almaty, Kazakhstan. Technical oversight of environmental program, evaluating migration of radionuclides at the Semipalatinsk Nuclear Test site.
- Greenpeace Argentina / Mineral Policy Center---Esquel, Argentina. Review of EIA (water, environ. issues) and conditions at proposed mine in Patagonia.

- Oxfam America / Sahel Development Foundation: Syama Mine, Southern Mali. Review of environmental conditions and documents related to an IFC-funded gold mine (2003); conduct technical workshops and policy meetings with Mali government and press (2004).
- Kivalina Relocation Planning Committee---Alaska. Litigation support to Center on Race, Poverty & the Environment regarding water quality issues, Red Dog Mine. Deposition testimony.
- Asociation de Organismos No Gubernamentales—Santa Rosa de Copan, Honduras. Independent review of water / environmental issues at San Andres mine; funded by Dan Church Aid (Danish government and NGOs) and Christian Aid (English NGO).
- Oxfam America / Friends of the Earth Int'l. / Global Green Grants---Quellaveco, Peru. Independent review of mining, water and environmental issues at request of Asociacion Civil "Labor", Lima.
- Oxfam America / Mineral Policy Center / Environmental Mining Council of B. C.: Tambogrande, Peru. Independent review of mining water and environmental issues. Includes numerous public presentations to citizens and governmental groups, including members of the Peruvian Congress.
- New Mexico Environment Department---New Mexico. Review of cost estimates for water treatment systems for closure plans / bonding calculations, Chino and Tyrone Mines.
- International Institute for Environment and Development—London, U.K. Consultant to MMSD project on sustainable development / mining issues.
- Technical Chamber of Greece---Thrace, Greece. Technical assistance to advisory arm of the Greek government and citizens groups regarding gold mining / environmental issues.
- Malerah-Wahlabul Native Title Claimants / Friends of the Earth—Sydney, Australia. Review of water quality issues related to cyanide leach gold operations on aboriginal lands, and testimony at Land and Environment Court.
- Loeb Aron &Co.---London, U.K. Preparation of report evaluating the Baia Mare, Romania waste spill for an investment banking firm.
- Centro de Investigacion y Planificacion del Medio Ambiental (CIPMA) / World Resources Institute / International Development Research Centre---Chile. Evaluation of environmental costs associated with copper mining in Chile.
- Carl Duisberg Gesellschaft / Univ. of Witwatersrand / United Nations---South Africa. Training in cyanide and environmental technology assessment issues.
- Dogrib Nation / Pape and Salter---Yellowknife, Canada. Geochemical consulting and testimony regarding the proposed Diavik diamond mine.
- Soros Foundation Kyrgyzstan---Bishkek, Kyrgyzstan. Water quality instruction to regulators and NGOs regarding mining, sampling, laboratory procedures, and general environmental issues. Review laboratory.

- General Chemical / Sierra Club---Piceance Basin, Colorado. Review of water quality, treatment, legal and policy issues regarding the proposed Yankee Gulch soda ash mine; hearing testimony.
- Sierra Club Legal Defense Fund / Okanogan Highlands Alliance----Crown Jewel Mine, Washington. Litigation support on water quality, geochemistry, treatment issues to groups opposing proposed gold operation; test case on federal mining law; deposition testimony.
- National Wildlife Federation---Carlota Mine, Arizona. Litigation support for challenge of EPA regarding water quality/ treatment issues at copper mine. Review of TMDL issues related to Pinto Creek for NWF and local citizens.
- International Rivers Network---Review of proposed dam project and associated mine water quality issues at the San Roque site, Philippines.
- Mineral Policy Center---Preparation of technical documents on the environmental behavior, analysis and toxicity of cyanides.
- Holnam Industries---Penrose, Colorado. Ground water quality/ geochemistry study for cement operation.
- World Resources Institute---mining water quality/ geochemistry assistance on Venezuelan forestry / mining environmental regulations, and environmental economics of copper mining practices, Chile.
- U.S. EPA / American Geological Services---French Gulch, Colo. Geochemical / treatment /remediation support at an abandoned mine site; negotiated Superfund issues.
- Stoel Rives / Richmond Hill Mine, So. Dakota. Review water quality treatment and geochemistry issues at a closed gold mine site with discharge violations.
- Nacho Nyak Dun First Nation / Pape and Salter—Yukon, Canada. Evaluation of proposed heap-leach gold mining facilities and practices for native group and barristers.

***1992—1996: Woodward-Clyde Consultants, Inc.***

-Molycorp / Unocal—Questa, New Mexico. Review of water quality, geochemical, & aquatic biology issues at a molybdenum mine / mill site.

-Minera Escondida Ltda.---Chile. Review of geochemical data for copper mine.

-Homestake Mining---Lead, South Dakota, U.S.A. Review of water quality and geochemical problems and waste rock storage and tailings stability issues.

-U.S. Bureau of Land Management / Summo Minerals—Lisbon Valley, Utah. Review of water quality and geochemistry, and assistance in preparation of an EIS at a proposed copper mining and recovery site.

-Southern Peru Copper Corp.--Toquepala, Peru. Design and oversight of water quality, geochemistry, and remediation issues at an open-pit copper mine, mill, and waste facilities.

-Cortez Mining/ Placer Dome / U.S. Bureau of Land Management - Pipeline Project, Nevada. Review of water quality and geochemistry and preparation of EIS-related reports at this proposed open pit gold site.

-Kennecott Utah Copper. Interacted with the law firm of Bogle and Gates to assist an active metal mining company in defending against a CERCLA listing. Activities involved interpreting water quality/geochemical and other environmental data within the Hazardous Ranking System (HRS) context.

-ASARCO - Leadville, Colorado. Oversight of water quality and geochemical activities at a historic metal mining and processing site where the client is involved in CERCLA negotiations. Interaction with State and EPA representatives and legal staff.

-Cambior Minerals - Metates Mine, Mexico. Water quality and geochemistry evaluation of a new gold property.

-Fraser Stryker and the Lindsey Chemical Co. - Nebraska. Technical support to legal staff involved in negotiations regarding a Superfund industrial processing site.

-W.R. Grace - Motorwheel Site, Michigan. Technical assistance to Grace legal staff involved in CERCLA negotiations at a hazardous waste site.

-Zortman Mining Co. / U.S. Bureau of Land Management. Technical and management responsibilities for water resources and geochemistry tasks in preparation of revised EIS at a gold-cyanide leach site with existing acid drainage problems.

-Echo Bay Mining, Lamefoot Mine, Republic, Washington. Responsible for geochemistry and water quality aspects of a supplemental EIS at a new gold mine site. Development of monitoring, testing and remedial recommendations to the BLM.

-Angelina Farms, Louisiana. Technical support to legal staff of oil production companies accused of contaminating groundwaters with brines.

-Amax Gold / Haile Mining, South Carolina. Water quality consulting at a gold mining site with existing acid drainage problems.

-Chino Mines, New Mexico. Technical evaluation of water quality and geochemical issues associated with leaching operations at an operating copper facility.

***1983 to 1992: Moran and Associates, Inc.:***

-Shea and Gardner / Rockwell--Rocky Flats Nuclear Plant, Colorado. Reviewed and evaluated geochemical studies; proposed future activities in preparation of potential environmental-criminal litigation.

-Saunders, Snyder, Ross and Dickson / American Water Development, Inc. - San Luis Valley, Colorado. Coordinated water quality and geochemistry activities in support of water rights litigation. Oversaw water quality sampling, evaluated water quality and remote sensing data, assisted attorneys in technical strategy development and opponents' depositions; supplied deposition testimony.

-Arnold and Porter / Keystone Ski Corporation - Keystone, Colorado. Designed water quality and geochemical sampling program for ski area expansion in a previously mined area. Evaluated data and proposed remediation activities.

-Advanced Sciences, Inc. / EG&G - Rocky Flats Nuclear Plant, Colorado. Evaluated existing water quality and geochemical sampling programs; prepared document on non-facility related sources of chemical constituents and background.

-City of Brighton - Brighton, Colorado. Evaluated existing surface and groundwater quality data and suggested remedial activities to deal with excessive manganese and dissolved organic concentrations. Provided testimony to City Council.

-Chadwick & Associates, Inc. / Newmont Mining - Telluride, Red Mountain, Colorado. Provided diverse water quality and geochemical consulting relating to remediation of acid mine drainage problems.

-Intergraph Corp. - Reston, Virginia. Assisted in technical development and marketing of a new environmental data management / GIS product.

-U.S. Forest Service - Salmon, Idaho. Geochemical / water quality consultant at the Beartrack mine site, a proposed cyanide-leach gold project.

-Earth Satellite Corporation / Navajo Nation / Patton, Boggs, and Blow - Window Rock, Arizona. Conducted a preliminary reconnaissance of water resources on the joint-use area of the Navajo/Hopi reservations using satellite imagery.

-Mission-Viejo / Morrison and Forester - Denver Basin, Colorado. Acted as a geochemical consultant in a groundwater rights dispute.

-Bunker Hill Corporation / Dames and Moore - Kellogg, Idaho. Reviewed field and laboratory water quality procedures at a CERCLA metal-mining and processing facility. Audited proposed laboratory.

-Saunders, Snyder, Ross, and Dickson / Adolph Coors Company - Golden, Colorado. Water quality consultant; reviewed data from Central City/Blackhawk, CERCLA site, and determined potential impact to the Coors water treatment plant. Provided testimony at stream classification hearings, Colorado Water Quality Control Commission.

-Colorado Water Resources and Power Authority - San Luis Valley, Colorado. Conducted water quality/geochemical and Landsat evaluations of deep groundwater to aid in development decisions.

-Armstrong, Teasdale, Kramer, Vaughan, and Schlafly / Anschutz Corp.-- Fredricktown, Missouri. Supervised technical activities of a CERCLA / SARA-related lawsuit; acted as a technical liaison with attorneys and regulators; managed consultants; authored reports; deposition testimony.

-Holland and Hart / White and Jankowski / Weller, Friedrich, Ward and Andrew / Breckenridge Ski Corporation - Breckenridge, Colorado. Technical supervision of water quality-related issues in a private lawsuit against Breckenridge Ski Corporation. Managed sampling and data interpretation; interacted with attorneys on strategy and assisted at depositions; authored reports; expert witness.

-Dames and Moore / Hecla Mining Corporation - Leadville, Colorado. Acted as hydrogeological/geochemistry consultant to Hecla on a natural resources damage suit; interacted with attorneys at Davis, Graham and Stubbs.

-Dames and Moore / Davis, Graham and Stubbs - Eagle Mine, Colorado. Supervised water quality/hydrogeology activities in preparation of a legal defense of Gulf and Western Corporation versus the State of Colorado in a natural resources damage suit; supervised and participated in all sampling; QA activities and report preparation; interacted with attorneys and regulators; assisted at depositions; deposition testimony; testified before Colorado Water Quality Control Commission on appropriateness of proposed metals standards.

-Jacobs Engineering - Albuquerque, New Mexico. Prepared policy documents on water quality/geochemistry procedures associated with the Uranium Mill Tailings Remedial Actions Project (UMTRA).

-University of Wisconsin. Designed a proposed groundwater exploration program for Gambia, West Africa, in conjunction with Earth Satellite Corporation.

-Harza Engineering Company / University of Michigan - Senegal, Guinea, and Gambia, West Africa. Evaluated potential impacts of new dam construction within the Gambia River basin. Reviewed local hydrogeology, mining production and exploration data; interacted with local officials.

-Engineering-Science, Inc. Faisalabad, Pakistan. Assisted in design of a well field for a groundwater supply in the central Punjab where high salinity and TDS were major problems; negotiated with local officials; prepared reports for Asian Development Bank.

***1981-1983: Gibbs & Hill, Inc.***

-Holme Roberts and Owen - Canon City, Colorado. Reviewed and interpreted existing hydrogeology and water quality data at the Cotter uranium mill and tailings; proposed future activities; interpreted background concepts, prepared position papers for attorneys in negotiations with State of Colorado.

-Earth Satellite Corporation - Sultanate of Oman. Conducted an interpretive study of regional groundwater potential in Oman, with the staff of Earth Satellite Corporation. Activities included interpretation of existing geology and Landsat imagery combined with conventional low altitude flight and ground reconnaissance. Prepared reports for government of Oman.

-Anschutz Mining Corporation - Fredericktown, Missouri. Managed water resource-related activities for environmental baseline studies at a proposed cobalt/ nickel mine. Designed sampling programs, oversaw sampling, data interpretation, and report preparation.

-Kemmerer Coal Company - Frontier, Wyoming. Managed and conducted hydrogeologic and water quality studies at a proposed open-pit coal mine. Supervised well installation, aquifer testing, sampling, report preparation; interacted with state regulators.

-Anaconda Copper Company - Rico, Colorado. Conducted an investigation of hydrology, water chemistry, and aquatic biology at a complex-ore mining district.

-Union Carbide Corporation - Uravan, Colorado. Managed and conducted a water quality monitoring program for a proposed uranium tailings disposal area and effluent evaporation basin. Assisted in design of geochemical testing program to evaluate potential leachate quality.

-Anschutz, Mining Corporation - Laredo, Texas. Managed and conducted an investigation of groundwater hydrology and soils geochemistry and associated hazardous wastes at a metal ore handling and reagent storage facility. Designed sampling protocol; prepared reports; negotiated with state regulators; interacted with attorneys at Baker, Botts.

-Snowmass Coal Company - Carbondale, Colorado. Managed and conducted hydrogeology investigation of an underground coal mine with steeply dipping seams.

-Marline Uranium Corporation / Union Carbide Corporation - Danville, Virginia. Managed water resources portion of a baseline investigation at a proposed hard-rock uranium mine site. Oversaw well installation monitoring programs and dewatering investigations.

-Southern Pacific Petroleum - Means, Kentucky. Conducted baseline hydrogeological/geochemical investigations at a proposed oil shale mine and retort facility.

***1980-1981: Envirologic Systems, Inc.***

-Central Arizona Association of Governments - Globe/Miami, Arizona. Conducted study to determine hydrogeologic/geochemical impact of long-term copper mining and processing facility. Designed monitoring programs; interacted with federal, state, local and tribal officials; prepared numerous reports.

-United Nuclear - Homestake Partners - Milan, New Mexico. Conducted hydrogeological/geochemical evaluation of an existing monitoring program for a uranium milling and waste-disposal facility.

-Homestake Uranium - Marshall Pass, Colorado. Hydrogeological / geochemical evaluation of a proposed, hardrock, open-pit uranium mine.

***1979-1980: Sultanate of Oman / Tetra Tech International*** - Muscat, Oman. Member of Water Resources Council Staff, Sultanate of Oman, based in Muscat, Oman. The Water Resources Council was an inter-ministerial body intended to coordinate all water-related activities within the Sultanate. Duties involved planning and design of surface and groundwater projects (both exploration and utilization) for the Omani government; development of water resources policy for the government; hydrogeological field work on both exploration and resource characterization projects - aquifer testing, borehole geophysics, water quality sampling, hydrogeologic mapping; review of work performed (or planned) by other consultants to the government, published reports on water resources of Oman.

***1978-1979: Science Applications Inc.:***

-EG&G - Idaho National Engineering Laboratory, Idaho Falls, Idaho. Managed a hydrologic investigation of transuranic nuclide migration in groundwater. Contributed geochemical expertise to evaluation of waste isolation and transport modeling.

-Kerr-McGee Corporation - Grants, New Mexico. Conducted investigation into geochemistry of selenium associated with uranium mining/ milling.

***1972—1978: U.S. Geological Survey Water Resources Division***; responsible for the design, management, and implementation of the following hydrogeological / geochemical studies:

-Metal-Mine Drainage - Colorado. Study of impacts of mining activities (metals, uranium, coal) on the quality of streams in all major Colorado mining districts.

-Selenium in Groundwater - Golden, Colorado. Hydrogeological / geochemical investigation of selenium, uranium and associated constituents at the margins of the Rocky Flats nuclear plant.

-Geothermal Resources - Colorado. Reconnaissance investigation of potential geothermal resources throughout Colorado.

-Underground Coal Mine Water Quality - Colorado. Evaluation of existing and potential water quality problems from underground coal mines.

-In Situ Uranium Leaching - Grover, Colorado. Study of geochemical and hydrologic processes associated with in situ uranium mining and reinjection of waste products.

-Alluvial Metal Transport - Telluride, Colorado. Investigation of metal (especially chromium) movement from tailings ponds into alluvium.

-Southwest Colorado Groundwater - Colorado. Study to determine availability and quality of groundwater in southwestern Colorado.

-Oil Shale Waters - Piceance Basin Colorado. Evaluation of disposal of saline groundwater discharged to the surface during oil shale development.

-Grace Coal Site - Axial Basin, Colorado. Hydrogeological / water quality study of proposed open-pit coal site.

***1970, 1971, Summers: Texas Bureau of Economic Geology.*** Evaluation of the aqueous geochemistry and biochemistry of Gulf Coastal sedimentary sulfur and uranium deposits and their relationships with hydrocarbons: interpretation of geologic and geophysical logs, water quality data.

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UNITED STATES OF AMERICA
NUCLEAR REGULATORY COMMISSION

BEFORE THE ATOMIC SAFETY AND LICENSING BOARD

| | | |
|---|---|---|
| In the Matter of | ) | |
| | ) | |
| POWERTECH (USA) INC., | ) | Docket No. 40-9075-MLA |
| | ) | ASLBP No. 10-898-02-MLA-BD01 |
| (Dewey-Burdock In Situ Uranium Recovery | ) | |
| Facility) | ) | |

**WRITTEN REBUTTAL TESTIMONY OF DR. ROBERT E. MORAN**

I, Dr. Robert E. Moran, do hereby swear that the following written testimony is true to the best of my knowledge:

The opinions and testimony below are based on my review of the materials in the hearing record, including written testimony, and those materials referenced in my previous declarations, my opening written testimony, and in the testimony below. My qualifications as an expert in hydrogeology and geochemistry are set out in my opening written testimony.

**Rebuttal Testimony: Contentions 2 & 3**

The opening written testimony provided by Powertech's consultants regarding Contentions 2 and 3 provides further support for my opening testimony regarding the inadequacy of baseline characterizations and resulting errors in characterization of the interrelated hydrogeology, water quality, and water quantity of the project area and region.

Based on my review of the written testimony of Powertech's consultants, Mr. Lawrence (APP-037), Mr. Demuth (APP-013), and Mr. Fritz (APP-046), it is my further opinion that adequate hydrogeological analysis and data gathering can be conducted without construction and operation of the Nuclear Regulatory Commission (NRC)-approved well field and is necessary for a scientifically competent, interdisciplinary analysis of baseline water quality, water quantity, and hydrogeology. Examples of such sources of information are contained in and include published reports (e.g. TVA, 1979; Boggs & Jenkins, 1980; Boggs, 1983; Knight Piesold, 2008).

**Contention 2: Baseline Characterizations are Inadequate**

A. Past Uranium Mining and Other Contamination.

1. *Expert Opinion*: Analysis of impacts from past mining and other contamination are critical to assessing the baseline water quality, and potential impacts of future mining activity at the proposed site.

2. *Response to Powertech Testimony:*

I have reviewed the opening written testimony of Mr. Lawrence (APP-037), Mr. Demuth (APP-013), and Mr. Fritz (APP-046) and it appears each confirms that the license conditions approved by NRC Staff allow a delay in the gathering of detailed hydrogeological data and water quality testing until after NRC license approval and National Environmental Policy Act (NEPA) analysis is complete. The confirmation of delayed gathering provides further support for my opinion that the data are inadequate to establish a hydrogeological and water quality baseline for the aquifers that would be impacted by the Dewey-Burdock Project.

Powertech's consultants confirm that the information that may be gathered in the future is critical to a baseline characterization and in turn, a reasonably complete analysis of the environmental impacts of the project. There is no doubt that this information was unavailable for review by expert agencies such as USGS and EPA, and experts such as myself who assisted persons participating in the NEPA process. The lack of data during the NEPA process and during the licensing process prevents an adequate disclosure and analysis of the impacts of the D-B Project, and prevents the analysis, comparison, and choice of adequate mitigation measures.

Powertech consultants are incorrect in asserting that the individual well fields must be constructed and put in operation before the requisite level of hydrogeologic testing, sampling and analysis can be performed. For example, Mr. Demuth (APP-013) answers a misleading question posed by Powertech:

> Q.29. Can Powertech conduct pumping tests for each wellfield prior to license issuance?
>
> A.29 No. Powertech cannot conduct the aquifer pumping tests for each wellfield prior to license issuance, since it cannot construct the wellfield monitoring network for any wellfield until the license is granted (see A.22 of this written testimony). [...]

Mr. Demuth's response and the original question are misleading in that the question implies that a licensed, operating wellfield is necessary to create a reliable baseline.

In my opinion, pumping tests designed to establish the baseline site characteristics can be designed and carried out without constructing the ultimate wellfield monitoring network. For example, both Tennessee Valley Authority (TVA) and Knight Piesold conducted pump tests within the Dewey-Burdock area prior to NRC permit approval. Also, Mr. Demuth confuses hydrogeological testing that is needed to establish, analyze, and disclose the hydrogeological setting as part of the NEPA-based NRC permit-approval with the more specialized production tests Powertech will conduct on constructed wellfields.

Mr. Demuth's answer at APP-13 A.29 also claims, without support, that the admitted delay in gathering baseline data "does not mean that information needed to assess potential groundwater impacts is lacking at this stage of the licensing process." It is my expert testimony that the information is lacking. The specific information lacking is listed in my Opening Written Testimony (OST-1) at C.2. Based on my experience and training, it is my opinion that it is standard hydrogeological practice to collect and interpret such data (see OST-1 at C.2) in order to define ground water flow pathways and possible future impacts. Such data are also needed to provide reliable inputs for any computer modeling that may be employed. The present Powertech modeling is based on incorrect hydrogeological assumptions and inadequate data and therefore generates unreliable predictions. In my opinion, Mr. Demuth's answer at APP-13 A.29 contradicts standard hydrogeological practices.

Powertech's consultants now assert that the data relied upon in its application materials and the NEPA analysis are not useful. For example, Mr. Lawrence asserts at APP-037 A.56 and A.57 that the D-B exploration boreholes are closed through natural processes and in other testimony that they are open. Mr. Lawrence also concludes at APP-037 A.80 and A.85 that these borehole problems have rendered the pump test results useless. Mr. Lawrence further testifies that some of the leakage was due to an improperly completed well, but he supplies no proof of the improperly completed well, and none of the earlier consultant's reports mentioned this limitation.

I agree that the Dewey-Burdock pump tests alone are inadequate to establish a hydrogeological and water quality baseline. Further, the previously undisclosed irregularities in the data provided by Powertech provide further support for my testimony that Powertech and the NEPA analysis both failed to adequately define the detailed hydrogeologic conditions of the Dewey-Burdock aquifers and confining zones, or likely impacts.

Throughout the written testimony of Powertech's consultants, each selects only information and sources that support their preferred conclusions and fail to analyze information or analyses that disclose difficult problems —which means they failed to include some of the most important, relevant hydrogeological studies. In my opinion, Mr. Lawrence and the other Powertech consultants simply ignore difficult problems, effectively sweeping them under the rug and out of view of persons reviewing the NEPA analysis and license materials. The unreliable hydrogeological and water quality baselines presented by Powertech and the NEPA analysis are confirmed where Powertech consultants' assertions contradict their own previous assertions regarding the reliability of existing data.

For example, Demuth testifies at APP-013 A.29: "NRC staff **reviewed** Powertech's procedures for locating and installing monitor wells and for conducting the pumping tests and determined those procedures meet regulatory requirements (see below). The results of those pumping tests **will be provided** to NRC and EPA staff for review and will have to demonstrate adequacy of the monitoring network prior to operating each wellfield." (emphasis added). Mr.

Demuth confirms that the hydrogeological information provided in the Dewey-Burdock documents is inadequate to reliably characterize hydrogeological conditions and evaluate future changes and impacts to water resources.

Mr. Demuth's statement at APP-013 A.32 goes on to argue that the NRC-approved pump tests were flawed (TVA & 2008) and do not confirm whether or not the site involves leaky aquifers. This inconsistent statement supports my contention that the FSEIS failed to adequately define the hydrogeologic behavior of the Dewey-Burdock aquifers, confining zones and likely impacts.

Mr. Demuth testifies at APP-013 A.12: "It is also my testimony that, according to NUREG-1569 and federal regulations in 10 CFR Section 40.32(e), a **license applicant is not permitted** until after license issuance to install a complete wellfield monitor well network that is used to establish Commission-approved background (CAB) groundwater quality within the production zone of each wellfield and upper control limits (UCLs) that are used for excursion monitoring in underlying, overlying and perimeter monitor wells." Similar to Mr. Demuth's misleading testimony at APP-013 A.29, the explanation at A.12 confuses testing and analysis that is routinely performed by hydrogeologists in order to understand numerous hydrogeologic processes in almost any project and before NRC permit approval, with requirements after NRC-permit approval.

Mr. Demuth at APP-013 A.53 states that industry "success" at historic ISL sites has been confirmed by studies partially-summarized at 3 ISL sites out of possibly 35 to 40 sites that have long-term operational histories. In my experience, no ISL site has ever been returned to baseline. Mr. Demuth's statements confirm that the FSEIS has not adequately summarized the industry aquifer restoration successes and failures. Mr. Demuth's assertions help explain that the failure to timely restore aquifers to baseline conditions after cessation of ISL operations is partly a result of delaying the collection of necessary hydrogeological and water quality data until after NRC Staff approval, which avoids scrutiny of expert agencies and the public. Thus, license conditions that delay collection of these necessary hydrogeologic and water quality data / information until after NRC permit approval ensures that much of the detailed information will never become public or face careful review by other agencies and the public in a NEPA process.

Last, at APP-013 A.33 Mr. Demuth cites the ground water samples collected by Johnson, but fails to mention that these USGS data contain many more chemical constituents than are included in the Powertech water quality data. In my opinion, many of the constituents identified by the USGS should have been included as part of the "baseline" monitoring data, but were not. Mr. Demuth also fails to note that these USGS samples, although useful for other purposes, were not collected after long-term pumping, and do not represent long-term conditions. These USGS water quality / geochemistry samples were not collected as part of an integrated hydrogeology / water quality study. As stated in my written testimony, reliable conclusions about leakage between geologic

units and ground water-surface water interactions require more detailed, integrated testing.

B. Inadequate Baseline Concept and Baseline Data.

1. *Expert Opinion*: The Application and Final Supplemental Environmental Impact Statement (FSEIS) are inadequate to establish a hydrogeological baseline for the aquifers that would be impacted by the Dewey-Burdock Project.

2. *Response to Powertech Testimony:* See response in A.2.

C. Fundamental Hydrogeologic Information is Lacking.

1. *Expert Opinion*: The FSEIS and Application lack necessary scientifically-defensible hydrological and hydrogeological information.

2. *Response to Powertech Testimony:* See response in A.2

D. Data Provided Entirely by the Applicant is not an Accepted or Reliable Basis for Analysis.

1. *Expert Opinion*: Analytical results that rely entirely on data provided by the project proponent are not considered reliable by professional hydrogeologists and other water experts.

2. *Response to Powertech Testimony*: See response in A.2

Powerech has split the water-related testimony among three consultants, none of whom claim to have preformed any of the original hydrogeological testing or water quality sampling. None of Powertech's testifying consultants claim to be familiar with the actual details that influence the larger interpretations. The result of this disconnect between data gathering and analysis/interpretation is to confirm the inadequacy of the data obtained and the lack of interdisciplinary analysis in the NEPA analysis.

**Contention 3: The Targeted Production Zones are Unable to Contain Fluids.**

My response to Powertech testimony provided by Mr. Lawrence (APP-037), Mr. Demuth (APP-013), and Mr. Fritz (APP-046) affecting Contention 3 applies across all my opinions. Further, Powertech consultant's written testimony is based on the false assumption that the targeted production zones are able to contain fluids and do not leak horizontally or vertically into other water-bearing zones. It is my opinion that the targeted production zones involve "leaky aquifers."

The written testimony of Powertech's consultants, like the application and NEPA documents, select only information and sources that support their preferred conclusions and fail to cite those in opposition—which means they failed to look at or cite some of

the most important, relevant hydrogeological studies. In my opinion, such a methodology is not scientifically defensible and not up to the industry standard. Powertech consultants' written testimony are based on assertions that contradict opinions of all the other investigators who actually conducted and interpreted the D-B pump tests (Boggs & Jenkins, 1980; Boggs, 1983; KP, 2008), who state that there is leakage between the Fall River and the Lakota through the Fuson, and leakage within the facies of the Lakota. Mr. Lawrence totally disregards the same and related inconvenient opinions within, for example, Gott, et. al. 1974; Keene, 1973; TVA Envir. Statement, 1979; Butz, et. al., 1980; Boggs, 1983; Bredehoeft, Neuzil & Milly, 1983; SRK, 2012.

Leakage between geologic facies was not addressed, even though the overall hydrogeological literature and my experience indicate that leakage occurs (between the mined aquifers and the "confining" units) at most ISL sites operated in similar fluvial sedimentary uranium hydrogeologic settings during long-term pumping. *However, because the detailed hydrogeologic and water quality testing are delayed until after NRC permit approval, most of this information never becomes available to the public.*

Mr. Demuth's testimony at APP-013 Q.7 provides an inadequate description and conceptual diagram as a basis for his further assertion: "Within an aquifer water flows by porous media flow in interstitial spaces between the sand grains that make up the aquifer. This is depicted in the enlargement on the right of the conceptual diagram." Mr. Demuth's simplistic approach is inapplicable and misleading when applied to the majority of inter-bedded sediment packages in the project area. Instead, much of the water in leaky aquifers is actually supplied via leakage from confining units after long-term pumping.

The erroneous picture presented by Mr. Demuth's simplistic approach is confirmed by basic hydrogeological principles discussed in my opening written testimony: For example, **Freeze & Cherry, 1979, Groundwater at** p. 320 discuss the dangers of calculations that assume any aquifer is confined. "The assumption inherent in the Theis solution that geologic formations overlying and underlying a confined aquifer are completely impermeable is seldom satisfied. Even when production wells are screened only in a single aquifer, it is **quite usual for the aquifer to receive significant inflow from adjacent beds. Such an aquifer is called a *leaky aquifer,* although in reality it is the aquitard that is leaky."** (emphasis added).

Freeze and Cherry go on to explain at p. 332 that "The most common geological occurrence of exploitable confined aquifers is in sedimentary systems of interbedded aquifers and aquitards. In many cases the aquitards are much thicker than the aquifers and although their permeabilities are low, their storage capacities can be very high. In the very early pumping history of a production well, most of the water comes from the depressurization of the aquifer in which the well is completed. **As time proceeds the leakage properties of the aquitards are brought into play and at later times the majority of the water being produced by the well is aquitard leakage. In many aquifer-aquitard systems, the aquitards *provide* the water and the aquifers *transmit* it to the wells." (emphasis added).**

It is my expert opinion that both quantity and quality must be addressed in an interdisciplinary manner because as the leakage progresses, the chemical quality of the water being pumped changes. Powertech failed to conduct hydrogeological testing that was integrated with water quality sampling and analysis.

It is my expert opinion that the Powertech consultants' testimony relies on oversimplified and conceptual assumptions to assert that the aquifer is totally confined. In my opinion, the limited data provided, read consistently with accepted hydrogeological principles, confirm that the D-B project involves leaky aquifers, which require additional data to adequately characterize.

**Contention 4: Failure to Adequately Analyze Ground Water Quantity Impacts.**

**A. Water Consumption**

1. *Expert Opinion:* The applicant will use and contaminate tremendous quantities of ground water, thereby preventing / restricting the use of these waters by others.

2. *Response to Powertech Testimony*:

Mr. Demuth answers Q.27 by stating at A.27 that "**The latter [hydrogeologic] information is not required to assess potential impacts to groundwater** but instead to confirm that proper operational and monitoring procedures are followed to prevent groundwater contamination." It is my opinion that Mr. Demuth's conclusion confirms that hydrogeologal information was ignored by Powertech and the NEPA documents. In my opinion, defining the hydrogeological setting is critical to analyzing potential ground water quantity impacts.

At A.45, Mr. Demuth wrongly asserts that water lost via evaporation from the waste ponds has no effect on the volumes of water used by the D-B project. Mr. Demuth wrongly asserts that my expert opinion was "based on a false premise – that water loss through evaporation would somehow increase the overall water consumption rate." My testimony is not based on the increase in consumption rate. My testimony is based on the conclusion that such evaporation and any other categories of water loss not accounted for in the FSEIS estimate will increase the total volumes of water used by the D-B project.

**B. Water Balance**

1. *Expert Opinion*: The FSEIS relied on an inadequate and unreliable analysis of water use, and failed to provide a water balance.

2. *Response to Powertech Testimony:*

Mr. Fritz does not indicate that he conducted any of the data collection or initial analysis. Instead, Mr. Fritz' written testimony appears to attempt to identify materials in the hearing record that could be construed as part of a water balance. The comments of Mr.

Fritz do not change my opinions or the basis of my opinion that the FSEIS does not contain a water balance.

For example, at APP-046 A.6, Mr. Fritz points out that "Groundwater use was a primary focus of the June 2011 TR RAI responses (Exhibit APP- 016-A through 016-BB), including providing a project-wide **water balance** in support of the discussion on handling liquid waste (P&R-14(c), Exhibit APP-016-B at 68-73). This RAI response provides a detailed description of the quantity of **water anticipated to be used from the production zone aquifer (Inyan Kara) and from the Madison aquifer** (primarily for groundwater restoration) during production and groundwater restoration operations. Much of this information has been incorporated into the FSEIS (i.e., Sec. 2.1.1.1.3.3)."

The question posed to Fritz at APP-013 Q.7 mischaracterizes my testimony. Mr. Fritz is asked: "How do you respond to the allegation that the FSEIS provides conflicting information on the volumes of water to be used such that the water consumption impacts of the project cannot be accurately evaluated (CI 2013 at 27, CI 2014a at 25, **Moran 2013 at 12**, OST 2013 at 19, OST 2014a at 19)?" The response at Moran 2013 at 12 is not related to volumes of water. It appears, from this and other examples, that Mr. Fritz and other Powertech consultants have simply inserted random supporting citations that are unrelated to my expert opinion that the FSEIS does not contain a water balance.

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Pursuant to 10 C.F. R. §22.304(d) and 28 U.S.C. §1746, I declare under penalty of perjury, that the foregoing is true and correct to the best of my knowledge and belief.

Signed on the 15th day of July, 2014

Robert E. Moran

Dr. Robert E. Moran, Ph.D.

# EXPERT OPINION REGARDING THE PROPOSED DEWEY-BURDOCK PROJECT ISL MINE NEAR EDGEMONT, SOUTH DAKOTA

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## INTRODUCTION

In early March 2010 I was contacted by Lilias Jarding (WMAN) to review an application to the US Nuclear Regulatory Commission for construction of an ISL facility (the Dewey-Burdock Project) for mining uranium near Edgemont, South Dakota. I had previously provided an expert opinion to the Western Nebraska Resources Council (among others) regarding ISL uranium mining near Crawford, Nebraska. I am offering this expert opinion regarding ISL uranium mining near Edgemont because I am concerned that the issues that I raised in the earlier opinion also apply to the proposed Dewey-Burdock Project. As I have stated previously, I am not against uranium mining in fact or principle. This issue isn't about uranium. It's about protecting the region's water supply, and the future inhabitability of southwestern South Dakota and adjacent Nebraska. In this document, I will briefly explain the basis for my concerns.

## PROFESSIONAL BACKGROUND

I have 20 years experience studying the rocks and fossils of northwestern Nebraska and adjacent South Dakota. From 1988-1991 I collected fossils from northern Sioux County, Nebraska for my dissertation work. From 1991-1996 I led field parties from the University of Nebraska State Museum while mapping the fossils and geology of the Oglala National Grassland in Sioux and Dawes counties, Nebraska. From 1996-2006 I led teams of geologists from the Nebraska Geological Survey that mapped in detail the surficial geology of most of northwestern Nebraska (a total of 80 1:24,000 quadrangles). The completion of this work frequently required detailed study of equivalent strata in adjacent South Dakota. These maps, including digital versions (ArcInfo) and supporting field notes, are available from the University of Nebraska-Lincoln School of Natural Resources (contact James B. Swinehart). As a direct consequence of this mapping, I have published peer-reviewed articles on the Chadron Formation (Terry & LaGarry 1998), the Brule Formation (LaGarry 1998), the mapping of surficial deposits (Wysocki & others 2000, 2005), and local faults (Fielding & others 2007). From 2006-2008 I continued this work as an Adjunct Professor of Geology at Chadron State College (CSC) in Chadron, Nebraska. During this time I worked with and advised students studying the region's groundwater, surface water, and geologic structures (principally faults). In May 2008, my CSC colleagues and I, along with Chadron residents, scientists from the Nebraska Geological Survey, the United States Geological Survey, the University of Nebraska School of Natural Resources, and the Upper Niobrara-White Natural Resource District, convened "Our Water, Our Future: a Town Hall Meeting." Our consensus opinion was that water shortages and declining water quality are real and worsening problems in northwestern Nebraska and the northern Great Plains region. Since 2008 I have been serving the Oglala Sioux Tribe as an Instructor in the Department of Math, Science, & Technology at Oglala Lakota College (OLC), and since 2009, as co-chair of that department. Since joining the faculty at OLC, I have been working with students and faculty to

continue to study the geology, groundwater, surface water, and heavy metal contamination of southwestern South Dakota and the Pine Ridge Reservation. In pursuing these studies, we have formed working partnerships with Chadron State College, the South Dakota Geological Survey, the South Dakota School of Mines and Technology, South Dakota State University, the University of Illinois Urbana-Champaign, the University of Illinois Center for Advanced Materials Purification of Water Systems, the Department of Health Physics at the University of Michigan School of Nuclear Engineering, the University of Washington Burke Museum, and the University of Washington Native American Research Center for Health. Our research has been funded for the next 5 years by the National Science Foundation Tribal Colleges and Universities Program.

## THE CONCERNS

My concerns regarding the Dewey-Burdock Project are centered around the problems of secondary porosity in the form of faults and joints, the lack of confinement, artesian flow, and the horizontal flow of water within the uranium-bearing strata. I found the Powertech's environmental report to be poorly referenced overall, but especially parts concerning the geology of the region. The conclusions concerning the geology within the proposed area are based on in-house studies and unpublished theses and reports. It is beyond the scope of this opinion to review the entire scientific literature for the region, but I provide the most readily available recent research. Where appropriate, I also refer to specific sections of Powertech's environmental report to the US Nuclear Regulatory Commission (NRC) for the construction of the Dewey-Burdock Project.

### The problem of secondary porosity

Secondary porosity, in the form of intersecting faults and joints, is common in all of the rocks north, east, and south of the Black Hills Dome, especially north of and along the Pine Ridge Escarpment (see Swinehart & others 1985). These faults and joints are generally oriented NW-SE and SW-NE, and are most likely a result of the ongoing uplift of the Black Hills of southwestern South Dakota. Although a few people consider the Black Hills uplift to have ended by the late Cretaceous (~65 Ma), the Black Hills were tectonically active in the late Eocene (Evans & Terry 1994), and continued to fault, fracture, and fold the rocks of northwestern Nebraska and southwestern South Dakota into the middle Miocene (Fielding & others 2007). Based on numerous small earthquakes along the Sandoz Ranch-Whiteclay Fault, the area is still tectonically active (McMillan & others 2006). These earthquakes are relatively mild, and don't significantly damage surface infrastructure. However, even small earthquakes represent shifting and flexing of the earth's crust, and are continuously creating, closing, and redistributing the secondary porosity of the region's rocks. This means that joints incapable of transmitting water one day may be able to transmit water at a later date. These faults and fractures transect all major bedrock units of the region. These faults likely connect the uranium-bearing strata to adjacent aquifers as well as modern river alluvium.

In 2007, Chadron Creek, the stream that supplies water to the city of Chadron, Nebraska, went dry for the first time in the citys' history. Subsequent study of the creek's water flow rates by Chadron State College students suggested that normal amounts of water are flowing from the

springs, but the water is disappearing into deeper alluvium or into fractures in the rock (Balmat & others 2008, Butterfield & others 2008). Following these observations, a Chadron State College graduate student began studying the widespread faults and lineaments of northwestern Nebraska and southwestern South Dakota using data collected by high-flying aircraft, satellites, and the space shuttle (Balmat & Leite 2008). Many of the faults in northwestern Nebraska and southwestern South Dakota persist for tens of miles (Diffendal 1994, Fielding & others 2007). Also, many of the ancient river deposits of the Tertiary strata, along with the alluvium deposited by modern rivers such as the Cheyenne River, the White River, and Hat Creek, follow fault zones because fractured rock erodes more easily. A review of the scientific literature shows that faults and joints are well-known in rocks surrounding the Black Hills, and are known to interconnect major aquifers and the land surface (Swinehart & others 1985, Peters & others 1988, Fielding & others 2007). Powertech's application asserts that although fault zones are known both north and south of the project area (section 3.3.2.1), there are no known faults within the project area and therefore little or no secondary porosity. This is a false perception, because joints (cracks in the rock lacking measurable displacement) are exceedingly common in this region and form the vast majority of secondary porosity and contaminant pathways.

**The problem of lack of confinement**

In order for ISL mining to be considered safe, the uranium-bearing, mined strata must be isolated from rocks above and below by confining layers. There are three principal pathways through which contaminated water could migrate away from the uranium-bearing strata through adjacent confining layers. The first, and most common, are along joints and faults (see above). Where present, joints and faults penetrate confining layers above and below. The second is through thinning or pinching out of confining layers. In their application to the NRC, Powertech concedes that the upper confining layers thin and there are breaches in the upper confining layers (sections 3.3.2.2, 3.4.3.1.7, 3.4.3.1.10, and 3.4.3.2). The third pathway for mine fluids to breach containment is through perforations made by wells. In Powertech's application, they repeatedly mention "thousands of exploratory wells," along with wells that supply drinking water (the uranium-bearing strata are a local drinking water supply) and water for livestock. In addition, many of these wells are abandoned and most likely improperly plugged (section 3.4.1.2). Once mining begins, and minerals are being extracted, flow pathways within the uranium-bearing rocks will change, potentially creating circumstances in which any one of these wells could allow lixiviant to breach confinement. Once into adjacent water-bearing strata or the land surface, contaminants can enter rivers and flow downstream with each successive rain event, or flow downgradient into other water supplies.

**The problem of artesian flow**

Artesian flow occurs when there is a hydrologic connection, through faults or highly permeable strata, between groundwater sources and the land surface. The weight of water in overlying strata exerts pressure downward into water within the uranium-bearing strata, which can then be released as artesian water flow where the topographically lower uranium-bearing strata is exposed at the surface, or where it is punctured by drilling. Artesian flow was observed or predicted by Powertech in their Dewey-Burdock Project proposal (sections 3.4.1.2, 3.4.3.1, and 3.4.3.1.7). Artesian flow is most likely where the upper confining layer is perforated by

secondary porosity (section 3.3.2.1), poorly constructed or improperly sealed exploration wells (sections 3.3.2 and 3.4.1.2), or thinning or absence of upper confining layers (section 3.4.3.1.7). Artesian flow could transmit lixiviant, the most toxic mineral-laden of waters, onto the land surface (and into Cheyenne River, White River, or Hat Creek alluvium) and discharge large amounts of contaminants into aquifers or faults in a very short time.

### The problem of horizontal flow

Confining layers adjacent to uranium-bearing strata limit the unwanted spread of contaminants from an ISL site. However, horizontal flows within the uranium-bearing strata are also of concern. Such flow can rapidly redirect lixiviant or mine waste away from the mine site and into unexpected breaches in the confining layers. In their application to the NRC, Powertech reports horizontal flows within the uranium-bearing strata (the Inyan Kara Group) of up to 35.5 meters/day (Chilson Member, section 3.3.2.2) based on local conditions, and of up to 6,000 $ft^2$/day (section 3.4.3.1.2) elsewhere in the Black Hills region. Even if secondary porosity, artesian flow, or lack of confinement did not contaminate nearby water supplies, down gradient flow along the Cascade and Chilson anticlines (Rothrock 1931a, 1931b, 1948) would transmit contaminants to the major, mapped faults north of the Pine Ridge in Nebraska in less than 5 years (using the smaller value).

## CONCLUDING REMARKS

Based on the arguments presented above, it is my expert opinion that ISL mining in the Edgemont, South Dakota should not be allowed. Artesian flow, the potential lack of confinement due to secondary porosity and drilling, along with potentially high horizontal flow in the uranium-bearing strata indicate that during the course of its operation the Dewey-Burdock ISL Project will most likely contaminate the region with unconfined lixiviant. This contamination could plausibly pollute groundwaters and surface waters southwards into Nebraska and surface waters within the Cheyenne River drainage eastwards into greater South Dakota. Also, based on my reading of Powertech's application, no review of the geologic literature was conducted. In my view, the use of outdated scientific literature, or in this case, a general lack of review of recent study, should not be seen as an opportunity to operate in a knowledge vacuum. Much of the Great Plains region was studied prior to the 1980's and the general acceptance of Plate Tectonics Theory, and therefore generally misrepresents the geologic setting of the region. This was true of the geologic literature used to justify ISL mining near Crawford, Nebraska, and is also true of the data used to justify proposed mining near Edgemont, South Dakota. It is incumbent upon potential ISL operators, as it is with any natural resource consumers, to seek out the most recent research and expert opinions on the geological settings in which they propose to operate.

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UNITED STATES OF AMERICA INT-020
NUCLEAR REGULATORY COMMISSION

BEFORE THE ATOMIC SAFETY AND LICENSING BOARD

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| In the matter of | ) | |
| | ) | |
| POWERTECH (USA) INC. | ) | Docket No. 40-9075-MLA |
| | ) | ASLBP No. 10-898-02-MLA-BD01 |
| (Dewey-Burdock In Situ Uranium | ) | |
| Recovery Facility) | ) | |

# REBUTTAL WRITTEN TESTIMONY OF DR. HANNAN LAGARRY

The following is my response or rebuttal to some of the facts and/or opinions of Powertech's witnesses.

## Contention 3

In their written testimonies, DeMuth (APP-013) and Lawrence (APP-037) assert that the law does not require Powertech, the Applicant, to have well field specific data prior to licensing, but that the acquisition of such data is a phased process once operation begins. DeMuth concedes the absence of pump testing in every proposed well-field for this reason. It appears by their testimonies that DeMuth and Lawrence concede that there will be excursions, which Powertech will try to correct as they mine and fix them once they become apparent. However, it would seem prudent that a license application presented for NRC review and evaluation would contain well field specific data in order to anticipate the location and nature of expected problems and to be able to develop detailed plans to rectify the problem.

Where is Powertech's plan for each well-field? Where has it worked before? Why is the Dewey-Burdock area so hydro-geologically identical to other mines to permit an evaluation of whether the "standard" plans will work there? Where is the independent evaluation by the NRC Staff? Instead, DeMuth extends simply a promise by Powertech to have plans that will work in place to fix the inevitable lack of containment it finds as the well-fields grow. This seems like a backhanded way of saying that in the end, confinement doesn't matter. It must as it relates to



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containment necessary to prevent contamination of water resources outside the license boundary.

Examination of Powertech's experts' CVs (APP-014, APP-038) reveals that, rather than use independent third-party academics or researchers, Powertech instead relies on insiders who stand to benefit from future contracts related to this project, should the issuance of the NRC licenses be upheld by this board. Such conflicts of interest are troubling where peoples' health and safety is at risk and objectivity is be required.

I note that Technical Report (APP-015A) describes "periodic releases of water from storage ponds." I find substantively lacking information as to how much contaminated water Powertech plans to release during any discharge, how often such releases are thought to be necessary, a discussion and analysis of environmental impacts from the contaminants in the water released. Again, it seems that promises of fixing any problems not known from the limited testing conducted by the Applicant are used as a substitute for site-specific plans to prevent the need for releases. If releases are necessary, detailed site specific plans to mitigate introduction of the numerous toxic and carcinogenic chemicals and minerals in this water should have been presented and evaluated by the NRC staff to ascertain its real effectiveness in protection water resources.

I also note that the Technical Report (APP-015B) has many of the same admissions and concessions as the FSEIS, including that mineralization at the site is contaminating local water, and that therefore contaminant pathways are already present (2.9.4.3). Almost all of the photos in the geology section of the Technical Report show the unmapped joints and faults I've opined about in several prior Expert Opinions regarding ISL mining in northwestern Nebraska and southwestern South Dakota. If faults and joints are so pervasive and ubiquitous in this region, why is Dewey-Burdock viewed as an exception? Is it because they're there but not being recognized? Is it because if recognized it would add to the problems of containment of this mining operation, indicate that regional water sources are threatened by it, and that issuing a license to Powertech was a mistake to be corrected? Is it because Powertech's recognition of such features would be fatal to their proposed mining operation?

The radiological survey (APP-015C) reports statistically anomalous high radiation levels left over from past mining but says they're not relevant without explaining

how they got there or why they don't matter. What if they are the product of contamination by artesian flow? Wouldn't such circumstances constitute a future problem and lead to more contamination? Powertech's expert testimony does not address this. Furthermore, Powertech's experts seem to be unaware that their proposed land application areas are on river terraces that will transmit the applied waste directly into local watersheds.

DeMuth and Lawrence specifically refute my 2010 assertion presented in this case that the Inyan Kara is unconfined by using cross sections based on e-logs (APP-015D, APP-15E). A copy of my 2010 Opinion is attached hereto as Ex INT-020a. Cuttings or core samples are less subjective, and would be available for third-party inspection.

However, the FSEIS concedes that the units are unconfined for the specific reasons I laid out in the most recent 2014 opinion in my Opening Testimony. Lawrence defers to DeMuth on the use and interpretaton of the cross sections supplied by Powertech, based on e-logs. These are contradicted by the FSEIS which concedes that the upper confining layer thins to 0. Also, Lawrence defers to USGS publications for the generalized structural geology and dismisses jointing, faulting, and breccia pipes because Powertech didn't report any. Did they look? Did they see joints (joints and small faults are visible but unmentioned in photographs in the Technical Report)? Were they focused on displacement or seismic activity? What about minor joints that in aggregate might constitute a problem? I would note from my experience and study, the nearby ISL mine at Crow Butte has faults which are visible from space and cut through the existing and proposed operation. Yet CAMECO, like Powertech is attempting to do, has never reported or acknowledged them.

DeMuth makes no mention of Powertech's FSEIS admissions and concessions, and doesn't address my main concern regarding jointing and faulting in the proposed project area. If they are correct, that applicable laws and regulations don't require that they gather their own site-specific data before receiving an ISL mining license, then somehow, the actual hydrogeology is of no real concern to the NRC. I would opine that such a "one size fits all" legal and regulatory framework is flawed and prejudices the process in favor of mining.

Powetech provides a structural map (APP-015D) that is largely blank over project area. Neither Powertech's experts or the provided exhibits describe how faults and

joints were prospected and mapped in the area, especially where photos Powertech presented in its Technical Report, show them in significant numbers (see also my response to APP015B, above).

APP016A shows that NRC had concerns about lack of confinement and artesian springs, something DeMuth urges, are not problems which have been found yet. Again, if found later, after the mining operation has started, whatever the problem is, it will somehow be dealt with. Demuth, Lawrence, Fritz (APP-046), and McKee (APP-053) all assert "these mines have operated safely for decades." However, the long list of safety and environmental violations listed at http://www.wise-uranium.org/umopusa.html substantially shows otherwise. Definitions of "safe" must vary widely to include so-called "reclaimed" water that is more contaminated that prior to the ISL mining of the aquifer.

Fundamentally the FSEIS infers that the NRC Staff trusts Powertech explicitly to act in the public's best interest and report potentially fatal data. History shows otherwise.

I swear that the above is true and correct to the best of my knowledge.

Dated this *15th* day of July, 2014.

*/s/ Hannan LaGarry*
HANNON LaGARRY



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Dr. LaGarry handed this statement in May 10

OST-029

UNITED STATES OF AMERICA
NUCLEAR REGULATORY COMMISSION

BEFORE THE ATOMIC SAFETY AND LICENSING BOARD

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| In the matter of | ) | |
| | ) | |
| POWERTECH (USA) INC. | ) | Docket No. 40-9075-MLA |
| | ) | ASLBP No. 10-898-02-MLA-BD01 |
| (Dewey-Burdock In Situ Uranium | ) | |
| Recovery Facility) | ) | November 21, 2014 |

**WRITTEN SUPPLEMENTAL TESTIMONY OF DR. HANNAN LAGARRY**

I, Dr. Hannan LaGarry, hereby declare as follows:

1. I am an expert in the above-captioned proceeding; my testimony, CV, and area of expertise are already in the record. To summarize, I am a stratigraphic mapper and full-time professor at Oglala Lakota College in Kyle, South Dakota. In preparing this declaration, I relied on the expertise gained through my training and experience in reviewing and interpreting borehole logs and other geologic data to create and review narratives, representations, and maps of subsurface geology and hydrogeology.

2. My testimony herein is based on my review of Powertech's recently disclosed borehole logs, maps, and other data. My testimony is also based on my review of the testimony and exhibits submitted by both NRC Staff and Powertech to the Nuclear Regulatory Commission Atomic Safety and Licensing Board, and my expert opinions offered before and during the hearing in Rapid City, South Dakota.

3. On November 12, 14, and 15, 2014 myself and 3 student assistants continued to review drillers' notes and borehole logs prepared by the Tennessee Valley Authority and recently disclosed by Powertech. This review was conducted at the Powertech offices in Edgemont, South Dakota.

   The available data consists of paper files contained in 28 bankers' boxes, 5 file cabinets, and 31 sets of mini logs (reduced to about 1/10$^{th}$ of the full-sized logs). Based on records I reviewed during my initial visit to the Powertech offices on September 14-16, 2014 these boxes, cabinets, and mini logs contain ***at least***:

   7515 total borehole logs
   7454 known borehole logs prior to acquisition of the recently described data
   3920 borehole logs owned prior to acquisition of the recently disclosed data
   3075 digitized data logs

These totals may underreport the number of logs made available, as I was not able to confirm whether my count was inclusive of all logs made available. Our understanding was that the newly disclosed borehole logs numbered over 4,000 data sets.

In total, my assistants and I were able to review drillers' notes from 4,177 boreholes (56% of the 7515 listed above) in 2.5 bankers' boxes, with at least 2.5 bankers' boxes of similar records remaining unexamined. We also examined 488 full-sized (in 3 boxes) and 1774 "mini" resistivity and gamma log pairs (30% of the 7515 listed above), with at least 6 bankers' boxes and 5 file cabinets of similar records remaining unexamined. The number of notes and logs examined was likely 5% fewer than the total number of records reviewed because some logs and notes were discovered to be moved or missing (see below). Also, there is overlap between the drillers' notes and the "mini" borehole logs reviewed. The "mini" logs, although briefly reviewed, did not contribute to the observations listed below.

My review confirmed my previous testimony that the raw data was not presented by modern modeling I would expect to find in such data compilations. Because of the limited time available and the lack of modelling, we did not attempt to reconstruct the geology of the proposed license area. Rather, we focused on the first-hand accounts of the geology of the site and the drilling conditions recorded by the geologists logging the wells. Based on our review of the data, we documented the following unique instances:

| | |
|---|---|
| 140 | open, uncased holes |
| 16 | previously cased, redrilled open holes |
| 4 | records of artesian water |
| 13 | records of holes plugged with wooden fenceposts |
| 6 | records of holes plugged with broken steel |
| 12 | records of faults within or beside drilled holes |
| 1 | drawing of 2 faults and a sink hole within a drilled transect |
| 7 | notations "do not record this value on drill hole maps" |
| 2 | notations "do not return this to landowner" |
| 63 | redacted borehole logs |

Many notes contained references to water at various levels and poor, muddy, or destroyed samples. We also found that, in the data sets we reviewed, blocks of records had been moved or were missing.

4. Based on the observations noted above, I offer the following expert opinions:

**Sample size**

We examined drillers' notes from 4,177 boreholes, which is at least 56% of the available data. In my expert opinion, while this sample likely underrepresents the total number of features listed above, it is sufficiently large to characterize the data and to reasonably reflect the geological conditions in the licensed area. In contrast, the NRC review of 34 boreholes

constitutes less than 1% of the available data, grossly misrepresents the sample, and is not scientifically valid or useful in any meaningful way.

**Open, uncased holes, including redrilled open holes**
**(Exhibit SNT25)**
Casing of boreholes prevents the unwanted migration, transfer, and cross-contamination of water within a borehole. Uncased holes allow unrestricted communication between water-bearing strata at the site. Each uncased hole is a breach of the confining layers assumed to restrict the movement of mining fluids and contaminants. Redrilling of previously cased holes destroys the pre-existing casing and returns the borehole to the open, uncased condition. In my expert opinion, while it is possible that confinement may yet exist in undrilled areas, there is no reasonable expectation that confinement remains in drilled areas.

**Artesian water**
**(Exhibits TRT44, ELT4)**
Artesian water is water that flows under pressure exerted by connected waters at higher elevations. The presence of artesian water in the licensed area clearly demonstrates such connections, and that there is communication of water between the aquifers onsite and offsite. Artesian flow allows the rapid transfer of water along the subsurface conduits through which it flows, and greatly increases the likelihood of large amounts of highly contaminated subsurface water reaching the surface and contaminating it. In my expert opinion, artesian flow demonstrates a lack of containment at the site and poses a significant risk of unexpected, serious contamination of the Cheyenne River and its tributaries.

**Plugged holes**
Typically, boreholes are plugged with concrete. Plugs made of wood rot and disappear. Plugs made of ferrous metals, including steel, rust and disappear. It is my expert opinion that, for purposes of determining aquifer isolation, boreholes plugged in such a way should be considered open, uncased boreholes.

**Faults and sinkholes**
**(Exhibits DS178 back side, DS392, IHK2, IHM32, IHM62, TRR17, TRT16, FBM95)**
During hearings before the ASLB in August of 2014, Powertech repeatedly asserted that faults and sinkholes were not present in the license area, and that the license was somehow unique in that regard. In my previous testimony, I offered the expert opinion that faults were almost certainly present, and the license area was most likely crossed by numerous faults. The observations I document herein demonstrate that my previous expert testimony was correct, and there are numerous faults present in the licensed area. Likewise, the drillers' notes document a sinkhole along a drilled transect associated with two closely spaced faults also intersecting the drilled transect. Sinkholes typically form along faults, as the fault allows the initial penetration of acidic surface waters, which then dissolve a conduit through the rock which eventually forma a cave that subsequently collapses to for the sinkhole.

**Suppression and redaction of data**
**(Exhibit TRJ111)**
Notations in the drillers' notes to withhold data imply that there was an attempt to deceive somebody about the character of particular boreholes. The possible motivation for withholding the data was not clear from our limited review in these instances. More troubling is the deliberate masking (redaction) of borehole log data. This information may not be recoverable without additional drilling adjacent to the original borehole, and is clear evidence that information was withheld for some reason. As in the previously mentioned withholding of data, what this is and why it was withheld cannot be determined. A competent and complete scientific review upon which a determination could be based that containment of mining solution can be achieved at the Dewey-Burdock property would account for this missing data.

**Water in boreholes**
The presence of water at various levels in the drill holes suggests that there are multiple aquifers present at the site, and in the case of uncased holes, open communication and unrestricted flow between water-bearing strata at the site.

**Poor, muddy, and destroyed samples**
Problems with samples can bias rock descriptions and create circumstances in which the confining units would be misidentified, leading to miscorrelations of strata and confining layers considered present when in fact they are not. In order to determine if miscorrelation or false identifications have occurred would require detailed redescription of the available data. In my expert opinion, conclusions based on such samples, such as the presence or absence of a confining layer, should remain tentative at best.

**Moved or missing data**
The amount of moved or missing data and its significance is difficult to ascertain from our brief review. It may have been extracted from the set it is part of and relocated to another box, withheld, or destroyed. Only a thorough review and inventory can determine the disposition of the missing data. A review of this data is necessary to form concrete conclusions as to the confining properties of the geological strata.

5. In conclusion, the numerous records of open holes, artesian water, faults, and sinkholes. My prior testimony and opinions regarding Contentions 2 and 3 are supported by the observations recounted here.

6. It is my further expert opinion that NRC-directed "spot check" of 34 borehole logs from somewhere between 1750 and 6000 available borehole logs does not provide a scientifically recognized analysis that can support any hydrogeological conclusion about the project area. In my professional experience, there are numerous methodologies for analyzing the raw data contained in borehole logs. There are also numerous methodologies for presenting the results of the analysis of the raw data. Modern methods typically result in GIS/three-dimensional visualization and modeling of systems or similar computer modelling based on the raw data

in borehole logs. A copy of the website is attached to confirm the widespread and accepted use of these methodologies within the profession.

7. A "spot check" of borehole logs is not proper where analysis has not been carried out and recorded by GIS/three-dimensional visualization and modeling or similar technique. The NRC Staff testimony indicates that Powertech has not conducted the necessary mapping of available data. In such a circumstance, NRC Staff's conclusions are not reliable where NRC Staff accepts assertions of scientific fact made by Powertech that are not supported by accepted methodologies used to review data in borehole logs.

8. The NRC Staff testimony makes no mention of the information contained in the drillers' notes. Drillers' notes are an important source of interpretive information, often revealing information not disclosed by sliding logs. For example, drillers' notes can reveal the location of caves, artesian water, and the intermittent absence of confining layers. Although my review is not complete, the drillers' notes I have reviewed do contain this type of information.

9. The NRC "spot check" of 34 data points does not provide a statistically reliable testimony or basis for any conclusions regarding confinement or hydrology. I teach various math and statistics courses at Oglala Lakota College. Multivariate statistics is one of the formal research tools required for my PhD in Geology from the University of Nebraska-Lincoln. I am charged with review of research students at OLC who frequently apply statistical methods in their capstone research sequence required for their BS in Natural Science. NRC Staff's "random" analysis lacks the basic safeguards applicable to those who would rely on statistical methods.

10. The minimum number of data points for a statistically valid and meaningful sample is generally 10%. In the Powertech instance the minimum acceptable sample size would be a randomly selected sample of at least 175 borehole logs. Based on the recent disclosure of over 4,000 previously withheld borehole logs, the appropriate sample would be 10% of the entire set, or about 575+ borehole logs checked. NRC Staff presents no basis for its so-called "random" selection. Without such information, professionals in my field cannot accept such assertions where it is possible that the limited data set resulted in poor methodology that is the hallmark of modern junk science. Having examined only 37 data points out of thousands available, NRC would have failed my Math 123 Introduction to Statistics class. None of my student researchers would be allowed to publish or present their research findings had they made such a fundamental error.

11. In my experience and training, NRC Staff's methodology is fundamentally flawed and the testimony based on the NRC Staff's review cannot be relied upon for any legitimate scientific purpose.

12. Although I relied on student assistants as appropriate, the testimony and opinion provided herein are based on my direct professional review and personal knowledge. Any errors or misinterpretations of data herein are exclusively my own.

*I declare under penalty of perjury that the foregoing is true and correct of my own knowledge. Executed in accord with 10 CFR 2.304(d).*

Executed in Chadron, Nebraska on November 21, 2014

Hannan E. LaGarry, Ph.D.

***Response**: For any given groundwater constituent, licensees and applicants are subject to the three groundwater quality standards listed in 10 CFR Part 40, Appendix A, Criterion 5B(5) – background, MCL, or ACL. Specifically, under Criterion 5B(5), the concentration of a hazardous constituent must not exceed (a) the NRC-approved background concentration of that constituent in groundwater; (b) the respective MCL value in the table in paragraph 5C if the constituent is listed in the table and if the background level of the constituent is below the value listed or; (c) an ACL established by the NRC. Under Criterion 5B(6),requests for ACLs would only be considered after a applicant has demonstrated that restoring the constituent at issue to background or MCL values is not practically achievable at a specific site. Only ACLs that present no significant hazard may be proposed by applicants for NRC consideration. The NRC may establish a site specific ACL for a hazardous constituent if it finds that the proposed limit is as low as reasonably achievable, after considering practicable corrective actions, and that the constituent would not pose a substantial present or potential hazard to human health or the environment as long as the ACL is not exceeded. A discussion of the additional Criterion 5B(6) requirements for ACLs is presented in Appendix C of the final SEIS.*

**Comments: MR010-005; MR011-005; MR017-021; MR017-023; MR012-042; MR012-043**
A commenter noted that NRC has not been able to accomplish restoration of groundwater to baseline values for all groundwater constituents in any ISL wellfield to date. Another commenter stated that NRC had mischaracterized the ISR mining's groundwater restoration efficacy history and unreasonably minimized the impacts from groundwater restoration. A commenter stated that restoration has only been accomplished by lowering the standards. Another commenter similarly stated that restoration to either background levels or MCL standards has been aspirational rather than a reality, and that regulators—whether NRC or Agreement States—have allowed ACLs to be established for some constituents. The commenter asserted that restoration standards have been a moving target for all ISR mining sites and that NRC has made it nearly impossible for a reader to analyze environmental impacts because of the lack of a detailed and comprehensive history of ISR restoration operations.

***Response**: The commenters are correct that, to date, restoration to backgroundwater quality for all constituents has proven to be not practically achievable at licensed NRC ISR sites (NRC, 2005; NRC, 2004; NRC, 2003). In the past, NRC has applied "class of use," a state designation under the SDWA, as a secondary restoration goal to approve these restorations. The "class of use" standard for restored groundwater quality was based on restoration standards provided in NUREG–1569. The "class of use" standard was neither treated nor approved as an ACL. The NRC has since determined that the primary and secondary restoration standards in NUREG–1569 are inconsistent with the restoration standards in 10 CFR Part 40, Appendix A, Criterion 5B(5). The NRC notified licensees and applicants in Regulatory Information Summary, RIS 09-05, dated April 29, 2009, that the restoration standards listed in NUREG–1569, Section 6.1.3(4) are not consistent with those listed in 10 CFR Part 40, Appendix A, applicant must commit to achieve the restoration standards in Criterion 5B(5).*

*For all licensees, NRC would require an ACL for any constituents that do not meet the primary baseline standards. NRC would perform an SER and environmental review when a licensee applies for a license amendment to establish ACLs for a particular constitutent after it demonstrates it is not practically achievable to restore the wellfield to either background or MCL levels.*

# Issues at Operating Uranium Mines and Mills - USA

(last updated 23 Dec 2020)

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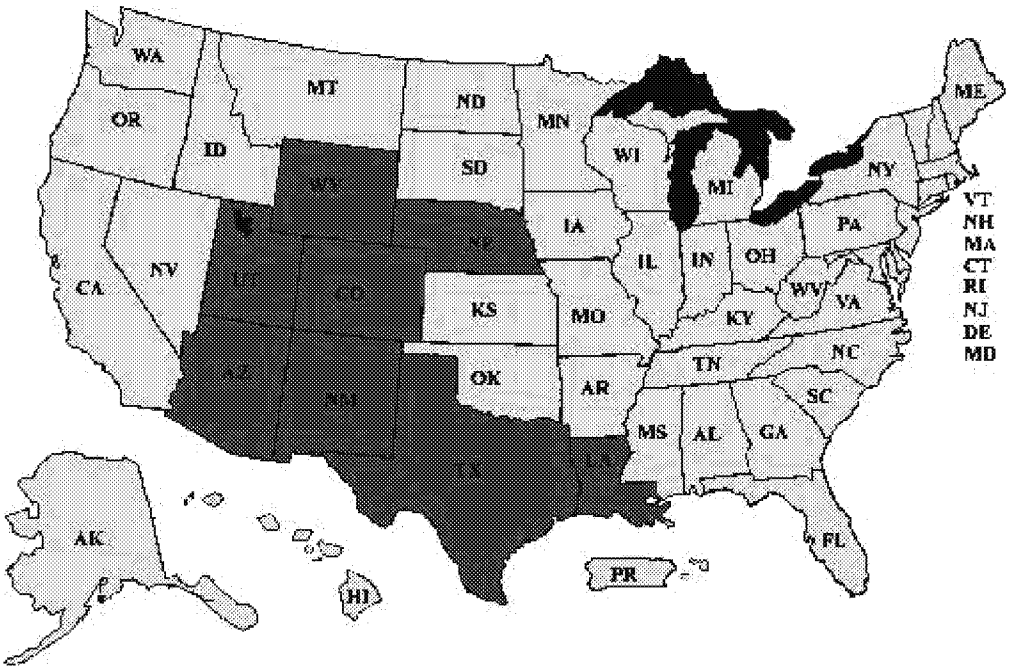



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> See also Issues for: New Mining Projects · Decommissioning Projects · Legislation & Regulations
> See also Data for: Deposits, Proposed and Active Mines · Old Mines and Decommissioning

# General

> See also: National Reports for Joint Convention on the Safety of Spent Fuel Management and on the Safety of Radioactive Waste Management (IAEA)

## U.S. domestic uranium production data for 2nd quarter 2020 for the first time withheld - because it is *too low to meter*?

> Download: U.S.DOE EIA: Domestic Uranium Production Report, Second-Quarter 2020 Aug. 2020 (318kB PDF)

And, the same happened with the data for the 3rd quarter 2020:
> Download: U.S.DOE EIA: Domestic Uranium Production Report, Third-Quarter 2020 Nov. 2020 (328kB PDF)

## President's budget proposes US$ 150 million for creation of uranium reserve in order to support struggling uranium mining companies

President Donald Trump's 2021 budget proposed $150 million for the creation of a U.S. uranium reserve as the administration seeks to help struggling producers of the fuel for nuclear power reactors. The money, if approved by Congress, would begin the process of purchasing uranium, Energy Secretary Dan Brouillette told reporters in a teleconference on the Energy Department's budget. (Reuters Feb. 10, 2020)
> Download: The Budget for Fiscal Year 2021 (p.385-430): Department of Energy (537kB PDF - White House)

The Consolidated Appropriations Act, 2021 approved by both chambers of Congress on Dec. 21, 2020, includes appropriations of US$ 75 million for a uranium reserve for nuclear weapons activities - that is half of the amount shown in the president's budget proposal. The bill now goes to the White House for the president's signature to become law.
> Download: Text of Consolidated Appropriations Act, 2021, Dec. 21, 2020 (8.6MB PDF)
*[Assuming the total expenditures of US$ 66 per lb $U_3O_8$ produced in the U.S. in 2018 (i.e. US$ 108.8 million for 1.647 million lb $U_3O_8$ produced, see: 2019 Domestic Uranium Production Report, DOE EIA, May 2020), the appropriated amount corresponds to 1.136 million lb $U_3O_8$, or 437 t U, corresponding to approx. 40% of the annual production capacity of the White Mesa Mill alone.]*

## U.S. uranium production reaches historic low

"U.S. production of uranium concentrate ($U_3O_8$) in the **first quarter of 2019** was 58,481 pounds [**22.5 t U**], down 83% from the fourth quarter of 2018 and down 74% from the first quarter of 2018." (emphasis added)
> Download: Domestic Uranium Production Report - Quarterly, Data for 1st Quarter 2019, U.S. DOE EIA, May 1, 2019 (PDF)

"U.S. uranium production in **2018** was the lowest in nearly 70 years:
The United States produced 1.47 million pounds of uranium concentrate [**565 t U**] in 2018, down for the fourth consecutive year and the lowest total since 1950, based on preliminary production data. Uranium production in the United States has declined since its peak of 43.7 million pounds [16,808 t U] in 1980 and has remained below 5 million pounds [1,923 t U] annually for more than 20 years." (emphasis added)
> View: DOE EIA release May 6, 2019

U.S. uranium production decreased further to 44,569 lb $U_3O_8$ [**17.1 t U**] in the second quarter, and to 32,211 lb $U_3O_8$ [**12.4 t U**] in the third quarter, then recovered slightly to 38,614 lb $U_3O_8$ [**14.9 t U**] in the fourth quarter of 2019.
Preliminary U.S. uranium concentrate production **totaled** 173,875 pounds of $U_3O_8$ [**66.9 t U**] **in 2019**. This amount is 88% lower than the 1,447,875 pounds of $U_3O_8$ [556.9 t U] produced in 2018 and is the **lowest annual production on record**.

> Download: Domestic Uranium Production Report - Quarterly, Fourth-quarter 2019, U.S. DOE EIA, Feb. 13, 2020 (PDF)

"U.S. production of uranium concentrate ($U_3O_8$) in the **first quarter of 2020** was 8,098 pounds [**3.1 t U**], down 79% from the fourth quarter of 2019 and down 86% from the first quarter of 2019." (emphasis added)
> Download: Domestic Uranium Production Report First-Quarter 2020, U.S. DOE EIA, May 2020 (325kB PDF)

### Natural Resources Defense Council issues study on environmental impacts of uranium in situ leach mining and related regulatory failures in the U.S.

> See here

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# Arizona

- Arizona 1 mine
- Pinenut mine

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> See also Issues for: New Mining Projects · Decommissioning Projects · Legislation & Regulations
> See also Data for: Deposits, Proposed and Active Mines · Old Mines and Decommissioning

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## Arizona 1 mine, Mohave County

> View deposit info

**Comment invited on Air Permit renewal for Arizona 1 uranium mine**: ADEQ proposes to issue Air Quality Control Renewal Permit No. 75725 to Energy Fuels Resources (USA) Inc. for the continued operation of the Arizona 1 underground uranium mine located in Mohave County, Ariz.
Submit comments by **June 6, 2019**.
> View: Public Notice, May 8, 2019, and related documents

**ADEQ issues Air Permit for Arizona 1 Mine**: On Oct. 13, 2016, ADEQ issued Air Quality Permit No. 63895 to Energy Fuels Resources (USA, Inc. for the Arizona 1 uranium mine.
> Download permit and related documents (ADEQ)

**ADEQ invites comment on revised draft Air Permit for Arizona 1 uranium mine**:
Submit comments by August 30, 2016.
> Download draft permits and related documents (ADEQ)

**ADEQ issues revised draft Air Permit for Arizona 1 uranium mine**:
The Arizona Department of Environmental Quality is still working on developing new, more environmentally protective air quality permits for three uranium mines in the Grand Canyon region.
The action comes after news broke late last year that elevated uranium levels had been measured in soils near Pinenut uranium mine, located 10 miles north of the Grand Canyon and owned by Energy Fuels Resources. In response, ADEQ decided to suspend its work on air quality permit renewals for all four uranium mines operated by Energy Fuels Resources.
ADEQ is now working to complete drafts of the new air quality permits for public review and comment. The revisions include faster execution of enhanced dust control measures if elevated uranium or radium levels are

detected and extensive changes to the required soil sampling and radiation survey plan to mitigate potential impacts from high wind.
The state department will host public hearings on the new draft permits in Flagstaff, Tuba City and Fredonia, which it hopes to begin in early summer. (Arizona Daily Sun Apr. 15, 2016)
> Download: Energy Fuels Resources (USA) Inc. Draft Permit No. 59874, March 23, 2016 (398k PDF)

**Northern Arizona 'Zombie Mine' Petition calls for reform of uranium mining regulations on public lands**:
> View here

**ADEQ invites comment on proposed Air Permit renewal for Arizona 1 uranium mine**:
Submit comments by August 21, 2014.
> Download: Public Notice ·Draft Permit ·Technical Support Document (PDF - ADEQ)

**Mining at Arizona 1 mine to cease due to depletion of resources**: Subject to the results of additional underground drilling, mining at the Arizona 1 mine is expected to cease in early FY-2014 due to the depletion of its known resources. (Energy Fuels Inc. Nov. 14, 2013)

**Court dismisses appeal against reopening of Arizona 1 uranium mine**: A federal appeals court has ruled against conservationists and tribes in their challenge of a uranium mine north of the Grand Canyon. The group had sued the U.S. Bureau of Land Management, alleging the agency relied on an outdated and inadequate environmental analysis in allowing the Arizona 1 Mine to resume operation. The 9th U.S. Circuit Court of Appeals ruled Monday (Feb. 4) that the BLM hasn't made any decisions that would trigger a new analysis and that the 1988 operation plan allows for temporary closures. (AP Feb. 3, 2013)

**Appeal challenges Arizona 1 uranium mine threatening Grand Canyon**: On Nov. 28, 2011, Conservation groups and American Indian tribes filed an appeal in the 9th Circuit Court challenging a lower court ruling that allowed a uranium mine near Grand Canyon National Park to re-open without updating decades-old environmental reviews. The Arizona 1 uranium mine is located near Kanab Creek immediately north of Grand Canyon National Park.
In 2010, conservation groups and tribes sued the Bureau of Land Management for failing to modernize 23-year-old mining plans and environmental reviews prior to allowing Denison Mines to resume uranium mining after the mine was shuttered in 1992. A federal judge in Phoenix this fall sided with the Bureau and the uranium industry saying no new plans or reviews were needed, prompting today's appeal.
The Arizona 1 is one of four existing uranium mines located in Grand Canyon's 1-million-acre watershed where the Obama administration has proposed a 20-year ban on new mining claims and uranium development on existing claims lacking valid existing rights. A final environmental impact statement was issued for the 1-million acre ban in October; a decision finalizing those protections could come as early as today. (Center for Biological Diversity Nov. 28, 2011)

**Reopened Arizona 1 uranium mine largely left to regulate itself**: Denison Mines began hauling ore out of the first and only uranium mine to reopen so far, 35 miles southwest of Fredonia, in December 2009. State environmental inspectors didn't arrive for a first inspection at the mine until it had already been open for about nine months. The Arizona Department of Environmental Quality (ADEQ) had unfilled requests for documents and inspections by engineers that it sought before the mine opened. Mine operators set to work without answering some of these requests.
The first inspection at the mine came in September, and ADEQ inspected at the ground level only, not traveling into the mine that reaches more than 1,252 feet below. Nevertheless, the inspection yielded what ADEQ deemed four "major violations."

- There were no pumps in the mine to eliminate any water there.
- A test measuring the permeability of the rock in the mine hadn't been done.
- A pipe was sticking through a lined pond that is intended to prevent groundwater contamination from ore or water pumped out of the mine.
- Plans for the mine didn't match what inspectors found when they visited, they wrote.

"ADEQ is neither equipped nor inclined to regulate these mines in a way that even remotely ensures against irretrievable harm to the environment," said Taylor McKinnon, public lands campaigns director at the Center for Biological Diversity.
In the same month ADEQ inspectors arrived, federal inspectors concerned with worker safety cited Denison and contractors with air quality violations, failure to properly label power switches, equipment safety violations, lack of firefighting equipment inspections, and with another violation that is still being contested. One contractor was injured at the mine site in 2009. In all, the Mine Safety and Health Administration found 38 possible mine safety violations at the Arizona 1 Mine in 2010, many of which Denison is contesting. (Arizona Daily Sun Jan. 16, 2011)

**Arizona 1 uranium mine operating illegally, EPA says**: A uranium mine north of the Grand Canyon is operating in violation of the law, and its owner could face thousands of dollars in fines as a result, the U.S. Environmental Protection Agency said. The agency issued a notice of violation this week to Denison Mines Corp. for its Arizona 1 Mine, which is about 20 miles from the Grand Canyon's northern border. The EPA said Denison failed to notify the agency as to when it would resume mining and that it did not secure the necessary federal approval before ventilating the mine or testing emissions.
Denison President Ron Hochstein said Tuesday (May 4) that he was surprised by the notice and believed the company was operating within the law. He said he was working with regulators to address those issues. (AP May 5, 2010)

> View older issues

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# Pinenut mine, Mohave County

> View deposit info

**Energy Fuels closes Pinenut mine for good, after increased uranium level found in soil nearby**: [The Arizona Department of Environmental Quality] reported that Energy Fuels Resources has ceased operations at Pinenut mine and transported all uranium ore to milling operations in Utah. The company is therefore no longer seeking to renew its air quality permit for that location. Permanent closure of the Pinenut mine is a long-term process and will require working with multiple agencies. (Arizona Daily Sun Apr. 15, 2016)

**Renewal process for air-pollution permit of three Grand Canyon mines suspended, as fourfold increased uranium level found in soil near Pinenut mine**: State environmental officials have suspended the air-pollution permit renewal process for three uranium mines near the Grand Canyon. Recent tests showed uranium content in the soil near one of the mines is four times higher than previously measured. Arizona Public Radio's Ryan Heinsius reports. The tests were conducted in July and October outside the perimeter of the Pinenut Mine facility. The analysis showed uranium in the soil at one out of the five testing sites had spiked since 2011 when the mine reopened.
The Arizona Department of Environmental Quality says the elevated level of the radioactive metal doesn't present an immediate public health risk. But the agency has pushed the mines' owner, Energy Fuels Resources, to boost measures to control radioactive dust. ADEQ has also mandated that the company expand soil testing in the area.
ADEQ is considering the renewal of air-pollution permits for all three mines, but will suspend that process as it evaluates the company's new dust-control plan at the Pinenut Mine. The agency will eventually open a new public comment period and hold meetings for the permit renewals. (KNAU Arizona Public Radio Dec. 30, 2015)

**ADEQ proposes to issue Air Quality Control Renewal Permit for Pinenut mine**:
Submit comments by January 4, 2015.
> Download ADEQ Public Notice, Dec. 2, 2015 (PDF)
> Download Draft Permit (PDF)
> Download Draft Technical Support Document (PDF)

**Conservation groups urge BLM to suspend Pinenut uranium mine in response to groundwater contamination**: Conservation groups have sent a letter urging federal regulators to suspend operations at a uranium mine near the Grand Canyon, where millions of gallons of uranium-laced groundwater threaten people and wildlife. Records from the U.S. Geological Survey show that the contaminated groundwater -- 80 times the limit set to protect public health and the environment -- have inundated the Pinenut uranium mine immediately north of Grand Canyon National Park. It is unknown whether deep aquifers and nearby springs in the national park are also being polluted.
> View Grand Canyon Trust release Aug. 4, 2014

**Pinenut uranium mine to continue operation into 2015**: On Apr. 23, 2014, Energy Fuels announced that it has revised its previous guidance and currently expects to continue mining at its 100% owned Pinenut Mine through 2014 and into the 1st quarter of 2015.

**Pinenut mine to be placed on care and maintenance due to market conditions**: Mining at the Pinenut mine is expected to continue into the middle of FY-2014 (July 2014), at which point the mine is expected to be placed on care and maintenance. Re-starting mining activities at Pinenut would be evaluated in the context of business and market conditions, including the $U_3O_8$ price environment. (Energy Fuels Inc. Nov. 14, 2013)

Energy Fuels Incorporated proposes to open the Pinenut Mine in Mohave County late this month or in early June, according to a statement from the Bureau of Land Management. (Arizona Daily Sun May 9, 2013)

The state Department of Environmental Quality approved an air quality permit for Denison's Pinenut mine this week. (Arizona Republic Mar. 11, 2011)

On Nov. 12, 2010, the Arizona Department of Environmental Quality started the public comment period for the proposed air quality permit for the Pinenut mine. Comment period ends January 14, 2011.
> View ADEQ public notice

On Sept. 1, 2009, the Arizona Department of Environmental Quality issued a Discharge Authorization for the 3.04 General Aquifer Protection Permit (APP) 100300 for the Pinenut Mine to Denison Mines (USA) Corp.
> View details (AZDEQ)

On June 19, 2009, the Arizona Department of Environmental Quality (ADEQ) issued a public notice opening the public comment period on the Water Quality General Aquifer Protection Permit for Denison Mines Corp.'s Pinenut mine. Comment period ends July 22, 2009.
> Download ADEQ notice and documents (select "Public Notices, Meetings and Hearings")

Denison Mines has been denied a state permit for the reopening of the Pinenut mine: The Arizona Department of Environmental Quality said Denison Mines proposed using outdated, 20-year-old liners and impoundment ponds to capture uranium mine-related runoff. In addition, ADEQ said Denison wasn't specific enough in describing pollution-control measures at the proposed mines.
(Arizona Daily Sun May 14, 2008)

# Colorado

> View extra page

# Louisiana

- IMC Global

> See also Issues for: New Mining Projects · Decommissioning Projects · Legislation & Regulations
> See also Data for: Deposits, Proposed and Active Mines · Old Mines and Decommissioning

## By-product uranium production from phosphate in Louisiana to cease

By-product uranium production is to 'permanently' cease at IMC Global's Uncle Sam and Faustina facilities in Louisiana. Low uranium prices are cited as the major reason for the decision by senior management. The facilities' combined production of 950 000 lbs U3O8 (365.4 tU) last year accounted for approximately 16% of uranium produced in the US; 1998 production is expected to be similar. Meanwhile IMC's New Wales and Plant City recovery facilities in Florida have remained on 'stand-by' since 1992. (UI News Briefing 98.49, Dec. 9, 1998)

# Nebraska

- Crow Butte ISL

> See also Issues for: New Mining Projects · Decommissioning Projects · Legislation & Regulations
> See also Data for: Deposits, Proposed and Active Mines · Old Mines and Decommissioning

## Crow Butte in-situ leach uranium mine, Dawes County, Nebraska

General · Three Crow Expansion · Marsland Expansion · North Trend Expansion · License violations and reportable events

> View mine details
> View NRC page

Uranium mining at Crow Butte is being opposed by Save Crow Butte

### General

> For more recent issues, see decommissioning issues

**Cameco requests permit amendment to place all mine units of mothballed Crow Butte in situ leach uranium mine in restoration phase**

"Due to unfavorable market conditions and depleted uranium concentrations in the permitted portion of the Chadron aquifer, CBO has suspended production operations and would like to continue restoration activities in as efficient a manner as possible. [...]"
> Download Cameco Resources letter to Nebraska Department of Environmental Quality (NDEQ), June 5, 2018

**NRC approves further 10-year extension of groundwater restoration schedule for Crow Butte in situ leach uranium mine**

On Apr. 3, 2018, Cameco submitted to NRC a license amendment request for an alternate groundwater restoration schedule for Mine Units 2-6. The request extends completion of groundwater restoration for these mine units to 2022 - 2025. This constitutes a delay of up to 10 years compared to the originally approved



ED_005364K_00005243-00276

groundwater restoration schedule (ML092220668).
> Download: Request for Alternate Decommissioning (Groundwater Restoration) Schedule, Apr. 3, 2018

On Dec. 14, 2018, NRC approved the requested 10-year extension of the groundwater restoration schedule.
> Download: NRC letter to Cameco, Dec. 14, 2018 (PDF)
> Download: Technical Evaluation Report, Dec. 14, 2018 (PDF)
> Download: Memorandum - Explanation for why actions qualified for selected categorical exclusion, Dec. 14, 2018 (PDF)
> Download: License SUA-1534, Amendment No. 4, Dec. 14, 2018 (PDF)

**Cameco plans to discontinue U.S. uranium mining operations**

On Feb. 9, 2018, Cameco made the following announcement in its quarterly report for the fourth quarter of 2017: "As a result of our decision to defer all wellfield development at the US operations, production will cease in 2018, which is expected to result in production of less than 100,000 pounds." (p.68)
> Download: Cameco 2017 Q4 MD&A, Financial Statements & Notes, Feb. 9, 2018 (1.7MB PDF)
[This concerns the Crow Butte, Smith Ranch-Highland, and North Butte operations.]

On Apr. 2, 2018, Cameco notified NRC of the forthcoming cessation of production at the Crow Butte mine: "[...] the remaining production and injection from producing mine units will be shut off in the next 60 days. [...] Within the next 21 months, Cameco resources will submit Alternative Decommissioning Schedules for Crow Butte Resources. [...] All production equipment will remain on standby to provide the option to restart full operations in the future should market conditions warrant. The above mentioned Alternate Decommissioning Schedule will include a request to defer equipment decommissioning [...]."
> Download: Cameco letter to NRC, Apr. 2, 2018 (PDF)

**Sharp rise of uranium value in monitoring well necessitates changes in groundwater restoration regime at Mine Unit 3 of Crow Butte in situ leach uranium mine**

"While ensuring stability trends in MU3 [Mine Unit 3], **well P246** (WH7 MU3) **exceeded the restoration value for uranium. The value for uranium went from .09 [mg/L] (9/26/14) to 4.04 [mg/L] (3/29/17)**. Based on a discussion with Nebraska Department of Environmental Quality (NDEQ), **MU3 was returned to IX/RO treatment** on September 15, 2017 in order to spot treat the well. Spot treatment is currently ongoing in contrast to the requested alternate decommissioning schedule which lists MU3 as in stability monitoring. **It is likely that mining solution from MU7 migrated into the area and impacted the water quality in P246**. In addition to resuming restoration activities around the well, CBO has implemented a monitoring program around MU2 and MU3 in order to prevent a similar event." [emphasis added]
> Download Annual Report of Changes, Tests, or Experiments, License No. SUA-1534, Docket No. 40-8943, Cameco Resources, Crow Butte Operation, Jan. 23, 2018 (34.1MB PDF)

**Cameco's Crow Butte in situ leach uranium mine obtains NRC exemption to simplify determination of occupational doses from inhalation of radionuclides**

The U.S. Nuclear Regulatory Commission (NRC) is issuing an exemption to Crow Butte Resources, Inc. (CBR) for the purpose of complying with occupational dose limits in response to a request from CBR dated September 21, 2015. Issuance of this exemption will allow CBR to disregard certain radionuclides that contribute to the total activity of a mixture when determining internal dose to assess compliance with occupational dose equivalent limits at its in situ uranium recovery (ISR) facility in Crawford, Nebraska.
> Federal Register Volume 81, Number 224 (Monday, November 21, 2016) p. 83289-83291 (download full text)
> Download: NRC License Amendment No. 1 and Safety Evaluation Report, Dec. 5, 2016
> Access: Docket ID NRC-2008-0208

**Nebraska DEQ invites comment on permit renewal for wastewater discharge of Cameco's Crow Butte in situ leach uranium mine**

The Nebraska Department of Environmental Quality (NDEQ) proposes to reissue with change the National Pollutant Discharge Elimination System (NPDES) permit for the Crow Butte Resources, Inc. d/b/a CAMECO RESOURCES Crow Butte Mine, 86 Crow Butte Rd., Crawford, NE (NPDES# NE0130613; SIC 1094). The mining facility produces uranium yellowcake by in-situ leach mining. The permit would authorize the LAND APPLICATION OF TREATED PROCESS WASTEWATER AT SITES WITHIN THE BOUNDARIES OF CROW BUTTE RESOURCES PROPERTY, located in the White River Basin, as specified by NDEQ. The permit would be issued for a period of up to five years and would restrict pollutant discharges to comply with the requirements of Department regulations.
Submit comments by September 23, 2016.
> View NDEQ Public Notice

**NRC Board rules that tribe's unwillingness to cooperate on identification of Traditional Cultural Properties does not preclude license renewal for Crow Butte in situ leach uranium mine**

The Nuclear Regulatory Commission's Atomic Safety and Licensing Board has released a Partial Initial Decision on challenges to renewal of the operating license of the Crow Butte uranium mine southeast of Crawford - and it's pretty much a split decision.
The Licensing Board agrees with opponents, including the Oglala Sioux Tribe, that NRC staff failed to meet National Historic Protection Act and National Environmental Polict Act requirements to work with the tribe to identify Traditional Cultural Properties in the mining lease area, but disagrees that the failures should result in denial of the license renewal.
The board says the unwillingness of the tribe and other intervenors to continue to participate in the consultation process with NRC staff weighs against their demand and that not granting renewal or extension would be an "undue hardship" on mine owner Cameco Resources and "unnecessary to cure the potential harms at issue." (Chadrad May 27, 2016)
> Download Partial Initial Decision LBP-16-07, May 26, 2016 (427k PDF)

On Oct. 8, 2020, the NRC denied Crow Butte Resources Inc.'s request to review LBP-16-07 (and LBP-15-11).
> Download: CLI-20-08 Memorandum and Order, Oct. 8, 2020 (PDF)

**Cameco defers wellfield development at Crow Butte situ leach uranium mine due to depressed uranium market**

On Apr. 21, 2016, Cameco announced that production is being curtailed at Cameco Resources' US operations by deferring wellfield development. The changes are expected to result in a reduction of about 85 positions, including employees and long-term contractors.
The US operations will continue to employ about 170 people to operate existing facilities and restore depleted wellfields, but new wellfield development will be stopped. The US operations will continue ongoing licensing efforts to maintain the option to resume development when market conditions significantly improve.

**Cameco now also involved in tax dispute with the United States**

> View here

**Truck carrying hydrochloric acid to Crow Butte uranium in situ leach mine overturns**

An Industrial Chemical truck from Denver, Colo., turned over approximately two miles from the Crow Butte Uranium Mine as it was making a delivery of hydrochloric acid to the facility. Dawes County Deputy Sheriff Scott Swickert said the accident occurred around 6 a.m. and was caused by the wintry weather conditions. "The

trailer got into the soft shoulder of the road and it sucked the trailer into the ditch," he said. A small valve on the trailer broke off in the wreck, and Swickert described the hydrochloric acid as dribbling out. Neither Swickert or Crow Butte Mine knows as yet how much of the acid was spilled.
Ken Vaughan, communications director with Cameco, Crow Butte's parent company, said mine staff helped build a berm around the site of the accident to contain the spill. The Dawes County Sheriff and the Nebraska State Patrol are controlling access to the scene. (Rapid City Journal Feb. 4, 2015)

**Nebraska DEQ invites comment on proposed permit renewal for Crow Butte deep disposal well**

The Nebraska Department of Environmental Quality is proposing to renew permit (NE0211670) and re-issue the permit (as NE0211670) to Crow Butte Resources, Inc. (CBR). CBR operates two Class 1 non-hazardous waste injection well designed to accept waste fluids generated at its in-situ uranium mining operation. The injection well is located in the Northwest Quarter of Section 19, Township 31 North, Range 51 West, Dawes County, Nebraska.
Submit comments prior to May 15, 2014.
(Lincoln Journal Star Apr. 3, 2014)
> Download Nebraska DEQ letter to NRC, Mar. 31, 2014 (ADAMS Acc. No. ML14100A234)

**Cameco requests further exemption from groundwater restoration schedule at Mine Unit 3 of Crow Butte in situ leach uranium mine**

By letter dated April 30, 2013, Cameco requested a further extension of the completion of groundwater restoration at Mine Unit 3 until July 1, 2016. On Aug. 20, 2009, NRC had already approved an extension to July 1, 2013.

**Crow Butte uranium mine site evacuated due to threatening wildfire**

On Aug. 31 and Sep. 1, 2012, the Crow Butte site was evacuated due to threatening wildfire to the east of the mine. During the evacuation, a crew of five employees remained on-site for security purposes. During the evacuation, all source material on the site was kept under 24 hour surveillance. The wildfires did not enter the licensed area and as a result there were no releases to the environment. (Cameco letter to NRC, Sep. 11, 2012)

**Cameco requests exemption from groundwater restoration schedules at Crow Butte in situ leach uranium mine**

By letter dated February 8, 2012, Cameco requested from NRC an exemption from the requirement to complete groundwater restoration within 24 months, because "the imposition of such precise, prescriptive timeframes to groundwater restoration in aquifers that are part of natural systems is not practicable".
By letter dated June 22, 2012, NRC refused to review the exemption request, since it is incomplete. NRC notes in particular the missing of a description of how the exemption would not endanger life, property, or common defense and security, and, how it would be in the public interest. NRC explicitly expresses its dissatisfaction with the progress of groundwater restoration at the Crow Butte site:

- "[...] staff notes that despite several years of effort to restore groundwater at the Crow Butte facility, only one wellfield restoration has been approved by the NRC."

**Cameco study claims solubility type classification of yellow cake from in situ leaching is 100% "fast"**

> View here

**NRC denies Cameco's request for extension of the period of groundwater restoration at Mine Unit 6 of Crow Butte in situ leach mine**

On Dec. 21, 2010, Cameco Resources requested NRC approval for an alternate restoration schedule for Mine Unit #6, extending the period of groundwater restoration to nine years - far beyond the regulatory requirement of 24 months.
On May 21, 2012, NRC denied Crow Butte Resources, Inc.'s request for an alternate restoration schedule for Mine Unit #6.

**NRC approves extension of the period of groundwater restoration at Crow Butte in situ leach mine**

On Aug. 20, 2009, NRC approved Crow Butte Resources, Inc.'s request to extend the period of groundwater restoration beyond the regulatory requirement of 24 months for each of the mine units currently in restoration (i.e., Mine Units 2 to 5).

**NRC staff finds no problem with groundwater impacts of existing in-situ leach uranium mines**

> View here

**$50,000 penalty imposed on Crow Butte Resources for violations at ISL uranium mine**

On May 23, 2008, the District Court of Lancaster County, Nebraska, imposed a $50,000 penalty on Cameco's subsidiary Crow Butte Resources for various violations at its Crow Butte in-situ leach uranium mine. According to the Nebraska Department of Environmental Quality, beginning on or about July 1, 2003, and continuing daily thereafter until March 31, 2006, Crow Butte Resources (CBR) violated its UIC Permit No. NE0122611

- by releasing well development water upon the surface of the ground during CBR's well development and drilling process,
- by using Chadron Formation well development water as drilling water,
- by constructing injection wells and mineral production wells in a manner that had the potential to allow the movement of fluid containing contaminants into an underground source of drinking water,
- by failing to provide written notification until May 12, 2006, upon becoming aware of the noncompliance on or about March 31, 2006.

> Download Complaint and Consent Decree May 23, 2008 (NE DEQ)

**License renewal of Crow Butte uranium ISL mine**

**NRC Board agrees to intervenors' demand to analyze impacts of possible land application of ISL wastewater at Crow Butte**: The Atomic Safety and Licensing Board dismissed all contentions filed by intervenors except one: "[...] But we find, in part, for Intervenors on Contention 12 (Contention 12B) and conclude that the EA is deficient as to its discussion of Crow Butte's possible land application of ISL wastewater. The NRC Staff must reach its own independent conclusion, based on technical support in conformance with NEPA as to any potential impacts of selenium on wildlife from Crow Butte's possible land application of ISL wastewater."
> Download: Second Partial Initial Decision, LBP-16-13, Atomic Safety and Licensing Board, Dec. 6, 2016 (1.1MB PDF)

On Nov. 29, 2018, the NRC Commissioners denied the intervenors' petition for review of the Second Partial Initial Decision, LBP-16-13.
> Download: Memorandum and Order CLI-18-08, Nov. 29, 2018 (386kB PDF)

**NRC Board to hold supplementary evidentiary hearing on intervenors' contentions against license renewal for Crow Butte uranium ISL mine**: The Atomic Safety and Licensing Board gives notice that it will convene a supplemental evidentiary hearing (on October 23, 2015) to receive testimony regarding Crow Butte Resources' contested application to renew its U.S. Nuclear Regulatory Commission license to operate an in-situ uranium leach recovery facility near Crawford, Nebraska.
> Download NRC release Oct. 16, 2015 (PDF)
> Federal Register Volume 80, Number 194 (Wednesday, October 7, 2015) p. 60720-60722 (download full text)

**NRC Board to hold evidentiary hearing on intervenors' contentions against license renewal for Crow Butte uranium ISL mine**: The Atomic Safety and Licensing Board gives notice that it will convene an evidentiary hearing (beginning on Aug. 24, 2015) to receive testimony and exhibits regarding the contested application of Crow Butte Resources, Inc. before the U.S. Nuclear Regulatory Commission seeking a renewal of its license to operate an in-situ uranium leach recovery (ISL) facility near Crawford, Nebraska. The Board also hereby gives notice that it will accept written limited appearance statements from members of the public regarding the License Renewal Application.
Written limited appearance statements may be submitted by August 28, 2015.
> Download: NRC news release Aug. 6, 2015 (PDF)
> Federal Register Volume 80, Number 137 (Friday, July 17, 2015) p. 42552-42554 (download full text)
> Access related documents: Crow Butte Resources Site (NRC)

**NRC renews license for Crow Butte uranium ISL mine**: On Nov. 6, 2014, the Nuclear Regulatory Commission announced that it has renewed Crow Butte Resources Inc.'s license to operate an in situ uranium recovery facility in Crawford, Neb., for an additional 10 years. The license now has an expiration date of Nov. 5, 2024.
> Download NRC release Nov. 6, 2014 (PDF)
> Federal Register Volume 79, Number 221 (Monday, November 17, 2014) p. 68490-68491 (download full text)

**NRC issues Final Environmental Assessment and finding of no significant impact for license renewal of Crow Butte uranium in situ leach mine**: NRC staff has determined that renewal of NRC license SUA-1534, which would authorize continued operation of the Crow Butte facility in Crawford, Nebraska for a period of up to 10 years will not significantly affect the quality of the human environment.
> Federal Register Volume 79, Number 210 (Thursday, October 30, 2014) p. 64629-64631 (download full text)
> Download Final Environmental Assessment For The License Renewal Of U.S. Nuclear Regulatory Commission License No. SUA–1534, October 2014
> Access Docket ID NRC-2008-0208

**NRC issues Safety Evaluation Report on license renewal of Crow Butte uranium in situ leach mine**: On Dec. 28, 2012, NRC released the Safety Evaluation Report on the license renewal of the Crow Butte uranium

ISL mine:
> Download Safety Evaluation Report License Renewal of the Crow Butte Resources ISR Facility, December 2012
On Aug. 18, 2014, NRC released a revised Safety Evaluation Report on the license renewal of the Crow Butte uranium ISL mine:
> Download Safety Evaluation Report (Revised), License Renewal of the Crow Butte Resources ISR Facility Dawes County, Nebraska Materials License No. SUA-1534, August 2014

**NRC issues draft of license renewal for Crow Butte uranium ISL mine**:
> Download NRC cover letter May 23, 2011
> Download NRC draft source material license

On Aug. 11, 2011, NRC released another draft of the license renewal for the Crow Butte uranium ISL mine:
> Download NRC cover letter August 11, 2011
> Download NRC draft source material license

On Nov. 15, 2012, NRC released another draft of the license renewal for the Crow Butte uranium ISL mine:
> Download NRC cover letter August 11, 2011
> Download NRC draft source material license

**Geologist raises concern over potential groundwater contamination at Crow Butte uranium ISL mine**: Hannan LaGarry, a Chadron State geology instructor, said the Crow Butte mine has ignored recent studies that show faults and fractures in underground layers of rock that could carry contaminants to aquifers used for drinking and livestock. LaGarry said he's not opposed to uranium mining but is concerned that the mine is relying on outdated studies of underground rock. "In recent years, we've found that the assumptions made by previous workers were false and that newer detailed work shows a different story," he said. (Omaha World-Herald Dec. 14, 2008)

> See also: Expert opinion regarding ISL mining in Dawes County, Nebraska, by Hannan E. LaGarry, Ph. D., July 2008

**Opponents to license renewal of Crow Butte uranium-mine granted hearing**: Opponents of a uranium mine at Crawford, Neb., that is seeking to renew its license have been granted a hearing by the Nuclear Regulatory Commission to voice environmental concerns. The commission has ruled in favor of granting a public hearing on several contentions raised by the Oglala Sioux Tribe; a tribal environmental group; seven individuals; and a northwest Nebraska environmental group, the Western Resources Council. The hearings likely would be held next spring, a commission spokesman said. (Omaha World-Herald Nov. 25, 2008)

**NRC announces establishment of Atomic Safety and Licensing Board for license renewal of Crow Butte uranium ISL mine**: This proceeding involves a license amendment application from Crow Butte Resources, Inc. seeking a 10-year renewal of its Source Materials License for the in situ leach uranium recovery facility located in Crawford, Nebraska. In response to a May 27, 2008 Notice of Opportunity for Hearing (73 FR 30426), petitions to intervene and requests for hearing have been submitted by (1) Elizabeth Lorina and Mario Gonzales representing the Oglala Sioux Tribe, (2) Shane Robinson and David Frankel representing multiple individuals and multiple organizations, and (3) Thomas J. Ballanco representing the Oglala Delegation of the Great Sioux Nation Treaty Council.

Federal Register: August 21, 2008 (Volume 73, Number 163) p. 49496-49497 (download full text)

**Residents voice opposition to production increase of Crow Butte uranium ISL mine**: Crow Butte Resources (CBR), a mining company on the South Dakota and Nebraska border, wants to increase its annual uranium production by 50 percent. To do that, they and their opposition went face to face before the Atomic Licensing Board on July 23, 2008. At the public hearing, dozens of homeowners from Pine Ridge voiced their opposition to CBR's plan to build a uranium mine near Crawford. They say the company's operation near Chadron is destroying natural resources. (KOTA July 23, 2008)

**NRC issues Opportunity To Request a Hearing on license renewal request of Crow Butte uranium ISL mine, and Order Imposing Procedures for Access to Sensitive Unclassified Non-Safeguards Information (SUNSI) for Contention Preparation**:
A request for a hearing must be filed by July 28, 2008.

Within ten (10) days after publication of this notice of opportunity for hearing any potential party as defined in 10 CFR 2.4 who believes access to SUNSI is necessary for a response to the notice may request access to such information.

Federal Register: May 27, 2008 (Volume 73, Number 102) p. 30426-30430 (download full text)

**NRC issues Notice of License Amendment Request of Crow Butte uranium ISL mine, and Opportunity To Request a Hearing**:
A request for a hearing must be filed by June 6, 2008.

Federal Register: April 7, 2008 (Volume 73, Number 67) p. 18823-18825 (download full text)

**Cameco applies for license renewal of Crow Butte uranium ISL mine**: By letter dated Nov. 27, 2007, Crow Butte Resources, Inc. applied for the renewal of Source Materials License No. SUA-1534 for the continued operation of the Crow Butte in situ leach uranium mine.
> Download renewal application documents

### Cameco to increase production from Crow Butte and Smith Ranch-Highland by 70%

On Dec. 4, 2007, Cameco announced that it is targeting to increase the combined production at its Crow Butte and Smith Ranch-Highland in-situ leach operations by 70% to 4.6 million pounds U3O8 [1,769 t U] annually by 2011. The planned production increase requires the restart of the idle Highland uranium recovery plant.

### Crow Butte Resources receives permission for increased plant throughput at in-situ leach mine

By letter dated Oct. 17, 2006, Crow Butte Resources requested from NRC a license amendment to increase the plant throughput from 5000 to 9000 gallons per minute (gpm). An additional production of 150,000 to 250,000 pounds of U308 [58 to 96 t U] per year is expected.
NRC issued an Environmental Assessment and Finding of No Significant Impact on Oct. 24, 2007.
> Download Environmental Assessment, Oct. 2007 (ADAMS ML072360287)
> Federal Register: October 31, 2007 (Volume 72, Number 210) p. 61693-61694 (download full text)
NRC issued the requested license amendment on Nov. 30, 2007.

### Crow Butte in situ leach uranium mine threatened by wild fire

On July 31, 2006, Crow Butte Resources notified the U.S. Nuclear Regulatory Commission of the wild fires east of Crow Butte Resources Central Processing Plant. The NRC was informed of the possible evacuation of the Crow Butte site should the fires continue to burn out of control.

### Crow Butte Resources plans to expand In Situ Leach operations

> "Division of Fuel Cycle Safety and Safeguards staff has learned that Crow Butte Resources (CBR) plans to expand its in situ leach (ISL) uranium extraction operations in Nebraska by operating up to four satellite facilities. CBR estimates that it will submit a license amendment application to NRC for the first satellite facility in May 2005, and an application for a second satellite facility is targeted for 2006 - 2007. Depending on economics, applications could be submitted to NRC for

license amendments for two additional satellite facilities in the 2007 - 2010 time frame. Although a memorandum of understanding to defer active groundwater regulation at ISLs may be executed with the State of Nebraska before the first license amendment is submitted in 2005, NRC must prepare environmental assessments for each application." (U.S. NRC SECY-04-0131 WEEKLY INFORMATION REPORT - WEEK ENDING JULY 16, 2004)

### NRC denies Wellfield Unit 1 groundwater restoration approval

By letter dated March 29, 2002, NRC, in a rare move, denied approval for the groundwater restoration at Wellfield Unit 1 of the Crow Butte in-situ leach facility.

> "Staff's analysis indicates that concentrations of ammonium, iron, radium-226, selenium, total dissolved solids, and uranium show strongly increasing concentration trends over the stability monitoring period. These trends indicate a reasonable likelihood that license limits would be exceeded in the near future."

> See also Federal Register: April 22, 2002 (Volume 67, Number 77) p. 19598

### Cameco writes down Crow Butte ISL property

On Nov. 7, 2000, Cameco announced the writedown of the Crow Butte ISL property. Cameco plans to continue to produce 800,000 pounds U3O8 (308 t U) per year.

### Nebraska Department of Environmental Quality is proposing relaxed limitations for Crow Butte ISL deep injection well

> "The Department is proposing to modify the existing permit by removing the injection limitations on flow rate. The limitation for pH is proposed to be changed from 5.0 - 8.5 to 5.0 - 9.5. Reporting for the temperature of the waste stream is proposed to be removed. The limitations for arsenic, barium, and selenium are proposed to be changed from 1 mg/l to 5 mg/l, 20 mg/l to 100 mg/l, and 2 mg/l to 1 mg/l, respectively. Testing for calcium is proposed to be added to the injection parameters with no injection limitation. Testing for cadmium, chromium, lead, mercury, and silver is proposed to be added with limitations of 1 mg/l, 5 mg/l, 5 mg/l, 0.2 mg/l, and 5 mg/l respectively." [...]

Comments or a request for a public hearing must be submitted by writing to Michael J. Linder, Director, Nebraska Department of Environmental Quality, P.O. Box 98922, Lincoln, Nebraska 68509-8922, prior to October 13, 2000.

### License renewal for Crow Butte ISL uranium mine (Nebraska)

The U.S. Nuclear Regulatory Commission has issued a *Finding of No Significant Impact* for the proposed license renewal of the Crow Butte in-situ leach uranium mine in Nebraska.
Any person whose interest may be affected by this proceeding may file a request for a hearing within 30 days from February 23, 1998.
> See notice in *Federal Register*, February 23, 1998 (Vol. 63, No. 35), p. 9023-9024 (download full notice).

## Three Crow Expansion project of Crow Butte uranium in situ leach mine

> View License Application (NRC)

On Mar. 19, 2019, Cameco Resources requested from NRC that the Three Crow license amendment application be removed from consideration.

On Oct. 11, 2012, Cameco Resources requested that NRC restart the application process for the Three Crow Expansion Area. Cameco has decided not to pursue the pipeline option at this time.

On Apr. 14, 2011, Cameco Resources requested the NRC suspend review of the Three Crow Expansion Area application so that the option of a pipeline to carry mine fluids directly to the main plant could be evaluated.

On Aug. 3, 2010, Crow Butte Resources, Inc. (CBR) submitted a request for an amendment to Source Materials License SUA-1534 for the development of additional uranium in-situ leach mining resources. The proposed development area is referred to as the Three Crow Expansion Area and will be used as a satellite facility to the main CBR plant.
> Download submitted documents (ADAMS Acc. No. ML102230009)

On July 12, 2010, the Nebraska Department of Environmental Quality received a Class III Injection Well Application and the corresponding Petition for Aquifer Exemption for Crow Butte Resources, Inc., Three Crow Expansion Area. (ADAMS Acc. No. ML102210326).

On March 4, 2009, Cameco submitted to NRC a revised notice of intent to request additional amendments to Source Materials License SUA-1534 for the development of additional uranium in-situ leach mining resources. The proposed development area for use as a satellite facility to the main Crow Butte plant is referred to as the Three Crow Expansion Area. It is Cameco's intent to submit a license amendment application, for this expansion area, during the first quarter of 2010.

## Marsland Expansion project of Crow Butte uranium in situ leach mine

> View NRC: Marsland Application

**NRC denies Oglala Sioux Tribe's petition for review re Marsland Expansion of Crow Butte uranium in situ leach mine**:
> Download: Memorandum and Order CLI-20-01, Apr. 13, 2020 (PDF)

**NRC panel to hold hearing on Marsland Expansion of Crow Butte uranium in situ leach mine**: The Atomic Safety and Licensing Board hereby gives notice that it will convene an evidentiary hearing to receive testimony and exhibits in this proceeding regarding intervenor Oglala Sioux Tribe's (OST) challenge to the May 2012 application of Crow Butte Resources, Inc., (CBR) seeking to amend the existing 10 CFR part 40 source materials license for its Crow Butte in situ uranium recovery (ISR) site to authorize CBR to operate a satellite ISR facility within the Marsland Expansion Area (MEA) in Dawes County, Nebraska. The evidentiary hearing will concern OST's admitted Contention 2, which raises hydrogeological- related environmental and safety matters regarding the proposed license amendment. In addition, the Board gives notice that, in accordance with 10 CFR 2.315(a) and the procedures specified below, it will entertain oral, written, and audio-recorded limited appearance statements from members of the public in connection with the issues raised by Contention 2.
To be considered timely, a written request to make an oral statement must either be mailed, faxed, or sent by email so as to be received by 5:00 p.m. Eastern Time (ET) on Monday, October 12, 2018 *[ehm, well, Oct. 12, 2018, is a Friday, at least in Europe...]*.
> Federal Register Volume 83, Number 149 (Thursday, August 2, 2018) p. 37828-37830 (download full text)
> Federal Register Volume 83, Number 188 (Thursday, September 27, 2018) p. 48874-48875 (download full text) *[this corrects a fax number given, but leaves the date discrepancy unresolved...]*
> Download NRC news release Aug. 15, 2018 (PDF)

**NRC releases final Environmental Assessment for Marsland Expansion of Crow Butte uranium in situ leach mine**: On Apr. 30, 2018, NRC released the Environmental Assessment for the Marsland Expansion of the Crow Butte uranium in situ leach mine.
> Federal Register Volume 83, Number 86 (Thursday, May 3, 2018) p. 19576-19577 (download full text)
> Download Enviromental Assessment (36MB PDF)
> Access Docket ID NRC-2012-0281

**NRC determines that Marsland Expansion project of Cameco's Crow Butte uranium in situ leach mine would have no adverse impact on federally listed species**: "[...] the NRC staff finds that all potential impacts on the northern long-eared bat and whooping crane resulting from the proposed action would be insignificant or discountable. Therefore, the NRC staff concludes that the proposed action may affect, but is not likely to adversely affect these species. The NRC staff finds that the red knot and black-footed ferret do not occur in the action area, and therefore, the proposed action would have no effect on these species."
> Download: Biological Evaluation of Impacts to Northern Long-Eared Bat, Whooping Crane, Red Knot, and Black-Footed Ferret, Marsland Expansion Area In Situ Uranium Recovery, March 2018 (41.7MB PDF)

**NRC releases Safety Evaluation Report for Marsland Expansion of Crow Butte uranium in situ leach mine**:
> Download: Safety Evaluation Report License Amendment for the Crow Butte Resources Marsland Expansion Area In-Situ Recovery Project Dawes County, Nebraska, Jan. 2018 (762kB PDF)

**NRC releases Draft Environmental Assessment in favour of Marsland Expansion of Crow Butte uranium in situ leach mine**: On Dec. 8, 2017, NRC released a Draft Environmental Assessment and Draft Finding of No Significant Impact on the Marsland Expansion of the Crow Butte uranium in situ leach mine: "[...] the NRC staff has preliminarily determined that amendment of SUA-1534, which would authorize the development of additional ISR operations at the MEA, would not significantly affect the quality of the human environment. Therefore, based on this preliminary assessment, an environmental impact statement (EIS) is not warranted, and, [...] a Finding of No Significant Impact (FONSI) is appropriate."
Submit comments by January 29, 2018.
> Download NRC news release Dec. 18, 2017 (212k PDF)
> Federal Register Volume 82, Number 240 (Friday, December 15, 2017) p. 59665-59666 (download full text)
> Download Draft Environmental Assessment for the Marsland Expansion Area License Amendment Application (3.5MB PDF)
> Access Docket ID NRC-2012-0281

On Dec. 7, 2017, NRC released a compiled Environmental Report for the Marsland Expansion of the Crow Butte uranium in situ leach mine:
> Download compiled Environmental Report

On Sep. 11, 2017, NRC released a revised Environmental Report for the Marsland Expansion of the Crow Butte uranium in situ leach mine:
> Download revised Environmental Report

On May 16, 2017, NRC released a revised Environmental Report for the Marsland Expansion of the Crow Butte uranium in situ leach mine:
> Download revised Environmental Report

On Jan. 31, 2014, NRC released Cameco's response to the RAIs dated March 22, 2013 on the Marsland Expansion Area Environmental Report:
> Download Marsland Expansion Area Environmental RAI

On Jan. 24, 2014, NRC released Cameco's response to the RAIs dated July 3, 2013 on the Marsland Expansion Area Technical Report:
> Download: Vol. 1 · Vol. 2

On Sep. 6, 2013, NRC released Environmental Report revisions for the Marsland Expansion of the Crow Butte uranium in situ leach mine:
> Download Environmental Report revisions

On Aug. 21, 2013, NRC released Technical Report revisions for the Marsland Expansion of the Crow Butte uranium in situ leach mine:
> Download Marsland Technical Report revisions

On May 10, 2013, the Atomic Safety and Licensing Board granted the hearing request of the Oglala Sioux Tribe and admitted it as a party to the proceeding.

On April 19, 2013, Cameco submitted to Nebraska DEQ an application for an Area Permit to install and operate Class I Nonhazardous Waste Injection Wells at the company's Marsland Expansion Area. "The purpose of the injection wells is to dispose of well field bleed water and a small volume of process water from ISR mining operations and wastewater generated by groundwater restoration activities."
> Download Class I Nonhazardous Waste Injection Wells Area Permit Application
> Download revised Class I Nonhazardous Waste Injection Wells Area Permit Application, Sep. 23, 2014 (NMED)

On Feb. 6, 2013, NRC gave notice that an Atomic Safety and Licensing Board (Board) is being established to preside over the following proceeding: Crow Butte Resources, Inc. (Marsland Expansion Area). Hearing requests were filed by the Oglala Sioux Tribe and a consolidated group of petitioners.
> Federal Register Volume 78, Number 29 (Tuesday, February 12, 2013) (download full text)

NRC announces opportunity to request a hearing and to petition for leave to intervene concerning Marsland Expansion project of Crow Butte uranium in situ leach mine:
Requests for a hearing or leave to intervene must be filed by January 29, 2013.
> Federal Register Volume 77, Number 231 (Friday, November 30, 2012) p. 71454-71458 (download full text)
> Access Docket ID NRC-2012-0281
> Download Technical and Environmental Report · more

On May 16, 2012, Cameco submitted the license amendment application for the Marsland Expansion. On June 14, 2012, first portions of the Technical Report and the Environmental Report appeared in NRC's ADAMS Document system.

On Oct. 27, 2010, Crow Butte Resources, Inc. advised that submission of the Marsland license amendment application is anticipated during the third quarter of 2011.

On March 4, 2009, Cameco submitted to NRC a revised notice of intent to request additional amendments to Source Materials License SUA-1534 for the development of additional uranium in-situ leach mining resources. The proposed development area for use as a satellite facility to the main Crow Butte plant is referred to as the Marsland Expansion Area. It is Cameco's intent to submit a license amendment application, for this expansion area, during the third quarter of 2012.

## North Trend Expansion project of Crow Butte uranium in situ leach mine

> View License Application (NRC)

**Cameco suspends North Trend Expansion Area license application for Crow Butte uranium in situ leach mine**: On Dec. 16, 2015, Cameco asked NRC to discontinue work on the North Trend Expansion Area license application and rather prioritize the Marsland Expansion Area application.

On July 26, 2013, NRC released the Safety Evaluation Report for the North Trend Expansion Area of the Crow Butte uranium in situ leach mine.
> Download: Safety Evaluation Report License Amendment for the Crow Butte Resources North Trend Expansion Area ISR Facility Dawes County, Nebraska, U.S. Nuclear Regulatory Commission, July 2013

On Aug. 11, 2011, the Nebraska Department of Environmental Quality issued the permit for the construction and operation of the North Trend Expansion Area of the Crow Butte uranium in situ leach mine.



ED_005364K_00005243-00287

Opposition to aquifer exemption for North Trend expansion of Crow Butte uranium in situ leach mine: Uncertainties regarding the presence of faults and factures in the land underlying northwest Nebraska are a major reason that the Crow Butte Resources uranium mine should not receive an 'aquifer exemption' for its proposed North Trend expansion project, opponents of the mine said Monday (Aug. 23).
Making a decision now to allow use of the estimated 1.85 billion gallons [7 million cubic metres] of water in the lower portions of the Chadron formation under the expansion area would be premature, countered David Frankel, an attorney representing mine opponents in hearings before the Nuclear Regulatory Commission. Detailed research by Chadron geologist Hannan LaGarry indicates that faults and fractures common in the area could link the Chadron aquifer to other water bearing layers, including the Brule and Arikaree, which are used for drinking water, he said. (Rapid City Journal Aug. 25, 2010)

The Nebraska Department of Environmental Quality has scheduled a public hearing regarding a proposal to exempt a portion of the Chadron Aquifer north of Crawford. This portion of the aquifer is associated with a proposed expansion area for the Crow Butte Resources (CBR) uranium mining facility. The proposed exemption would prevent that designated area of the aquifer from being used as a drinking water source in the future. The public hearing is scheduled for Monday, August 23, 2010.
> View Nebraska DEQ Crow Butte Resources news page

On January 6, 2010, Crow Butte Resources submitted to the Nebraska Department of Environmental Quality (NDEQ) a revised version of its application for a Class III Underground Injection Control (UIC) Permit for the North Trend Expansion project of its Crow Butte uranium in situ leach mine.
> Download revised application documents (ADAMS Acc. No. ML100432281)

The ownership of the Crow Butte Resources uranium mine near Crawford by a Canadian mining company is a legitimate issue for argument in deciding whether the mine should be allowed to expand its operation to a nearby site, a three-member panel of Nuclear Regulatory Commission judges has ruled. In a decision issued Jan. 27, 2009, the NRC judges also said that questions of the impact of low levels of arsenic in water returned to aquifers during mining operations, the relationship between arsenic exposure and diabetes and information about an alleged cluster of pancreatic cancer in the Chadron area can also be raised during hearings on the mine's proposed North Trend expansion. (The Chadron News Feb. 10, 2009)
> Download Memorandum and Order LBP-09-01 Jan. 27, 2009 (ADAMS Acc. No. ML090270965)

On April 29, 2008, an NRC Atomic Safety and Licensing Board Panel (ASLBP) ordered as follows:
"In this Memorandum and Order, in addition to ruling on three pending matters on which the participants are in dispute, we find that Petitioners WNRC, Owe Aku, and Debra L. White Plume have shown standing to participate in the proceeding, and admit three of their joint contentions, in modified form. The first two of these concern alleged contamination of water resources and potential resulting environmental and health issues; the third concerns the extent of consultation that is required with tribal leaders regarding a prehistoric Indian camp located in the region of the proposed expansion site, under the National Historic Preservation Act."
> Download Memorandum and Order LBP-08-06, April 29, 2008 (ADAMS Acc. No. ML081200636)
> Download Revised Memorandum and Order LBP-08-06, May 21, 2008 (ADAMS Acc. No. ML081430342)

On November 12, 2007, seven Petitioners from parts of the poorest region in the United States asked the Nuclear Regulatory Commission (NRC) to participate in decisions relative to uranium mining and its harmful effects in northwestern Nebraska and the Lakota (Sioux) Pine Ridge Indian Reservation in Southwest South Dakota. According to NRC sources, this is the first request to intervene in an NRC proceeding relating to the expansion of an existing uranium mining operation in approximately 17 years. The petitioners are Thomas Cook, Chadron Native American Center, Slim Buttes Agricultural Development Corp., High Plains Community Development Corp., Western Nebraska Resources Council, Debra White Plume, and an Oglala Lakota nonprofit organization called Owe Aku. (UN Observer Dec. 7, 2007)

On Nov. 8, 2007, the Nebraska Department of Environmental Quality dismissed CBR's petition for aquifer exemption, due to deficiences identified in CBR's Technical Review of Aquifer Exemption Petition dated August 15, 2007.

On May 30, 2007, Crow Butte Resources, Inc. (CBR) submitted a request for an amendment to Source Materials License SUA-1534 for the development of additional uranium in-situ leach mining resources. The proposed development area for use as a satellite facility to the existing main plant is referred to as the North Trend Expansion Area.
> Download application documents (ADAMS Acc. No. ML072540671)

## License Violations and reportable events at Crow Butte ISL uranium mine (Nebraska)

- Sep. 22, 2020: Injection well fails 5-year mechanical integrity test
- May 29, 2020: Monitor well excursion
- May 21, 2020: Monitor well excursion
- Mar. 3, 2020: Production well fails 5-year mechanical integrity test
- Jan. 31, 2020: Production well fails 5-year mechanical integrity test
- Jan. 2, 2020: Evaporation Pond 1 liner leak
- Aug. 22, 2019: Monitor well excursion
- July 11, 2019: Production well fails 5-year mechanical integrity test
- June 24, 2019: Production well fails 5-year mechanical integrity test
- June 5, 2019: Monitor well excursion
- May 29, 2019: Evaporation Pond 1 liner leak
- May 2, 2019: Monitor well excursion
- Apr. 18, 2019: Monitor well excursion
- Apr. 9, 2019: Monitor well excursion
- Mar. 27, 2019: Monitor well excursion
- Mar. 25, 2019: Monitor well excursion
- Nov. 28, 2018: Monitor well excursion
- June 1, 2018: Monitor well excursion
- Sep. 12, 2017: 27,287 gallon spill of injection solution
- Aug. 29, 2017: Monitor well excursion
- July 27, 2017: Production well fails 5-year mechanical integrity test
- Mar. 14, 2017: Injection well fails 5-year mechanical integrity test
- June 8, 2016: Evaporation Pond 1 liner leak
- May 5, 2016: two Monitor well excursions
- Apr. 21, 2016: Monitor well excursion
- Apr. 20, 2016: Injection well fails 5-year mechanical integrity test
- Nov. 19, 2015: Monitor well excursion
- Oct. 27, 2015: Monitor well excursion
- Aug. 17, 2015: Injection well fails 5-year mechanical integrity test
- Aug. 13,2015: Monitor well excursion
- July 9, 2015: Monitor well excursion
- July 2, 2015: Injection well fails 5-year mechanical integrity test
- June 3, 2015: Monitor well excursion
- May 28, 2015: Monitor well excursion
- May 27, 2015: Monitor well excursion
- May 21, 2015: Monitor well excursions
- May 19, 2015: Monitor well excursion
- Apr. 14, 2015: Monitor well excursion
- Feb. 11, 2015: Monitor well excursion
- July 22, 2014: Monitor well excursion
- July 2, 2014: Failure to sample the underdrains of a leaking pond and to submit a corrective action plan
- May 20, 2014: Monitor well excursion
- May 8, 2014: Monitor well excursion
- May 7, 2014: Evaporation Pond 1 liner leak



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- Dec. 10, 2013: Monitor well excursion
- Sep. 11, 2013: Monitor well excursion
- Aug. 22, 2013: Well fails 5-year mechanical integrity test
- Aug. 6, 2013: Well fails 15-year mechanical integrity test
- Jun. 5, 2013: Radiation dose in unrestricted area exceeds 0.02 mSv/h standard
- Mar. 14, 2013: Evaporation Pond 1 liner leak
- Jan. 18, 2013: Well fails mechanical integrity test
- Oct. 24, 2012: Well fails 20-year mechanical integrity test
- Aug. 20, 2012: Well fails 5-year mechanical integrity test
- June 4, 2012: Well fails 5-year mechanical integrity test
- May 25, 2012: Monitor well fails 15-year mechanical integrity test
- Oct. 7, 2011: Monitor well excursion
- Aug. 9, 2011: Exceedance of Well Head Manifold Pressure Limitations
- July 18, 2011: two wells fail 5-year mechanical integrity test
- June 1, 2011: Evaporation Pond 1 liner leak
- May 27, 2011: two Monitor well excursions
- May 24, 2011: Monitor well excursion
- Mar. 16, 2011: Monitor well excursion
- Jan. 13, 2011: Monitor well excursion
- July 8, 2010: Monitor well excursion
- July 6, 2010: Well fails 5-year mechanical integrity test
- June 22, 2010: Excursions at two monitor wells "due to increased groundwater levels"
- June 22, 2010: Monitor well excursion
- June 16, 2010: Excursions at three monitor wells "due to increased groundwater levels"
- June 11, 2010: Evaporation Pond 3 liner leak detected
- May 10, 2010: Well fails 5-year mechanical integrity test
- Apr. 13, 2010: Excursion at monitor well due to "natural conditions"
- Dec. 31, 2009: Evaporation Pond 4 Liner Leak
- Nov. 19, 2009: Well fails 15-year mechanical integrity test
- Oct. 15, 2009: Mechanical integrity test missed for two wells
- June 18, 2009: Evaporation Pond 4 liner leak detected
- June 11, 2009: Monitor well excursion
- June 5, 2009: Evaporation Pond 1 liner leak detected
- April 27, 2009: Monitor well placed on excursion status
- April 17, 2009: Production well fails 5-year mechanical integrity test
- June 4, 2008: Exceedance of Well Head Manifold Pressure Limitations
- May 31, 2008: Monitor well placed on excursion status
- May 23, 2008: $50,000 penalty imposed for violations
- May 19, 2008: Monitor well placed on excursion status
- April 29, 2008: Five-year mechanical integrity test missed for 42 wells
- September 26, 2006: Monitor well placed on excursion status
- May 5, 2006: leak detected at Pond 4
- January 19, 2006: Monitor well placed on excursion status
- October 27, 2005: Injection well leak detected
- August 4, 2005: Monitor well placed on excursion status
- June 28, 2005: Monitor well placed on excursion status
- June 17, 2005: Monitor well placed on excursion status
- May 2, 2005: Monitor well placed on excursion status
- May 14, 2004: leak detected at Pond 1
- December 23, 2003: Monitor well placed on excursion status
- December 26, 2002: Monitor well placed on excursion status
- September 10, 2002: Monitor well placed on excursion status
- April 4, 2002: Monitor well placed on excursion status
- December 4, 2001: Monitor well placed on excursion status

- March 2, 2001: Monitor well placed on excursion status
- September 10, 2000: Monitor well placed on excursion status
- May 26, 2000: Monitor well placed on excursion status
- April 27, 2000: Monitor well placed on excursion status
- March 6, 2000: Monitor well placed on excursion status
- July 2, 1999: Monitor well placed on excursion status
- August 7, 1998: Spill of 10,260 gallons of injection fluid
- March 21, 1998: Monitor well placed on excursion status
- August 12, 1997: Discovery of Pinhole Leaks in Upper Liner of Process Water Evaporation Pond

(details on post-Nov.1,1999, events available through ADAMS, Docket No. 04008943)

# New Mexico

- Mt. Taylor

> See also Issues for: New Mining Projects · Decommissioning Projects · Legislation & Regulations
> See also Data for: Deposits, Proposed and Active Mines · Old Mines and Decommissioning

## Mt. Taylor mine, Cibola County

Mine Permit No. CI002RE

> View deposit info
> View Pending Mine Applications, Regular Existing: Mount Taylor Mine (NM EMNRD)

> View more recent issues

**Company abandons plan for reactivation of Mt. Taylor uranium mine**: In a stunning victory for Native communities, Rio Grande Resources (RGR), owner of the Mt. Taylor uranium mine, notified the Mining and Minerals Division (MMD) of the New Mexico Energy, Minerals and Natural Resources Department of "cessation of mining operations" and RGR's intention "to begin closure plan activity."
RGR had been granted Return to Active status under their permit Dec. 29, 2017. The mine had been in Standby status since 1999.
MASE and Amigos Bravos appealed the permit revision. After hearings May 5, 2018, the Mining Commission issued their Final Order Aug 1, 2018, upholding the Return to Active status. The two organizations then appealed that ruling to the First Judicial District Court in Santa Fe; when that court upheld the Mining Commission decision, the groups appealed to the State Court of Appeals, where the case is currently located.
According to RGR, "From initiation of the closeout contracting process to completion of the closeout activities on site is estimated to take about 16 months. The first 5-6 months would be taken up by project management and contractor procurement, followed by 9-10 months of actual construction activities on site from mobilization through demobilization." (Los Alamos Daily Post Jan. 4, 2020)

**New Mexico Mining Commission holds meeting and hearing on petition against permit for reactivation of Mt. Taylor uranium mine - petition denied**: The New Mexico Mining Commission will hold a regular meeting and a public hearing at 9:00 AM, Monday, May 7, 2018 (and Tuesday, May 8, if necessary). During the meeting, the Mining Commission will conduct a public hearing on Petition 18-01 - In the Matter of the Petition for Review of the Director's Action, dated December 29, 2017, Permit Revision 13-2 to Permit No. CI002RE, filed by The Multicultural Alliance for a Safe Environment and Amigos Bravos on February 28, 2018. Petitioners request a review of the Mining and Minerals Division Director's decision to grant Rio Grande Resources' application for a permit revision allowing the Mt. Taylor Mine to return to "active" or "operational" status.

Intervenors and interested participants desiring to present evidence shall submit a written notice of intent to do so to the Commission not later than 5:00 PM, Friday, April 27, 2018.
> Access: Mining Commission - Meetings and Hearings
> Download: Notice of Public Meeting and Hearing of the New Mexico Mining Commission, Mar. 27, 2018 (41kB PDF)
> Download: Petition, Feb. 28, 2018 (3.5MB PDF)

On July 27, 2018, the New Mexico Mining Commission denied the petition.
> Download: Final Decision and Order (826kB PDF)

The Gallup Independent reports the Multicultural Alliance for a Safe Environment and Amigos Bravos have asked the New Mexico Court of Appeals to review a lower court ruling that upheld the New Mexico Mining Commission's decision to permit the Mount Taylor Mine to return to active status. (AP Sep. 4, 2019)

**Environmental groups fight against state permit for reactivation of Mt. Taylor uranium mine**: Environmentalists are seeking to keep an idle uranium mine in western New Mexico from becoming active again, saying the designation will allow it to delay cleanup.
The Multicultural Alliance for a Safe Environment and Amigos Bravos are asking the New Mexico Mining Commission to review a recent decision by state Mining and Minerals Division Director Fernando Martinez to allow the Mount Taylor mine to return to "active," or operational, status, the Gallup Independent reports.
The groups say there is no realistic likelihood that mining will take place for the foreseeable future. "The director's decision directly contradicts the New Mexico Mining Act's plain language, which restricts 'operational' mines to those that are producing minerals," said Eric Jantz, staff attorney at the New Mexico Environmental Law Center, which is representing the groups. "The director has unilaterally created an entirely new category of mine activity - 'zombie mines' - that have been given new life in an effort to avoid cleanup."
The Mount Taylor Mine has been on standby status for more than 20 years. Its owner, Rio Grande Resources, announced in 2014 that it planned to ask regulators to change the status to active. (Albuquerque Journal Mar. 19, 2018)

**State issues permit for reactivation of Mt. Taylor uranium mine**: On Nov. 22, 2017, Rio Grande Resources notified NRC that the New Mexico Environment Department (NMED) issued a mine active permit the same day, and that the company plans to submit the application for a uranium mill in the fourth quarter of 2022.

**State announces hearing on proposed reactivation of Mt. Taylor uranium mine after 25 years of inactivity**: The New Mexico Energy, Minerals and Natural Resources Department, Mining and Minerals Division ("MMD") hereby gives notice of a public hearing on the application by Rio Grande Resources Corporation, the operator of the Mount Taylor Mine, for changing the status of the mine from standby to active, and update the closeout plan and required amount of financial assurance under Revision Application 13-2.
The public hearing is scheduled for Friday, December 4, 2015 at 10:00 AM.
Submit comments by January 4, 2016 (Comment period extended).
> Download Public Hearing Notice, Oct. 22, 2015 (PDF - MMD)
> Download Revision 13-2 related documents (MMD)

**Discharge Permit renewal and modification for Mt. Taylor uranium mine**: The New Mexico Environment Department (NMED) issued a draft Discharge Permit renewal and modification (Discharge Permit) to Rio Grande Resources Corporation for the Mt. Taylor uranium mine.
Submit written comments or request public hearing within 30 days from June 27, 2014.
> Download: Public Notice (PDF - NMED)
> Download: DRAFT Discharge Permit DP-61 Renewal and Modification (655k PDF - NMED)

**Court orders new hearing in Mt. Taylor uranium mine permit**: In a hearing this morning, state District Court Judge Raymond Ortiz handed a victory to community groups in a case concerning Rio Grande Resources' Mount Taylor uranium mine near Grants. In a ruling from the bench, he agreed that the New Mexico Mining and Minerals Division (MMD) failed to provide the public with meaningful opportunities to participate in the

process to renew the mine's standby mining permit.
He focused on three issues:

- The agency failed to allow MASE and Amigos Bravos to raise concerns about environmental safeguards, namely the protection of water from contamination by the mine.
- The agency wrongly declared the company's entire economic viability report off-limits to any member of the public, although the report was an important factor in the permitting decision.
- The agency wrongly issued the permit before considering whether or not the financial assurance (reclamation bond) was adequate, and without letting the public provide input on the bond.

(NMELC July 22, 2013)

**Group seeks public hearing over proposed reactivation of Mt. Taylor uranium mine after 23 years of inactivity**: Today, the New Mexico Environmental Law Center (NMELC) filed a request for a public hearing regarding a proposed permit revision to put the Mt. Taylor uranium mine on active status. The mine, near Grants, NM, has been inactive (on "standby" status) without cleanup for 23 years. The mine's owner, Rio Grande Resources, received a fourth renewal for the standby permit in January 2012, but on April 12, 2013 it notified the public it was seeking a revision to change the mine's status to "active". The NMELC filed the hearing request on behalf of its clients, Amigos Bravos and the Multicultural Alliance for a Safe Environment (MASE). (NMELC May 10, 2013)

**Mine agency to take input on renewal of standby permit requested for Mount Taylor uranium mine**: The New Mexico Mining and Minerals Division has set a public hearing for Rio Grande Resources Corporation's application to renew "Standby Status" for its Mount Taylor Mine on Wednesday, Aug. 17, at 5 p.m. in the Cibola County Convention Center.
A standby permit allows the mine operator to let the mine remain inactive without having to do any clean up. The permit lasts for five years. The Mount Taylor mine is located one mile northeast of San Mateo. The mine is an existing underground uranium mine that extracted uranium ore from depths of more than 3,000 feet below ground surface using room-and-pillar and stope mining methods. Uranium ore was produced from the mine from 1979 to 1982 and from 1985 to 1990. The mine has been inactive since January 1990. A copy of Rio Grande Resources' application for the renewal of Standby Status is available at the Mother Whiteside Memorial Library and in Santa Fe at the Mining and Minerals Division's office. These documents are also available for viewing on the MMD website. (Cibola Beacon Aug. 15, 2011)

Rio Grande Resources Corporation (RGR) submitted a Standby Status Renewal Application for its Mt. Taylor Mine. The mine is an existing uranium mining operation using underground mining techniques to extract uranium ore from depths of over 3000 feet below ground surface using room-and-pillar and stope mining methods. There are no milling facilities within the proposed Standby area. The Mine has been inactive since January 1990 until the present.
> View Standby Status Application (NM EMNRD)

A groundwater discharge permit is being sought for Mount Taylor Uranium Mine and Mill owned by Rio Grande Resources, according to the New Mexico Environment Department. Gerald Schoeppner of NMED's Groundwater Quality Bureau said Wednesday that the company has an existing discharge plan for its mine that it's trying to renew, "but that's one of the pieces of the puzzle that's missing - how they're planning to treat their mine water for the dewatering to meet standards."
The Mount Taylor mine previously was a conventional mining operation "and they plan to operate it as a conventional mine in the future," Schoeppner said. The mine site is located just outside the 8,000 foot elevation boundary established in the June 2008 emergency designation of Mount Taylor as a Traditional Cultural Property.
Rio Grande Resources controls uranium operations and mineral resources acquired by General Atomics from Chevron Resources in 1991. The Mount Taylor project, a conventional underground mine, contains the largest uranium resource in the United States and is currently on standby, according to the company's Web site. Chevron began commercial production at Mount Taylor in 1986, initially shipping the ore to its Panna Maria mill in south

Texas for processing. The mine was placed on standby in 1989. (Gallup Independent Feb. 19, 2009)
> Download NMED Public Notice Feb. 13, 2009 (PDF)

> See also: Cotter aims to reopen Cañon City (Colorado) uranium mill in 2014 to process ores from Mt Taylor mine (New Mexico)

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# Texas

- Alta Mesa ISL
- Hobson ISL
- Palangana
- Vasquez ISL
- Kingsville Dome and Rosita ISL

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> See also Issues for: New Mining Projects · Decommissioning Projects · Legislation & Regulations
> See also Data for: Deposits, Proposed and Active Mines · Old Mines and Decommissioning

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Uranium mining in South Texas is opposed by South Texas Opposes Pollution (STOP).

## Alta Mesa ISL, Brooks County

> View deposit details

### TCEQ approves groundwater restoration performed at Production Area 1 of Alta Mesa in situ leach uranium mine

On Mar 29, 2018, Energy Fuels Inc. announced that it has achieved a major environmental milestone at its Alta Mesa Uranium Project in Texas. On March 16, 2018, the Company received a notice from the Texas Commission on Environmental Quality ("TCEQ") confirming that the Company accomplished final groundwater restoration at Production Area 1 ("PAA1"). Now that TCEQ has deemed wellfield restoration complete, the Company can proceed to well plugging and final closure of PAA1, including a reduction of the reclamation bond on the project and the return of restricted cash.

### "Unplanned" fire at Alta Mesa in situ leach uranium mine

> "A fire occurred within the Mestena Uranium LLC License Area in the vicinity of PAA-3 on August 9, 2016. The fire was discovered at approximately 1545 CDT by US Border Patrol agents who were conducting activities in the vicinity. Mestena personnel discovered the fire at about the same and upon investigation determined the fire required additional support at which time the local fire department was notified and arrived on site at approximately 1620 CDT to battle the fire.
> Fire crews declared the fire out/controlled by 2000 [CDT]. No injuries occurred during the firefighting activities. [...]
> The fire burned approximately 60 acres, most of which was within the PAA-3 Mine Area. The fire damaged or destroyed surface infrastructure associated with the in-situ mining activities permitted under UIC permit UR03060PA3. [...]"
> (Event Notification Report for August 19, 2016, U.S. NRC)

### Mesteña Uranium LLC cited for well plugging deficiencies at exploration wells

On Nov. 23, 2010, the Railroad Commission (RRC) of Texas sent a Deficiency Letter to Mesteña Uranium LLC regarding a Well Plugging Affidavit for Uranium Exploration Permit 125B-1. (Texas RRC Nov. 29, 2010)

### TCEQ issues Agreed Order over penalty of $2,000 to Mesteña Uranium LLC

Texas Commission on Environmental Quality: Enforcement Orders:
An agreed order was entered regarding Mesteña Uranium, L.L.C., Docket No. 2007-1010-UIC-E on December 20, 2007 assessing $2,000 in administrative penalties with $400 deferred. (Texas Register, January 18, 2008, Volume 33 Number 3, Pages 449-634, In Addition)

### TCEQ issues Agreed Order over penalty of $2,000 to Mesteña Uranium LLC

Texas Commission on Environmental Quality issues Agreed Order over penalty of $2,000 to Mesteña Uranium LLC for failing to secure acceptable financial assurance. (Texas Register, September 21, 2007, Volume 32 Number 38, Pages 6451-6688, In Addition)

> See older issues

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## Hobson In Situ Leach mine, Karnes County (Texas)

> View deposit details

> View decommissioning issues

### Texas Commission on Environmental Quality proposes Agreed Order imposing $11,581 penalty on multiple violations at Hobson uranium in situ leach mine

> COMPANY: South Texas Mining Venture L.L.P. dba Hobson Mining Project; [...]
> RULES VIOLATED: 30 TAC §305.125(1) and §331.67(a)(1)(B), 40 Code of Federal Regulations §146.67(f), and Underground Injection Control (UIC) Permit Number Waste Disposal Well (WDW) 168, Permit Provision (PP) IX. Recordkeeping Requirements, **by failing to keep complete and accurate records of all monitoring according to permit requirements**; 30 TAC §331.4 and §331.64(d)(4)(A) and UIC Permit Number WDW168, PP VII.F, Operating Parameters, **by failing to cease injection of waste fluids when monitoring indicates a loss of mechanical integrity has been detected**; and 30 TAC §331.64(g) and UIC Permit Number WDW168, PP VIII.H, Monitoring and Testing Requirements, **by failing to conduct corrosion monitoring of well materials on a quarterly basis**;
> PENALTY: $11,581; [..., emphasis added]

Submit comments by **May 4, 2020**.
> View: Texas Register, April 3, 2020, Volume 45, Number 14, In Addition: Texas Commission on Environmental Quality, Agreed Orders

### Hobson plant starts processing of uranium-loaded resins from Palangana in situ leach mine

On Dec. 1, 2010, Uranium Energy Corp announced that it has started the processing of the first shipment of uranium-loaded resins at its Hobson processing plant. This shipment and the start of processing follows the Company's announcement on November 17, 2010 of the initial in-situ recovery (ISR) of uranium at Palangana in South Texas.

> See also Palangana ISL mine

### TCEQ invites public comment or request for public meeting about proposed license transfer for Hobson, Tex-1, and Mt Lucas mines

The Texas Commission on Environmental Quality (TCEQ) invites public comment or request for public meeting about the proposed license transfer for the Hobson, Tex-1, and Mt. Lucas mines from Everest Exploration to South Texas Mining Venture L.L.P.
All written public comments and requests must be submitted within 30 days from the date of newspaper publication of this notice.

> View TCEQ notice: Texas Register, May 28, 2010, Volume 35 Number 22, Pages 4275-4526, In-addition
> View TCEQ notice: Texas Register, June 4, 2010, Volume 35 Number 23, Pages 4527-4766, In-addition

### License renewal for Hobson In Situ Leach processing plant (Texas)

On December 22, 2006, Everest Exploration, Inc. submitted on behalf of South Texas Mining Venture, LLP, an application for renewal of the Hobson Facility Radioactive Material Handling License to the Texas Department of State Health Services. This renewal application allows the Hobson Facility to continue operations as a uranium processing facility and provides the regulatory authorities with necessary information concerning the company's plans to increase the facility's processing capacity to over 1,000,000 pounds of U3O8 (385 t U) per year. (Energy Metals Corporation April 4, 2007)

### License Renewal for Everest Exploration Hobson In Situ Leach mine (Texas)

> "Everest Exploration for renewal of an Underground Injection Control (UIC) Well, Permit No. WDW-168. The Executive Director has prepared a draft permit.
> The applicant currently operates an in-situ uranium mine. Wastes generated on-site are non-hazardous. The injected wastes include: barren solution bleed, restoration waste stream, process waste streams, and tailings or wastes produced by or resulting from the extraction or concentration of uranium, other associated wastes such as ground water and rainfall contaminated by the above authorized wastes, spills of the above authorized wastes, and wash waters and solutions used in cleaning and servicing the waste disposal well system equipment which are compatible with the permitted waste streams, reservoir and well materials. WDW-168 was initially put in service in 1979. The facility is located 0.5 mile southwest of Hobson on Farm-Market Road 81, Karnes County, Texas.
> SIGNED MAY 7, 1999" (TNRCC Items Signed by Executive Director 7 May 1999)

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## Palangana in-situ leach mine, Duval County (Texas)

> View deposit info

**Palangana uranium in situ leach mine obtains state authorization for operation of fourth Production Area**: On May 27, 2015, Uranium Energy Corp announced that the Palangana ISR Mine has received the required permits, and is now fully permitted for extraction in new resource areas with a larger Mine Permit and Aquifer Exemption. The expanded mine area boundary is now 8,722 acres versus 6,200 acres previously and includes Production Area-4.

**Production of Palangana in situ leach mine reduced in response to low uranium prices**: Uranium Energy Corp. is cutting production as prices trade at a seven-year low. Uranium Energy will reduce output at its Palangana mine so the project just breaks even, the Vancouver-based company said in a statement today. The savings will be used to develop the company's larger Goliad and Burke Hollow projects. (Business Week Sep. 5, 2013)



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**Palangana uranium in situ leach mine obtains state authorization for operation of third Production Area**: On Dec. 7, 2012, Uranium Energy Corp announced the receipt of a Production Area Authorization from the Texas Commission on Environmental Quality, allowing for the commencement of operations at Production Area-3 of the Company's Palangana Mine located in South Texas. With wellfields and well control facilities in place already, operations at Production Area-3 has commenced while operations at Production Areas 1 and 2 are ongoing.

> View older issues

# Vasquez in-situ leach mine, Duval County (Texas)

> View deposit details
> See more recent issues

## Vasquez ISL mine shut down

During the fourth quarter of 2008, URI shut down the last wellfield at Vasquez. (URI March 11, 2009)

## Vasquez ISL mine production below expectations

"Production costs for the third quarter of 2006 were $56.92 per pound compared with $23.57 per pound in the prior year's third quarter. The higher production costs were primarily due to higher capital and operating costs compared with the prior year and also due to the change in the estimated recovery factor of for the Vasquez project from 70% to 50%."
"The Vasquez project has provided significant technical challenges since its inception in 2004 due to the unique geochemical composition of its ore body and the degree of re-reduction found in the uranium deposited within the formation. When uranium has been "re-reduced" it has in nature been oxidized, reduced and then subjected to additional reductants which results in the uranium being less accepting of oxidation for extraction. These factors have contributed to our production costs at Vasquez rising from $20.32 per pound in 2005 to over $46.00 per pound in 2006."
"Our third quarter production consisted of 26,074 pounds [10 t U] from our Vasquez project [...]. Last year's third quarter production of 65,797 pounds [25.3 t U] was produced completely from the Vasquez project. As discussed, given the challenges at this property, its level of production has measurably declined and was below expectations." (URI Nov. 14, 2006)

"[...] Vasquez has continued to operate below expectations. At the beginning of the project in 2004, our mining plan indicated we could produce the Vasquez property at an annual rate of 700,000 pounds [269 t U]. The geological and chemical problems we experienced in 2005 caused us to revise that estimate downward to an annual capacity of 400,000 pounds [154 t U]. [...]" (URI Sep. 19, 2006)

> See older issues

# Kingsville Dome and Rosita in-situ leach mines, Kleberg County (Texas)

> View deposit data: Kingsville Dome · Rosita

> View decommissioning issues Kingsville Dome

## Texas Commission on Environmental Quality grants hearing on proposed license renewal and amendment for deep disposal well at Kingsville Dome uranium in situ leach mine

> Download: TCEQ Marked Agenda April 27, 2018 (PDF - View Item 1)
> Download: Docket No. 2018-0319-WDW

## State regulator orders US$ 21,177 penalty with $4,235 deferred for violations in connection with disposal well at Kingsville Dome uranium in situ leach mine

On Dec. 19, 2016, the Texas Commission on Environmental Quality filed an agreed order to Uranium Resources, Inc., for six violations noted in connection with an underground injection waste disposal well at its Kingsville Dome uranium in situ leach mine. The violations include in particular "failing to maintain annulus pressure of at least 100 pounds per square inch greater than the injection tubing pressure to prevent leaks from the well into unauthorized zones and to detect well malfunctions", among others. The penalty amounts to US$ 21,177.
> View: Texas Register, December 30, 2016, Volume 41 Number 53, Pages 10487-10720, In Addition

On Apr. 4, 2018, the Texas Commission on Environmental Quality adopted an agreed order regarding Uranium Resources, Inc., Docket No. 2016-1222-WDW-E on April 4, 2018, assessing $21,177 in administrative penalties with $4,235 deferred.
> View: Texas Register, April 13, 2018, Volume 43 Number 15, Pages 2205-2314, In Addition
> Download: Docket No. 2016-1222-WDW-E (2.6MB PDF)

## Texas Commission on Environmental Quality grants hearing on proposed license renewal and amendment for Kingsville Dome uranium in situ leach mine

On Oct. 7, 2015, the Texas Commission on Environmental Quality (TCEQ) granted the hearing requests of local residents regarding URI's application for renewal and major amendment of the permit for its Kingsville Dome uranium in situ leach mine.
> Download TCEQ Marked Agenda Oct. 7, 2015 (84k PDF) (see Item 4)
> Download TCEQ Docket No. 2015-1268-UIC (43k PDF file containing download links to actual documents)
The hearing will be held on March 3, 2016, in Kingsville, Texas.
> Download Notice of Hearing, Jan. 26, 2016 (48k PDF)

However, on June 15, 2016, URI requested to withdraw the applications to renew and amend the permit.

> See also: URI lets license for Kingsville Dome uranium in situ leach mine expire

## Elevated uranium concentrations found in off-site domestic well near Kingsville Dome in situ leach uranium mine

> "[...] The bleed at PA-3 [production area three] did not contain the increased pressures caused by injection of leaching fluids. A hydraulic gradient was rapidly established between the injection wells and the mine boundary, as shown by a rise in water levels in monitor wells surrounding PA-3. This gradient drove mining solution beyond the mine boundary. These excursions affected a well on the Garcia property, approximately 300 m down gradient of the mine. Since mining began, uranium concentrations in the Garcia well have increased from less than 200 µg/L, to more than 600 µg/L. This is the first time that contaminants in an off-site domestic well have been linked to ISL uranium mining in the United States of America."

Excursions of Mining Solution at the Kingsville Dome In-situ Leach Uranium Mine, by George Rice, in: 2012 - 2013 Austin Geological Society Bulletin, Volume 9 (3.9MB PDF), p. 18-34

## Texas Commission on Environmental Quality invites comment on proposed approval of expansion of Rosita uranium in situ leach mine

URI, Inc. (URI) has applied to the Texas Commission on Environmental Quality (TCEQ) for an amendment to Radioactive Material License R03653. URI conducts recovery of uranium by the in situ leach methodology. This amendment authorizes URI to expand operations at their Rosita Project by authorizing an increase of the licensed area and authorizing an additional remote ion exchange unit in the added licensed area.
You may submit public comments or request a public meeting about this application. The TCEQ may grant a contested case hearing on this application if a written hearing request is timely submitted. All written public comments and requests must be submitted within 30 days from the date of newspaper publication of this notice.
> Texas Register October 8, 2010, Volume 35 Number 41, Pages 9003-9166

## Whistleblower speaks out against methods once used by Uranium Resources Inc. at Kingsville Dome uranium in situ leach mine (Texas)

Roland Burrow worked as a wellfield operator for Uranium Resources, Inc., outside Kingsville, Texas a decade ago. He says the company at the time was regularly flushing high volumes of water into the mine field that would have expanded groundwater pollution beyond its permitted area, posing a potential future risk to the residents of Kingsville. He claims also to have witnessed the falsification of monitoring-well data, which must be regularly submitted to the state to show the contaminated water is contained at the mine site.
He tried unsuccessfully to get the TNRCC and FBI involved, and was fired. He moved a couple counties over, but now a URI offshoot wants to mine in his backyard (at Goliad), and he's decided to fight.
> Watch video Uranium mining whistleblower by *paleish*, Sep. 8, 2009 (Youtube)

## Kingsville Dome ISL mine to shut down again

During the fourth quarter of 2008, URI shut down one operating wellfield at Kingsville Dome. The two Kingsville Dome wellfields that remained in production at December 31, 2008 are expected to be depleted by the end of the first quarter of 2009. In Kleberg County, the economic downturn is leading to a slowdown at a uranium plant that's been around for two decades. In fact, the company plans to shut down temporarily over the next month and start working on restoration. (URI Mar. 11, 2009)
The uranium mining plant opened up in 1988. Ever since then, critics have asked how the company plans to clean up. With a slow down expected soon, workers have started that process.
Word about the mining coming to end concerns opponents of the uranium mines. South Texas Opposing Pollution (STOP) leaders said these mines need to be cleaned up. "They have been in the process of cleaning up in the last 20 years," said Mark Walsh, a member of STOP. "They have not cleaned out any area yet; Area 1, 2 or 3." (KIII TV3 Jan. 27, 2009)

## Startup of Rosita ISL mine delayed and shut down

On June 9, 2008, Uranium Resources, Inc. announced that there has been a delay in the startup of its Rosita wellfield as a result of a number of aquifer related technical issues.
On March 11, 2009, Uranium Resources, Inc. announced that the Rosita wellfield, which proved to be a technically challenging and therefore, higher cost operation, was shut-in during October, 2008, due to lack of economic feasibility in the current price environment.

## Production starts from new wellfield at Kingsville Dome ISL mine

Uranium Resources, Inc. announced on July 19, 2007, that it started production at Wellfield 14 located on the Company's Kingsville Dome project in South Texas. The Company expects to produce 120,000 to 140,000 pounds U3O8 [46 to 54 t U] over a one-year period from this wellfield. Total production costs are projected to fall within the range of $25 to $30 per pound.

The Company plans to bring its next wellfield at Kingsville Dome online in the fourth quarter of this year. The new wellfield should also produce approximately 120,000 to 140,000 pounds U3O8 within a twelve-month period.
The Company produced a total of 109,000 pounds U3O8 [42 t U] during the first quarter, and 136,000 pounds U3O8 [52 t U] during the second quarter 2007.

## Restart of Kingsville Dome and Rosita ISL mines delayed

"Delays in restarting production at Kingsville Dome and Rosita have continued. Kingsville was restarted in April 2006. We planned to bring on three new wellfields, one in August and two in September. Weather problems and a shortage of available drill rigs and logging trucks have pushed off the expected startup of these wellfields by at least one month. At Rosita, the shortage of drill rigs and logging trucks has delayed estimated production until the first quarter of 2007. The shortage of drill rigs and logging trucks is the result of intense industry-wide competition for exploration and development tools." (URI Sep. 19, 2006)

## Study finds URI Inc failed to restore groundwater quality after in-situ leach mining at Kingsville Dome

Kleberg County Citizen Review Board contracted this study by Dr. George Rice in which he found that Uranium Resources, Inc failed to restore water quality after mining.

Effects of URI's Kingsville Dome Mine on Groundwater Quality, Final Report, Prepared for the Kleberg County URI Citizen Review Board By George Rice, July 2006 (ALTURA)

## License renewal for Kingsville Dome ISL mine

### Hearing request granted on license renewal for waste disposal injection wells at Kingsvill Dome ISL facility

On July 14, 2004, the Texas Commission on Environmental Quality granted the hearing requests by Eleuterio & Enedelia Saenz, Kleberg County and the STOP organization on the applications by URI, Inc., for renewal of permits for two Underground Injection Control wells, WDW-247 (this well has not been constructed) and WDW-248 (constructed), which authorize the continued disposal of industrial nonhazardous waste. The wells are located at the Kingsville Dome Uranium Mine in Kleberg County, approximately eight miles southeast of the City of Kingsville, five miles east of the City of Ricardo, east of Highway 77, and adjacent to Farm Road 1118. (TEXAS COMMISSION ON ENVIRONMENTAL QUALITY, marked agenda, July 14, 2004)

## Extension of Kingsville Dome ISL mine (3rd production area)

### Texas regulator approves extension of Kingsville Dome ISL uranium mine

State regulators have given a uranium company the go-ahead to expand its mine near the small South Texas town of Ricardo, despite the protests of residents who say the operation is fouling the groundwater. The Texas Commission on Environmental Quality ruled on Feb. 22, 2006, that Dallas-based Uranium Resources Inc. could begin mining near the rural Kleberg County community. Commissioners even overruled a Texas administrative law judge who had recommended that the company only be allowed to open the new mine after it cleaned up the groundwater in two older mining areas. (San Antonio Express News Feb. 23, 2006)
> Download Texas Commission on Environmental Quality Commissioners' Marked Agenda Feb. 22, 2006 (PDF)

### Hearing request granted on application for third production area authorization for the Kingsville Dome Mine



ED_005364K_00005243-00300

On July 14, 2004, the Texas Commission on Environmental Quality granted the hearing requests by URI, Kleberg County and the STOP organization on the application by URI, Inc., for a third production area authorization for the Kingsville Dome Mine Site under existing Permit No. UR02827-001. The proposed production area authorization number is UR02827-031. The site is located in Kleberg County, approximately eight miles southeast of the City of Kingsville, five miles east of the City of Ricardo, east of Highway 77, and adjacent to Farm Road 1118. The authorization would allow injection into specified zones for the purpose of uranium production. The production zone is the Goliad formation at a depth of 420 feet to 810 feet. (TEXAS COMMISSION ON ENVIRONMENTAL QUALITY, marked agenda, July 14, 2004)

## URI plans to resume mining at Kingsville Dome

During 2004, URI plans to continue actively working towards the completion of the permitting for the Kingsville Dome property. It is anticipated that this will be complete by early 2005 allowing the commencement of production at Kingsville Dome later that year. (URI March 23, 2004)

## Kingsville Dome and Rosita ISL facilites to be placed on standby

In view of the depressed uranium market, Uranium Resources, Inc. announced that it plans to shut-in and place on stand-by its Kingsville Dome and Rosita in-situ leaching facilites in South Texas no later than the end of the first quarter of 1999. The Company will maintain certain activities at the Kingsville Dome and Rosita sites including the continuation of its ongoing restoration efforts. (URI release Nov. 16, 1998)

## Kingsville Dome ISL license violations and reportable events

### Uranium Spill - URI, Incorporated - Kingsville, Texas

"On January 24, 2000, the Licensee notified the Agency of a spill of 'bleed water' that occurred on October 26, 1999, when a feed line became disconnected from a main trunk line. A well field operator discovered a flange connection between a feed line and a main trunk line had separated resulting in a 2000 gallon (7.6 $m^3$) spill. The area was on higher ground causing the water to flow down and collect in a low area inside the fenced property. The spill covered an area of approximately 4800 square feet (446 $m^2$) and was contained onsite."
[SUMMARY OF INCIDENTS FOR FORTH QUARTER 1999, Texas Department of Health, Bureau of Radiation Control]

### Spill of Radioactive Material - URI, Inc. - Kingsville, Texas

"On June 1, 1999, the Licensee notified the Agency of a spill of approximately 9000 gallons (34 $m^3$) of restoration water containing 2.7 parts per million of uranium. The spill was due to a disconnect in the flow line from the well to the disposal pond. All spilled water was contained on-site."
[SUMMARY OF INCIDENTS FOR THIRD QUARTER 1999, Texas Department of Health, Bureau of Radiation Control]

### Uranium Spill - URI, Inc. - Kingsville, Texas

"On January 22, 1998, the Licensee notified the Agency of a uranium spill involving 15,000 gallons" (57 $m^3$) "of mine solution fluid containing 35 parts per million uranium that occurred on January 22, 1998. The spill occurred along an extraction line and was contained within the licensed area."
[SUMMARY OF INCIDENTS FOR FIRST QUARTER 1998, Texas Department of Health, Bureau of Radiation Control]

### Uranium Spill - URI - Kingsville, Texas



ED_005364K_00005243-00301

"On September 29, 1997, the Licensee notified the Agency of a uranium spill involving 5000 gallons" (19 $m^3$) "of pregnant mine solution containing 81 parts per million uranium that occurred on September 29, 1997. The spill occurred along an extraction line and was contained within the licensed area."
[SUMMARY OF INCIDENTS FOR FOURTH QUARTER 1997, Texas Department of Health, Bureau of Radiation Control]

**Uranium Spill - URI - Kingsville, Texas**

"On September 16, 1997, the Licensee notified the Agency of a uranium spill involving 3000 gallons" (11 $m^3$) "of barren mine solution containing 6.7 parts per million uranium that occurred on September 16, 1997. The spill occurred at the end of a lateral line and was contained within the licensed area."
[SUMMARY OF INCIDENTS FOR FOURTH QUARTER 1997, Texas Department of Health, Bureau of Radiation Control]

## Rosita ISL license violations and reportable events

**Uranium Spill - URI, Inc. - San Diego, Texas**

"On December 17, 1997, the Licensee notified the Agency of a uranium spill involving 7000 gallons" (26 $m^3$) "of pregnant solution that occurred on December 17, 1997. The spill occurred on the extraction side of a lateral line. The spill was contained and 2500 gallons were recovered and deposited in a disposal pond."
[SUMMARY OF INCIDENTS FOR FOURTH QUARTER 1997, Texas Department of Health, Bureau of Radiation Control]

**Uranium Spill - URI, Inc. - San Diego, Texas**

"On December 4, 1997, the Licensee notified the Agency of a uranium spill involving 7000 gallons" (26 $m^3$) "of pregnant solution that occurred on December 4, 1997. The spill occurred on the extraction side of a lateral line. The spill was contained and 3500 gallons were recovered and deposited in a disposal pond."
[SUMMARY OF INCIDENTS FOR FOURTH QUARTER 1997, Texas Department of Health, Bureau of Radiation Control]

**Uranium Spill - URI, Inc - San Diego, Texas**

"On October 13, 1997, the Licensee notified the Agency of a uranium spill involving 6600 gallons" (25 $m^3$) "of pregnant solution that occurred on October 13, 1997. The spill occurred from the extraction side of a line that was attached to a main trunk line to the plant. The spill was caused by improper fusion of two joints. The spill was contained within a licensed area."
[SUMMARY OF INCIDENTS FOR FOURTH QUARTER 1997, Texas Department of Health, Bureau of Radiation Control]

**Uranium Spill - URI - San Diego, Texas**

"On September 30, 1997, the Licensee notified the Agency of a uranium spill involving 5000 gallons" (19 $m^3$) "of pregnated solution that occurred on September 30, 1997. The spill occurred at the injection side of a lateral line and covered approximately 400 square feet. The spill was contained and deposited in a disposal pond."
[SUMMARY OF INCIDENTS FOR FOURTH QUARTER 1997, Texas Department of Health, Bureau of Radiation Control]

**Uranium Spill - URI - San Diego, Texas**



ED_005364K_00005243-00302

"On September 1, 1997, the Licensee notified the Agency of a uranium spill involving 30,000 gallons" (114 $m^3$) "of barren injection water containing 1.5 parts per million uranium that occurred on September 1, 1997. The spill occurred at a booster pump on the main barren trunk line covering approximately 1200 square feet." [SUMMARY OF INCIDENTS FOR THIRD QUARTER 1997, Texas Department of Health, Bureau of Radiation Control]

# Utah

- Daneros mine
- La Sal Mines Complex (Denison)
- Pandora Mine
- Rim mine
- Velvet mine
- White Mesa mill

> See also Issues for: New Mining Projects · Decommissioning Projects · Legislation & Regulations
> See also Data for: Deposits, Proposed and Active Mines · Old Mines and Decommissioning

## General

### Southern Nevada Water Authority blames uranium mining near Moab for uranium in Colorado River

Southern Nevada's top water official is raising concerns about "measurable quantities" of uranium showing up in the Colorado River, the region's primary source for drinking water. Southern Nevada Water Authority chief Pat Mulroy blames uranium mining, particularly near Moab. In a letter Monday to federal Interior Secretary Dirk Kempthorne, Mulroy urges the department to "carefully evaluate" the effect on water quality before authorizing new mining claims near the river. (Salt Lake Tribune June 20, 2008)

## Velvet mine, San Juan County

> View deposit info

### Anfield Resources seeks discharge permit for Velvet uranium mine

Submit comments by **Nov. 8, 2019**.
> Access: 2019 Public Notices: Water Quality: Anfield Resources-Velvet Mine (UT DEQ)

### Vanadium by-product recovery under consideration for idle Shootaring Canyon uranium mill

> View here

### Positive Preliminary Economic Assessment announced for the Velvet-Wood uranium mine project, assuming uranium price more than doubles

On June 27, 2016, Anfield Resources Inc. reported the results of its Preliminary Economic Assessment ("PEA") with regard to the Velvet-Wood Uranium Project. Velvet-Wood, as discussed herein, consists of two mine areas, located in Lisbon Valley, Utah and the Shootaring Canyon Uranium Mill, located in Ticaboo, Utah.
In the PEA, initial mineral processing will be via conventional vat or heap leaching methods conducted at Anfield's existing mineral processing facility, the Shootaring Mill, which lies approximately 180 miles from the Velvet-Wood mine area. Under this scenario, only those portions of the Shootaring Mill necessary for the final processing of pregnant leach solutions, from either a vat or heap leach facility, will be refurbished.
The PEA assumes a uranium sales price of US$ 65/lb $U_3O_8$, that is 2.5 times the current spot market price.
> Calculate Mine Feasibility

### Preliminary Economic Assessment commissioned for the Velvet-Wood uranium mine project

On Feb. 10, 2015, Anfield Resources Inc. announced that it has engaged BRS, Inc. to complete a preliminary economic assessment for the Velvet-Wood Project.

### Discharge permit renewal for idle Velvet uranium mine

Submit comments by close of business on June 30, 2014.
> View Public Notice, May 28, 2014 (Utah DEQ)

## Rim mine, San Juan County

> View deposit info

### Utah Division of Water Quality invites comment on proposed renewal of permit for water treatment plant at Energy Fuel's Rim mine

Public comments are invited any time prior to the deadline of the close of business on **June 25, 2016**.
> Download Public Notice, May 23, 2016 (PDF)
> Download Fact Sheet Statement of Basis (PDF)
> Download Wasteload Analysis (PDF)
> Download Draft Permit (PDF)

### Utah Division of Water Quality announces settlement agreement on violations at Energy Fuels' Rim mine

On June 26, 2013, Utah DEQ announced it has reached a settlement agreement with Energy Fuels Resources resolving alleged violations of the Utah Water Quality Act at the Rim mine. Energy Fuels agrees to pay a penalty of US$ 1,167.
Public comments on the proposed settlement agreement are invited prior to close of business July 26, 2013.
> Download Notice of Violation and Settlement Agreement, Docket No. I12-04

### Utah Division of Water Quality invites comment on proposed renewal of permit for water treatment plant at Denison's Rim mine

Public comments are invited any time prior to the deadline of the close of business on May 27, 2011.
> Download Public Notice, April 27, 2011 (PDF)
> Download Fact Sheet Statement of Basis (PDF)
> Download Wasteload Analysis (PDF)
> Download Draft Permit (PDF)

# La Sal Mines Complex (Denison), San Juan County, Utah

> View deposit info
> Download Utah OGM files
> View BLM Moab field office project site

## General

### Utah approves La Sal Mines expansion and directs Energy Fuels to reclaim Snowball waste rock pile

On September 2, 2020, the Utah Division of Oil, Gas & Mining issued a "Conditional Approval of Amended Notice of Intention to Commence Large Mining Operations" for the La Sal Mines Complex, La Sal, Utah. This notice combines the 4 mines into one mine: Beaver Shaft, La Sal, Pandora, and Snowball.
DOGM also informed Energy Fuels Resources (USA) Inc. of the need to reclaim the Snowball Mine. DOGM request that Energy Fuels submit a schedule, including interim steps, for reclamation of portions of the Snowball Mine no longer needed for mining operations and complete the reclamation no later than November 30, 2021. The Snowball waste rock is next to a steep, narrow dirt road on BLM land. (Uranium Watch Sep. 8, 2020)
> Download: Conditional Approval, Sep. 2, 2020 (DOGM - PDF)

### Expansion of La Sal complex uranium/vanadium mines obtains BLM and FS approval

On Feb. 26, 2018, Energy Fuels Inc. announced that it has received approval from the U.S. Bureau of Land Management ("BLM") and U.S. Forest Service ("USFS") for the expansion of its 100%-owned La Sal Complex of uranium/vanadium mines.
> Download project documents (BLM)

### Environmental Assessment for La Sal mine released for public comment

On July 5, 2012, BLM released the Environmental Assessment for the La Sal mine for public comment. The public review and comment period will end on August 21, 2012 (comment period extended).
> Download Public Notice and Environmental Assessment (BLM)

On Dec. 2, 2013, BLM announced that the Forest Service has new NEPA requirements under its 36 CFR 218 regulations. The Environmental Assessment (EA), Forest Service Finding of No Significant Impact (FONSI) and Forest Service Decision docment will be made available for a 45-day objection period. This is expected to occur in January 2014.

On September 25, 2014, the Manti La Sal National Forest posted the Environmental Assessment and a draft decision and FONSI on its Schedule of Proposed Action (SOPA) report for a 45 day objection period.
File objections within 45 days of September 25, 2014.
> Download La Sal Mines Complex Project Documents (Forest Service)
> Download Objections filed by Uranium Watch and others, Dec. 22, 2014 (927k PDF - Uranium Watch)

**U.S Forest Service sends decision on La Sal Mines Complex Environmental Assessment back to drawing board**: "On March 20, 2015, US Forest Service (USFS) ruled favorably on Uranium Watch et al.'s Objection to the La Sal Mines Complex Plan of Operations Amendment, the project EA, and the USFS draft Decision Notice and Finding of No Significant Impact (FONSI). In the 38-page decision, the Objection Reviewing Officer found that the FONSI was not supported by the EA and the project record. He instructed the Forest Supervisor to hold the issuance of the Decision Notice until all concerns and instructions in the decision have been addressed. At the end of this process, the Bureau of Land Management (BLM) will issue its final decision." (Uranium Watch Mar. 26, 2015)
> View Center for Biological Diversity release, March 26, 2015

**Activist denounces poor supervision of radon emissions from uranium mines near La Sal**

A southern Utah activist wants state regulators to be more thorough and more transparent in how they handle hazardous emissions from Utah's uranium mines. Sarah Fields, representing Moab-based Uranium Watch, told the Utah Air Quality Board this week that state regulators have failed to carry out basic duties when it comes to cancer-causing radon emissions from uranium mines near La Sal in southeastern Utah's San Juan County. Fields conceded that Denison's operations now release radon at doses lower than those considered harmful by the Environmental Protection Agency, although that hasn't always been the case. She also insisted DAQ (Division of Air Quality) doesn't have all the information it needs to ensure the mines are operating safely. As an example, she questioned if it was appropriate for DAQ to allow a vent - one that had been cited in an August 2010 notice of violation from the EPA - within a quarter-mile of the La Sal School. (Salt Lake Tribune Apr. 5, 2012)

**Denison Mines commences operation of La Sal mine without air quality approval order, no BLM plan of operation, and minimal environmental assessment**

Denison Mines Corporation (Denison) has begun the operation of the La Sal Mine, one of the mines in the La Sal Mines Complex, without an updated Plan of Operations and Environmental Assessment and without an modified Approval Order from the Utah Division of Air Quality (DAQ). (Uranium Watch June 20, 2011)

**Continuing health and safety violations at La Sal Mines Complex**

The operators of the La Sal Mine Complex, Denison Mines (USA) Corporation (Beaver Shaft Mine) received 10 citations and 2 orders, Reliance Resources LLC (Pandora Mine) received 5 citations and one order from the Mine Safety and Health Administration (MSHA) for health and safety violations in March. This is in addition to 11 citations in January, with proposed penalties of $13,372. MSHA has not yet assessed the penalties for the March citations.
Two of the March orders were issued because MSHA found hazardous conditions underground similar to previously identified hazardous conditions that had resulted in sections of the mines being closed off to workers. These included hazardous ground conditions related to scaling and support-the same type of conditions that caused the fatal accident in May 2010-and the need to wear respirators when the radon daughter concentrations exceed 1 Working Level. The mines have previously been cited for these hazardous conditions.
(Uranium Watch April 5, 2011)

Additional Information (Pandora Complex Mine ID 4200470):
> Access MSHA - Mine Data Retrieval System

**Community environmental organizations call for EIS for La Sal Mines Complex**

Uranium Watch, Canyonlands Watershed Council, Center for Biological Diversity, Glen Canyon Group of the Sierra Club, Grand Canyon Trust, and Living Rivers has called for a full Environmental Impact Statement (EIS) for the expansion of the La Sal Mines Complex, La Sal, Utah.
The groups submitted comments for the Bureau of Land Management and US Forest Service-Manti-La Sal

National Forest environmental review of the November 2010 Plan of Operations Amendment. The comments included an Environmental Protection Alternative. The mining complex is owned by Denison Mines (USA) Corporation, which also operates the Beaver Shaft. Reliance Resources LLC operates the Pandora Mine. (Uranium Watch Jan. 31, 2011)
> Download Scoping Comments - January 31, 2010 (570k PDF)

**BLM and Forest Service invite comment on planned expansion of operations at La Sal Mines Complex**

The proposed action would approve the following activities on public lands managed by BLM and FS at the La Sal Complex:

- Expansion of an existing development rock pile at the Pandora Mine;
- Temporary construction of drilling sites and access trails for exploration drilling;
- Installation of ventilation holes to provide for inflow and exhaust of air to support underground mining; and
- Compilation of activities previously approved by two existing BLM Plans of Operations, one FS Plan of Operations, and associated amendments into one Plan of Operations that will address the entire La Sal Mines Complex.

BLM's comment period ends January 31, 2011.
> View BLM announcement Jan. 4, 2011
> Download La Sal Mines Complex Documents (BLM)

The Forest Services' comment period ends March 24, 2011.
> Download La Sal Mines Complex Documents (USDA Forest Service)

## Daneros mine, San Juan County, Utah

> View deposit info
> See also: Uranium Watch Daneros Mine page

**Expansion of Daneros uranium mine obtains BLM approval**

On Feb. 26, 2018, Energy Fuels Inc. announced that it has received approval from the U.S. Bureau of Land Management ("BLM") for the expansion of its Daneros mine.
> Download project documents (BLM)

**BLM invites comment on Environmental Assessment for proposed expansion of Daneros Uranium Mine**: The Bureau of Land Management (BLM) Monticello Field Office is seeking public comment on an environmental assessment for a proposal to modify a mine plan for the Daneros Uranium Mine in San Juan County.
The proposed modifications include expanding facilities at two mine portals, adding ventilation holes and expanding the mine surface area from 4.5 acres to 46 acres. Under the modified plan, total production of uranium ore is expected to increase from 100,000 tons over seven years to 500,000 tons over 20 years. Submit comments by August 1, 2016 (Comment period extended).
> View: BLM release June 15, 2016 · BLM release July 5, 2016
> View/Download: DOI-BLM-UT-Y020-2016-0001-EA (Daneros Mine Plan Modification) (BLM)

**BLM seeks public input on proposed operating plan modification for continued development of Daneros uranium mine**: "This Modification includes components necessary to support additional mine development and mine operation beyond 2012. This Modification is designed to facilitate mineral development activities for a minimum of five and up to approximately 20 years of continued production, depending on market conditions

and other factors."
Scoping comments will be accepted by until March 14, 2014.
> Download BLM release Feb. 5, 2014 (PDF)
> Download Daneros Plan of Operations, Dec. 2013

**Daneros mine to be placed on standby for poor economics**: On Oct. 17, 2012, Energy Fuels Inc. announced that it will shift its short-term focus toward lower cost sources of U3O8 production within its asset portfolio. As a result of this revised production strategy, Energy Fuels will be placing the Beaver and Daneros properties on the Colorado Plateau on standby over the course of the first quarter of FY 2013.

> View older issues

## Pandora mine, San Juan County, Utah

> View deposit info
> Download Utah OGM files

**Mine Safety and Health Administration settles with Reliance Resources on penalties for fatal accident at Pandora mine in 2010**: Mine Safety and Health Administration (MSHA) has settled with Moab based Reliance Resources LLC for penalties associated with the fatal mine accident at the Pandora Mine on May 26, 2010. Reliance Resources operated the mine in La Sal, Utah, for Denison Mines Corporation, a Canadian company. Hunter Diehl was killed when large rock fell on him. He was manually scaling loose material from the rib when it fell.

- MSHA fined both Denison and Reliance Resources $5,000 each for failing to report the mine accident (later reduced to $3,500).
- Reliance Resources was also cited for failing to examine ground conditions. The penalty for this violation was $70,000, but it was reduced to $49,000.
- The penalty of $52,500 for not assuring that "scaling shall be performed from a location which will not expose persons to injury from falling material, or other protection from falling material shall be provided," was reduced to $36,700.
- The company was also fined $15,200 for violating the provision that "work shall not resume in the blast area until a post-blast examination addressing potential blast-related hazards has been conducted by a person with the ability and experience to perform the examination." This was reduced to $10,640.

It has takenover three years to resolve these and other contested penalties. There were 46 violations at the Pandora Mine in 2010. (UraniumWatch Oct. 31, 2013)

**Pandora mine to be shut down**: On Oct. 17, 2012, Energy Fuels Inc. announced that it will cease mining at the Pandora property during the second quarter of FY 2013, pending the depletion of its identified uranium and vanadium resources.

**Pandora mine operator fined $92,600 for fatal accident**: The Mine Safety and Health Administration (MSHA) has issued a penalty of $92,600 to Reliance Resources, LLC, for two violations from the fatal accident on May 26, 2010, at the Pandora Mine (Mine ID 4200470), La Sal, San Juan County, Utah. (UraniumWatch May 7, 2011)

**More worker health and safety violations at La Sal mines**: The January 2011 Mine Safety and Health Administration (MSHA) inspections resulted in 5 worker health and safety violations at the Pandora Mine for Reliance Resources LLC and 6 violations at the Beaver Shaft for Denison Mines (USA) Corp. All MSHA violations were associated with the failure of the mine operators to properly protect the workers from exposure

to radon daughters (short lived, highly radioactive particulates from the decay of radon) in the mines.
Both Denison Mines and Reliance Resources were cited for exposure of workers to air with concentrations of radon daughters exceeding 1.0 working level (WL) in active workings and for the failure of workers to wear respirators in areas where the radon daughters exceed 1.0 WL. Reliance Resources was also cited for improper ventilation, not posting inactive workings where radon daughter concentrations are about 1.0 WL, and failure to calculate and record complete individual exposures in active working areas with radon daughter concentrations are more than .03 WL. This followed an inspection of December 20 when Denison was fined $6,000 for exposure of workers to radon daughters above the acceptable level, improper ventilation, and failure to calculate and document worker exposure to radon daughters, or progeny.
At the beginning of December, Denison was citied for 12 other violations, some for the same violations that Reliance Resources was cited for after Hunter Diehl was killed at the Pandora Mine 2010. Denison failed to correct hazardous conditions associated with scaling and support and failed to have a competent person examine each working place at least once each shift for conditions that may adversely affect safety or health.
In 2009 Denison received 13 citations; Reliance Resources received 14; total penalties for all were $3,629. In 2010, Denison received 34 citations and orders; total penalties of $18,304. Reliance Resources received 18 citations and orders; total penalties of $2,664 (this does not include any penalties associated with the fatal Pandora Mine accident on May 26, 2010).
Denison has been ajusting its ventilation system to reduce radon emissions so that they do not exceed the standard for doses to the nearest residents, La Sal School, and road maintenance shed. It is difficult for Denison to meet both the dose standard for off-site exposures to radon and the underground worker exposure standards. (UraniumWatch March 3, 2011)
> Access MSHA - Mine Data Retrieval System (Mine ID: 4200470)

**Judge approves drilling at Pandora uranium mine in Manti-La Sal National Forest**: A federal judge will allow a uranium mining company to drill several new holes in the Manti-La Sal National Forest. Three Moab conservation groups had asked Judge Dale A. Kimball to halt the drilling planned by Denison Mines Corp. at its Pandora Mine, claiming the U.S. Forest Service permitted the project without an adequate environmental study. Uranium Watch, Center for Water Advocacy and Living Rivers argued that Denison would create radioactive air emissions and heavy metal contamination if it drills 16 exploration holes and two radon vent holes, a project approved by the Forest Service. Kimball gave more weight to Denison's environmental expert, who said there was no significant risk of environmental harm. Kimball also wrote that the Forest Service followed procedural rules when it allowed the project without environmental assessments or impact statements. (Salt Lake Tribune Sep 14, 2010)

**Groups file suit to stop expansion of Pandora uranium mine in La Sal, Utah**: Uranium Watch, Center for Water Advocacy, and Living Rivers, conservation groups located in Moab, Utah, yesterday (July 29) filed suit in federal district court in Salt Lake City to halt uranium exploration and the construction of radon vent holes on U.S. Forest Service land in the Manti-La Sal National Forest in La Sal, Utah.
The complaint filed with the United States District Court for the District of Utah challenges a decision by the Moab/Monticello Ranger District to permit the drilling of 16 exploration drill holes and 2 radon vent holes as part of the expansion of the Pandora Uranium Mine.
Radon is vented to the surface from the underground mine operations so that the miners will not breath in the radon gas and be exposed to the short-lived highly radioactive particles that are produced when radon decays. The proposed radon vents would add to the amount of radon gas and radioactive particulates released in the vicinity of the community of La Sal, on the south slope of the La Sal Mountains. In 2009, the amount of radon released from the uranium mines in La Sal jumped from 300 Curies to over 4,500 Curies, according to Denison's annual reports to the Utah Division of Air Quality. Radon is released from vents near the Beaver Shaft not far from the La Sal Elementary School. (Uranium Watch, July 30, 2010)

**Uranium miner dies in rockfall accident in Pandora mine**: A 28-year-old uranium miner from Moab died Wednesday (May 26) morning after he was hit by falling rock in the Pandora mine near LaSal, San Juan County. (The Salt Lake Tribune May 26, 2010)
Federal regulators faulted a Utah company for safety lapses in the death of a uranium miner who was killed by a large rock slab he was peeling off a tunnel wall near La Sal. A Mine Safety and Health Administration report

released Thursday (Sep. 23) said Reliance Resources LLC of Moab was cited for inadequate worker training and failing to test a tunnel wall for loose rock. The citations were rescinded after the company took corrective measures. The report says 28-year-old Hunter Diehl ("deal") of Moab was using a pry bar to pull off loose slabs May 26 when one fell on top of him. He was pronounced dead later at a hospital. Reliance Resources operates the Pandora mine for another company, Denison Mines (USA) Corp. (Business Week Sep. 24, 2010)
> Download MSHA Report of Investigation, Sep. 23, 2010 (355k PDF)

A public input period is under way to comment on an air-quality permit for the Pandora uranium mine in La Sal, San Juan County. Moab-based Uranium Watch has requested a hearing. Director Sarah Fields raised a concern about the proximity of venting to an elementary school. The deadline for written comments is July 3, 2009. (The Salt Lake Tribune June 9, 2009)
> View Utah DEQ DAQ Permits out for public comment ("Denison Mines (USA) Corp, La Sal Mine")

On Sep. 14, 2006, International Uranium Corp. announced it has reached an agreement with Reliance Resources, LLC to conduct contract mining at the Company's Pandora Mine, located near LaSal, Utah. The Pandora Mine is a previously developed mine last operated in the late 1980's. Mining activities are underway and ore shipments to the Company's White Mesa Mill in Blanding, Utah will begin in early October 2006.

## White Mesa uranium mill (Utah)

> See extra page !

# Wyoming

> View extra page

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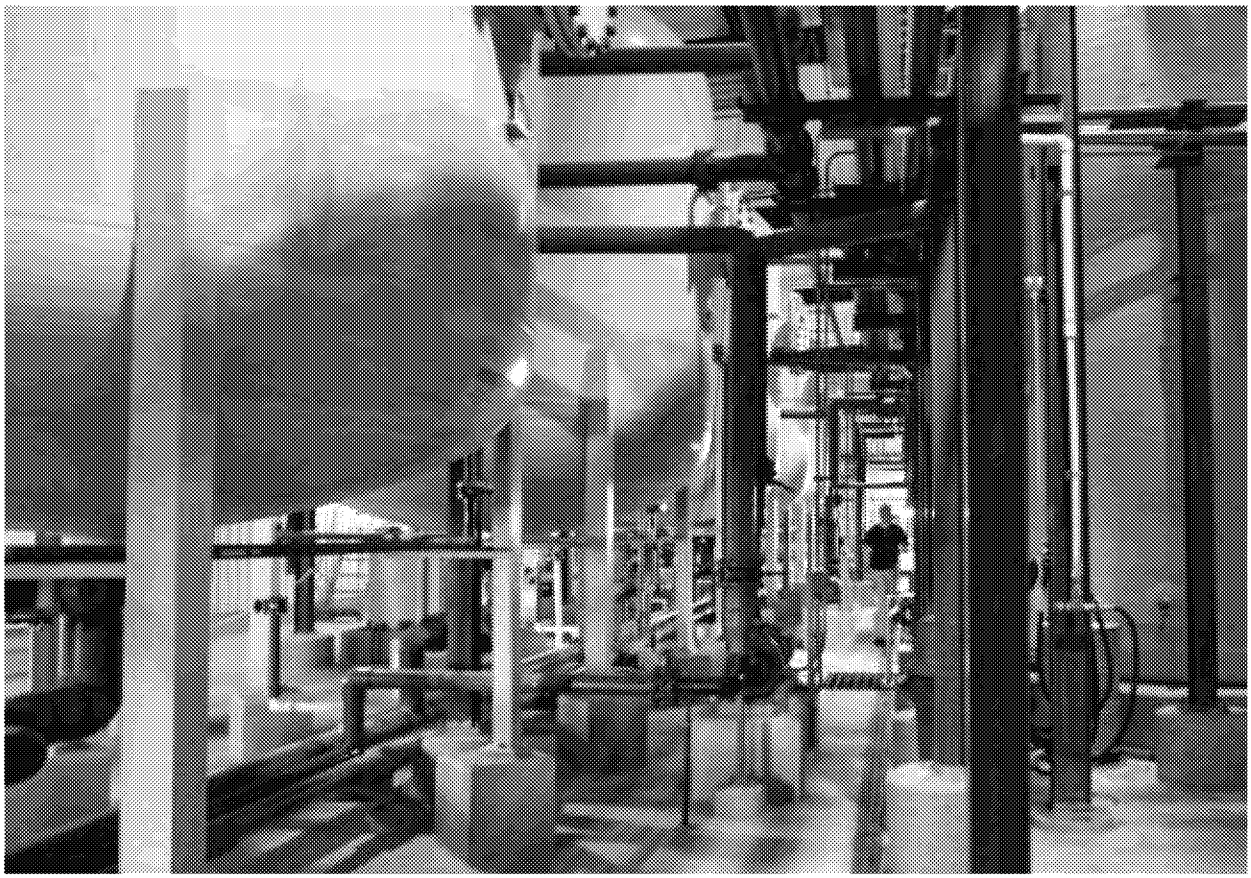
https://rapidcityjournal.com/news/leaks-spills-and-other-problems-at-in-situ-uranium-mines-across-the-country/article_694a875f-aa4e-5abd-9d23-2da9536acb73.html

FEATURED

# Leaks, spills, and other problems at in situ uranium mines across the country

Daniel Simmons-Ritchie Journal staff
Sep 23, 2013



A worker walks between tanks in the main processing facility Friday, Aug. 31, 2012, at Cameco's Smith Ranch-Highland uranium operation near Glenrock, Wyo. Smith Ranch-Highland is the largest uranium production facilit in the U.S.

Casper Star-Tribune file, Alan Rogers

Daniel Simmons-Ritchie Journal staff



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Powertech, a Canadian company that is proposing to begin mining uranium near Edgemont, has worked for years to reassure South Dakotans that its mine will not only be environmentally friendly, but that there are plenty of other mines across the country to prove that safety record.

But a closer look shows that hasn't always been true.

In the run-up to today's state permitting hearing in Rapid City, the Journal compiled a list of some of the worst environmental issues at in situ leach uranium mines across the country. The data was collected from newspaper clippings, state records, federal records, and academic reports published over the past 40 years.

The Journal sent its list to Powertech last week and asked how the company would prevent incidents that occurred at other mines. The company responded with an 8-page letter describing the mine's safety features, mitigation procedures, and how its operation would be regulated. The company also noted that the Journal didn't provide sourcing to its list and therefore it was unable to verify all of the listed problems.

Because Powertech's response was too long for print publication, the Journal has published it **online**. The Journal has also provided links to documents that formed the basis of its list.

Below is a look at those incidents, listed by mine name, the mine's location, the company involved, and what happened:

• **Willow Creek mine, Johnson & Campbell Counties, Wyo. (Uranium One):** An active mine that has operated under different companies since the late 1970s. Today it is divided between two sites: the Irigaray plant and the Christensen Ranch satellite facility. When the operation was under the ownership of Wyoming Mineral Corporation in the late 1970s and early 1980s, the state **found** the Irigaray site experienced repeated fires, migrations of injection solution in groundwater, and that basic tests were also not being performed.

In 2011, the state issued a **violation** after it was discovered that 7,000 to 10,000 gallons of sodium chloride brine was released into a dry ephemeral stream at the Irigaray site. The company took two weeks to notify the state, when notification should have occurred in 24 hours. In 2010, the state found problems with contaminants migrating through groundwater from the Christensen Ranch site. Glenn Mooney, a geologist for the Wyoming Department of Environmental Quality, sent a **letter** to the company and noted that uranium levels were "over 70 times" the maximum contaminate threshold in groundwater near the mine's permit boundary. Mooney wrote that the finding "is a major concern to WDEQ". In 2011, the state issued a violation after discovering the company was failing to properly conduct groundwater tests.

• **Bruni mine, Bruni, Texas (Cogema Mining):** A now decommissioned mine that operated through the 1970s and 1980s. Between 1975 and 1981, the state **recorded** 23 incidents of leachate spills. Between 1978 and 1981, the state also recorded four such spills of waste ponds on the mine surface or in shallow areas above the uranium deposit.

The largest leak contaminated groundwater for a year before it was found and repaired. The state also found the company was improperly storing radioactive material. In 1977, the state tried to fine the company and eventually reached an out-of-court settlement of $42,500. After retiring the mine, the company struggled to return the groundwater to its pre-mine chemical composition. The company, like many other in situ mining operators in Texas, requested that the state lower its restoration standards.

• **Clay West and Burns mines, George West, Texas (U.S. Steel):** A pair of now decommissioned mines that were run by U.S. Steel from 1975. The state **found** workers were frequently exposed to unsafe levels of radiation. An inspection in 1980 found gamma radiation levels were so high they "pegged the meter" due to problems containing uranium dust in the plant loading area. The company would later discover that uranium fluid was leaking into the ground, saturating the soil around the plant, and coating its drainage field and septic tank in uranium. In 1985, the state discovered

that workers for three companies in Corpus Christi were exposed to unsafe levels of radiation while repairing a machine for the company. Overall, due to pipe ruptures, the company reported more than 22 surface spills at the site, releasing an estimated 1,199,647 gallons of radioactive and toxic chemicals.

• **Mt. Lucas mine, Dinero, Texas (Everest Exploration):** A now decommissioned mine run by Everest Exploration. The company was given permission to dispose of untreated radioactive wastewater by Lake Corpus Christi. Between 1984 and 1986, the company irrigated the waste on a 22-acre patch of land 300 yards from the lake. In 1987, radioactivity was 47 times above normal and six times higher than allowed by the company's operating license. The state **found** half of the irrigation water had percolated into the water table, potentially endangering surface and groundwater.

• **Goliad exploration wells, Goliad County, Texas (Uranium Energy Corp):** A recently permitted but presently inactive mine in Goliad County. Two residents **sued** Uranium Energy Corp in 2008 after the company conducted exploratory drilling in the area. The lawsuit charged that the company drilled 70 exploratory bore holes but failed to close them properly, allowing storm runoff to flow into them and contaminate the county's groundwater. A group of residents say the well water in their area became slimy and discolored and only returned to normal after drilling stopped. A federal judge dismissed the lawsuit and advised the county to pursue the matter through the state courts or a state administrative body. The county filed two new lawsuits this year. The first lawsuit was filed against the Texas Department of Environmental Quality for improper testing and analysis of groundwater. The second lawsuit was filed against the Environmental Protection Agency for similar reasons.

• **Smith Ranch-Highland mine, Douglas, Wyo. (Cameco Resources):** Cameco, under a subsidiary called Power Resources, has been mining in the area since 1988 and the operation remains active. In 2007, the state discovered the company was **violating** its agreements to restore groundwater to pre-mining condition. The state also **found** that the company had experienced an "inordinate

number of spills, leaks and other releases" and that it was failing to detect, report and track spills as it should be. That included, in that year alone, a surface **spill** of 3,700 gallons of fluid containing uranium and trace minerals (although the company managed to recover 3,500 gallons). The company **also spilled** 11,600 gallons of disposal solution.

In addition, the state **found** the company was only budgeting $40 million for reclamation when the state calculated it would cost $150 million. The company **reached** a $1.4 million settlement with the state over the permit violations and doubled the company's bond from $40 million to $80 million. Despite the settlement, the state has continued to find violations on a routine basis at the mine over the past five years. From September 2008, the state has fined the company a total of $88,000 for improperly capping drill holes, incorrectly reporting its capping practices, failing to perform certain groundwater tests, and operating outside its permit boundaries. In March this year, the state issued a **violation** for the migration of injection fluid through groundwater outside the mining area, but it has not issued a fine yet.

• **Crow Butte site, Crawford, Neb. (Cameco Resources):** Nebraska's sole in situ leach mine was opened in 1991 and remains active. In 2008, a district court in Nebraska **imposed** a $50,000 penalty for violations including a surface spill and for constructing wells between 2003 and 2006 in an area that had the potential to contaminate underground drinking water. The company waited for more than a month and half to tell the state when it realized it was mining where it shouldn't.

• **Kingsville Dome, Kleberg County, Texas (Uranium Resources Inc.):** A permitted but currently inactive mine that was opened in 1988. A hydrologist commissioned by Kleberg County released a **report** in 2006 on how groundwater was effected by the mine. George Rice found that the water quality didn't meet drinking standards before mining began, but the quality had worsened in most of the site after mining and despite restoration efforts. While Rice found that no domestic wells had been affected by the contaminated water, he believed it could migrate outside of the mining boundaries if not properly restored.

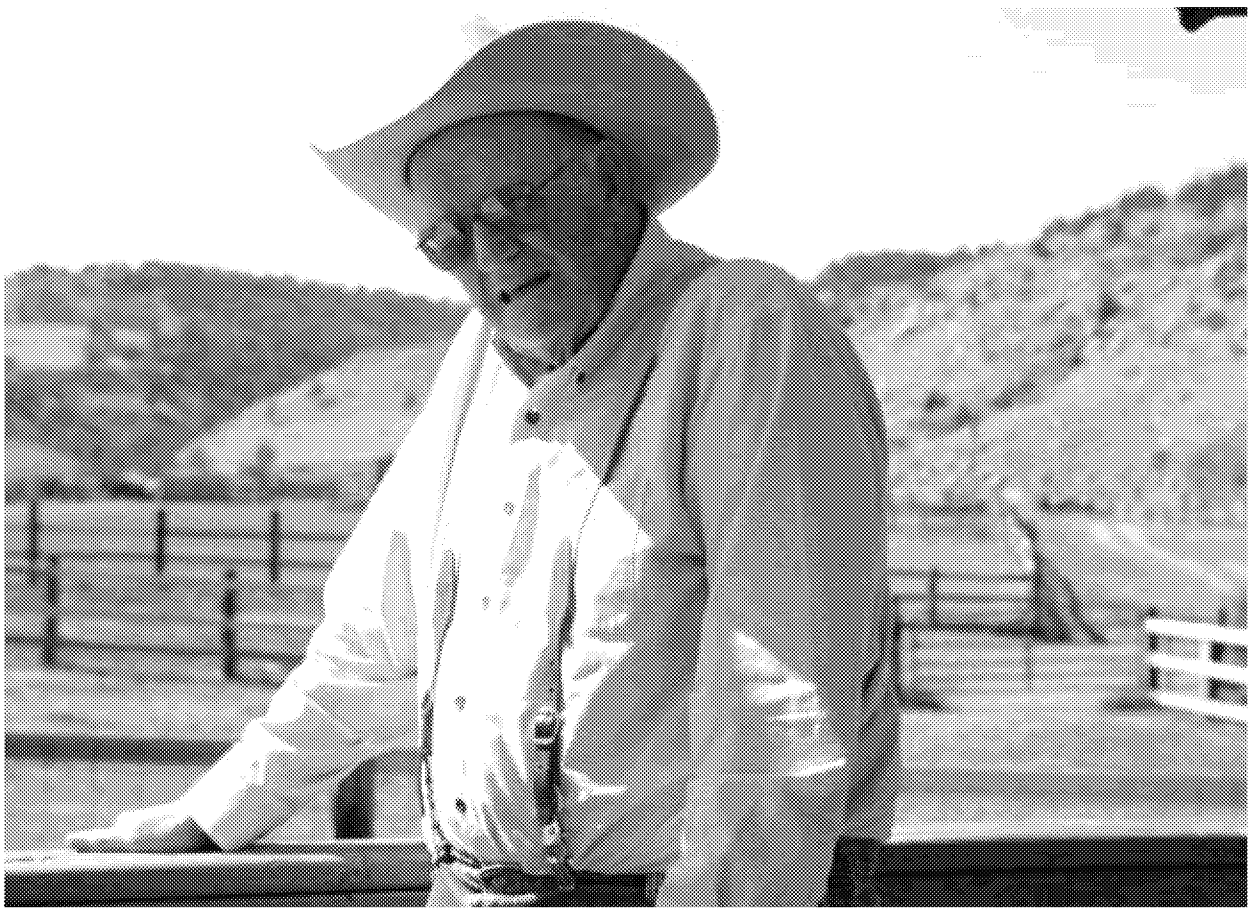
This year Rice wrote a paper, as yet unpublished, that he says shows that contaminants, particularly uranium, have moved about 1,000 feet from a production site and into a well used for livestock. Rice says while the concentration of uranium in the well was always unsafe for human consumption, but it has now tripled. He believes it will continue to spread with the groundwater's natural flow. The state of Texas acknowledges the high level of uranium, but disputes Rice's conclusion.

https://rapidcityjournal.com/news/powertech-showdown-critics-point-to-loose-regulation-and-contamination-at-mines-across-america/article_3e66956d-eab2-5910-9f93-4492b3c7ada3.html

SPOTLIGHT

# Powertech showdown: critics point to loose regulation and contamination at mines across America

Daniel Simmons-Ritchie Journal staff
Sep 23, 2013



Dayton Hyde, owner of the Wild Horse Sanctuary south of Hot Springs, is worried Powertech's proposed uraniun mine north of Edgemont could contaminate the water supply on his land.

Chris Huber, Journal staff

Daniel Simmons-Ritchie Journal staff

An "in situ" uranium mine isn't the open-pit mine that your grandparents may remember: backers say it is clean, safe, virtually hidden from view, and does not scar the earth.

For seven years that has been the promise of Powertech, a Canadian company that is proposing to build South Dakota's first in situ leach uranium mine — a $51 million project that would draw uranium from beneath the surface of the land near Edgemont.

But as the company reaches a critical stage in its permitting process, that promise has come under increasing fire from critics in South Dakota worried about the project's possible environmental impact. The result has been a tense back and forth this year between Powertech and its opponents, with each side accusing the other of spinning the truth and manipulating the facts.

To separate fact from fiction, the Journal spent the past month investigating the claims of both Powertech and project critics. The Journal interviewed more than a dozen sources, from hydrologists to regulators, from environmental lawyers to industry spokespeople, and reviewed scores of academic reports, newspaper clippings, and state records on the environmental impacts of ISL uranium mines.

The newspaper's findings include:

• While no mining venture can prevent all risk, some in situ mines have had a dubious **track record** of regulatory compliance; from a mine in Texas that exposed workers in the 1980s to dangerously high levels of radiation, to a mine in Wyoming in 2008 that earned a $1.4 million fine from the state for failing to restore contaminated groundwater as promised.

• There is consensus among federal regulators that, despite the promises of mining companies, groundwater at a mining site cannot be restored to its pre-mining condition. In every instance, regulators have had to relax restoration standards because escalated concentrations of certain chemicals, like uranium and arsenic, could not be reduced.

• There is relatively little research on the movement of chemicals, like uranium, in groundwater once mining is finished. An analysis of groundwater samples by a hydrologist in Texas this year shows the first potential evidence of uranium flowing into a livestock well from a nearby mine. The state of Texas disputes those findings.

• The regulation of in situ mining varies from state to state, but South Dakota could be **particularly vulnerable** to environmental risks due to a weakening of regulations and the state's abandonment of its rights to regulate mine operations.

Mark Hollenbeck, local project manager of Powertech, maintains that the claims against in situ mining operations are largely based around fear of the unknown.

He said in situ mining has become the preferred method to extract uranium across the country over the past 40 years, largely due to its benign impact on the environment. Rather than digging down to reach uranium as in conventional strip mining, an in situ operation instead pumps water into the ground and redraws that water, then laced with uranium, back to the surface.

That uranium is then transported to a processing plant where it is transformed into uranium rods to fuel nuclear power plants.

Hollenbeck argues that not only is the project beneficial to American energy independence, it will be an economic boon for the southern Black Hills.

"Any time you add 100 jobs in a rural area in South Dakota it's a big deal," he said. "And these aren't minimum-wage jobs, these are jobs you can raise a family with."

But critics, including an array of environmental groups and area residents, say those short-term benefits aren't worth the long-term risks.

Beginning today at the Best Western Ramkota hotel in Rapid City, dozens of attorneys, activists, and area residents will offer public testimony against Powertech's proposed mine. The hearing, held by the State Board of Minerals and Environment, is expected to last all week.

For those testifying, like Bruce Ellison, an attorney for the Clean Water Alliance, it's a showdown that he believes every South Dakotan should be watching closely.

"Hopefully we are going to show there's too many unanswered questions," he said. "Why should we put our water at risk?"

**Past in situ problems**

South Dakotans don't have to look far to see how in situ mines have operated in other communities.

While uranium mining is a niche industry, in situ mines are largely clustered around the uranium-rich lands of Wyoming. South Dakota's western neighbor hosts three of the six in situ sites currently operating in the U.S.

For in situ critics like Shannon Anderson, an organizer based in Sheridan, Wyo. for the Powder River Basin Resource Council, Wyoming's experience demonstrates the problems with in situ mining.

"I think it's important that if you're getting into this industry you know the history of what's happened in other states," she said.

Among the biggest issues, Anderson says, is the incident that led to a $1.4 million settlement the state reached with one mining company in 2008 over frequent violations.

At the Smith Ranch-Highland site, in Eastern Wyoming, the state found an "inordinate number of spills, leaks and other releases." The state also found that the company, Power Resources, was significantly under-budgeting for reclamation and that it was shirking its promises to restore contaminated groundwater.

At that mine and others in Wyoming, Anderson is particularly concerned about violations relating to what the industry calls "excursions." An excursion is an early warning signal that chemicals pumped into the ground, or loosened by the pumping

process, are beginning to drift through groundwater away from the site. When excursions are detected, in situ operations are supposed to adjust pumping methods so chemicals are drawn back.

An excursion itself does not imply that chemicals have migrated outside of the site, but critics fear that when excursions are detected, companies do not always adequately contain those chemicals, and that they have the potential to contaminate surrounding water supplies.

In 2010, a state geologist studied a long-running excursion at the Willow Creek site in Eastern Wyoming. The geologist found uranium levels were more than 70 times the maximum contamination level at the edge of the company's permit boundaries, as later reported by ProPublica, a non-profit news service.

Anderson said those types of problems suggest an industry that either has a blasé attitude toward regulations, or an inability to safely conduct operations.

"I know there are inspection and compliance problems for most of the industry," she said.

But state regulators and the industry dispute that assertion.

Nancy Nuttbrock, administrator of the land quality division for Wyoming's Department of Environmental Quality, said many of the in situ violations are for isolated incidents.

"Generally speaking, the operators are diligent about their compliance efforts," she said.

Nuttbrock said that the state's settlement with Power Resources was a rare event. She said it had sent a message that other operators should pay close attention to restoration agreements.

Marion Loomis, executive director of the Wyoming Mining Association, also said most violations within the in situ industry are for small issues.

"There were violations but most of them were leaks on the surface that could have been controlled, and should have been controlled," he said. "They weren't because they weren't restoring the aquifer or they were mining improperly. Some were paperwork violations that shouldn't happen either, but they weren't violations that harm the groundwater or the aquifer."

Anderson responded that both Nuttbrock and Loomis are not entirely accurate in their assessments.

She also said it wasn't fair to suggest there haven't been issues relating to restoration; she said the $1.4 million settlement against the Smith Ranch-Highland was closely related to the company's lax restoration efforts.

"There was definitely a component of the company putting an emphasis on mining rather than restoration," she said. "And restoration was taking years longer than anticipated, which we have seen at all of these mines."

Anderson was also skeptical that the $1.4 million fine had necessarily sent a message to the industry. She said Smith Ranch-Highland had continued to rack up violations after the fine.

According to state records, Wyoming has fined Power Resources a total of $88,000 since September 2008. The issues ranged from improperly capping drilling holes to failing to perform groundwater tests.

Asked how Powertech would avoid issues that happened at other in situ sites, Hollenbeck released a detailed response to the Journal describing the safety features at its proposed mine.

"So it's not so much you can have a perfect system that doesn't ever have an issue, it's how you handle issues," he said. "And if you have leaks, how you mitigate those."

**Can water be restored?**

But beyond how well Powertech may follow state and federal rules, what critics worry most is that those rules themselves are systemically flawed.

One of their biggest concerns relates to the restoration of groundwater. Concentrations of chemicals like uranium increase drastically in the groundwater of an in situ site during its operation. Under federal regulations, when a company has finished mining, it is required to restore groundwater to its pre-mining quality by pumping fresh water into it.

But Rich Abitz, a Cincinnati-based geo-chemist who has studied in situ operations, said that the restoration process comes with important caveats.

In every instance that state or federal regulatory authorities have overseen the restoration of an in situ site, they have relaxed their definition of "pre-mining" water quality for mining companies.

That happens, Abitz said, because full restoration of groundwater at an in situ site is virtually impossible.

"This is something that has been developed over tens of thousands of years," he said. "You can't go and disturb that chemical environment and expect that to return to its initial state in a few decades."

The Nuclear Regulatory Commission, a federal agency which plays a leading role in regulation of most in situ sites in the U.S., acknowledges that full restoration is not possible.

In a 2009 report, NRC staff reported that mines appear unable to reduce escalated levels of certain chemicals in groundwater, particularly iron, manganese, arsenic, selenium, uranium, vanadium, and radium-226. Escalated levels of those elements are generally unsafe for human consumption.

Eric Jantz, a staff attorney for the New Mexico Environmental Law Center, said another problem with in situ restoration is that data on the water's pre-mine condition is usually distorted to begin with.

Jantz said mining companies themselves do the bulk of water testing and supply that information to federal regulators. Companies tend to cherry pick data that makes groundwater appear unusable so that they can gain permits to begin mining. As a byproduct, that means pre-mine quality is rarely an accurate picture of water quality.

Jantz is fighting a long-proposed mine near Crownpoint, N.M., on behalf of local communities. Jantz said that the company behind the project, Uranium Resources, was able to earn a permit from the Environmental Protection Agency in 1989 because it convinced the agency that the existing water was undrinkable.

Jantz said while there is contaminated water on the site, the company's own data showed that there were portions that were drinkable. "Once the uranium mining begins, that water is going to be destroyed," he said.

Robert Moran, a hydro-geologist and geo-chemist, believes that Powertech's proposed site hosts better water than the company has presented in its reports to the Nuclear Regulatory Commission.

Moran has examined the company's permitting material on behalf of the Black Hills Wild Horse Sanctuary, which sits 20 miles from the site and is staunchly opposed to its operation.

Powertech says that its data shows the groundwater in the proposed site is unusable. As one metric, the company points to radon levels that range up to 1,540 times the Environmental Protection Agency's standard for drinking water.

But in detailed testimony to NRC, Moran said while the area has been contaminated by open-pit mining and past exploration of uranium in the 1950s, there are still surface and ground areas that are uncontaminated or relatively uncontaminated.

"Experience at similar sedimentary uranium sites indicates that significant quantities of uncontaminated ground water likely exist, and could be used for other livestock, agricultural, domestic, etc., uses," he wrote.

He charged that NRC had failed to make Powertech provide "statistically adequate, reliable, pre-operational baseline data" on the site's groundwater.

Powertech defended that all the groundwater information it has supplied to regulators is in step with requirements by the NRC.

"The NRC license application was accepted for detailed technical review by NRC, signifying that it met the acceptance criteria for this site characterization monitoring," the company wrote in a statement.

Asked to comment on federal findings that water can not be restored to pre-mine quality, Powertech officials said the company is committed to restoring groundwater within rules set by the NRC.

The company also reiterated that within its proposed mining area, there are no drinking water wells and that the water exceeds South Dakota health standards.

**Can it migrate?**

Opponents of Powertech's proposal maintain that all prior evidence from in situ mines suggests that concentrations of chemicals like uranium in water will escalate.

Their biggest fear is not simply that those contaminants will remain in the groundwater after mining has finished, but where they will flow after that.

For mining companies and industry regulators, that concern is easily dismissed.

The NRC said in a statement that based on its historical licensing information there is no evidence that domestic wells, livestock wells, or nearby groundwater sources have been impacted by an in situ mine.

The Texas Commission on Environmental Quality said in a statement that there is no evidence that water supplies had been contaminated outside of an in situ mine's permitted boundaries.

"Texas regulations that apply to in situ mining of uranium are designed to protect underground sources of drinking water from contamination from such mining," spokesman Terry Clawson wrote.

But environmental watchdogs contend that those conclusions are based on a lack of data.

Geoff Fettus, a senior attorney for the Natural Resources Defense Council, said that another of the flaws in federal in situ regulation is a lack of long-term monitoring.

If the companies and regulators don't continue extensive sampling at a decommissioned site, he and other environmental activists argue, no one else can.

"We don't have the resources as a federal agency does to go mine by mine and see the spread of contaminants – if any," he said.

And while state and federal regulators contend otherwise, there is evidence at least one well in the country may have been contaminated due to its proximity to an in situ mine.

George Rice, a private hydrologist based in San Antonio, Texas, has found escalated concentrations of uranium at a livestock well about 1,000 feet away from the Kingsville Dome mine in Texas. The mine began production in 1988 but is currently inactive.

Rice said that while the uranium concentrations at the livestock well he analysed have always been unsafe for humans, the concentrations have tripled since the mine began operating in the area.

Now, Rice said, the well water is unsafe for livestock too.

Rice has submitted his findings to the Texas Commission on Environmental Quality and the operator of the Kingsville Dome mine, Uranium Resources, for review.

"This is the first case that I'm aware of that contaminants from an in situ mine have moved from a property and affected a domestic well," he said.

Asked for comment on Rice's findings, the Texas Commission on Environmental Quality said it was aware of the uranium concentration at that well, but disagreed with Rice's conclusion.

In a statement, the department said the groundwater is naturally high in uranium and that, based on an analysis by Uranium Resources, the concentrations only appear elevated because of changes to sampling procedures.

But Rice said the state's argument doesn't explain the higher concentrations of uranium. He said he had already explained in his report to the state that changes in sampling procedures couldn't adequately explain such a drastic increase in uranium levels.

"It's an easy bureaucratic response that doesn't cause any trouble," he said. "So they are not rocking any boats by simply repeating what the mine says."

Rich Abitz, the Cincinnati geo-chemist who has studied in situ mines, has looked at Rice's work and believes his conclusion is sound. He also believes that similar findings would be discovered at other in situ mines if extensive sampling was done.

However, Abitz cautioned, that doesn't mean that contaminants like uranium will spread hundreds of miles with groundwater flows.

He said chemicals like uranium are mobilized because they've been oxygenated by the in situ process. When they reach an area without oxygen, they will eventually become immobile. In addition, the contaminants will disperse as they travel.

That means that the uranium from the Kingsville Dome mine will likely only travel a few miles with the natural flow of the groundwater. And, because groundwater tends to move slowly, it will take decades for the contaminants to travel that distance. It is unlikely, he said, that contaminants will reach the town of Kingsville, population 26,000, about 10 miles away.

However, Abitz said that anyone living in the immediate groundwater path of the Kingsville Dome mine, or any other in situ mine, should be concerned about the impact to their well water. In dry states like Texas where water is scarce, that is no small issue. "The thing is," he said, "you have destroyed a large volume of water."

**A project in motion**

For Lilias Jarding, an organizer with the Clean Water Alliance, that risk of groundwater contamination isn't worth taking.

Although Powertech's proposed site is in a rural area of ranch land, and migration of contaminants might potentially reach only a few miles outside of the site, she said that could still make dozens of wells unusable for generations.

Jarding pointed to one of the company's permit applications, which showed 43 livestock wells and 18 domestic wells in a 1.2-mile radius of the site.

But Jarding believes the stakes at this week's permit hearing, where she will be testifying, are bigger than that. If the project is approved, Jarding believes it will open the floodgates for other mining companies interested in uranium deposits in the Black Hills and east of the Missouri River.

"It's potentially an issue for the whole state in terms of control of our water," she said.

Hollenbeck maintains that those concerns are groundless. He said there is still no confirmed evidence that contaminants have spread from an in situ uranium site into neighboring water supplies. He also reiterated that opponents are overstating the quality of the groundwater in the immediate site.

"This pristine water?" Hollenbeck said. "This is not pristine. This is lousy quality water."

As Powertech's representatives sit down in the same room as opponents this week for permit hearings, Hollenbeck said he's confident that the company will cut through the spin.

"When we go to hearings and use facts and science," he said. "You are going to find out most of what they are saying is not true."

## This week's permit hearings

State Board of Minerals and Environment hearings:

Sept. 23: 10 a.m. start the first day, large-scale mine permit at the Best Western Ramkota Hotel and Conference Center in Rapid City in the Sylvan I and II rooms.

Public testimony will occur between 10 a.m. and noon on this day only.

Sept. 24 to 26: Case between Powertech and opponents continues each morning at 8:30 a.m. at Best Western Ramkota Hotel and Conference Center.

Sept. 27: Case between Powertech and opponents continues at 8:30 a.m., at the Rushmore Plaza Civic Center's Alpine Ponderosa Room, in Rapid City.



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Argus Leader.

NEWS

# Ex-federal scientist at center of uranium fight

**Jonathan Ellis** jonellis@argusleader.com

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It was billed as an informational meeting. A chance for Black Hills residents to learn more about a controversial proposal to mine uranium near Edgemont.

But when the meeting in Hot Springs ended on the night of Feb. 7, 2013, project opponents felt they had been snowballed with a sales pitch for the mine. Mark Hollenbeck, the project manager for mining company Powertech USA, had given a glowing appraisal of the project. Benjamin Snow, president of the Rapid City Economic Development Corp., touted uranium and energy production as a boon to the Black Hills.

Of particular concern to opponents was a presentation by Ray Johnson, a scientist with the U.S. Geological Survey who had been studying the Dewey-Burdock site on behalf of the Environmental Protection Agency. Johnson's half-hour presentation left mining opponents questioning whether he and the federal government were on the side of Powertech.

"I remember making the comment when I left that [Johnson] and Ben Snow must have been on the payroll of Powertech, because they were really selling snake oil at the meeting," said mining opponent Rick Summerville in an interview last week.

Project opponents eventually filed ethics complaints with USGS regarding Johnson.

The *Argus Leader* filed a Freedom of Information Act request last year for emails that Johnson received or sent about the Powertech mining proposal at Dewey Burdock. Powertech's bid to mine at the site of an old uranium operation has been among the most contentious issues in South Dakota in years. The company is currently trying to acquire federal and state permits for the project.

The *Argus Leader*'s FOIA request resulted in the release of hundreds of pages of emails to and from Johnson. Among the findings in those emails:



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■A pro-Powertech organization, the Southern Hills Economic Development Corp., hosted the Hot Springs meeting and a second one that occurred in May in Custer. The organization, which includes Hollenbeck on its board, reimbursed the federal government for Johnson's expenses to travel to the meetings.

■The emails include several to and from Powertech executives. They show that Johnson had a cordial relationship with Powertech's leadership. At one point, Powertech's president recommended Johnson as a speaker for a workshop on uranium recovery hosted by the National Mining Association.

■While Johnson was friendly with Powertech's leadership, there is no evidence that he provided a biased study. The emails show that Johnson struggled with the bureaucratic hurdles at USGS to get his reports edited and approved for publication. Those hurdles are meant to ensure that USGS's reports are based wholly on science.

Johnson left the federal government shortly after his study of the Dewey-Burdock site was finished. He now works as a scientist for a company in the uranium industry.

In an email to the *Argus Leader*, Johnson said that he has never received money from Powertech. An agreement between the company and USGS stipulated that Powertech would provide the USGS with access to wells and core samples, but it barred any monetary exchange.

"The goal in all of my research and presentations was to provide unbiased scientific information to all stakeholders," he said. "Unfortunately, not everyone has agreed with the 'unbiased' part."

**The Hot Springs meeting**

The study of groundwater and the chemical composition of the Dewey-Burdock site was almost complete when Johnson, in January 2013, received an invitation from Cindy Turner, then the director of the Southern Hills Economic Development Corp., to attend an informational meeting in Hot Springs. The two already had talked by phone when Turner sent the formal invitation by email.

"We would like to invite you to speak about in situ mining, what you have observed at the Powertech mining location, and how the process is regulated and monitored," Turner wrote. "It is our intent [sic] have a meeting that will present factual and understandable information to the public regarding this project."

Turner also offered to pay Johnson's expenses to make the journey from Denver. But that required approval from the USGS ethics office. Johnson sent an email to Nancy Baumgartner, a deputy ethics counselor in Reston, Va., asking for permission to accept Turner's invitation to pay his expenses.

"This is a great opportunity for the USGS to provide our unbiased science to the local community," Johnson wrote to Baumgartner. Baumgartner replied a few hours. She approved Southern Hills' offer to pay Johnson's expenses.

The 30-minute presentation ultimately landed Johnson in the middle of the controversy surrounding Powertech's proposal.

Hollenbeck had preceded Johnson during the meeting, which was attended by about 100 people. On a few occasions, Johnson referred to Hollenbeck's presentation, as if verifying certain aspects of what Hollenbeck had said. Johnson described the in situ recovery mining technique, in which oxyginated water is pumped into the ground to dissolve uranium and how that uranium-laden water is then pumped back to the surface and extracted. He also described the monitoring wells that surround the mines, which are used to detect contaminated water that might be escaping from the mining site.

But Johnson also pointed out some of the risks associated with ISR mining. About 11 minutes into his presentation, he noted there were no guarantees that an operation wouldn't generate excursions of mining fluids.

Later, he referred to a study of water quality at former ISR facilities. The study, he noted, showed that in some instances, it's difficult to get groundwater quality back to pre-mining levels.

"A lot of things we do as humans, it's not no impact," he told the audience. "There is some impact. I just want to give you an idea of what's the scale, what's the potential impact. My job is not to recommend what is good or bad. It's just to let you know that this is what looks reasonable, and this is what might be expected."

Despite those warnings, opponents came away from the meeting convinced that Johnson was on Powertech's side. They found it galling that he dismissed concerns that the aquifer in which mining would take place wasn't connected to aquifers used for drinking water. Johnson also had told the audience that given the geologic features of the area, it would take 10,000 years for groundwater to migrate from the mining site to Edgemont.

They also were upset that the slides Johnson used included the USGS logo, which made it seem as if the federal government was endorsing the project.

Jillian Anawaty, who recorded the presentation, said she felt that Johnson and the others had given a best-case scenario for mining in which nothing goes wrong.

"That's not reality," she said last week.

Powertech opponent Jim Petersen was not at the meeting, but he said he started receiving emails about it as soon as it was over.

"People perceived the federal government was blessing this project in a very, very positive way," he said.

The *Rapid City Journal* had covered the meeting. The paper's story indicated that the proposal had been pitched as a positive by some of those who participated.

Johnson was concerned that it appeared as if USGS was touting the project as a positive. On Feb. 11, he emailed a link of the story to a superior at USGS. He indicated in his email that his talk had been vetted by a colleague for any "red flags." He noted that "naysayers" — those critical of the mining proposal — were making negative comments about the meeting and the meeting's sponsor.

"Just wanted you to be aware of this article, in case we get any inquiries," he wrote.

**Pleased at Powertech**

While opponents fumed about the meeting, Powertech officials thought it had gone off well. In particular, they liked Johnson's presentation.

On Feb. 20, Powertech spokeswoman Michelle Brich — sister of Sen. Mike Rounds — emailed Johnson for a copy of the talk. Johnson responded that he couldn't release it until it had been cleared for publication.

"No hurry," Brich responded. "It was a good presentation and appreciated."

On March 11, Johnson sent an email to Richard Clement, Powertech's president and CEO. On Feb. 5, Clement had emailed Johnson, recommending him as a speaker for a National Mining Association event later that year. In his March email, Johnson indicated to Clement that he could no longer be a speaker because the USGS was refusing to pay his expenses. The USGS was cutting expenses because of sequestration and budgetary wrangling between the president and U.S. House.

Clement responded that day: "Thanks Ray for the note. It's too bad that it is hard to figure out what is important in this administration. Anyway, you did a great job at the meeting in Hot Springs. Maybe when the budget negotiations are complete, we can get back to normalcy."

In an interview last week, Clement said they had liked Johnson's work over the preceding three years.

"We saw the output of his work, and we liked it enough to ask him to be a speaker," said Clement, who recently retired as president and CEO but remains on the Powertech board.

Johnson's conclusions were good for Powertech, Clement said. Those who deny that reality, he added, are simply against mining.

"It was very favorable," Clement said. "The project's pretty simple."

For those who favored the project, the Hot Springs meeting was deemed a success. By April, Turner and Powertech officials were planning another presentation, this time in Custer. The meeting took place in May, and Johnson was again a featured speaker.

About a week later, the USGS published a report that Johnson co-authored. The report analyzed the composition of core samples taken by Powertech at the proposed mining site.

On May 28, Johnson sent an email to Jim Bonner, Powertech's vice president of exploration, alerting him that the report had been published.

"Nothing too surprising if I recall correctly," Johnson wrote, "but the vanadium data (and other metals) will hopefully be useful for you."

He ended the email with "Cheers, Ray."

Bonner responded later that date, thanking Johnson for the link to the report.

"It sounds like your presentation at Custer went very well," Bonner wrote. "We keep getting closer and closer, one of these days ..."

**Opponents want explanation**

In September, the State Board of Minerals and Environment started hearings on Powertech's mining permit. Johnson was not present. Opponents demanded that he be forced to testify and explain his contention that mining would not cause cross contamination in the region's aquifers. A lawyer for Powertech accused one opponent of slandering Johnson.

The *Rapid City Journal* captured the exchange in an article. Robert Moran, a Colorado-based hydrologist working for opponents, emailed a copy of the story to Johnson and his superiors. Moran wrote that comments made by Powertech's lawyer "are technically irresponsible and reflect very poorly on the USGS and Dr. Johnson."

Johnson did not respond to Moran.

In an interview last month, Moran said he's critical of Johnson, Powertech and others studying the proposal because they are relying on baseline water quality assessments that in his view are flawed. Those baseline water samples already are contaminated from uranium mining that took place at Dewey-Burdock during the 1950s, 1960s and 1970s. Moran thinks it would be more appropriate to establish baselines of what the water was like before mining ever took place there.

He also noted that thousands of bore holes have been drilled at the site over the decades, and a large percentage were never filled. Those holes have created "vertical pathways" between the various aquifers, which would make those used for drinking water more susceptible to contamination if mining occurs.

Moran, who worked for the USGS in the 1970s, didn't approve of Johnson participating in the Hot Springs and Custer forums, which he described as "traveling PR shows" for Powertech.

"You've got a guy doing a dog-and-pony show for a mining company, and he's listed as a survey person," Moran said.

At the same time that mining opponents were attacking Johnson during the permitting hearing in September 2013, emails show that Johnson was applying for a job in the private sector. Many of Johnson's emails alluded to budget constraints, and funding for his study at Dewey-Burdock was eventually eliminated.

Eventually, Petersen and another Powertech opponent, Rebecca Leas, filed ethics complaints with USGS regarding Johnson. In January 2014, Petersen spoke with Baumgartner, the ethics officer who had approved the request to allow Southern Hills to pay Johnson's expenses. By then, Johnson already had departed USGS, but his conclusions still were being used by Powertech and its supporters.

Petersen said he was satisfied that Baumgartner didn't understand the relationship between Southern Hills and Powertech.

"My impression of her was she was trying to the right thing," he said.

Last month, Baumgartner told the *Argus Leader* that she does review sponsoring organizations that request to reimburse USGS scientists for possible conflicts. But in the case of Southern Hills, she said it appeared to be just another economic development organization.

"I know now what the issues are, but I honestly don't know how we would have determined that there was this relationship," she said.

In his email to the *Argus Leader*, Johnson said his talks were approved and followed USGS rules and procedures.

"For those talks, neither the Southern Hills Economic Development Corp. or Powertech provided input into the content of my talk in any way," he said. "Given all of this, the entity that pays for travel expenses is irrelevant for the USGS employee, but may not be irrelevant in the minds of some opponents."

He also added that ISR mining has the potential to have less environmental impacts than the open-pit mining that started at Dewey-Burdock in the 1950s.

"However," he added, "prudent caution still needs to be exercised in the protection of groundwater resources. The exact way to provide this protection is often very site specific and is not always easy to get agreement from all of the nearby stakeholders."

**The Dewey-Burdock project**

Powertech USA has been working for years to reopen the Dewey-Burdock site 15 miles northwest of Edgemont to renewed uranium mining.

Mining was conducted there in the 1950s and 1960s, and it also was the site of a uranium processing facility. All of it was decommissioned, and the site was cleaned up through the 1980s. Edgemont has been struggling economically ever since.

Unlike the previous open pit mines, Powertech wants to use in situ recovery mining. Under this process, oxygenated water is pumped into an ore body. The dissolved uranium is pumped back to the surface and extracted into yellow cake. Water is returned to the ore body and the process continues.

There is strong support in the community for the project. But others fear that uranium and other toxic metals could be released from the mining area into local groundwater supplies.

The opponents have been fighting the project at every turn.

For Powertech, it's been slow going. The company has been at it for years, but mining still appears to be a long way off.

The company has a license from the Nuclear Regulatory Agency, said Powertech Chief Operating Officer John Mays, but it still must get permits from the Environmental Protection Agency and the state for mining and water.



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## Ground Water

An overview of the ground-water framework is presented in this section of the report. Additional information is presented in a subsequent section of the report describing the ground-water resources.

The hydrologic setting of the Black Hills area is schematically illustrated in figure 30, and the distribution of the hydrogeologic units was presented previously in figure 19. The major bedrock aquifers in the Black Hills area are the Deadwood, Madison, Minnelusa, Minnekahta, and Inyan Kara aquifers. Minor bedrock aquifers occur in other units, including confining units, due to fracturing and interbedded permeable layers. Infiltration of precipitation on outcrops is the primary source of recharge to most bedrock aquifers. The unconsolidated units, which includes alluvium and **colluvium**, are considered aquifers where saturated.

***The major bedrock aquifers in the Black Hills area are the Deadwood, Madison, Minnelusa, Minnekahta, and Inyan Kara aquifers.***

Many of the sedimentary units contain aquifers, both within and beyond the study area. Within the Paleozoic rock interval, aquifers in the Deadwood Formation, Madison Limestone, Minnelusa Formation, and Minnekahta Limestone are used extensively. These aquifers are collectively confined by the underlying Precambrian rocks and the overlying Spearfish Formation. Individually, these aquifers are separated by minor confining layers or by low-permeability layers within the individual units. Extremely variable leakage can occur between these aquifers (Peter, 1985; Greene, 1993).

Confined (artesian) conditions generally exist within the aquifers, where an upper confining layer is present. Under confined conditions, water in
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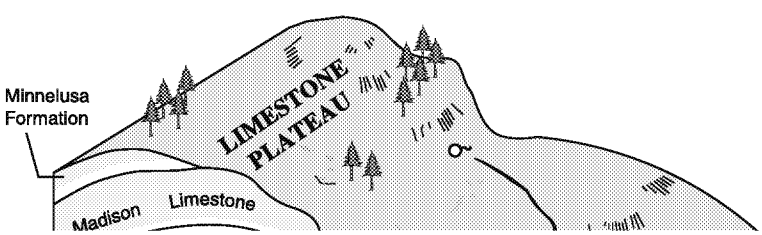
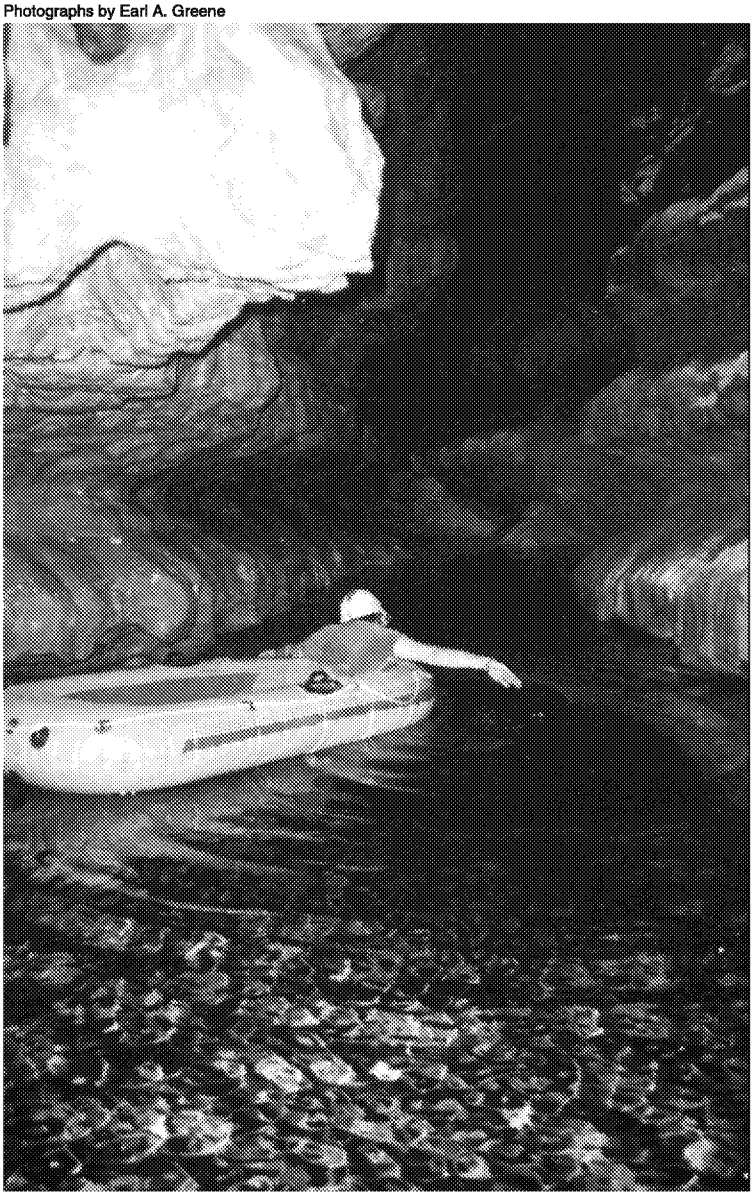



EXPLANATION

Photographs by Earl A. Greene



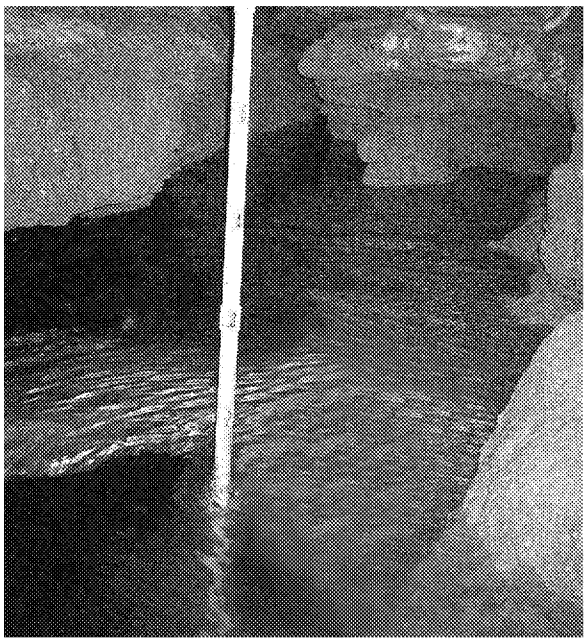


**Figure 31.** Large solution openings, such as these in the Madison Limestone, provide conduits that store and transmit large volumes of water. Six large lakes, including Windy City Lake in the left photograph, have been discovered in Wind Cave about 500 feet below land surface. In the right photograph, the staff gage measures the water depth, which is about 1½ feet deep in a cave lake near Rapid City.

extensive **secondary porosity** and permeability. The entire Madison Limestone and the Englewood Formation were included in the delineation of the Madison aquifer for this study. Thus, in this report, outcrops of the Madison Limestone and Englewood Formation (fig. 19) are referred to as the out-

Minnelusa aquifer receives significant recharge from streamflow losses and precipitation on the outcrop. Streamflow recharge to the Minnelusa aquifer generally is less than to the Madison aquifer because much streamflow is lost to the Madison aquifer before reaching the outcrop of the Minnelusa

https://rapidcityjournal.com/news/local/full-fix-unlikely-for-failed-oil-well-near-wasta/article_6cf0efa9-92a6-5b78-8a3c-f81bcec93c5e.html

# Full fix unlikely for failed oil well near Wasta

Scott Waltman Journal correspondent
Jan 23, 2017

An oil derrick stands along the horizon southwest of Wasta in 2013 as an RV travels past on Interstate 90. The financial fallout from the failed drilling operation is affecting local firms and the state.

Journal file

Scott Waltman Journal correspondent

PIERRE | The drawn-out saga of a failed attempt to drill for oil on land near Wasta appears to have come to an end, but the drill bit stuck in the earth may never be removed and the well may never be fully capped.



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The state Board of Minerals and Environment decided last week to take what's left of more than $2 million that was invested in an attempt to dig an oil well near Wasta in eastern Pennington County.

Board members approved oral rulings and findings by acting Chairman Bob Morris that the well was improperly capped.

As a result, the state Department of Environment and Natural Resources will get two surety bonds jointly worth $130,000.

The findings will be put in writing and are expected to be approved at the board's next meeting. That will likely be March 16.

Since no objections are expected, that's little more than a formality.

Leon Somsen of Yankton is essentially the last man standing in the failed venture. He consented to forfeiting the two certificates of deposit and to the revocation of a drilling permit issued to Quartz Operations.

While testifying, he had the look of a man who just wanted a discouraging process to end.

"Quartz Operations never made any money," he said, adding that it doesn't have any equipment either.

When questioned, he said he initially invested $300,000.

In spring 2013, when the well was being dug about 45 miles east of Rapid City, investors had ponied up more than $2 million combined and were still running short, Somsen said.

Mike Lees, a hydrologist with DENR's minerals and mining program, detailed the agency's history with Quartz:

The endeavor began in November 2012, when Quartz initiated contact with DENR about digging the well. That same month, an initial $20,000 bond was submitted.



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The plan was to probe to 9,700 feet through a dense layer of pre-Cambrian rock in hopes of striking oil.

On March 5, 2013, two drilling permits were deemed complete. Six days later, the state requested a second $110,000 after DENR officials expressed concerns about the well and whether it could succeed.

It did not.

Ultimately, the digging of one well — Northern Points 1 — was approved and drilling started in April 3, 2013.

Trouble followed soon after.

By April 5, the bore was 4,800 feet deep. But then a drill bit broke about 2,760 feet below the surface, after going through several aquifers.

While attempting a repair, Quartz broke another pipe with a larger diameter.

On May 11, the company attempted to plug the well without state authorization, and the well collapsed on itself at 1,130 feet. The next day, Quartz pulled the well, again without authority.

From then, Lees said, Quartz had a year to restore the surface. The May 2014 deadline was missed, but Quartz graded the area in September 2014 and restored vegetation in June 2015, he said.

Still buried in the ground are the drill bit and a sizable stretch of drill pipe.

There is an upside to the debacle, though.

Previously, DENR officials were concerned about the intermingling of water from different aquifers because of the drilling.

The top of Minnelusa Aquifer is roughly 3,900 feet below ground. About 800 feet below it is the Inyan Kara Aquifer.



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Lees testified that the Inyan Kara Aquifer, which is the source of Wall's water and is tapped by other wells in the area, is of better quality. But, he said, any water that might have seeped into it from Minnelusa would be minimal and would flow no farther than 1,400 feet in 50 years.

Derric Illes, state geologist, echoed those comments. He said the water would flow away from the nearest well, and even if it somehow reached it, any Minnelusa water would be highly diluted.

Lees said the improperly capped well is a compliance issue that merits the forfeiture of the bonds and drilling license, but is not a significant environmental problem.

He said the DENR estimates it would cost $2 million to plug the well by digging another hole, then boring laterally. But he's skeptical it would work and said it's certainly not worth the cost.

Lees said he doesn't even know if the Minnelusa and Inyan Kara aquifers are interacting.

So DENR will take the $130,000 and use it for whatever future needs there are at the site of the Wasta well.

Steve Blair, assistant attorney general representing DENR in the case, said he could have subpoenaed other Quartz investors who are out of state, but that is a complex process that just wasn't worth it.

He agreed with a board member who summarized the situation as "what's done is done."

All six board members voted to seize the bonds and pull Quartz's drilling license.



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https://rapidcityjournal.com/news/local/state-taking-130k-from-failed-wasta-oil-driller/article_4c5ead29-b352-588e-aa5c-e1e3261dbb93.html

FEATURED

# State taking $130K from failed Wasta oil driller

Seth Tupper
Mar 17, 2017

An oil derrick stands along the horizon southwest of Wasta in 2013 as an RV travels past on Interstate 90. The financial fallout from the failed drilling operation is affecting local firms and the state.

Journal file

Seth Tupper

State taking $130K from failed Wasta oil driller SHARE THIS

A state board has t en final action to capture $130,000 from a failed oil-drilling company, while knowledging that an open borehole left deep in the earth near Wasta could be polluting underground water.

The Board of Minerals and Environment met by teleconference Thursday and approved the findings of fact, conclusions of law and order in the case of Quartz Operations LLC. The order revoked the company's oil and gas permit and required the company to forfeit $130,000 worth of bonds held in certificates of deposit at a Pierre bank. The money will be applied to any future expenses at the company's failed drilling site, according to past testimony in the case.

The amount of the forfeited bonds pales in comparison to the estimated $2 million that would be needed to plug the aquifers penetrated by the company's borehole.

There is no plan to undertake such an effort, though, because of past expert testimony indicating that the environmental impact to the aquifers is likely minimal and a plugging operation might be impossible.

Quartz Operations was registered as a corporation in November 2012 by Natali Ormiston, of Deadwood. The company obtained state permits in March 2013 to drill two wells in eastern Pennington County, despite concerns expressed by the state Department of Environment and Natural Resources.

"The Department felt that the location, depth, and target formation of the proposed wells, coupled with Quartz's lack of experience in the oil and gas field, suggested a higher than typical bond amount should be set," said the findings of fact.

The company had submitted a $20,000 bond with its application, but the Board of Minerals and Environment required an additional $110,000 as a condition of issuing the permits.

Drilling of the first well began in April 2013 with a goal of reaching 9,700 feet, but the company lost drilling fluid circulation after hitting sediment at about 4,800 feet.

The drillers attempted to plug the area where fluid circulation was lost. The entire 4,800-foot drill string was moved in and out of the hole multiple times. On the third attempt, the bottom of the drill assembly stuck at 2,760 feet.

Later, the company tried and failed to retrieve the stuck drill stem, leaving a 150-foot section in the borehole.

The company also attempted to plug the well but failed when the borehole collapsed at about 1,130 feet. The company then plugged the upper portion of the well with cement structures and reclaimed the surface area with vegetation.

The second well was never drilled, and the permit for that well expired.

The unplugged portion of the first well's borehole could provide a pathway for upward flow of Minnelusa Aquifer water into the Inyan Kara Aquifer. That's problematic, because the Minnelusa is believed to have more total dissolved solids than the Inyan Kara. In other words, the Minnelusa could be flowing into the Inyan Kara and degrading the Inyan Kara's water quality.

The DENR said it does not have sufficient data on the Minnelusa Aquifer in the area of the well to precisely estimate its water quality. But the department estimates that the worst case scenario might be an average of 20,000 milligrams of total dissolved solids per liter. That is 20 to 40 times higher than the level of dissolved solids in the Inyan Kara Aquifer, which is 500 to 900 milligrams per liter.

The findings of fact said that if water does flow from the Minnelusa into the Inyan Kara, it is estimated that the water would not move faster than 28 feet per year, or 1,400 feet over a 50-year period.

DENR officials have said they will monitor water wells in the area.

Contact Seth Tupper at **seth.tupper@rapidcityjournal.com**

**Seth Tupper**
Enterprise Reporter
Enterprise reporter for the Rapid City Journal and author of "Calvin Coolidge in the Black Hills."

**State taking $130K from failed Wasta oil driller**

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**Crawford, Nebraska 69339-0169**

**(308) 665-2215**
**(308) 665-2341 – FAX**

September 11, 2012

CERTIFIED MAIL
RETURN RECEIPT REQUESTED

Attn: Document Control Desk, Deputy Director
Decommissioning and Uranium Recovery Licensing Directorate
Division of Waste Management and Environmental Protection
Office of Federal and State Materials and Environmental Management Programs
Mailstop T8-F5
U.S. Nuclear Regulatory Commission
Washington, DC 20555-0001

Subject: Source Materials License SUA-1534
Docket No. 40-8943
Evacuation Due to Threatening Wildfires

Dear Deputy Director:

On August 31, 2012, at 1530 hours a call was received by the Dawes County Sheriff's Office ordering an evacuation of the mine site due to threatening wildfire to the east of the mine. Calls were immediately made to Ron Burrows (voice message), Project Manager and the NRC 24 Hours Operations Center to inform them of the evacuation. The Operations Center indicated they would place a follow-up call to Mr. Burrows. A voice message was also left with Lindsey Phillips the site's Program Specialist with the Nebraska Department of Environmental Quality (NDEQ). During the evacuation, a crew of five Crow Butte employees remained on-site for security purposes.

On September 1, 2012 at 1700 hours the evacuation order was lifted. The mine was re-started on September 2, 2012 at 0700 hours. The 24 Hours Operations Center and the NDEQ were notified of the re-start at 0700 hours on September 2, 2012.

During the evacuation, all source material on the site was kept under 24 hour surveillance. The wildfires did not enter the licensed area and as a result there were no releases to the environment.

This report is submitted in compliance with License Condition 12.2 of Source Materials License SUA-1534.

FSME20

If you have any questions or concerns on this matter, please do not hesitate to call me at 308-665-2215 ext. 114.

Sincerely,

Larry Teahon

Larry Teahon
Manager, Safety, Health, Environment, and Quality

Enclosures: As stated.

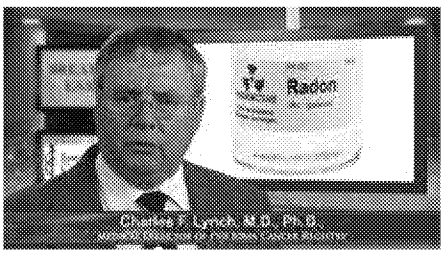
cc: Ron Burrows - NRC
Lindsey Phillips - NDEQ
CBO - File
ec: CR - Cheyenne

An official website of the United States government.

# Health Risk of Radon

## "Do you know about radon?"

Dr. Bill Field at the University of Iowa and the Iowa Cancer Consortium have prepared "Breathing Easier" to help educate physicians on the dangers of radon and the link between the radioactive gas and lung cancer. Watch the videos! EXIT




Charles Lynch, M.D., medical director of the Iowa Cancer Registry, hosts the video and asks other physicians the simple question: "Do you know about radon?" Dr. Lynch stresses physicians' vital role in delivering information on radon to their patients.

See also:

- Radon Media Campaigns
- Basic Radon Facts
- A Guide for Health Care Providers - Reducing the Risk From Radon: Information and Interventions EXIT

*This publication was supported in part by grant number XA-83576001 from the U.S. Environmental Protection Agency.*

## Learn More About Lung Cancer



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The following sources provide a wide range of good information about lung cancer, prevention, and treatment.

- American Cancer Society EXIT
- American Lung Association EXIT
- National Cancer Institute EXIT ; Radon and Cancer - National Cancer Institute Fact Sheet EXIT
- Memorial Sloan-Kettering EXIT
- Web MD - Slideshow: A Visual Guide to Lung Cancer EXIT

**On this page:**


- Exposure to radon causes lung cancer in non-smokers and smokers alike
- Radon risk if you smoke
- Radon risk if you have never smoked
- Studies find direct evidence linking radon in homes to lung cancer
- Biological Effects of Ionizing Radiation (BEIR) VI Report: "The Health Effects of Exposure to Indoor Radon"
- 2003 EPA Assessment of Risks from Radon in Homes
- The U.S. Surgeon General issues national health advisory on radon
- World Health Organization's international radon project
- Radon-related lung cancer deaths compared to other select cancers


# Exposure to Radon Causes Lung Cancer In Non-smokers and Smokers Alike

**The Facts...**

- **Lung cancer** kills thousands of Americans every year. Smoking, radon, and secondhand smoke are the leading causes of lung cancer. Although lung cancer can be treated, the survival rate is one of the lowest for those with cancer. From the time of diagnosis, between 11 and 15 percent of those afflicted will live beyond five years, depending upon demographic factors. In many cases lung cancer can be prevented.

- **Smoking** is the leading cause of lung cancer. Smoking causes an estimated 160,000* cancer deaths in the U.S. every year (American Cancer Society, 2004). And the rate among women is rising. On January 11, 1964, Dr. Luther L. Terry, then U.S. Surgeon General, issued the first warning on the link between smoking and lung cancer. Lung cancer now surpasses breast



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cancer as the number one cause of death among women. A smoker who is also exposed to radon has a much higher risk of lung cancer.

- **Radon** is the number one cause of lung cancer among non-smokers, according to EPA estimates. Overall, radon is the second leading cause of lung cancer. Radon is responsible for about 21,000 lung cancer deaths every year. About 2,900 of these deaths occur among people who have never smoked. On January 13, 2005, Dr. Richard H. Carmona, the U.S. Surgeon General, issued a national health advisory on radon.
    - World Health Organization's international radon project
- **Secondhand smoke** is the third leading cause of lung cancer and responsible for an estimated 3,000 lung cancer deaths every year. Smoking affects non-smokers by exposing them to secondhand smoke. Exposure to secondhand smoke can have serious consequences for children's health, including asthma attacks, affecting the respiratory tract (bronchitis, pneumonia), and may cause ear infections.
    - For smokers the risk of lung cancer is significant due to the synergistic effects of radon and smoking. For this population about 62 people in a 1,000 will die of lung-cancer, compared to 7.3 people in a 1,000 for never smokers. Put another way, a person who never smoked (never smoker) who is exposed to 1.3 pCi/L has a 2 in 1,000 chance of lung cancer; while a smoker has a 20 in 1,000 chance of dying from lung cancer.

## Radon Risk If You Smoke

from "A Citizen's Guide to Radon: The Guide to Protecting Yourself and Your Family From Radon"

| Radon Level | If 1,000 people who smoked were exposed to this level over a lifetime*... | The risk of cancer from radon exposure compares to**... | WHAT TO DO: Stop smoking and... |
|---|---|---|---|
| **20 pCi/L** | About 260 people could get lung cancer | 250 times the risk of drowning | Fix your home |
| **10 pCi/L** | About 150 people could get lung cancer | 200 times the risk of dying in a home fire | Fix your home |
| **8 pCi/L** | About 120 people could get lung cancer | 30 times the risk of dying in a fall | Fix your home |



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| | | | |
|---|---|---|---|
| **4 pCi/L** | About 62 people could get lung cancer | 5 times the risk of dying in a car crash | Fix your home |
| **2 pCi/L** | About 32 people could get lung cancer | 6 times the risk of dying from poison | Consider fixing between 2 and 4 pCi/L |
| **1.3 pCi/L** | About 20 people could get lung cancer | (Average indoor radon level) | (Reducing radon levels below 2 pCi/L is difficult.) |
| **0.4 pCi/L** | About 3 people could get lung cancer | (Average outdoor radon level) | |

Note: If you are a former smoker, your risk may be lower.
* Lifetime risk of lung cancer deaths from EPA Assessment of Risks from Radon in Homes (EPA 402-R-03-003).
** Comparison data calculated using the Centers for Disease Control and Prevention's 1999-2001 National Center for Injury Prevention and Control Reports.

## Radon Risk If You Have Never Smoked

| **Radon Level** | **If 1,000 people who never smoked were exposed to this level over a lifetime*...** | **The risk of cancer from radon exposure compares to**...** | **WHAT TO DO:** |
|---|---|---|---|
| **20 pCi/L** | About 36 people could get lung cancer | 35 times the risk of drowning | Fix your home |
| **10 pCi/L** | About 18 people could get lung cancer | 20 times the risk of dying in a home fire | Fix your home |
| **8 pCi/L** | About 15 people could get lung cancer | 4 times the risk of dying in a fall | Fix your home |
| **4 pCi/L** | About 7 people could get lung cancer | The risk of dying in a car crash | Fix your home |



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| | | | |
|---|---|---|---|
| **2 pCi/L** | About 4 person could get lung cancer | The risk of dying from poison | Consider fixing between 2 and 4 pCi/L |
| **1.3 pCi/L** | About 2 people could get lung cancer | (Average indoor radon level) | (Reducing radon levels below 2 pCi/L is difficult.) |
| **0.4 pCi/L** | | (Average outdoor radon level) | |

Note: If you are a former smoker, your risk may be higher.
* Lifetime risk of lung cancer deaths from EPA Assessment of Risks from Radon in Homes (EPA 402-R-03-003).
** Comparison data calculated using the Centers for Disease Control and Prevention's 1999-2001 National Center for Injury Prevention and Control Reports.

## Studies Find Direct Evidence Linking Radon in Homes to Lung Cancer

(2005) Two studies show definitive evidence of an association between residential radon exposure and lung cancer. Two studies, a North American study and a European study, both combined data from several previous residential studies. These two studies go a step beyond earlier findings. They confirm the radon health risks predicted by occupational studies of underground miners who breathed radon for a period of years.

Early in the debate about radon-related risks, some researchers questioned whether occupational studies could be used to calculate risks from exposure to radon in the home environment. “These findings effectively end any doubts about the risks to Americans of having radon in their homes,” said Tom Kelly, Former Director of EPA’s Indoor Environments Division. “We know that radon is a carcinogen. This research confirms that breathing low levels of radon can lead to lung cancer.”

- Read the "Iowa Radon Lung Cancer Study" EXIT by Dr. William Field on radon-related lung cancer in women.
- Read the "Radon in Homes and Risk of Lung Cancer: Collaborative Analysis of Individual Data from 13 European case-control studies" EXIT by Dr. David Hill.



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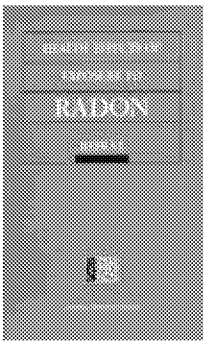


# Biological Effects of Ionizing Radiation (BEIR) VI Report: "The Health Effects of Exposure to Indoor Radon"

The National Research Council published the report, entitled: "Health Effects of Exposure to Radon: BEIR VI, Committee on Health Risks of Exposure to Radon (BEIR VI)". This report by the National Academy of Sciences (NAS) is the most definitive accumulation of scientific data on indoor radon. The report confirms that radon is the second leading cause of lung cancer in the U.S. and that it is a serious public health problem. The study fully supports EPA estimates that radon causes about 15,000 lung cancer deaths per year.

The ISBN number for the book is 0-309-056454-4; National Academy Press, 516 pages, 1999. The listed hardcover price for the book is $54.95 U.S. and $66.00 Intl. The Report can be read and purchased from The National Academies Press.

- Read the Executive Summary and the Public Summary EXIT

# Report: EPA's Assessment of Risks from Radon in Homes

In 2003 the Agency updated the estimates of lung cancer risks from indoor radon based on the National Academy of Sciences' (NAS) latest report on radon, the Biological Effects of Ionizing Radiation (BEIR) VI Report (1999). EPA worked closely with the Science Advisory Board (SAB), an independent panel of scientific experts, to determine how best to apply the risk models developed by the BEIR VI committee. The SAB's advice and recommendations were incorporated modifying and extending the methods and approaches used in BEIR VI to construct a single model yielding results midway between the results obtained using the two models preferred by the BEIR VI committee. The Agency's updated calculation of a best estimate of annual lung cancer deaths from radon is about 21,000 (with an uncertainty range of 8,000 to 45,000), which is consistent with the estimates of the BEIR VI Report. A single risk model also permitted the Agency to calculate a numerical estimate of the risk per unit exposure [lung cancer deaths per working level month (WLM)] which will be used to update estimated lung cancer risks from radon in various publications, including A Citizen's Guide to Radon.



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- EPA's Assessment of Risks from Radon in Homes EPA 402-R-03-003.

Former U.S. Surgeon General Richard H. Carmona

## Former U.S. Surgeon General Richard H. Carmona, Releases National Health Advisory on Radon

(January 13, 2005) U.S. Surgeon General, Richard H. Carmona, issues a Health Advisory warning Americans about the health risk from exposure to radon in indoor air. The Chief Physician urged Americans to test their homes to find out how much radon they might be breathing.

Dr. Carmona also stressed the need to remedy the problem as soon as possible when the radon level is 4 pCi/L or more, noting that more than 20,000 Americans die of radon-related lung cancer each year.

- The Full Press Release EXIT

## World Health Organization's International Radon Project

(2009) The World Health Organization (WHO) says radon causes up to 15% of lung cancers worldwide. In an effort to reduce the rate of lung cancer around the world, the World Health Organization (WHO) launched an international radon project to help countries increase awareness, collect data and encourage action to reduce radon-related risks.



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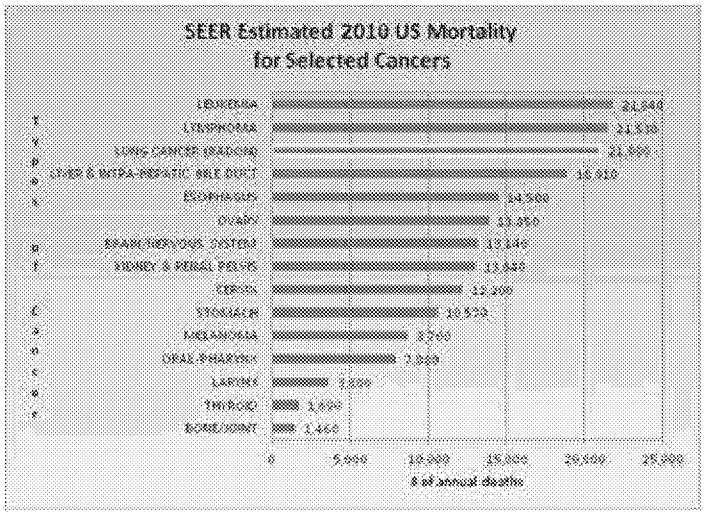
The U.S. EPA is one of several government agencies and countries supporting this initiative and is encouraged by WHO's attention to this important public health issue.

"Radon poses an easily reducible health risk to populations all over the world, but has not up to now received widespread attention," said Dr. Michael Repacholi, coordinator of WHO's Radiation and Environmental Health Unit. He went on to say that "radon in our homes is the main source of exposure to ionizing radiation, and accounts for 50% of the public's exposure to naturally-occurring sources of radiation in many countries."

- Visit the World Health Organization's International Radon Project EXIT site.

## Radon-related Lung Cancer Deaths Compared to Other Select Cancers

The following graphic compares EPA estimates of the annual radon-related lung cancer deaths to other selected cancers. The other mortality numbers in this graphic were obtained from the National Cancer Institute's 2010 Surveillance, Epidemiology, and End Results (SEER) estimated US mortality numbers (PDF) (1 pp, 15 K, About PDF).

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Assessment of wind- and soil- related hazards associated with abandoned uranium mines in the North Cave Hills, Harding County, South Dakota

- **Author:** Kyrian Onyeukwu
- **Subjects:** Geological Engineering (Thesis)$$I01SDBOR_SMT
- **Description:** The potential for wind erosion of abandoned mine sites and spoils was evaluated from analysis of dust and soil samples collected from selected field sites within an approximately five-mile radius of the North Cave Hills area in Harding County, South Dakota. A technical methodology was also developed for the evaluation of airborne movement of contaminated sediment generated from historic uranium mining sites.; Dust samples were collected at 30 sites with a portable wind tunnel and a soil scoop, and bulk soil samples were collected from each site. Atmospheric dusts settled from the air were captured to evaluate air quality upwind and downwind of the abandoned mine sites using ambient samplers. Background radiation measurements at sites and on samples were taken by means of a Geiger counter. All collected dust samples were geochemically analyzed with an inductively couples plasma mass spectrometer (ICP-MS) to determine metal contaminant concentrations. Bulk soil samples were mechanically sieved to obtain grain size distributions, and smaller particles of silt and clay were further analyzed with a laser particle sizer.; Average background radiation measured at site locations and on samples was about 50 counts per minute. Analyte concentrations in dust samples ranged from about 0.5 mg/kg for uranium to about 24 mg/kg for vanadium. Fifteen samples contained uranium in concentrations above a statistical background value of 0.74 mg/kg, were widely distributed throughout the area, and had a NW-SE directional spike in the predominant wind direction. All samples contained arsenic and five were above the background value of 11.93 mg/kg. Radiochemical concentrations of uranium and thorium radionuclides in dust samples ranged from 0.01 picocuries per gram (pCi/g) to 1.2 pCi/g,and were comparable to average values of containment concentrations given by the U.S. Environmental Protection Agency (EPA) for radionuclides in sedimentary and igneous rocks.; Results obtained from sieve analysis indicated that the soils are generally poorly sorted and consist predominantly of very fine to medium sand. A map of variation in soil erodibility in the area was produced. The grain size distribution and concentration of analytes in dust samples showed a NW-SE trend confirming the regional impact of wind energy in the transport of material in the area. A range of impact threshold wind velocity of about 7 to 15 mph was estimated for the North Cave Hills, and above threshold wind speeds are common in the area. Metal concentrations increased with decreasing grain size. Results from laser analysis showed a typical fine grain-size range of about 1 to 100 microns. The content of fine soils or particulate matter (PM) in the soils was small and indicates that wind-blown dust constitutes a minor part of erosion process in the area.; Experiments conducted to evaluate sampling protocol based on 1) wind tunnel, 2) soil scoop, and 3) fine dust sieved through a 230-mesh screen, indicate that these methods provide valid data to evaluate airborne movement of contaminated sediment generated from historic uranium mining sites through airshed.
- **Publisher:** Thesis(M.S.)--South Dakota School of Mines and Technology, Rapid City, 2007.
- **Creation Date:** 2007
- **Format:** xii, 192 leaves: ill. (some col.); 29 cm..
- **Language:** English
- **Local Note:** The potential for wind erosion of abandoned mine sites and spoils was evaluated from analysis of dust and soil samples collected from selected field sites within an approximately five-mile radius of the North Cave Hills area in Harding County, South Dakota. A technical methodology was also developed for the evaluation of airborne movement of contaminated sediment generated from historic uranium mining sites.$$I01SDBOR_SMT; Dust samples were collected at 30 sites with a portable wind tunnel and a soil scoop, and bulk soil samples were collected from each site. Atmospheric dusts settled from the air were captured to evaluate air quality upwind and downwind of the abandoned mine sites using ambient samplers. Background radiation measurements at sites and on samples were taken by means of a Geiger counter. All collected dust samples were geochemically analyzed with an inductively couples plasma mass spectrometer (ICP-MS) to determine metal contaminant concentrations. Bulk soil samples were mechanically sieved to obtain grain size distributions, and smaller particles of silt and clay were further analyzed with a laser particle sizer.$$I01SDBOR_SMT; Average background radiation measured

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  - Devereaux Library THESES

# Environmental Impacts from the North Cave Hills Abandoned Uranium Mines, South Dakota

James Stone[1] and Larry Stetler[2]

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**Abstract.** This study evaluated environmental impacts from historical uranium mining to soil, water, and air resources occurring on private lands surrounding the North Cave Hills complex within Custer National Forest, northwest South Dakota. Surface water concentrations of As, Cu, Mo, U, and V exceeded established background concentrations within approximately 27 km of stream length flowing below abandoned mines. Uranium concentrations in soils were mostly below the background value of 22 mg/kg and had a generally decreasing trend with increasing distance from the source areas, with higher values were associated with washover deposits and channeling of sediments.

## Introduction

Uranium exploration in northwestern South Dakota began in 1954 when the Atomic Energy Commission planned to fly airborne surveys over the Slim Buttes. Weather conditions precluded flying the Slim Buttes and instead, the survey was flown over the North Cave Hills (NCH) (Curtiss, 1955). As a result, the first claims were staked in the NCH on August 15, 1954 and mining ensued that year. Mine sites were located primarily within an approximately two mile wide northwest trending strip crossing the central NCH, referred to as the hot zone. Mining was permitted under the General Mining Laws and Public Law 357, which required no form of restoration. Most mines and mining prospects were located on United States Forest Service (USFS) administered land, but at least two actively mined sites and several prospects and exploration cuts and digs were located on

private land surrounding the NCH. Most of the uranium mines were abandoned coal strip mines located on relatively flat areas along the top of the numerous buttes that characterize the area. Mining consisted of the removing overburden (up to 80 feet) to reach the ore zone which consisted of uranium-bearing lignite beds. Mining activity increased through the next decade but ceased altogether in 1964.

During mining, most of the overburden and mine spoils were pushed over the edges of the buttes where subsequent erosion has spread materials over almost 1,000 acres in the NCH alone. Since mining ceased, additional deposition has occurred down-slope onto private land by water and wind transport. The bluffs and slopes immediately below mine sites often were covered by spoils forming highly over-steepened talus slopes, several of which have failed or are deeply incised. Currently, spoils are mostly devoid of vegetation and their composition has promoted water channeling, gullying, and tunneling. In addition to mined sites, numerous prospecting pits or contour benches were excavated on both USFS and private land and have been mapped and documented (Pioneer, 2005). Characterization of the abandoned mine sites on USFS land has occurred (Pioneer, 2005; Portage, 2005) but no work had characterized off-site impacts on surrounding private land. A Joint Venture agreement between the United States Department of Agriculture-Forest Service and the South Dakota School of Mines and Technology (including a subcontract with Oglala Lakota College) was established in 2006 to address potential off-site impacts. Funding for this on-going study has been provided through US-EPA CERCLA. Objectives of the NCH project were to determine whether heavy metal and radionuclide environmental contaminants have been transported from historical mine sites located on USFS land onto surrounding private land. Mechanisms of environmental transport most likely include the following:

- erosion of spoil sediments through surface runoff into adjacent drainages;
- erosion of spoil sediments through slope failures below mined bluffs
- dissolution of hazardous metals within runoff water that form tributaries to streams;
- erosion/deposition of small particle contaminants by wind transport;
- infiltration of hazardous metals and radionuclides into local and regional ground water aquifers.

## Methods

Target analytes for metals and radionuclides and analytical methods and procedures for determination of analyte concentration were similar to those used in previous investigations (Pioneer, 2005; Portage, 2005). Metals of interest included: U, As, Se, Cu, Mo, Pb, Th, and V. Water samples were further analyzed for gross alpha radiation, $Ra^{226}$, and $U^{235}$.

A watershed approach was developed to discern potentially impacted surface waters. It was assumed that all runoff water and eroded sediments (except for wind erosion) would ultimately end up in adjacent drainages and subsequently



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migrate downstream through established drainage networks. Surface-water sampling events were divided into two separate phases. Initial Phase I sampling evaluated target analyte concentrations of all potentially impacted drainages at the USFS/private land boundary. Phase I data also were used to establish background concentrations based on sampling locations assumed to be unaffected by mining activities. These data were used subsequently to evaluate which drainages were most heavily impacted. After evaluation of the Phase I results, drainages with the highest environmental concern were selected for Phase II sampling which continued downstream to a point where target analyte concentrations were comparable to established background levels. Phase I and II sampling located are shown in Figure 1.

Ground-water quality was evaluated by selecting 34 wells that were evenly distributed around the NCH within eight km of the USFS boundary. Approximately half of the wells were domestic supply wells and the others were stock wells. Well depths ranged between 10 and 240 m and represented shallow unconfined alluvial aquifers and deep confined aquifers. Samples were collected after pumping a volume of water equal to or exceeding two times the casing volume.

Airborne dust particulates were collected from 30 locations in two sampling phases. Phase I sampling occurred within the set 8 km radius from the USFS boundary. These data were used to establish background concentrations in regions where impacts from wind were assumed to be negligible. Phase I results were utilized to identify directions and regions to obtain additional samples in Phase II until a reduction in concentrations were observed. Airborne dust particulates were collected using a portable wind tunnel (Stetler, 1999) following these criteria:

- sites were high elevations above stream courses to ensure dust was either deposited directly by air or was derived by soil-forming processes;
- sampling sites were designed in a 'gridded' network around the NCH and were sufficiently distributed in accordance with the prevailing wind directions;
- sites were at locations that had physical indications of the presence of fine-grained surface materials derived from mechanisms excluding fluvial processes;
- locations had surfaces where dry and loose fine-grained materials were readily available to wind processes and could be collected either from the existing surface or generated through preparation of a standard loose surface (Saxton et al., 1998).

Additional dust samples were collected using a stainless steel soil scoop to skim the extreme upper layer of soil from the surface in areas inaccessible to the wind tunnel.

Samples collected to represent potential environmental transport by the above listed mechanisms were compared to established background values calculated using:

$$mean + 3x \text{ standard deviation} \quad (1)$$

These values were determined using samples collected from non-impacted drainages and represent natural metals concentrations. For airborne dust particulates, a background value of mean + 2 × standard deviation was used.



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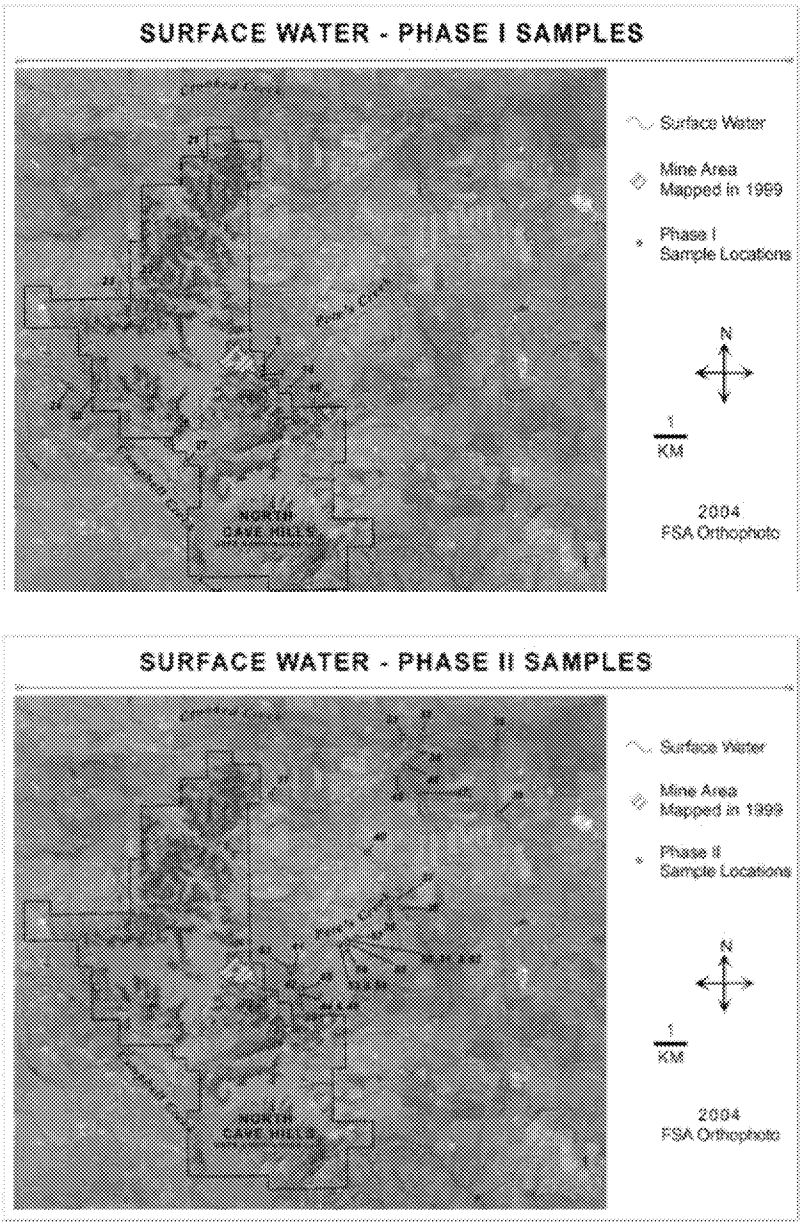


**Fig.1.** North Cave Hills Phase I and II surface water sampling locations.



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## Results

The key metals of interest in this study were U and As, although concentrations for the full suite of analytes listed above were determined from each sample. A complete listing of all metals and detailed discussion of trends and occurrences were given by Stone et al. (2007) or can be downloaded at http://uranium.sdsmt.edu. In the following text, only U and As results will be presented.

### Soils

Soil samples were collected from cores (0.3—8 m deep) drilled in numerous watersheds surrounding the mined and non-mined areas. Two or more composite samples were prepared from most of the deeper cores. Shallow cores yielded a single sample. Background concentrations were determined using sites representing pristine environments not affected by mining.

Uranium concentrations in soils were mostly below the background value of 22 mg/kg and had a generally decreasing trend with increasing distance from the source areas (Stone et al., 2007). Higher values were associated with washover deposits and channeling of sediments. Values exceeding 3× background were located immediately below Bluff B (Figure 2).

Arsenic concentrations followed a trend similar to U concentrations. Background concentration was 32 mg/kg and was exceeded at several locations at values up to 64 mg/kg. The highest As value (96 mg/kg) was at the site with the highest U concentration.

Results showed that 14 watersheds were potentially impacted by sediment transport from previous mining activity. The most impacted area was in the Upper Pete's Creek drainage below Bluff B where two U samples were 3× and 4× of background. All other U concentrations were below 2× background.

### Surface Water

Fourteen watersheds were identified within the study that were potentially impacted by uranium mining. Four pristine watersheds were used to determine background concentrations for all analytes. Sampling of surface water was completed in two phases; Phase I was a large-scale attempt to define contamination regionally, and Phase II sampling isolated impacted areas and delineated contaminant extent. Results indicated there were two impacted areas: the Upper Pete's Creek watershed below and east of Bluff B where surface waters were derived from direct runoff of the spoils piles, and the Schleichart Draw which received runoff down the western slopes of the North Cave Hills.



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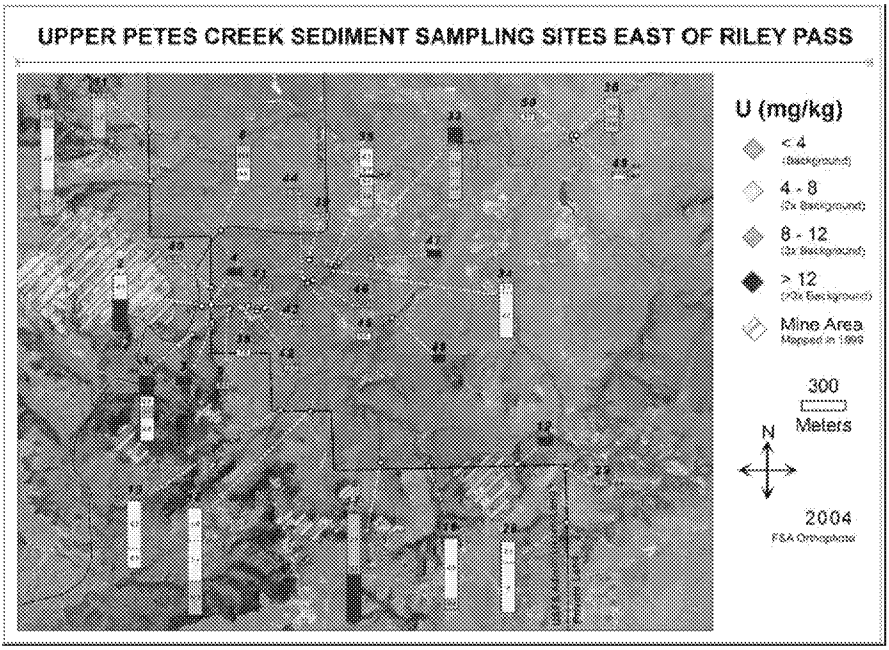


**Fig 2.** Uranium concentrations of core samples in the upper Pete's Creek.

Phase I sampling indicated elevated U and As concentrations in both watersheds. Elevated U concentrations in the Upper Pete's Creek drainage ranged from 2.9× to 5× above the background value of 0.027 mg/L. Elevated As concentrations ranged from 28× to 33× above the background value of 0.020 mg/L. In Schleichart Draw, elevated U concentrations were 3.6× background. These results were used to define Phase II sampling to isolate the contamination and identify locations with the greatest contamination.

Phase II sampling indicated severe contamination in the Upper Pete's Creek watershed below and to the east of Bluff B where the highest U and As concentrations were 23× and 89× background, respectively (Figure 3). Sampling in the downstream direction showed that natural attenuation of contaminant concentrations has occurred within a distance of ~5 km below Bluff B. Below-background values were observed for all analytes at the confluence of Pete's Creek and Crooked Creek, ~ 15 km northeast of Bluff B.

## Ground Water

Contaminant occurrence was ubiquitous in ground-water samples at all depths of wells tested and was distributed within the study area both up and down gradient. The exceptions were thorium, arsenic, and vanadium, which were not detected in any samples. Trends of occurrences suggest that metals detected were regional, naturally occurring contaminants and not directly attributable to uranium mining.



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Water quality was compared against maximum contaminant levels (MCLs) established by the US EPA (US EPA, 2006). Uranium was detected in seven wells and ranged from 0.001 to 0.064 mg/L. One well was 0.064 mg/L and exceeded the MCL of 0.03 mg/L by a factor of two. This well was 18 m deep and was fed by shallow alluvial gravels with hydraulic connectivity to uraniferous lignites updip from the well. A second well contained a U concentration of 0.027 mg/L and was also a shallow well in alluvium.

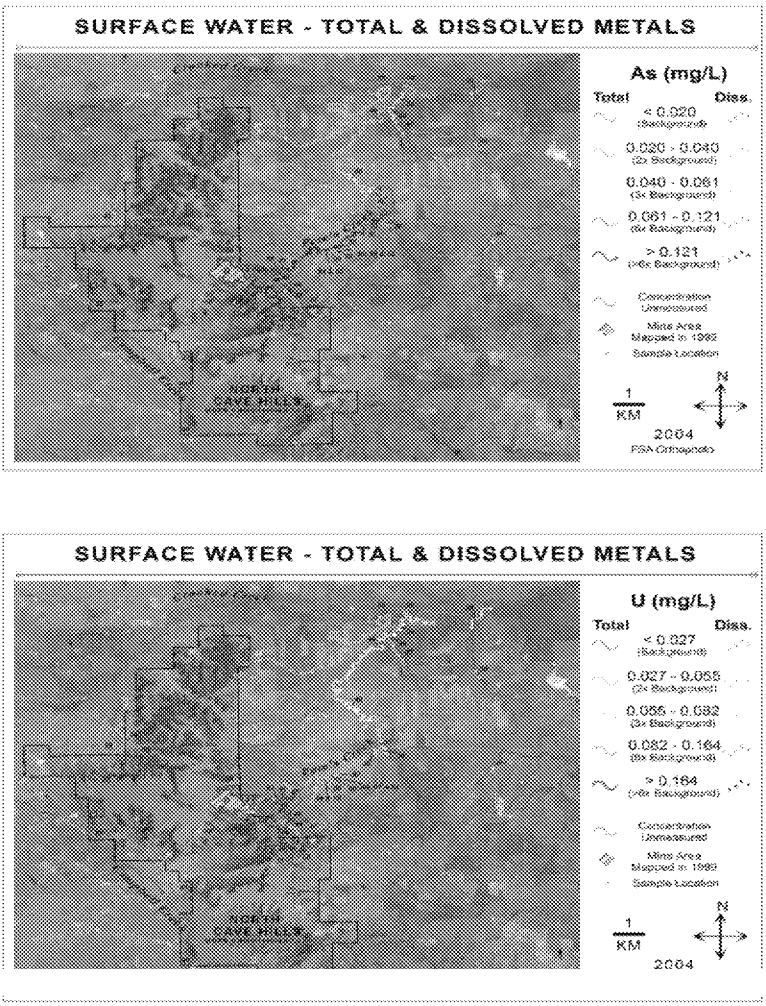


**Fig 3.** North Cave Hills surface water results for total and dissolved arsenic and uraniu



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Many elements in the U decay series can contribute radionuclide counts in a sample. Analysis to determine which element contributed what amount of radioactivity is expensive and time-consuming. Thus, gross alpha counts were used to assess the radioactivity of the sample. The EPA has established a MCL of 15 pCi/L for gross alpha. Twenty-six of the 34 wells contained gross alpha radiation ranging from 1.8 to 44.4 pCi/L. Distribution of these wells were up and down gradient and at depth from 18 to over 240 m. Three wells exceeded the MCL for uranium. The two highest concentrations were the shallow wells discussed above and the third highest concentration was a 122-m-deep well completed into the Fox Hills sandstone located northeast of Bluff B.

In addition to U concentrations and gross alpha contents, three wells contained $Ra^{226}$ in concentrations ranging from 0.5 to 0.7 pCi/L and were all well below the MCL of 5 pCi/L. Two of the wells had concentrations of 0.7 pCi/L and were the same wells as those with the highest gross alpha contents discussed above. $U^{235}$ was detected in five wells at concentrations between 0.3 and 1 pCi/L, up and down gradient of the mine sites. There is no MCL for $U^{235}$

Data collected and analyzed during the ground-water study indicate that metals and radionuclides were natural components of the ground-water systems. Further, the distribution of the contaminants shows metals were dissolved between the recharge areas to the west and the North Cave Hills. It is not clear if the abandoned uranium mines in the North Cave Hills contribute directly to the metals content of the ground water. Most likely the chemistry of surface water and local springs were affected by the mines but the deep aquifers should not be affected directly. Shale confining layers above the deep sources theoretically protect infiltrating waters from reaching these aquifers. The exception would be the presence of deep fracture systems allowing local infiltration to reach the water table, i.e., a leaky confining layer. These conditions will be evaluated in future studies.

## Aerosols

Results of the surface dusts indicate the general ubiquity of target analytes in the soils around the North Cave Hills. Uranium was present in all but two samples and arsenic was present in all samples. Vanadium, copper, and thorium also were present in all samples and lead occurred in all but one sample. Molybdenum and selenium had the least occurrences.

Thirteen samples contained uranium concentrations in excess of the calculated background value of 0.74 mg/kg. Distribution of these sites extended across the entire sampling area and were classified into three distinct domains:

1. Eight locations, including the three with the highest uranium concentrations (1.96, 1.66, and 1.6 mg/kg), occurred in a northwest to southeast trend cutting across the center of the North Cave Hills and containing the largest abandoned uranium mine areas. The long axis of this high-concentration area also correlated to the predominant wind direction, indicating a probable wind influence on the observed distribution. The greatest uranium concentration (1.96 mg/kg)



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occurred on the western side of the North Cave Hills below and upwind of Bluffs J-K and upwind of all of the abandoned mine sites;
2. Two locations north of the North Cave Hills had uranium concentrations greater than 1.0 mg/kg and both were in a direction of minimal above-threshold wind occurrences;
3. Two locations in a topographic low between the North and South Cave Hills (Bull Creek drainage) had uranium exceedences.

Uranium concentrations were below background levels in all areas away from these three identified areas of high concentrations.

Arsenic was detected in all samples and five contained concentrations above the calculated background value of 11.93 mg/kg. All exceedence concentrations were east and south of the North Cave Hills. However, concentrations below the background level that were between 9.8 and 11.6 mg/kg were located near the exceedence locations and appeared to form a similar northwest to southeast pattern across the center of the North Cave Hills as was noted for uranium domain 1. Two locations in the north were close in value to the As background level that corresponded to uranium domain 2. Thus, there is some evidence for wind distribution of fine particles that contained these metals

## Discussion

Significant environmental degradation has occurred from transport of heavy metals and radionuclides downstream of abandoned uranium mines in the North Cave Hills. The most impacted regions occurred down gradient of Bluff B and in Schleichart Draw in the SW of the study area. Surface water contained U and As up to 90× background values and sediment had concentrations 4× background levels. Metals in sediments and surface water were naturally attenuated within ~15 km below the mine sites, although large deposits of contaminated soils occurred on private lands

Ground water contained many metals and radionuclides in both the up and down gradient directions and at shallow to deep aquifer depths. This indicated that metals contamination was regional in extent and most likely were not affected by U mining

Aerosol dust had significant metals concentrations in nearly all locations sampled. Uranium was ubiquitous and contained at least one plume of high concentrations that correlated to the predominant wind direction. All metals concentrations in aerosols were decreasing or below background levels within about 15 km from the mine sites. Although U, As, and other metals were detected in aerosols, their concentrations were on average seven times less than metals concentrations in soils, indicating aerosol transport of metals remains low



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Surface water and sediment investigation concerning abandoned uranium mines in the South Cave Hills, North Cave Hills, and Flint Buttes region, Harding County, South Dakota

- **Author:** Emmanuel Tuombe
- **Subjects:** Civil and Environmental Engineering (Thesis)$$I 01SDBOR_SMT
- **Description:** A watershed approach was used to define migration of arsenic and uranium from abandoned uranium mines in North Cave HIlls, South Cave Hills, and Flint Buttes. The first phase of the project was completed in 2006 and focused on the North Cave HIlls. The second phase of this project, completed during the Summer of 2007 field season, focused on the assessment of off-site migration (i.e. leaving USFS administered lands) of arsenic and uranium within potential contaminated drainages consisting of sediments and surface waters from the North Cave Hills, the South Cave Hills, and the Flint Buttes complex located in Harding County, South Dakota.; The 2005 arsenic and uranium background concentrations (0.02 mg/L and 0.027 mg/L, respectively) were used for the determination of contamination extent in surface water for this study. For sediment contaminant concentrations, 26 mg/kl arsenic and 4 mg/kg uranium were used for this study as background, Sediment and surface water sample down-gradient from the Flat Top mine located on private land in Flint Buttes exceeded established background total metal concentrations for arsenic and uranium. Arsenic concentration varied from less than background to more than 36x background for surface water and from less than background to greater that 3x background for sediment. Uranium concentration varying from less than background to more than 9x background for surface water, and from less than background to greater than 3x background for sediments were determined in the drainages of the study area. The North Cave HIlls area exhibited the greatest degree of contaminant for arsenic and uranium in its drainages.; In general, the South Cave Hills contained elevated contamination for arsenic and uranium but the contamination was not transported from the South Cave Hills. The Flat Top mine located on private land in Flint Buttes contained elevated concentration of arsenic and uranium in drainages flowing into Pete's Creek, Coal Bank Creek, and Big Nasty Creek. This study determined that arsenic and uranium from abandoned mines located on USFS-lands have migrated onto private land and have contaminated surface water and sediments in surrounding drainages. Also, the Flat Top minesite located on private property was a significant source of contamination for its surrounding drainages.
- **Publisher:** Thesis(M.S.)--South Dakota School of Mines and Technology, Rapid City, 2008.
- **Creation Date:** 2008
- **Format:** x, 148 leaves: ill. (some col.) ; 29 cm..
- **Language:** English
- **Local Note:** A watershed approach was used to define migration of arsenic and uranium from abandoned uranium mines in North Cave HIlls, South Cave Hills, and Flint Buttes. The first phase of the project was completed in 2006 and focused on the North Cave HIlls. The second phase of this project, completed during the Summer of 2007 field season, focused on the assessment of off-site migration (i.e. leaving USFS administered lands) of arsenic and uranium within potential contaminated drainages consisting of sediments and surface waters from the North Cave Hills, the South Cave Hills, and the Flint Buttes complex located in Harding County, South Dakota.$$I01SDBOR_SMT; The 2005 arsenic and uranium background concentrations (0.02 mg/L and 0.027 mg/L, respectively) were used for the determination of contamination extent in surface water for this study. For sediment contaminant concentrations, 26 mg/kl arsenic and 4 mg/kg uranium were used for this study as background, Sediment and surface water sample down-gradient from the Flat Top mine located on private land in Flint Buttes exceeded established background total metal concentrations for arsenic and uranium. Arsenic concentration varied from less than background to more than 36x background for surface water and from less than background to greater that 3x background for sediment. Uranium concentration varying from less than background to more than 9x background for surface water, and from less than background to greater than 3x background for sediments were determined in the drainages of the study area. The North Cave HIlls area exhibited the greatest degree of contaminant for arsenic and uranium in its drainages.$$I01SDBOR_SMT; In general, the South Cave Hills contained elevated contamination for arsenic and uranium but the contamination was not transported from the South Cave Hills. The Flat Top mine located on private land in Flint Buttes

contained elevated concentration of arsenic and uranium in drainages flowing into Pete's Creek, Coal Bank Creek, and Big Nasty Creek. This study determined that arsenic and uranium from abandoned mines located on USFS-lands have migrated onto private land and have contaminated surface water and sediments in surrounding drainages. Also, the Flat Top minesite located on private property was a significant source of contamination for its surrounding drainages.$$I01SDBOR_SMT

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Availability and location:

South Dakota School of Mines & Technology:

- Available:
  - Devereaux Library ARCHIVES
  - Devereaux Library THESES

Surface water and sediment investigation concerning abandoned uranium mines within the Slim Buttes region, Harding County, South Dakota

- **Author:** Albertus-Benham, Hannah.
- **Description:** Vita. ; Includes abstract. ; M.S.,South Dakota School of Mines and Technology, Rapid City,2009 ; As part of ongoing environmental investigations of historical uranium mines in northwestern South Dakota, sediment and surface water samples were collected to evaluate the impacts associated with contaminant migration from past uranium mining activities. The third phase of this project completed during the Summer 2008 field season included the assessment of off-site migration (i.e., leaving USFS administered lands) of heavy metals and radionuclides within drainages from the Slim Buttes region of Custer National Forest, Harding County, South Dakota. This study employed a watershed monitoring approach, where both major and minor drainages emanating from the Slim Buttes were sampled. Sediment and surface water samples were analyzed by the EPA region 8 contract laboratory using ICP-MS following EPA methods 200.2 and 200.7. In addition, Hilltop abandoned mine site on USFS administered land was characterized using a hand-held x-ray fluorescence spectrometer (XRF) for insitu determination of metals and radionuclide concentrations located within the mine bench soils and associated spoil piles in collaboration with Oglala Lakota College. In the southeastern Slim Buttes, U and As sediment concentrations exceeded 4x and 2x background (>5.28 and 16.78 mg/kg), respectively, while surface water concentrations exceeded 3x and 2x background (>99.6 and 110.4 ug/L), respectively, at several locations within Antelope Creek and its tributaries. All of these sampling locations were downstream from Hilltop minesite as well as other mine sites. In the western Slim Buttes U and As sediment concentrations were greater than 2x background and surface water concentrations over 3x background. In the eastern Slim Buttes, U in sediment was determined to be greater than 7x background (>9.24 mg/kg) within Rabbit Creek downstream from Square Top Butte mine site. Sediment samples analyzed by synthetic precipitation leaching procedure(SPLP) and evaluated using element concentration pattern graphs (ECPGs) suggest uranium was readily mobilized from mining impacted drainages. In general average concentrations were higher for impacted sample sites than for un-impacted sample sites, however no statistically significant different was identified. Additional field sampling events are recommended for the 2009 field season to determine the extent that the Slim Buttes mine sites may have impacted contaminant migration within the regional watersheds.
- **Language:** English
- **Source:** WorldCat

# Final Report: North Cave Hills Abandoned Uranium Mines Impact Investigation

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# APPENDIX

## Appendix A Analytical Results

Appendix A1 SDSM&T Surface Water Data

Appendix A1 SW All WQ Parameters Phase I ELI.pdf
Appendix A1 SW pH,ORP Field Measurements.xls
Appendix A1 SW Results.xls

Appendix A2 SDSM&T Ground Water Data

Appendix A2 Groundwater Quality Analytical Results.xls
Appendix A2 GW-C Fiest well construction log.pdf
Appendix A2 GW-Clarkson Ranch well construction log.pdf
Appendix A2 GW-D Oritham well construction log.pdf
Appendix A2 GW-E Johnson well construction log.pdf
Appendix A2 GW-Fiest, Gilbert well data.xls
Appendix A2 GW-G Miller well construction log.pdf
Appendix A2 GW-J Clarkson well construction log.pdf
Appendix A2 GW-J Miller well construction log.pdf
Appendix A2 GW-L Brown well construction log.pdf
Appendix A2 GW-L Brown well construction log.pdf
Appendix A2 GW-N Ketchum well construction log.pdf
Appendix A2 GW-results.xls
Appendix A2 GW-T Hafner well construction log.pdf
Appendix A2 GW-T Kalisiak well construction log.pdf
Appendix A2 GW-USGS well locations.pdf
Appendix A2 GW-USGS WQ data Welch.txt
Appendix A2 GW-USGS WQ data Welch(2).txt
Appendix A2 GW-USGS WQ data Rotenberger.txt
Appendix A2 GW-USGS WQ data Rotenberger(2).txt
Appendix A2 GW-USGS WQ data Rotenberger(3).txt
Appendix A2 GW-USGS WQ data Johnson.txt

Appendix A3 SDSM&T Air Particulates Data

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Appendix A3 WT Total Metals Analytical Results.xls

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# 1.0 Introduction

This final report has been prepared as part of the North Cave Hills Area Abandoned Uranium Mines Impact Investigation conducted under a Joint Venture agreement between the United States Department of Agriculture-Forest Service (Forest Service) and the South Dakota School of Mines and Technology (SDSM&T), and a subcontract with Oglala Lakota College (OLC). Funding for this on-going study has been provided through US-EPA Region 8. This report describes both the field and laboratory methods used to collect data, and results for the evaluation of potential environmental impact of abandoned uranium mining and exploration sites in the North Cave Hills, Harding County, South Dakota. Specifically, this final project report addresses:

- Off-site migration of sediment spoils and associated metals and radionuclides from the North Cave Hills region of USFS administered lands into potentially impacted drainages (sediments and surface waters);
- Sliding, slumping, and sheet erosion of mining spoils and associated metals and radionuclides from USFS administered lands onto adjacent private lands;
- Off-site migration of airborne dust particulates and associated metals and radionuclides by wind erosion of mining spoils from USFS administered lands onto adjacent and regional private lands;
- Potential contamination to the regional ground water supply by introduction of metals and radionuclides into regional aquifers that provide drinking water to local residents and livestock.

# 2.0 Background Information

The North Cave Hills area is part of the Sioux Ranger District, Custer National Forest, Region 1 of the USFS. The complex is located approximately 25 miles north of Buffalo, South Dakota (Harding County Seat) and 150 miles north-northwest of Rapid City, South Dakota. Ludlow, South Dakota, is the closest municipality located 5 miles due east (Fig. 2.1).

## 2.1 Geomorphology

The North Cave Hills rise about 400 feet above the surrounding plains to an altitude of approximately 3,400 feet. They are characterized by steep-sided and generally flat-topped, forested buttes rimmed by 60-150 feet high sandstone cliffs. Below the cliffs, softer sedimentary rocks including shale, siltstone, coal and loosely cemented sandstone form steep, grass-covered slopes. From a geomorphic perspective these slopes contain evidence of geologically rapid retreat. Erosion of the softer sedimentary rocks below the sandstone cliffs promote rockfall from above and ultimate cliff retreat resulting in smaller butte areas through time. Most of the rim slopes and canyons are steep-sided, mantled by rock debris, and contain relatively deep box canyons all of which are indicators of the rapid rates of erosion. There are many locations around the main platform that show naturally occurring small-scale solifluction, sliding, and slumping. The entire platform is tilted by several degrees to the north-northeast and is divided here into three geomorphic units: 1) a highly dissected, more rugged tableland to the north,



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bounded in the south by Devils Canyon; 2) an adjoining broad, central table bordered to the south by the deeply incised drainage of Schleichart Draw; and 3) a southern table which is dissected into a northern and southern unit by Davis Draw.

## 2.2 Geology

Regional bedrock consists of the Late Cretaceous Pierre Shale, Fox Hills sandstone, and the Hell Creek Formations. Overlying Tertiary rocks include the Ludlow and Tongue River Formations (Table 2.1). Both the Pierre and Fox Hills units outcrop further south, outside of the study area (Fig 2.2).

The oldest rocks in the study area are the Hell Creek Formation clay, carbonaceous shale, siltstone, and sandstone units. The Formation is exposed in a small window along Bull Creek and major drainages at the base of the North Cave Hills. The Cretaceous-Tertiary contact is gradational and poorly exposed. Thus, is has been generally assigned to the lower-most coal unit in the overlying Tertiary rocks.

The lower-most Tertiary Ludlow Formation consist of gray to buff colored and relatively unconsolidated sandstone, siltstone, and clayey sand and silt units that weather yellowish gray. Occasional cross-bedding and ripple marks are evident in the sandy parts and ironstone concretions are ubiquitous throughout. Lignite coal and ligniferous shale units, referred to as 'blackjack', are ubiquitous in the Ludlow. The lower 200 feet of the Formation is designated as 'unnamed coal beds'. Above the lower zone, the major coal units are the Lonesome Pete coal zone, coal bed B, C coal zone, carbonate coal zone, and coal bed D.

The Ludlow-Tongue River Formation contact is sharp and marked by the appearance of the first massive sandstone outcrop. The lower-most sandstone, immediately above the Ludlow Formation, is yellow to brown, cross-bedded, slightly cemented with calcite, and massive having a thickness of 30-100 feet. The unit also forms the principle aquifer in the area. The upper sandstone unit is massive, non-calcareous, loosely consolidated and ranges up to 135 feet thick. A uranium ore zone consisting of impure lignite beds intercalated in siltstone and claystone units occurs about 110-150 above the base of the Formation. These coal units have high uranium concentrations and can be several feet thick. This unit also separates the lower and upper sandstone units.

Weathering and erosion of the above sequence has formed resistant sandstone rim rock capping the North Cave Hills. Tertiary Tongue River Formation rocks form the rim rock and are underlain by shallow slopes comprised of loosely consolidated sand, silt, and clay layers with intercalated coal seams of the Tertiary Ludlow Formation. Strata are relatively flat-lying with a regional dip of 1-2 degrees to the NE, but also display several areas of gentle folding and possibly faulting which control the orientation of local dip directions.

Curtiss (1955) noted "a well-defined right-angle joint pattern, which trends north-south, east-west is conspicuous in the basal Tongue River massive indurated sandstone, particularly in the North Cave Hills. Therefore, joint control may provide excellent permeability channel ways for the downward movement of uranium charged solutions into the Tongue River and Ludlow



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formations from the overlying White River sediments"*(before White River Formation was stripped away by erosion in the North Cave Hills)*. It is also possible that these same joints, which are evident at the base of many abandoned uranium mines, are conduits for entry of contaminants into underlying sandstone aquifers.

Regionally, broad anticline-syncline pairs oriented in an approximate ~N35°W direction lay to the west and extend into SE Montana. These features are the southeastern-most extension of the Ordovician Cedar Creek Anticline. The Cave Hills region lies about 15 miles to the E-NE of this structure but its presence may impact the dip orientation of the platform areas in the Cave Hills and be partly responsible for the orientation of the surface drainage system that has developed.

The presence of deep-seated fractures on massive sandstone beds at the base of many abandoned uranium mines suggest that deep ground water flow directions could be impacted by these features. Fracture systems are important in flow direction studies in that more volume of water may be conducted through fractures (secondary porosity) than through the primary porosity and be in a different direction than the regional dip of the aquifers themselves. This condition can be exacerbated in densely fractured rock or where the fractures are large. For example, it is known from the Black Hills that fracture flow can be many orders of magnitude greater than incipient porosity flow. Thus, ground water flow patterns can be affected by fracture patterns and density. In addition, the wide range of depths to the Hell Creek aquifer (~150-250+ ft) also suggests that local stratigraphic highs and lows might impact flows immediately around any particular well.

## 2.3 Surface Water Hydrology

The regional drainage pattern is strongly controlled by the regional structural grain, the prominent form being a conjugate set of fractures striking approximately N50-55°W and N10-50°E. Major, broad drainages dissecting the North Cave Hills have their headwaters close to the eastern edge of the tables and flow toward the northwest in the northern part and to the southwest in the southern part, essentially crossing the whole platform. Northern drainages are captured by Crooked Creek, which flows north around the North Cave Hills on their western side and then turns east to ultimately join the North Fork of the Grand River at Haley-Bowman Reservoir in North Dakota. Southern drainages are captured by Campbell Creek flowing toward the southeast along the southwestern side of the North Cave Hills. Campbell Creek flows into Bull Creek which joins the South Fork of the Grand River. The North and the South Forks of the Grand River are the major contributories to Shadehill Reservoir, the major reservoir in northwestern South Dakota. Drainages on the eastern edge of the North Cave Hills only cut back into the tables for relatively short distances of up to about one half of a mile. In the northern and central tables, these easterly drainages are all parts of the headwaters or contributories to Petes Creek which flows north along the eastern side of the Cave Hills and joins Crooked Creek at the northern end of the North Cave Hills. East-flowing drainages of the southern table are part of the headwaters of Big Nasty and Jack Creeks which both join the South Fork of the Grand River. Therefore, all water draining of the North Cave Hills ultimately enters the Shadehill Reservoir.

On the prairie parts surrounding the buttes, channel morphology is more representative of a dry, supply limited system and is consistent with much of the western plains and Rocky Mountains that have been in a period of erosion and incision for approximately the past 140 years.



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Climatic shifts between arid and humid since the cessation of glaciation in the Late Pleistocene (~12,000 yrBP) has led to the development of a terrace system along many western stream valleys that represent these changing climates. Humid periods were times of aggradation in stream valleys and arid periods were times of erosion often accompanied by channel deepening. At least four such periods have been identified by terraces surrounding incised stream channels, i.e., each elevated terrace marks a previous valley fill. A return to more arid conditions after the end of the Little Ice Age (ca. 1880) was typified by gully erosion and in the western US, was exacerbated by grazing and sod-busting (Leopold, 1994). Typical western South Dakota prairie channels are narrow and deep and often contain between 1-3 terraces above the current channel. A recent study by Roeser (2004) confirmed a predominant 'F' channel type exists in NW South Dakota. F channels are defined as entrenched systems having high to moderate width/depth ratios and moderate sinuosity (Rosgen, 1996) In addition, it is common that undercut banks fail promoting more stable conditions locally and in time will generate sufficient sediment in the channel to reestablish a stable channel system. Roeser (2004) also evaluated the stage of channel evolution these stream were currently in using Schumm's channel evolution model (CEM) (Schumm et al., 1984). Northwestern South Dakota channels were classified as primarily existing in CEM stage IV, a stabilizing entrenched channel with several channels in CEM stage III (active bank-widening promoted by bank failure). The end-point for these systems is a CEM stage IV, a stable entrenched system with a developed floodplain. Evolution from stage III to stage IV will, by nature of the process, produce additional sediment load to the stream systems until stabilization has been achieved.

Several spring horizons, generally associated with thicker lignite seams, encircle the North Cave Hills on USFS administered land. Two prominent horizons occur just above and below the indurated sandstone cliffs of the Tongue River Formation, and a third just above the base of the grass-covered slopes. Many of these springs are perennial. In addition, several of the springs are developed for stock watering and at least two springs are known to be used for domestic supplies. All watersheds are marked by numerous small stock dams and several larger-sized reservoirs on and off USFS administered land. Smaller dams and reservoirs are generally designed for 100% capture without a spillway or stand-pipe design.

## 2.4 Groundwater Hydrology

Groundwater supplies all of the human and stock watering needs in and around the North Cave Hills groundwater study area, defined as the area within a 5 mile radius outward of the Forest Service boundary (Fig. 2.3). Sources of groundwater include springs, shallow unconfined aquifers, and deep confined aquifers. At the time of this study two ranch homes were being supplied drinking water from a spring source, three homes were supplied by shallow alluvial systems, two consisting of localized aquifers having no lateral extent and one sourced from alluvial materials along an ephemeral stream channel, and the remaining homes were supplied by deep aquifers. Aquifer depth varied from 30 to 55 feet for the unconfined alluvial systems to >100 feet for the confined aquifer systems.

There are no established water distribution systems for human consumption and each household is supplied from a local well or small feed-line system connecting multiple homes on the main ranch from one local supply well. There are at least 2 identified distribution systems that are



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used for stock watering where a single well supplies more than a single ranch's stock water. All other stock water supplies are from individual wells.

Water sources were characterized as local or regional. Local supplies were classified as water derived from either a spring or a shallow unconfined aquifer and regional supplies were classified as water derived from deeper confined aquifers. Waters feeding the local supplies were derived from either precipitation infiltration on the sandstone bluffs or precipitation filling small and isolated alluvial patches. Springs emerge when downward infiltrating water encounters an impermeable layer exposed in the many canyons that downcut through the bluffs. These type of springs are ubiquitous in the region and occur on Forest Service and private land mostly near the sandstone bluffs. Many of the spring locations are marked on the USGS 7.5 minute quad map series that cover the region. Shallow alluvial aquifers occurred where topographic lows were filled by alluvium above an impermeable shale. Three such systems were identified in the study area; two were isolated accumulations of aquifer material having limited lateral extent (additional wells drilled nearby failed to penetrate any alluvium) and the third occurred in shallow alluvium along an ephemeral channel, the extent of which was undetermined. All three of these wells were between 30 and 55 feet deep and were produced using a jet pump (depth to water <25 feet). Regional supplies were classified as water sources obtained from a deep confined aquifer (>100 feet) that was recharged in zones removed from the North Cave Hills area. The majority of these wells were sourced in the Cretaceous Fox Hills sandstone (Fig. 2.2), a 25-200 foot thick grayish-white to brown marine sandstone unit (Paterson and Kirchner, 1996; Page et al., 1956) that is utilized regionally as a drinking water source. The Fox Hills lies below the Hell Creek formation that is up to 425 feet thick and consists of brown shale and gray sandstone with thin lignites in the upper half and mainly sandy beds in the lower half (Paterson and Kirchner, 1996). Some wells may be developed within the lower Hell Creek and the well depth will be dependent upon local stratigraphy.

Local stratigraphy for depths below the surface to several thousand feet is mostly unknown. All landowners in the study area were surveyed to obtain well information such as total depth, depth to water, producing formation, and production tubing size. However, no landowner possessed a well log that could define the stratigraphy or the exact depths of the producing formation. Partial well information was obtained from various sources and included twelve photocopies of well completion reports from the SD DENR, two records of location and depth data having no stratigraphic information from the SD DENR, and six well records from the USGS National Water Information System (NWIS) that correlate to wells tested in this study. Copies of all these reports are provided within Appendix A2.

Stratigraphic control was established using published geologic maps (Page et al., 1956; Pipiringos et al., 1965) in conjunction with well logs from 55 oil wells drilled throughout the region. Two cross sections were constructed using a subset of the database of 55 wells (Fig. 2.4). Sections A-A' from west to east and B-B' from south to north utilizing 6 and 10 well logs, respectively. All well depths were corrected to the Kelly Bushing elevation (reference elevation during oil drilling and based on sea level as '0' elevation. The resultant probable flow directions and gradients for the confined groundwater system in the Fox Hills Fm are a W-E dip of 38 feet per mile and a S-N dip of 21 feet per mile (Fig. 2.5). The resultant average dip direction is north east at ~30 feet per mile, or ~0.3° and is in agreement with published values of a north east dip of



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between 10 and 40 feet per mile (Page et al., 1955). Published USGS studies (Pipiringos et al., 1965) also indicate a general northward dip of about 25 feet per mile. Although this is a low slope, it suggests water will flow in a northeasterly direction away from the Cave Hills and toward the center of the Williston Basin.

## 2.5 Regional Climate and Wind Patterns

The climate in the study area is typical intercontinental arid characterized by warm, mostly dry summers and cool dry winters. Typical moisture trends include a bimodal precipitation distribution centered on June and late September and averages ~12" per year. On average, snowfall accumulation is rare and does not contribute significantly to the total precipitation amount. Long-term average high temperatures range from 30°F in January to 85°F in July and August. Agronomically, the region is managed as arid lands.

Long-term climate trends for the North Cave Hills area were obtained from surrounding locations that are part of the RAWS climate achieve maintained at the Western Regional Climate Center housed at the Desert Research Institute (DRI) at University of Nevada, Reno (http://raws.dri.edu). Sites utilized in this study include RAWS sites at Cannonball Creek MT, Hackberry Creek MT, Knowlton MT, Sand Creek ND, and Camp Crook SD (Fig. 2.6). These stations ranged from 40 to ~100 miles from the North Cave Hills. Three of the sites were located to the north or northwest (Sand Creek ND, Cannonball Creek and Knowlton MT) and two sites were located to the south west (Camp Crook SD and Hackberry Creek MT).

Wind roses were constructed for each of the five sites indicating the predominate wind direction in this region is from the northwest (Fig. 2.6). The secondary predominance is from the southeast at three sites (Cannonball and Hackberry Creeks MT and Sand Creek ND) and from the southwest at two sites (Knowlton MT and Camp Crook SD). The least predominant wind direction is out of the northeast. The resultant wind frequency of occurrence for the four primary direction quadrants has the following distribution: 35% from the northwest, 22% from the southwest, 21% from the southeast, 14% from the northeast, and 7% calm (<1.3 mph). Average wind speeds, from highest to lowest, are from the northwest at 10.9 mph, the northeast at 8.6 mph, the southeast at 8.2 mph, and from the southwest at 7.7 mph.

Wind speed and its interaction with dry soil particles are the critical factors that lead to erosion events (Stetler, 2002). Any particular soil or loose material will produce wind-eroded sediment as a function of these two factors. However, in a constant wind speed, wind erosion and dust transport will be controlled by the particle size distribution of the soil mass and the availability of these particles to the wind stream; i.e., the surface should be dry and devoid of surface crust and heavy vegetation. Studies have shown that one soil type will vary with another in respect to the required wind velocity to produce wind-eroded dust (Stetler and Saxton, 1996) and the determination of that particular wind speed is not trivial. Additionally it has been shown that for a natural size distribution of particles (such as a soil), a given wind velocity will entrain particles of many grain sizes (Nickling, 1988). Thus, for natural silt-loam soils, a threshold wind speed of ~10-11 mph will be sufficient to entrain and transport a wide range of the dust- and silt-sized particles (Saxton, 1995), given dry and loose surface conditions. For large regional studies with an absences of detailed entrainment data, such as the current project, it is sufficient to assume a



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threshold wind velocity based on the wind frequency distribution and soil properties.

Analysis of the wind frequency data, wind roses, and soil particle size distributions, has led to the selection of a conservative threshold wind speed of 13 mph for the North Cave Hills area. Although this value is slightly higher than the threshold wind speeds given above it correlates well to Saxton's data (1995) and also reflects the lower range of a wind speed category used in the Beaufort Scale, which is the basis for the wind frequency data that were used. Based on this analysis, wind speed in excess of the threshold value from all directions occurs 23.2% of the time, or about one day out of every four. On a quadrant basis, above threshold wind speed occurs 60% of the time when the wind is from the northwest (one out of every seven days), 18% of the time when wind is from the southeast 12% of the time when wind is from the northeast, and 10% of the time when wind is from the southwest. It should be noted that even though the northeast quadrant is the least predominant wind direction (14% of the time), it is the third most abundant quadrant in terms of above threshold winds at 12%.

This analysis indicates that above threshold wind speeds are common having a probability of occurrence of one in four. The greatest potential for soil erosion is from winds originating out of the northwest, which also correlates to the quadrant having the highest average wind speeds. Erosion potential under these wind conditions will vary based on antecedent moisture conditions in the soil, vegetative cover, and development of surface crusts, all of which impede grain entrainment processes. However, visual inspection correlates well to the precipitation record and indicates that the greatest potential for wind erosion processes occur between the early spring to late summer-early fall time periods. High winds associated with the changing seasons (winter to spring and summer to fall) also contribute to this time period as being the most active in terms of dust generation. Lastly it should be noted that soil erosion can occur at any time, particularly if mechanical disturbance of the soil surface has occurred.

## 3.0 Historical Mining Activities

Only a few coal claims were located in Harding County prior to 1920. Uranium exploration began in 1954 when the Atomic Energy Commission decided to fly airborne surveys over the Slim Buttes (approximately 20 miles to the east of the Cave Hills). According to Curtiss (1955), "Messrs. Ellis and Fiegen, pilots from Spearfish, were scheduled to fly over the buttes, but a high wind precluded their operations. Instead, they flew over the Cave Hills and recorded high anomalies. As a result, they staked the first claims on August 15, 1954. Since that time, activity in this area has been intense."

Active mining started around 1954. Mine sites are located primarily within an approximately two-mile broad, northwest trending strip crossing the central North Cave Hills ("hot zone"). Mining was permitted under the General Mining Laws and Public Law 357, which required no form of restoration. Most mining and mining prospects are located on USFS administers land, but at least two actively mined sites and several prospects and exploration cuts and digs are situated on private land surrounding the North Cave Hills. These uranium mines are abandoned coal strip mines located on relatively flat areas along the top of the buttes. Mining consisted of the removal of up to 80 feet of overburden to reach the uranium bearing lignite beds ("ore



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zone").

Extensive mining activity occurred in the early 1960s in an effort to supply contracts for uranium, but all active mining in the area ceased shortly thereafter in 1964. Documented mine sites, spoils, exploration activities and subsequent erosion of spoils cover almost 1,000 acres (see Table 3.1 and Fig. 3.1). Most of the spoils were pushed over the edges of buttes onto the steep slopes below the rim rocks during mining (Fig. 3.2). Additional spoils have been deposited down-slope by subsequent water and/or wind transport. At these sites, the sandstone cliffs are mostly covered, and the overall slope angles are highly over-steepened. The spoils are also mostly void of vegetation, and their composition is also conducive to water channeling and tunneling. All these conditions contribute to high erosion rates and also make these sites highly prone to sliding and slumping. At two sites, Bluffs B and H, the spoils have slid and/or slumped onto adjacent private land, and subsequent sheet erosion of these deposits formed shallow depositional cones and veneers of sediment down gradient (Fig. 3.3). Uncontrolled, channeled runoff from the spoils locally also caused up to approximately 12 feet deep gully erosion. At several sites highly radioactive material was left exposed on the pit floors or spoils.

In addition to the mining sites, numerous prospecting pits or contour benches are visible in the field on both USFS administered and private lands and have been mapped and documented in the area (Pioneer, 2005). These mostly obvious, but sometimes also overgrown and sublime features were made by dozers or backhoes to expose outcroppings of fresh rock. One mine site on private land on Flint Butte, located immediately northeast of Ludlow, has been hypothesized as a potential source of molybdenosis in cattle grazing at and in the near vicinity of this site (Stone et al., 1983). Molybdenosis results from the interactions of Cu, Mo, sulfide, and sulfate in the rumen and tissues of ruminants, which make Cu metabolically unavailable (Stone et al, 1983).

## 3.1 Control Structures and Previous Mitigation Activities

In 1987, the USFS installed five sedimentation ponds (constructed using a common standpipe design) on USFS administered land to contain/control runoff and offsite migration of sediments from the Riley Pass Mine, the site with the largest erosion potential. Ponds #1 and #2 were installed on the eastern side of the pass just above the relocated Riley Pass Road in the headwaters of Pete's Creek. Ponds #3, #4, and #5 were constructed on the western side in Schleichart Draw just below the mine site. Another pond is planned to be constructed for capturing runoff into Pete's Creek from the spoil piles along the northeastern side of Bluff B. This part of the drainage is presently not contained by any control structure.

A series of other ponds and reservoirs exists further down the Schleichart draw along the western side of the North Cave Hills. According to a chronologic series of aerial photographs, Schleichart Dam Reservoir was constructed in1935 by the Civil Conservation Corps (CCC) (Laurie Walters-Clark, USFS, personal communication) before regional uranium mining operations began. Further downstream within this drainage, the Schleichart Ducks Unlimited Pond was completed in late summer of 1987 as part of a (now abandoned) wildlife habitat improvement project. Just at the USFS boundary of this drainage on land recently acquired by the USFS is Brown Reservoir. This reservoir captures all of Campbell Creek and Davis Draw drainages. Brown Reservoir was most likely constructed before 1958, but after 1938 (probably in the early 1950's;



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J.D. Brown, local rancher, personal communication).

The sedimentation ponds filled up rapidly over the years. Ponds #3, 4, and 5 were cleaned out by the USFS in 1990, and all ponds (#1-5) were cleaned out again in 1997 and 2004. The competence of these ponds was tested during several strong rainfall events. Many stock dams and reservoirs on private land overflowed and were breached during a significant rain event that occurred in 1992 when a highly localized thunderstorm dumped up to 10 inches of rain within approximately three hours along the northeastern side (Randy Feist, local rancher; personal communication) and up to 2-4 inches along the western side of the North Cave Hills (Mert Clarkson, local rancher; personal communication). This event caused localized flooding and breaches/overflow of stock dams and sedimentation ponds on USFS administered land. In a possible response to this event, the culvert at pond #2 had to be replaced and the road reconstructed in 1993. During another event in 1995, the culvert in pond #5 failed and was repaired and the road was reconstructed in 1997. Sedimentation ponds were subsequently cleaned out and repaired after this event (Laurie Walters-Clark, USFS, personal communication). The sediments removed from these ponds were dumped at a designated site within Bluff B. At this time it is not known how these or other significant rainfall events during- and post-mining affected the spread of mine spoils and associated metals and radionuclide loads within the local and regional drainages.

## 3.2 Previous Investigations

Previous investigations were mainly focused on USFS administered land and consisted of surface soil, sediment, and water samples. A comprehensive compendium of all data and conclusions is presented in the USFS-Pioneer Investigations Report (2005). These studies document higher than normal, though widely varying, concentrations of target analytes in background samples of soil, sediment, and water. They also show a wide variance in concentrations of target analytes in mine spoils and in sediments and surface water of drainages impacted by mining. Significant changes in contaminant concentrations are obvious for surface water samples taken at the same site, but in different years (1999 and 2000) during the month of August (Pioneer, 2005).

Concentrations range from below the established average background to 10 times higher for sediment samples in impacted drainages and several 100 times higher for spoil samples at mapped mine sites. Bluffs B and H were identified as the areas of most concern. Bluff B is of concern due to the large amount of disturbance resulting from past mining activity while Bluff H appears to have a higher contaminant level. Pete's Creek and Schleichart Draw were shown to be the two drainages most impacted by the mining activities.

All measured contaminant concentrations in water, except total uranium and $U^{235}$, exceeded 3 times background water downstream from Bluff I (RP-SW-Il through -15). Bluff B (RP-SWB3) and Bluff J (RP-SW-J2 and -J3) were below three times background for total uranium and $U^{235}$. Since only four locations with available surface water flow were sampled, samples RP-SW-I1 through –I5 were collected after a storm event.

Surface water upstream of Schleichart Draw Reservoir (RP-SW-SP6) exceeded 3 times



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background for arsenic, copper, lead, molybdenum, selenium, thorium, vanadium, $Ra^{226}$, and TSS. Surface water downstream of the Schleichart Draw Reservoir (RP-SW-SP7) exceeded 3 times background for arsenic, copper, lead, molybdenum, vanadium, $Ra^{226}$, and TSS, but at significantly lower concentrations than the upstream sample, indicating the reservoir is removing contaminants from surface water. Surface water below the Ducks Unlimited Pond (RP-SW-SP8) exceeded 3 times background only for molybdenum and $Ra^{226}$, and again, all contaminants were at significantly lower concentrations than the sample collected upstream of the Ducks Unlimited Pond, indicating the pond is also removing constituents from surface water. Re-sampling upstream and downstream of the Ducks Unlimited Pond (RP-SW-SD2 and -SDl, respectively) in 2000 showed only arsenic exceeding background concentrations at both locations. Arsenic, molybdenum and TSS concentrations were higher downstream of this pond than upstream.

Surface water sample data were compared with the EPA's Acute Ambient Water Quality Criteria (AAWQC; EPA, 1996) and the State of South Dakota Surface Water Criteria. The AAWQC only exist for arsenic (360 μg/L), copper (17.7 μg/L), and lead (82 μg/L).The AAWQC for arsenic and lead were exceeded for all the sediment ponds and above the Schleichart Draw Reservoir, but not below. The AAWQC for copper was exceeded for all the sediment ponds above and below the Schleichart Draw Reservoir, but not below the Ducks Unlimited Pond. The AAWQC for copper and lead were exceeded for Sample RP-SW-I1.

Following the collection of each water sample, a sediment sample was collected from the streambed or sediment pond. Arsenic concentrations in sediment downstream from Bluffs D, F, G, and H exceed 3 times local background. Molybdenum concentrations exceeded 3 times background downstream from Bluffs B, C, D, F, G, H, and I. $Ra^{226}$ concentrations in sediment downstream from Bluffs B, C, D, F, and H, and Sediment Pond 2 exceed 3 times local background. $U^{235}$ concentrations exceed 3 times background downstream from Bluffs B, C, D, and F.

The sediment particle size data show a significant reduction in the median grain size (the $D_{50}$ coefficient) occurring at all downstream sample locations relative to the background locations for each of the bluffs, except for Bluffs A, C, E, J, and K, the western sides of Bluffs F and H, the northern side of Bluff I, and the southeastern end of Bluff B. A few of the sediment particle size sample locations show greater amounts of fine-grained materials (less than #200 mesh silt) relative to the background sediment (30% fines).

All of the sediment pond samples (RP-SE-SPI through -SP5) have both significant median grain size reduction and significant fine sediment relative to background, indicating that they are performing their function of removing sediment. Stream sediments downstream from the Schleichart Draw Reservoir have 20% more fines than the upstream sediment (79% versus 59%). Similarly, stream sediments downstream from the Ducks Unlimited Pond have 5% more fines than the upstream sediment (84% versus 79%). This was attributed to the lower ponds removing more of the larger size sediment than the fines.

Field surveys by Pioneer in 1999 and 2000 in the North Cave Hills for gamma radiation show background levels of 10 to 20 μR/hr (microRem/hour) and localized readings of up to 4000 μR/hr in black sediments within the mined areas. The very high average readings of 6,000 to



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60,000 and 10,000 to 35,000 counts per minute (CPM) for Bluffs B and H, respectively, and the maximum readings of over 800,000 CPM in some lignite samples in the Portage, 2004 study could not be confirmed. Our own preliminary investigations during two field reconnaissance trips show the following, uncalibrated, radiometric readings: background of 40-70 CPM (counts per minute); general mining spoils ranging from background readings to about 300 CPM, with localized coal pieces of 300-700 CPM, and, on the west side of Bluff H, spoils of ochre sandstone rich in brown to yellow colored phosphatic concretions with localized readings of 300-700 CPM; open face cuts of lignites within the mined areas registered at about 600-4000 CPM; one, localized fragment of black-colored sandstone found in the spoils of Bluff B showed a reading of 45,000 CPM. None of the prospecting pits or contour benches surveyed by our preliminary surveys showed readings above background.

## 4.0 Project Objectives

The overall objective for this investigation was to determine whether heavy metal and radionuclide environmental contaminants have been transported from historical mine sites on lands administered by the Forest Service onto private lands. Mechanisms of environmental transport were thought to include:

1. Erosion of spoil sediments through adjacent drainages;
2. Dissolution of hazardous metals within runoff water and groundwater; and
3. Erosion/deposition of small diameter spoils particles by wind transport.

The field sampling objectives were developed to ascertain whether surrounding private lands have been negatively impacted by migrating contaminants from historic mining sites within the watersheds surrounding the North Cave Hills area, and determine whether such contaminants pose a potential health risk to the surrounding population. As a result, the field sampling protocol were developed to:

1. Establish background concentrations and variability for the environmental contaminants (target analytes) addressed within this study;
2. Determine whether present contaminant concentrations exist in surface waters and sediments coming off USFS administered land and whether they can be attributed to impacts stemming from historical uranium mining and exploration;
3. Discriminate whether sources of environmental contaminants found within down-drainage surface waters and sediments on private lands can be attributed to historical mining and exploration operations on USFS administered land, from naturally occurring mineralization, or from other historical mining and exploration activities in the drainage;
4. Determine if heavy metals and radionuclides exist in aquifers used by private parties for domestic and/or stock use in a perimeter of 5 miles around the North Cave Hills area, and establish potential sources and migration pathways if present;
5. Quantify whether wind erosion serves as a potential contaminant migration source from mine spoils on USFS administered land;
6. Determine if down-gradient contamination within ambient air dust may be attributed to mine spoils on USFS administered land.



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# 5.0 Field Sampling Strategies

As outlined above, previous site investigations primarily focused on environmental conditions within USFS administered land, and had not addressed potential environmental impacts that may have migrated offsite onto private lands. The sampling strategy developed to discern potentially impacted surface waters was a "watershed" approach. It was assumed that all runoff water and eroded sediments (except for wind erosion) would ultimately end up in the adjacent drainages and subsequently migrate downstream through the drainage networks. Based upon the overall goal of assessing the environmental impacts of historical mining activities on surrounding private lands, the surface water sampling events were divided into two distinct phases, Phase I and Phase II. For the initial Phase I sampling events that occurred during June 2006, target analyte concentrations of all potentially impacted drainages leaving USFS administered land were determined at or near the USFS-administered/private land boundary. Additionally, background concentrations for the target analytes were established for drainages based on sampling locations of drainages assumed to not be impacted by the mining activities. The gathered data were subsequently used to evaluate which drainages were most heavily impacted. Total and dissolved metals concentrations were analyzed for most water samples collected (some Phase I, all Phase II samples) to ascertain the primary phase of potential contaminants mobility (e.g., associated with $< 0.45$ μm sized sediments or sub-colloidal) within the watershed.

After initial evaluation of the Phase I results, the drainage with the highest environmental concern was selected for Phase II sampling. For this phase, downstream sampling continued to a point where target analyte concentrations were comparable to established background levels. Phase I results indicated that the Pete's Creek drainage appears to be the most heavily impacted, and thus was selected for Phase II sampling.

## 5.1 Target Analytes

Target analytes for metals and radionuclides chosen for this study (Table 5.1) were similar to those used within previous investigations, thus allowing direct comparability of the data (except for Denver, Knight, and Piesold, 1991). Analytical methods and procedures for determination of analyte concentration were also similar to those employed within previous studies with the exception of our study analyzing for both total and dissolved metals concentrations for the surface water samples. In addition, this study analyzed for select anions and other water quality characteristics (Table 5.2) to further characterize contaminant geochemical mobility.

## 5.2 Background Sampling

Previous investigations determined background concentrations for the target analytes in soils in undisturbed areas within the same stratigraphic interval as the mined lignite ("ore zone") and in sediments and surface water in drainages deemed to be not impacted by mining activities. Judging by these data (a compilation of all data and average concentrations are listed in Portage, 2005, Appendices A and B), soil contaminant concentrations vary widely depending on two factors:



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1. Sample location within or outside of the "hot zone" crossing the central North Cave Hills; and
2. Soil type, meaning a lignite or non-lignite based sample.

Based on map analysis and an initial field reconnaissance performed in March 2006, three control drainages were initially selected to represent various "background" conditions for the surface water sampling. The number of control drainages used was increased depending on sampling medium (as discussed within individual results sections). Sampling locations for these drainages are all near or at the USFS/private land boundary, and surface water samples were taken at these sites for establishing background. Detailed discussion regarding background sampling locations and results have been provided within the individual results sections.

### 5.3 Surface Water Quality Standards

The Draft Applicable or Relevant and Appropriate Requirements for the Riley Pass-Mine Site, South Dakota Department of Environment and Natural Resources (DENR) Water Quality Standards (DENR 2002 as presented in Pioneer 2002) are shown in Table 5.3. These results were used to compare regional surface water results to DENR water quality standards.

## 6.0 Surface Water Results

Results of the surface water investigations completed during June and July 2006 for the North Cave Hills complex are presented herein. Sampling events for the determination of surface water quality within the North Cave Hills complex were divided into two distinct and separate sampling events:

- Phase I where collection of (available) surface water samples within drainages located at the interface between USFS administered lands and private land occurred. Phase I sampling locations are show in Figure 6.1;
- Phase II where comprehensive sampling of the Pete's Creek drainage and connected sub-drainages occurred. Pete's Creek was considered as most likely impacted by historical mining operations that occurred on both public and private lands. Phase II sampling locations are shown in Figure 6.2.

Previous investigations (Pioneer 2002) had shown that elevated heavy metal and radionuclide concentrations existed within sedimentation ponds #1 and 2 which were constructed to collect sediment-laden runoff from Bluff B. These sedimentation ponds are located near the headwaters of the Pete's Creek drainage.

### 6.1 Establishment of Background Concentrations

Based on map analysis and an initial field reconnaissance performed in March 2006, four control drainages were selected to represent various "background" conditions for surface water sampling. These sampling locations were considered to be outside of the predominant



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mineralization zones within the North Cave Hills area, and thus best represent non-mining impacted drainages. Sampling locations for these drainages are all near or at the USFS/private land boundary, and surface water samples were taken at these sites for establishing background.

1. NCH SW 21: Smaller northwesterly drainage with an area of approximately 2/3 of one square mile fed by Cox Springs #'s 1 and 2. No mining or exploration activities are documented in this watershed. This drainage represents "pristine" conditions outside of the "hot zone" in the highly dissected northern part and flows into Crooked Creek;
2. NCH SW 24: Uppermost drainage of Campbell Creek draining almost exclusively private land with an area of approximately one square mile. This sample location is situated at the upper end of a stock dam. Any drainages coming off USFS administered land on the southwestern side enter Campbell creek below this point; and
3. NCH SW 26: Icebox Canyon and the drainage immediately to the west fed by Travers Spring #2 which drain part of the "hot zone" on the southwestern side. No mining or exploration activities are documented in this watershed. This site is a relatively large side drainage (approximately one square mile) of Schleichart Draw and Campbell Creek. The sampling location is located at the upper end of a stock dam on State land.
4. NCH SW 31: Spring water from Randy Fiest homested. Sample collected at end of wellhead adjacent to horse corral. Source of water is shallow spring located on USFS administered land.

Sampling locations and results from the four background surface water sampling sites (NCH SW 21, 24, 26, 31) are presented Figure 6.3 and Table 6.1. Background concentrations were established by calculating the mean analyte concentration from the 4 sampling sites and adding 3 standard deviations to the mean concentration. The resulting "background" concentration is considered to statistically represent the regional background concentration for five of the eight analytes measured (arsenic, copper, molybdenum, uranium, and vanadium. The other analytes measured (lead, thorium, and selenium) were found to be consistently below SDSM&T EMES lab analytical detection limit (< 0.005 mg/L), and as a result, a background concentration could not be established.

The established background concentrations for total arsenic, copper, molybdenum, uranium, and vanadium are 0.020, 0.039, 0.040, 0.027, and 0.007 mg/L respectively, suggesting that for a regional basis, naturally elevated concentrations of these metals exist and are likely not attributable to historical mining activities

For the overall assessment of surface water quality within the North Cave Hills complex, total and dissolved metals concentrations were compared to our established regional background concentration for both Phase I and II sampling events. Contaminant concentrations found to exceed the established background (i.e., greater than the mean + 3 standard deviations) were considered to be "greater than background" and thus presumably "impacted" from historical mining operations. Within Table 6.1, analytical results have also been reported as "> background", ">3x background" and the ratio of analyte concentration to background (x background) to describe the level or degree of contaminant concentration relative to background. Results have been classified as "impacted" when the analytical results were greater than established background. The background concentrations for contaminant metals established for

surface water in this study are similar to previous studies (Pioneer 2005).

## 6.2 Phase I Results

Initially, through our review of available hydrologic maps and through preliminary field reconnaissance, approximately 26 potential surface water sampling sites were identified along the USFS-administered land/private land boundary. However during the Phase I field sampling events of June 2006, not all of the identified sampling sites had appreciable drainage that would allow the collection of a water sample. As a result, a total of 17 Phase I samples were collected representing 9 sampling locations. Sample locations for Phase I samples are shown in Figure 6.1. Phase I samples were analyzed for water quality parameters outlined within Tables 5.1 and 5.2. In addition, select samples were analyzed for radiochemical parameters (gross alpha, $U^{235}$, $Ra^{226}$) at sampling locations thought to exhibit elevated total uranium concentration based upon total uranium analytical results. $U^{235}$ was chosen to provide comparison between Pioneer 2005 data and results from this study. $U^{238}$ however would be a more appropriate contaminant to determine since typically >95% of total uranium is commonly present as $U^{238}$ in common aqueous-based environmental samples. Future sampling events (i.e., South Cave Hills and Slim Buttes) will analyze for $U^{238}$ instead of $U^{235}$.

The majority of the Phase I metal and radionuclide results were analyzed only for total metal concentrations. The sampling and analysis protocol was modified near the completion of the Phase I sampling to include both total and dissolved metals concentrations, thus allowing a better characterization of contaminant transport within the corresponding water column. For Phase I, dissolved and total metal concentrations are reported only for samples NCH SW 1-5, 2-5, 27-2, and 28-2, with the remaining Phase I results only providing total metal concentration. A summary of the total and dissolved (if measured) metals concentrations from the Phase I study are presented in Table 6.2.

The area with the highest surface water concentrations of arsenic and uranium, the contaminants of greatest concern for this study, were found in the headwaters of the Pete's Creek drainage. The upper reaches of the Pete's Creek drainage is fed from sediment and surface water runoff from Bluff B (Figure 6.4), and samples collected at the discharges of sedimentation ponds #2 (NCH SW 1) and #1 (NCH SW 2) contained the highest average concentrations of total arsenic (0.676 and 0.569 mg/L, respectively) and total uranium (0.135 and 0.080 mg/L, respectively) for the Phase I study. In addition, elevated arsenic and uranium concentrations were found at sampling sites NCH SW 16 (drainage from Bluff H) and NCH SW 18 (drainage from Bluffs F and G). Sites NCH SW 1, 2, and 18 exceeded background concentrations for arsenic (28 to 33x background), copper (2.3 to 4.2x), molybdenum (2.7 to 4.97x), uranium (2.9 to 5.0x), and vanadium (21 to 39x), and thus met the "impacted" criteria of greater than established background (i.e, greater than the mean plus 3 standard deviations for the background sites). Note all surface water vanadium concentrations did not meet external quality control (QC) data assessment criteria, and thus may only be used as estimated concentrations (see Data Validation section). For site NCH SW 16, concentrations exceeded background for arsenic (0.114 mg/L, or 5.6x background) and molybdenum (0.092 mg/L, or 2.3x background), and slightly for uranium (0.029 mg/L, or 1.0x background).



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For the remaining Phase I samples, sites NCH SW 27 and 28 reported several contaminant concentrations that exceeded background. Site NCH SW 27, located near the terminus of Schleichart Draw as it crosses the USFS road onto private land (Figure 6.5), exceeded background for copper (0.063 mg/L average, or 1.6x background), uranium (0.097 mg/L, or 3.6x background), and vanadium (0.008 mg/L, or 1.2x background). Further down Campbell Creek near the discharge of an existing stock dam (Figure 6.6), site NCH SW 28 exceeded background for copper (0.067 mg/L average, or 1.8x background), molybdenum (0.049 mg/L, or 1.2x background), and uranium (0.044 mg/L, or 1.6x background). For the remaining Phase I sampling sites, background concentrations were exceeded arsenic at NCH SW 25 (0.028 mg/L average, or 1.4x background), copper at site NCH SW 23 (0.048 mg/L average, or 1.3x background), and vanadium at site NCH SW 25 (0.025 mg/L, or 3.9x background). All other Phase I sampling sites were reported less than background for arsenic, copper, molybdenum, uranium, and vanadium.

## 6.3 Phase II Results

Comprehensive sampling was performed to determine the extent of metal contamination within Pete's Creek and its tributaries. This Phase II sampling event was performed on June 21 and 22, 2006. Discussions regarding the Phase II sampling results has been divided into two sections:

1. Upper Pete's Creek: the drainage area between the USFS administered land/private property interface (closest to the abandoned mines) and south of Tufte Road (Figure 6.2, Table 6.3);
2. Lower Pete's Creek: the drainage area located north of Tufte Road, continuing north to the confluence of Crooked Creek, and further downstream of Crooked Creek east until the stream passes beneath South Dakota State Route 85 (also shown in Figure 6.2, Table 6.3).

Results from the Phase II sampling events have been graphically displayed within the following figures:

1. Extent of contamination within Pete's Creek and its tributaries relative to established background concentrations for arsenic (Figure 6.7), copper (Figure 6.8), molybdenum (Figure 6.9), uranium (Figure 6.10), and vanadium (Figure 6.11). Sampling sites and color designations based upon stream concentrations relative to background (background, 2x background, 3x background, 6x background, and greater than 6x background) have been included within these figures;
2. Concentration of arsenic (Figure 6.12), copper (Figure 6.13), molybdenum (Figure 6.14), uranium (Figure 6.15), and vanadium (Figure 6.16) plotted as a function of stream distance downstream from Bluff B within Pete's Creek. In addition, major sub-drainage locations and corresponding contaminant concentrations have been included (e.g., flow from Bluffs F,G, H, I1, and I2 show using blue lines and symbols) . Background (black line) and 3x background (green line) have been designated to show the degree of stream impairment relative to background.



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### 6.3.1 Upper Pete's Creek

Within the upper Pete's Creek drainage, site NCH SW 16 was sampled to determine the extent of contamination potentially associated with Bluff H spoils at the USFS administered land/private property interface (Figure 6.17), and these results (discussed in Phase I) showed that significantly elevated concentrations of metal contaminants existed. Sample NCH SW 29 was chosen to assess whether contaminant loading within the upper Pete's Creek could be attributed to localized lignite coal outcroppings commonly found within the upper Pete's Creek drainage and sub-drainages. Sample NCH SW 29 was taken immediately downgradient of a lignite spring discharge (Figure 6.18), and was assumed to presumably not contain contaminants associated with Bluff H spoils and runoff. Results from this lignite spring showed slightly elevated concentrations of copper (0.041 mg/L, or 1.1x background), molybdenum (0.053 mg/L, or 1.3x background), and vanadium (0.011 mg/L, or 1.7x background), and thus contains substantially lower concentrations of metals compared to sites directly influenced by minesite runoff. Further downstream within the upper Pete's Creek drainage, two additional lignite outcroppings were sampled (NCH SW 55, 56) and were found to contain elevated copper (0.120 and 0.126 mg/L, or 3.1 and 3.3x background, respectively) and vanadium (0.042 and 0.039 mg/L, or 6.5 and 6.0x background, respectively). These results suggest that regional lignite outcropping seeps and springs within the upper Pete's Creek drainage do not appear to be a significant source of contaminant loading, with the exception of copper and vanadium. The elevated vanadium concentrations within the natural lignite outcroppings were found at concentrations significantly greater than background, and thus appear to be a natural source of vanadium loading. As discussed earlier, vanadium concentrations did not meet QC data assessment criteria, and thus may only be interpreted as estimates. Neither arsenic nor uranium concentrations exceeding background were found at these lignite outcrop areas.

Within the network of sub-drainages containing runoff from Bluffs F, G, H, I1, I2, sites NCH SW 44 (west fork side drainage; sampled standing water within depressed cow imprints), NCH SW 45 (lower confluence of drainages; standing water), and NCH SW 46 (upper east drainage; cow imprints in sediments) all were found to have contaminant concentrations greater than background. Metal contaminant concentrations exceeded background for arsenic (4.4 to 9.6x background), copper (2.0 to 5.9x background), molybdenum (1.7 to 8.6x background), uranium (2.7 to 11x background), and vanadium (9.4 to 35x background) at these three sites, suggesting that surface runoff and spoil migration from Bluffs F, G, H, I, and I2 have impacted this regional water quality which eventually drains into Pete's Creek. The overall contaminant impact from these sub-drainage may be seen within Figures 6.12 through 6.16 (blue symbols and lines). Overall contaminant concentrations within Pete's Creek did not appreciably increase due to loading from this sub-drainage, however contaminant loading was typically greater than 3x background for arsenic, molybdenum, uranium, and vanadium, while copper was found to be greater than background. Additional surface water sampling is planned for the 2007 field season to confirm metal contaminant concentrations in this area, especially during appreciable flow events since samples collected from standing water may be influenced by metal dissolution from local sediments.

The area that exhibited the greatest degree of contamination was the northern-most sub-drainage from Bluff B. This unnamed tributary flows cross Riley Pass Road/USFS Route 3120 northeast



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of sedimentation ponds #1 and 2, and historical sediment flows within this tributary have been documented within the Portage (2005) study. Periodic movement of spoils and overburden from this region of Bluff B appear to be a significant source of sedimentation loading within the upper Pete's Creek drainage. For example, during our field sampling events, a very large area (approximately 10 to 20 acres) of historical sediment deposition was observed in the vicinity of sampling site NCH SW 43, up-gradient of the confluence of the northern Bluff B tributary and the main drainage of Pete's Creek. It appears that extensive sediment migration during high flow events from this uncontrolled tributary is responsible for the large degree of sedimentation observed (Figures 6.19, 6.20). Sedimentation appears to occur when surface water velocities, carrying suspended fines and spoil materials from the northern reaches of Bluff B overburden, diminish as the drainage gradient decrease. This relatively slower velocity occurs immediately upstream of the confluence with Pete's Creek. Currently there is no sedimentation pond to collect and minimize uncontrolled surface runoff from northern Bluff B spoils, however conversations with Laurie Walters Clark of the Custer National Forest Sioux Range District confirm that a sedimentation pond will likely be constructed during the 2007 field season. Surface water sampling site NCH SW 43 was located near the head of the large sedimentation zone, approximately 500 m upstream of the Pete's Creek confluence. This sampling site had the highest total metal concentrations observed during the duration of this study. The contaminant concentrations were consistently greater than concentrations observed within Pete's Creek upstream of this tributary (site NCH SW 42), as shown by the lone red circles within Figures 6.12 through 6.16 (at a distance 1.5 km from Bluff B). Contaminant concentrations measured at site NCH SW 43 that were found to be significantly above background include arsenic (1.807 mg/L, or 89x background), copper (0.524 mg/L, or 14x background), uranium (0.638 mg/L, or 23x background), and vanadium (0.473 mg/L, or 73x background). Molybdenum (0.121 mg/L) was found to be only slightly above background (3x). The ratio of dissolved to total metals concentrations for the contaminant ranged from 0.07 for vanadium to 0.23 for uranium, suggesting that the majority of contaminants are associated with the suspended particulate (> 0.45 μm) phase, and subsequently these high contaminant concentrations appear to be heavily influenced by sediment loading. Interestingly, dissolved molybdenum concentrations were significantly greater than its corresponding total molybdenum concentration for this site (NCH SW 43; 8.2x greater), as well as other sampling sites within the upper Pete's Creek drainage (NCH SW 1, 2, 37, 38, 39, 41, 42, 50, 52, 54). None of the other analytes tested were found to consistently show this trend of higher dissolved versus total metal concentrations. Had other samples showed a similar pattern, the probable source of error could be attributed to errors in sampling or digestion. Instead, the high dissolved metals concentrations could be an artifact of sample digestion where filtration (0.45 μm) appears to concentrate or have a "high affinity" for dissolved molydbenium when leached the from suspended sediments. However this speculative explanation has not been supported within the literature. Further review of this phenomena will be undertaken during future sampling events (i.e, South Cave Hills study). The ratio of dissolved to total molybdenum did normalize (less than 1.0) at sampling sites further down Pete's Creek (greater than 13.5 km from Bluff B).

Samples collected further downstream of the sedimentation zone (5.0 km downstream from Bluff B) within Pete's Creek show that attenuation of contaminant concentrations is readily occurring. Sampling sites NCH SW 52, 54, and 57 indicate that contaminant concentrations decrease considerably between stations 1.5 to 5 km as shown within Figures 6.12 through 6.16). For



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example, total arsenic decreased from 1.052 mg/L (52x background) at site NCH SW 41 to 0.283 mg/L average (14x background) at site NCH SW 57 within this segment of Pete's Creek (3.2 km stream length). The other contaminants showed a similar level of decrease, except for molybdenum. In addition, the ratio of dissolved to total metal concentrations for most contaminants increased significantly within this same reach of Pete's Creek, suggesting that the majority of the contaminant load appears to be associated with dissolved materials. A lower ratio of dissolved to total metals would suggest a higher percentage of metals would be associated with larger, suspended particulates. Thus it appears that the active sedimentation zone (NCH SW 43) is a major sink for the removal of sediment-bound metals. However, the high concentration of dissolved metals down-gradient of the sedimentation zone suggests that metal dissolution (leaching from deposited sediments) is occurring, and thus the deposited "fines" are acting as a major source of metal contaminants found down-stream.

A slight increase or stabilization of contaminant concentrations occurred between sampling sites NCH SW 41 and 54 where sub-drainages from Bluffs F, G, H, I1, I2 flow north into Pete's Creek. While a sample was not collected at this confluence, this sub-drainage appears to be another source of contaminant loading within Pete's Creek. As seen in Figures 6.12 through 6.16, concentrations highlighted with blue diamonds show this sub-drainage is a source of contaminant loading within Pete's Creek, however the loading is not as significant as the contaminant loading from the northern Bluff B sub-drainage (NCH SW 43). Contaminant concentrations down gradient of this confluence (NCH SW 50) show all contaminants exceed 3x background except for copper. Dissolved to total metal concentration ratios ranged from 0.47 for vanadium to 1.05 for copper, confirming again that the metals are either dissolved within the surface waters, or associated with the colloidal fines (< 0.45 μm) and are not easily settled.

Sampling site NCH SW 57 was located immediately downstream of a large outcropping of lignite coal seams within the Pete's Creek drainage (located 5.7 km from Bluff B; Figure 6.21). The lignite outcroppings do not appear to be a source of contaminant loading into Pete's Creek as contaminant concentrations did not increased appreciably when compared to upstream concentrations (i.e, NCH SW 50).

Further downstream within upper Pete's Creek, all metal concentrations (except for molybdenum) increased slightly at sampling site NCH SW 37, located immediately downstream of a sub-drainage flowing from the Flint Hills area (9.1 km downstream from Bluff B). This un-named drainage consists of overland flow and runoff from the Flint Hills region located south of Tufte Road and both east and west of State Route 85. In addition, overland flow from the Slaba "Flat Top" abandoned uranium minesite (Figure 6.22) located northeast of Ludlow is contained within this watershed. The Flat Top minesite is significant in size (similar to Bluff B) and is located completely on private property. Sampling site NCH SW 36 contained metal concentrations exceeding background for uranium (0.035 mg/L, or 1.3x background), copper (0.175 mg/L, or 4.5x background), and vanadium (0.019 mg/L, or 2.9x background). Additional sampling within the Flints Buttes drainage area, especially within the vicinity of the Flat Top minesite, is planned during the 2007 field season to assess whether this mine is a significant source of contaminant loading into Pete's Creek, in addition to other regional watersheds.



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### 6.3.2 Lower Pete's Creek

Further attenuation of contaminant concentrations occurred within lower Pete's Creek drainage north of Tufte Road. At sampling site NCH SW 49, located downstream of a confluence with a drainage from the northern Flint Hills area (north of Tufte Road), concentrations were in excess of 3x background only for arsenic (0.076 mg/L, or 3.7x background) and vanadium (0.020 mg/L, or 3.2x background); all other contaminants were between 1.3 and 2.6x background. The unnamed side tributary (NCH SW 47, 48) was not a source of contaminant loading as all contaminants except arsenic (1.6x background) and vanadium (1.8x background) were less than background.

Crooked Creek prior to the confluence with Pete's Creek (NCH SW 33) had metal concentrations less than 3x background for all contaminants. Arsenic (1.5x background), copper (1.4x background), and vanadium (2.1x background) were slightly greater than background. Downstream of the confluence of Pete's Creek and Crooked Creek (NCH SW 32; 22.9 km downstream from Bluff B), all contaminants were less than 3x background, and only copper (0.085 mg/L, or 2.2x background), molybdenum (0.050 mg/L, or 1.3x background), uranium (0.043 mg/L, or 1.6x background), and vanadium (0.014 mg/L, or 2.2x background) exceeded established background. The source of these contaminants within Crooked Creeks appears to be from Pete's Creek due to the relatively low contaminant concentrations within Crooked Creek above the Pete's Creek confluence (NCH SW 33). At the final sampling location where Crooked Creek flows beneath SD RT 85 (NCH SW 35; Figure 6.23), all contaminant concentrations were less than background except for uranium (0.030 mg/L, or 1.1x background) and vanadium (0.010 mg/L, or 1.5x background). A side tributary draining an area east of SD RT 85 and north of the Flat Top abandoned uranium minesite (northeast of Ludlow; site NCH SW 39) showed only elevated concentration of copper (0.230 mg/L, or 6.0x background); all other contaminants were less than background.

## 7.0 Groundwater Results

A total of 39 groundwater analysis were performed, including duplicate samples, from a total of 34 wells that were selected based on the following criteria:

- Wells that fed a domestic supply;
- Wells that were stock water wells;
- Wells that provided a uniform distribution around the North Cave Hills.

Figure 7.1 shows the well locations and classification based upon domestic or stock water usage. Sampling protocol used was SDSM&T-SOP-FCGW-R02-0506 and is located in the sampling and analysis plan prepared in March 2006. Analysis of the groundwater was the most comprehensive of the sampling performed in this study. Table 7.1 shows the water quality parameters that were analyzed for each sample.

Well coverage around the North Cave Hills was adequate to obtain representative water quality parameters for the region. One potential 'hole' existed in the data and that was the large grazing



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areas southwest of the North Cave Hills. No wells were present inside this area and the stock tanks were all connected via a distribution system sourced in alluvial gravel along Bull Creek.

The critical parameters for this study were the radionuclides and metals contained in the groundwater. Results from each well were compared to established water quality limits for any parameter using the values in Table 7.2.

Figures 7.3 through 7.10 contain individual metals and radionuclide maps for each metal analyte detected and include gross alpha, $Ra^{226}$, $U^{235}$, and total copper, lead, molybdenum, selenium, and zinc. Total thorium, arsenic, and vanadium were not detected in any of the wells. Table 7-3 contains the complete list of analyte detections from all wells. Using these maps and tables the following general trends were observed.

Twenty six of the thirty four wells tested contained gross alpha emitters. Three wells in the study area exceeded US EPA drinking water MCL for gross alpha (15 pCi/L) and from high to low were 44.4, 29.6, and 19.6 pCi/L. All three of these wells were located to the east and north east of Forest Service administered land. One of the wells was within one mile of the Forest Service boundary and the other two wells were approximately 5 miles to the east of the boundary. The two most contaminated wells were in shallow unconfined aquifers of limited extent. The third was a 400 foot deep well. Most of the wells that contained gross alpha were from deep confined aquifers and the distribution of positive hits around the perimeter of the North Cave Hills suggests that gross alpha is a naturally occurring component in the groundwater system and except for the three wells specified above, does not constitute a water quality problem based on the established MCL.

Uranium was detected in seven wells and ranged from 0.001 to 0.064 mg/L. The MCL is 0.03 mg/L. One well exceeded this value and one well was slightly under the MCL at 0.027 mg/L. Both of these wells were the same wells having the two highest values of gross alpha and are located to the east of the Forest boundary. The other wells containing uranium are located on the eastern and southeastern side of the North Cave Hills and were below the MCL.

Gross alpha and uranium values can be tentatively compared to a 1980 study titled the National Uranium Resources Evaluation (NURE) which tested water wells and soils across the US. These results were given in parts per billion uranium so are not directly comparable to gross alpha (pCi/L) but do correlate to uranium values obtained in the present study. The NURE data indicates trends in distribution of occurrence that appear to be similar to those mapped in this study (Fig. 7.11). Highway 85, Bull Creek, and Ludlow are shown on the NURE map for orientation. High uranium values can be noted to occur near Ludlow, about 5 miles west of Ludlow and about 5 miles north of Ludlow. These areas correlate well to the areas having the highest gross alpha and uranium values detected in this study. In addition, in a general sense the values appear to decrease in the down gradient direction.

USGS NWIS data were obtained for wells within the vicinity of well locations that showed gross alpha exceedences from this study. Table 7.4 shows the comparisons between the USGS and this study. Blank spaces indicate either a no detect or concentration was below detection limits. The N/A marking in the USGS data indicate analytes were not analyzed. Figure 7.12 shows the



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locations of these wells. Comparison of the data shows there is close agreement in well locations but well depths vary between the two data sets indicating the wells were developed in different strata. Thus, formation data are inconclusive. However, areas that were shown to have high uranium concentrations at the time of the NWIS data correlate to areas of high uranium values from this current study.

The Johnson well sites, NW of the Riley Pass uranium mining areas, have 1 well that both data sets plot on top of each other. The depths do not correlate, however. The NWIS data were collected from a 64 foot deep well and the data from this study were collected from a 400 foot well. Appendix A2 contains a notice of well construction for this site (Elmer Johnson) documenting a 400 foot depth and was drilled in 1973. The NWIS data sheet clearly states a 64 foot well depth indicating a second, and shallower, well exists nearby. Uranium concentrations in both wells are low but the 400 foot well was approximately 1.5 times above the MCL for gross alpha at 19.6 pCi/L. The second Johnson well, shown on figure GW-3 to the west of the USGS well, did not contain uranium but had a gross alpha just under the MCL at 12.4 pCi/L. There are two wells tested that are between the Johnson wells and the Riley Pass mine sites that had measured gross alpha values of 8.4 and 6.2 pCi/L and well depths of 380 (R. Fiest) and 550 (T. Kalisiak) feet, respectively. These data no not allow further speculation as to the reason there are high gross alpha concentrations at a further distance from the abandoned uranium mines than wells closer to the mine sites. All of these wells were reported by the landowners to be completed in the Fox Hills formation.

Two USGS wells at the Welch site near Ludlow are closely located to the existing domestic supply well that is 55 feet deep (see Appendix A2 for a SD water well completion report). The USGS wells are reported to be 50 and 49.2 feet deep and completed in the Ludlow member of the Fort Union formation. The 50 foot well has geochemical data showing a uranium concentration of 0.022 mg/L which correlates well to a value of 0.027 mg/L determined for the 55 foot well which was constructed in 1995 (see Appendix A2 for a SD water well completion report). These two wells are ~100-200 feet apart and were completed in the same shallow alluvial sand.

The Rotenberger site had a total of five wells that were plotted and compared. The three wells from the USGS dataset were 100, 164, and 190 feet deep and the wells from the current study were reported by the landowner to be 60 and 300 feet deep. The 300 foot well was constructed in the past few years and currently is the primary water supply for the ranch. Well results did not contain any uranium and had 3.5 pCi/L gross alpha. Three of the four shallow wells have geochemical data and all contain high uranium concentrations above the MCL of 0.03 mg/L. The 60 foot well also contained 3 times the gross alpha MCL and was measured as 44.4 pCi/L.

All of these data suggest that uranium concentration in groundwater has been present at least since the mid 1970's and has not attenuated.

Three wells contained $Ra^{226}$ in concentrations ranging from 0.5 to 0.7 pCi/L and are all well below the MCL of 5 pCi/L. Two of the wells had concentrations of 0.7 mg/L and were the same wells as ones having the highest gross alpha contents. All of these wells were located to the east-northeast of the Forest boundary.



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$U^{235}$ was detected in five wells in concentrations between 0.3 and 1 pCi/L. Four of these wells were located to the east-northeast and one was to the west of the Forest Service boundary. There is no MCL for $U^{235}$ and this radioactivity is grouped with the total gross alpha count.

Three wells had copper detects and all were well below the MCL of 1.3 mg/L. These wells were all located within 1 mile from the Forest Service boundary. Twelve wells contained molybdenum with concentrations ranging from 0.005 to 0.015 mg/L. All but two of these wells were located to the east of Forest Service administered land. Selenium was present in two wells at concentrations of 0.005 and 0.021 mg/L, both of which were below the MCL of 0.05 mg/L. The selenium wells were both located on the eastern side of the North Cave Hills. Two wells contained lead, both at a concentration of 0.02 mg/L which is slightly above the MCL of 0.015 mg/L. These wells were located close to the Forest Service boundary, one to the southeast and one to the northeast.

Groundwater sources in the North Cave Hills area contain metals and radionuclides, some of which exceed the US EPA MCL for that species (Table 7.4). Of the wells tested, three contained gross alpha values above the MCL. The landowners of these wells are as follows: William Rotenberger (44.4 pCi/L gross alpha), Mickey Welch (29.6 pCi/L gross alpha), and Merle Johnson (19.6 pCi/L gross alpha). At the time of testing all three of these wells were being used as domestic water sources. Since testing has been completed, one of the wells has been discontinued (W. Rotenberger) and water is being hauled from a nearby deep well. The other two wells are currently being used. One well exceeded the uranium MCL (W. Rotenberger) and two wells exceeded the lead MCL (R. Fiest and J.D. Brown).

Data collected and analyzed during this groundwater study suggest that the metals and radionuclides are components of the groundwater systems within the study area. Further, the distribution of the contaminates suggests these are from natural sources and are ubiquitous in occurrence, particularly gross alpha and zinc. It is indeterminate if the abandoned uranium mines in the North Cave Hills contribute to the metals content of the water. Most likely the chemistry of surface water and local springs are affected by the presence of the mines but the deep aquifers should not be impacted directly. Shale aquicludes above the deep sources protect infiltrating waters from reaching these aquifers, which are recharged away from the local area. The exception to this would be the presence of deep fracture systems allowing local infiltration to reach the water table, i.e., a leaky aquifer. More extensive studies are currently being planned that will be conducted in 2007 to identify if such fractures exist and determine the impact they might have on the deep groundwater system. Composition and pathways of precipitation infiltrated to groundwater is also being investigated with studies to be initiated in spring 2007.

## 8.0 Airborne Particulate Results

Evaluation of airborne contamination to surrounding lands due to entrainment of fine-grained soil particles was analyzed from thirty locations where aerosol dusts were collected using a portable wind tunnel and collection of fine surface materials using a soil scoop plus analysis of ambient atmospheric dust-fall into elevated dust traps at three locations. Wind tunnel locations



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were selected based on the following criteria:

- Elevations above a drainage channel or stream course to ensure deposition of potentially contaminated dust was by air or was derived by soil forming processes;
- Locations within a 'gridded' network that was accessible and sufficiently distributed in accordance with the prevailing wind directions;
- Locations that had physical indications of the presence of fine-grained surface materials that were derived from either in-situ soil development, wind-blown deposition, or other factors leading to fine-grained materials;
- Locations where surfaces where dry and loose having fine-grained materials available to wind processes and could be either collected from the existing surface or generated through preparation of a standard loose surface.

Ambient atmospheric dust-fall traps were sited based on the following criteria:

- Site locations on the highest accessible elevation locations having a clear, unobstructed wind fetch either toward or away from the North Cave Hills uranium mines;
- Sites that were aligned within the predominant wind direction extending for at least five miles in both the up- and down-wind directions;
- Locations where potential for local disturbances or generation of aerosols were minimal.

In addition, a bulk soil sample was collected at each location a surface dust sample was collected.

Aerosol dusts were collected and analyzed in two phases after initial analysis of phase I sampling indicated the potential for a wind-blown contamination plume to exist in a southeast direction away from the North Cave Hills mine area. Phase II sampling extended the area of coverage to the southeast. Figure 8.1 shows the final sites for both the wind tunnel samples and the ambient atmospheric dust-fall traps.

## 8.1 Bulk Soils Analysis

Soil from each sampling location was collected and sieved using the following mesh sizes: 18, 35, 60, 100, 120, 140, 170, 200, 230, 270, 325, and 400 mesh. These have corresponding diameters of 1000, 500, 250, 149, 125, 105, 88, 74, 62.5, 53, 44, and 37.5 microns, respectively. Particles finer than 37.5 microns were collected in a pan and later analyzed using a laser particle sizer. Appendix A3 contains a summary data sheet for each sampling location that includes the sieve results and a percent-finer-than grain size plot. These data were utilized to gain an understanding of the physical nature of the surface soils in the study area and to evaluate the potential for availability of entrainment and transport of contaminated dust.

Soils in the study area contained fine-grains although variation existed across the study area. There were five sites containing coarse soils, defined as having >40% of the grains larger than 1.0 mm, and were distributed relatively evenly around the North Cave Hills. The ten finest-grained soils, defined as having greater than 10% fine dust (particles smaller than 0.037 mm), were widely and evenly distributed around the North Cave Hills but were further away from the



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bluffs than the fine-grained soils (see Fig. 8.1 for site locations). This represents a normal sedimentological pattern; coarse-grained materials occur closest to the source area (in this case the sedimentary rock in the North Cave Hills). The patterns also suggests soil genesis was in-situ and was a function of erosion and let-down of the land surface. Low-lying areas closest to the current highlands were the last to be eroded down and, thus, contain the coarsest grains.

The primary focus of this study was entrainment and transport of potentially contaminated dust particles and are defined as grains <0.1 mm (<100 μm) that are available to eolian processes. For all soils, particles <0.1 mm constituted between a high of 52% of the soil (NCH-WTS-34-1) and a low of 12.7% of the soil (NCH-WTS-27-1). Seven out of the thirty sampling locations contained >40% dust particles and nineteen of the thirty sites contained >25% dust particles. Averaging all soils in the study area, 29% of the particles were <0.1 mm in size and theoretically available to dust entrainment and transport.

In general terms, particles having a diameter less than 1 mm (1000 μm) are considered available for aeolian (wind-blown) processes which include transport of particles on the surface (rolling), near the surface (bouncing), and above the surface (elutriation) (Stetler, 2002). For a surface composed of dry, loose material, the exact grain size moving by each of the three sub-processes is most dependent upon the wind speed, roughness of the surface, and percent surface cover. Two important additional factors to the process include antecedent soil moisture (measured in terms of the number of days since the last precipitation event) and the disturbance of the soil either by natural (animal) or artificial (human-induced, i.e. tillage) mechanisms. The former is important in terms of the creation of a surface crust that even though dust exists in the soil, moisture will preferentially orient the grains in a surface-parallel fashion which greatly increases its stability and resistance to wind processes. Such crusts can remain stable for extended times given no disturbances occur on the soil. Thus, grass fields and natural areas with significant grass cover (~>50%) can remain almost totally resistant to wind erosion processes regardless of the wind speed. The later factor is most important in breaking up a surface crust and making the soil susceptible to wind erosion processes. Thus, pastures (from animals) and cropped fields (from tillage) can become highly susceptible to wind erosion processes even if the soil type is identical to a neighboring field that does not experience surface disturbances. Additional complicating factors include the timing of the use as a pasture and the timing of the tillage operations within the yearly precipitation cycle. It is possible, then, to use land as pasture and/or cropped fields and maintain a low potential for wind erosion of the dust. This last scenario may be applicable to the abandoned uranium mine areas as surface crusts would likely form and dissipate annually as a function of precipitation and disturbances. It would be expected for these areas to be susceptible or resistant to erosion at varies times.

The foregoing discussion was necessary to establish a complete picture of the erosion process and understand, at least fundamentally, the role of the critical controlling factors. This is important in two ways in regard to the private lands where samples were collected: 1) potentially contaminated dusts that may have originated from abandoned uranium mine areas would have responded to aeolian processes acting on a surface having a different set of controlling factors than the surfaces tested and sampled in this study; and 2) the potential contamination of private lands from dust originating on abandoned uranium mine lands is being evaluated on the potential for the test site to produce transported contaminated dust. Thus, analytical results may be



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evaluated in two ways given these conditions: 1) metals contamination from sample sites would be attributed to deposition of dust originating from contaminated abandoned uranium mines; or 2) metals contamination from sample sites would be attributed to natural in-situ soil generating processes and may contain a detectable increase in concentration of specific metals that originated from abandoned uranium mines.

Laser sizing of the particles from the pan (material sieved through the 37.5 μm screen) was performed to further characterize the fine dust particles. Results are contained in Table 8.1. These analyses were based on a machine-set percentile where the percentile value of the measured mass had a particle size greater than the listed size in microns. For example, sample NCH-WTS-23-1, 16% of the dust had a diameter equal to or greater than 43 μm and 95% of the measured mass had a diameter equal to or greater than 11 μm. It is important to note that laser particle measurements are fundamentally different than using a sieve where the former is based on time-of-flight measurements through a volume and are considered 'aerodynamic' diameter. These values can vary significantly from the sieve diameters which are based on the diameter of the 'c' axis of the particle that is able to be physically forced through a square mesh opening. Thus, it is entirely possible that a particle is able to sieve through the 37.5 μm screen and be classified as >50 μm during a laser sizing measurement. More important, in the aeolian process that particle will either be able to be entrained by the wind or it would not, regardless of the sizing technique utilized in lab measurements.

Results of the laser sizing indicate that fine aerosol dusts exist in the soils that were sampled during this study, although in small amounts. Based on the above discussion of aeolian processes and controls it is difficult to make an assessment of the potential sources of the dust. The complication arises from not being able to specifically answer the question if these materials were derived from an upwind source or if the were derived in-situ as part of natural soil processes. Further research would be required to address these questions. However, it is possible to assess the susceptibility of the soils tested to entrainment processes that would liberate the fine dust based on the dust content. Past studies (Stetler and Saxton, 1996; Busacca et al., 1997; Saxton et al., 1998; Saxton et al., 2000) have focused on the particles that are 10 micrometers in aerodynamic diameter or less, the $PM_{10}$ content, as a basis for susceptibility. It has been shown that soils that have about 4% of freely occurring $PM_{10}$ particles are highly susceptible to erosion and liberation of fines (Stetler and Saxton, 1996) and such an abundance of fine particles is a rarity. Comparison of this value to those listed in Table 8.1 show that all but one soil sampled in the North Cave Hills area contain <1% $PM_{10}$ and range between 0.11 and 1.1% with an average of 0.55%. Thus, soils in the study area contain low amounts of aerosol particulates.

## 8.2 Aerosol Dust Results

Field duplicates were collected at a ratio of 1:10 and independent lab duplicates at a ratio of 1:10 yielding a total of 36 analyses. Table 8.2 contains all of the analytical results listed by site number and Figure 8.2 shows a site-composite of analytical results as a bar chart that gives the uranium concentration in mg/kg for each site. Figures 8.3 through 8.10 contain individual metals maps of eight metals including arsenic, copper, molybdenum, lead, selenium, thorium, uranium, and vanadium. In addition, a copper/molybdenum results are presented in Figure 8.11.



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Target analytes for this study were focused on uranium and arsenic with lesser emphasis placed on the other metals. The basis for evaluation of increased metals contamination, or impairment, was by establishing a statistical background concentration in soils distributed throughout the sampling area and comparing that value to all sampling locations. Ten background sites were selected based on uranium concentrations and are indicated by bold type in Table 8.2. The statistical background value was computed as 2 times the Standard Deviation of the background concentrations plus the mean of the background sites. For non-detects, the minimum detection limit of the analytical equipment was used and was 1.0 mg/kg for Cu and 0.5 mg/kg for all other metals. The statistical background values are listed in Table 8.2 for each analyte.

Analytical results of the surface dusts indicate the general ubiquity of target analytes in the soils around the North Cave Hills. Uranium was present in all but two samples and arsenic was present in all samples. Vanadium, copper, and thorium were also present in all samples and lead occurred in all but one sample. Molybdenum and selenium had the least occurrences.

Fifteen samples contained uranium concentrations in excess of the calculated background value of 0.74 mg/kg and two of these were duplicate samples at the same location resulting in thirteen locations that were above background concentration. Distribution of these sites extend across the entire sampling area but can be classified into three distinct domains. Eight locations, including the three with the highest uranium concentrations (1.96, 1.66, and 1.6 mg/kg) all occur on a northwest to southeast trend cutting across the center of the North Cave Hills (blue circle on Figure 8.2) and includes the largest abandoned uranium mine areas. The long-axis of this high concentration area also correlates to the predominant wind direction corridor indicating a probable wind influence on the observed distribution. The greatest uranium concentration (1.96 mg/kg) occurs on the west side of the North Cave Hills below and upwind of Bluffs J-K and is upwind of all of the abandoned mine sites. Topographically this area forms a small bowl where swirling winds often entrain coal dust from exposed formations on the side of the hill. This local 'haze' was observed on several trips to the area in the past year. There are two locations north of the North Cave Hills that have uranium concentrations greater than 1.0 and both are in a direction of minimal above threshold wind occurrences (upper red circle on Figure 8.2). However, local topographic influences and the distance between the weather sites analyzed and these locations could account for variations in the indicated wind directions. The last two locations having uranium exceedences occur in the topographic low between the North and South Cave Hills in the Bull Creek drainage (lower red circle on Figure 8.2). Uranium concentrations decrease to below background levels in all areas away from these identified areas.

Arsenic was detected at all sampling locations and five contained concentrations above the calculated background value of 11.93 mg/kg. All exceedence concentrations were located to the east and south of the North Cave Hills. However, concentrations below the background level that were between 9.8 and 11.6 mg/kg are located near to the exceedence locations and appear to form a similar northwest to southeast pattern across the center of the North Cave Hills (Fig. 8.3) as was noted for uranium. There are also two locations in the north that are close in value to the background level and correspond to the high uranium concentrations in the north.

Thirteen locations contained selenium concentrations above the calculated background value of



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0.56 mg/kg. A factor to be considered was that 16 samples showed an analytical non-detect and the detection limit of 0.5 mg/kg was substituted for the calculation of the background concentration value. The largest grouping of selenium occurrences were located to the south and southeast of the study area. The sites with the highest concentrations were also located in this area (Fig. 8.7) and were in the general downwind direction of the prevailing wind. One exceedence was located in the north and one was located immediately west of Bluffs J-K.

Molybdenum was detected in all but five samples and six locations contained concentrations above the calculated background value of 1.03 mg/kg. Molybdenum occurrences were widely distributed throughout the study area. All exceedences occurred to the east and southeast of the Riley Pass mine area (Fig. 8.5). Four of these sites appear to be aligned with the prevailing wind direction corridor, similar to the pattern noted for uranium, but two locations (NCH-WT-10-2 and NCH-WT-35-1) fall outside of this corridor, one to the north and one to the south.

Vanadium was detected in all samples and four locations had concentrations above the calculated background value of 22.01 mg/kg. All four exceedence locations were in the extreme southeast portion of the study area (Fig. 8.10) approximately 5 miles south of the observed wind corridor defined by uranium values and do not appear to be aligned with the prevailing wind direction in relation to the Riley Pass mines. Based on mass, vanadium was the highest contributing metal in the soils and averaged 15.9 mg/kg.

Three locations contained copper concentrations above the calculated background value of 12.51 mg/kg and was detected in all samples. All three exceedence locations were in the extreme southeast of the study area (Fig. 8.4) and were the same locations as the three northern-most vanadium exceedences. Vanadium and copper distributions appear very similar in the sense that areas of high and low values are geographically similar. Copper concentrations do not appear to align to the prevailing wind – uranium mines corridor.

One location contained a thorium concentration above the calculated background value of 3.82 mg/kg and was detected in all samples. The exceedence site was located directly north of the North Cave Hills and was not aligned within the prevailing wind – uranium mines corridor (Fig. 8.8).

Lead was detected in all samples but no location contained concentrations above the calculated background value of 14.63 mg/kg (Fig. 8.6). In terms of geographic distribution of the range in concentrations, lead is very similar to both copper and vanadium maps. There are no obvious trends in lead concentration to the prevailing wind direction and uranium mine locations.

Copper/molybdenum ratios were generated for all sites that contained concentrations of both metals (Fig. 8.11). Ratios ranged from 2.80 to 24.96 and averaged 11.32 and only three locations had a ratio <5.0. The three lowest ratios have the following distribution: the lowest (NCH-WT-31-1: 2.8) occurs about seven miles southeast of the Riley Pass mines on the highest elevation site and within the wind – uranium mine corridor; the remaining two sites (ratios of 3.02 and 4.13) occur to the northeast of the Riley Pass mines in the Pete's Creek drainage which contained significant molybdenum concentrations and low Cu/Mo ratios in the surface water system. Although these sampling sites were well above drainage level, it is possible that either wind was



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a factor or the soils developed from parent materials having an elevated molybdenum concentration and thus, the low Cu/Mo ratios. These analyses show that Cu/Mo ratios are all >2.0 and indicate no potential impairment areas due to high molybdenum concentrations.

Three duplicate lab samples were submitted to an independent laboratory for comparative analysis. The three duplicates samples were obtained from sample numbers NCH-WT-10-2, NCH-WT-20-2, and NCH-WT-30-1. Table 8.3 contains the analytical results for these three samples from both the independent lab and SDSM&T EMES. Figure 8.3 is a graphical display of the data. Appendix A contains individual plots showing a metal-by-metal comparison. The magnitude of the concentrations obtained from the independent lab were almost all higher than those values obtained at the SDSM&T EMES lab. This trend was also observed with lab duplicates from the soil core and sediment samples. Greatest variations occurred for vanadium, thorium, and selenium (SDSM&T EMES results were all less than the minimum detection limit of 0.005 mg/L) with uranium concentrations having the highest agreement. Further discussion regarding data validation and QC has been described within the Data Validation section of this report.

In summary, the analyses indicate the hypothesis for potential airborne dust contamination appears to be partially valid. Uranium concentration distribution show the highest correlation to the abandoned mine sites and the prevailing wind direction forming a northwest to southeast plume. However, the seemingly lack of correlation between uranium and other metals would not support a common wind-derived dust source. Theoretically, wind blowing across a region and entraining and transporting contaminated dust particles would then deposit these particles indiscriminately at some location in the downwind direction. The result would be a nearly uniform chemical signature and the various sampling locations would contain similar metals concentrations. Metals maps show that lead, vanadium, copper, and selenium have the highest concentrations to the southeast of the North Cave Hills. Molybdenum concentrations are highest immediately east of the Riley Pass mines and then to the southeast but are all more northerly of the concentrations for lead, vanadium, copper, and selenium. Uranium concentration are above background both to the northwest and to the southeast (up- and down-wind) of the Riley Pass mines, the only metal having this distribution. Thus, although it appears wind processes could be partially responsible for transporting and depositing dust containing uranium contaminants, the distribution between the other metals are too varied to support this as the primary process.

Absolute values of the metals concentrations in dust at all sampling sites are overall low when compared to those obtained during soil coring. Comparison to concentrations in soils derived from soil coring show that, for example, uranium concentrations average 7.6 times higher than the average concentration from the soil dust samples. Therefore, wind may be a factor in transport and deposition of contaminated particles but the data show the concentration values are low and the identified uranium plume rapidly drops to below background concentrations within the sampling area.

## 8.3 Ambient Dust Results

Three ambient dust collectors were installed across the study area on April 29, 2006, and are shown in Figure 8.1. Ambient dust samples were collected at the following times: August 2,



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2006 (all three sites), September 1, 2006 (1 site), October 4, 2006 (all sites), and November 22, 2006 (all sites), yielding a total of three samples at each site and four samples at site NCH-AD-2.

Samples collected on October 4 and November 22 were submitted for analysis but there was insufficient mass to create a duplicate sample per QC requirements. Thus, only analytical results from August 2 and September 1 are included within this report. Table 8.4 contains the analytical data.

Site NCH-AD-1 is the furthest upwind location and is about five miles to the northwest of the abandoned uranium mines and was pre-selected as the background site which would record the composition of dust in the incoming air masses. Site NCH-AD-2 was located about two miles downwind of Bluff B and one-half mile south of Bluff H with the intension of recording a potential local source of contaminated aerosol dusts. Site NCH-AD-3 was located five miles downwind of Bluff H and was located to record the composition of the air masses moving away from potential contamination sites after providing time for aerosol mixing.

Initial sample collection on August 2 indicated bird droppings were problematic, particularly in location NCH-AD-2 which was located near forested lands. Indeed, bird droppings constituted a majority of this sample. Samplers were bird-proofed on September 1 and a wet sample was collected at site NCH-AD-2; the other two sites were dry and the bird-proofing was installed without disturbing the sampler. All subsequent samples were collected from bird-proofed samplers (Fig. 8.12) having an upper spiked ring which eliminated birds from perching on the rim and dropping contributions into the sampler. Sample Number NCH-AD-2-1-ELI was a lab duplicate sent out to an independent lab from the first round of samples.

Data in Table 8.4 are inconclusive in terms of the apparent disparity between the concentration values on the collection dates. However, there is an apparent trend in the concentration values on both collection dates with an observed increase in concentrations between sites NCH-AD-1 and NCH-AD-2 and then decreasing concentrations between sites NCH-AD-2 and NCH-AD-3. All metals except vanadium and thorium show this trend for the August 2, 2006 sample date.

These initial results indicate that air transport of contaminated dusts may be occurring. They would also suggest incoming air masses already contain concentrations of the analytes in question. However, the data do not allow for conclusive statements or conclusions. All samplers were removed for the winter on November 22, 2006 and will be re-deployed in the spring 2007 to collect additional data. In addition, a total of eight ambient samplers will be deployed throughout the region during the next field season.

## 8.4 $PM_{10}$ aerosol Sampling Program

Fine particulate dust less than 10 micrometers aerodynamic diameter ($PM_{10}$) were proposed to be collected at various locations around the North Cave Hills if equipment could be obtained to do the sampling. Instruments required for this work were not obtained (by loan) until September 2006 and after refurbishing motors and cleaning the samplers, significant rains had occurred in the sampling area effectively shutting off the dust production for the winter. This work will be initiated in spring and summer 2007 for both the North and South Cave Hills and Slim Buttes.



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## 8.5 Proof of Concept

Alternate methods of sampling and collecting the dust component of the soil were explored in addition to the use of the wind tunnel. These alternate methods included:

- sieving out and analyzing the finest dust from a bulk soil sample (from one 3-4" deep hole yielding about 150-200 grams of soil) using a 400 mesh sieve (37.5 μm diameter);
- using a stainless steel soil scoop in the field to gently graze the surface and collect the upper-most layer of fines and dust from several different locations within an area of at least 100 $ft^2$.

In addition to these experiments, the stainless steel soil scoop was used to gently graze the surface of a recently run wind tunnel test plot so that evaluation could made on any potential differences in surface composition before and after a wind tunnel run.

Wind tunnel tests were conducted by establishing a standard surface over which to place the working section of the tunnel. A standard surface was prepared by using a standard garden rake to vigorously disturb the surface to a depth of at least 1", deeper if possible. This serves two primary purposes: 1) it creates equal surface conditions at all sites; and 2) it allows dust generation to become a function of the soil properties and not a surface crust, vegetation, or some other factor. A standard surface has been used extensively by the author in previous wind tunnel experiments on the Columbia Plateau (Stetler and Saxton 1996, Saxton et al. 2000).

Once the wind tunnel has been set up on the standard surface, a sampler was placed at the exit of the working section to catch eroded and transported dust. Each test lasted 8 minutes, the first 4 minutes at a wind speed of approximately 35 mph and the last 4 minutes at a wind speed in excess of 40 mph. Previous work has shown that dust generation stagnates after a few minutes (usually much less) of constant wind so increasing the speed provides a second burst of dust from the surface. In the Air Results section earlier in this document was a discussion on percent $PM_{10}$ content in the soil. Table 8.1 shows that soils in the study area contained <1% $PM_{10}$ and most of the soil were half that value. The interpretation is that these soils do not inherently contain a high amount of aerosol dust particles and, thus, dust generation should be expected to be low regardless of even the most favorable surface conditions. Anecdotal evidence from the author while working on the Columbia Plateau is germane to this discussion and is as follows: wind tunnel runs on the Columbia Plateau was conducted on soils that had up to 4% $PM_{10}$ content. During a run, visible dust could be observed exiting the working section of the tunnel almost throughout the duration of the 8 minute run. In situations where the surface became unproductive, dust could be observed to move at each wind speed increase. Mass of the samples collected was generally in the 2-5 gram range. At the North Cave Hills, visible dust was observed during only 1 wind test. At test start-up when the surface goes from '0' to '35' mph wind speed, no dust was observed in the air, save the noted single test. Placing one's hand at the exit of the working section was the only method used to verify particles were moving, i.e., they pelted the hand. Collected soil mass after the 8 minute run was 1 gram maximum and much less on several runs. This indicates that 'blown dust', although a common process visible on windy days, constitutes a minor part of the erosion processes.



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Therefore, a field method which yields identical chemical results to wind tunnel samples but is easier to collect a significant mass of fines was the focus of these experiments.

The results shown in Figure 8.13 confirms that there is no difference in chemical analysis between a wind tunnel sample and sampling from the wind tunnel trackway using the soil scoop. These data are also shown with an analysis of the fine dust sieved through a 400 mesh screen from only one hole. There are not significant differences between these three methods. The raw data for this site is shown in Table 8.5. This table shows data from four additional sites where samples were obtained by the wind tunnel, soil scoop, and sieving a bulk soil sample. Each analyte shows a close comparison between concentration values obtained from the various method utilized to collect the dust sample. There are some variations between methods but none are significant and are well within the range of concentrations reported for all test sites in Table 8.3.

It may at first appear surprising that comparable values could be obtained using all four of the methods described. However, this simply indicates that in the local area from which the samples were obtained that the chemical signature was more a function of the soil generation and not due to wind factors. Thus, analyses from a bulk soil sample obtained from a 3" deep hole give almost the same results as from using a wind tunnel over 30 $ft^2$ of prepared surface or from scooping the surface dust from over a $100ft^2$ area.

Results indicate that either of the above methods is valid. Recommendations are to utilize the wind tunnel in critical and easily accessible locations and use the soil scoop elsewhere

## 9.0 Soil Results

The soil study was performed to determine the overall extent of spoils and soil movement from the North Cave Hills abandoned minesites. Aside from the potential for airborne contamination of soils, soil quality on private land may be affected directly at two general locations where mine spoils from Bluffs B and H have actively encroached the USFS-administered/private land interface. Sediment movement typically occurs by sheet erosion and gullying and/or by slumping and sliding. For this study, three soil cores were taken at each site (Bluffs B and H) in the vicinity of the spoil pile toes to a depth of 5 feet through a veneer of eroded sediments into virgin soil. This depth was deemed to be sufficient after visual field inspection of each core. Two composite samples were taken per core, one above and one below the spoils/soil interface. In addition, surface soil was more extensively sampled on private land below the spoils of Bluff B.

### 9.1 Background Concentration of Target Analytes

Both sites represent a similar geological setting in that they are located to the east and directly below an abandoned mine within the "hot zone". Therefore, concentrations for the target analytes of the lower sampling intervals of all six cores were included in the determination of the background to gain a more significant number of samples, rather than to establish separate backgrounds for each site. A seventh background sample was taken from the lower interval of a sediment core in a shallow drainage to the east of Bluff B which penetrated in-situ formation



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(Table 9.1).

The upper limit of the background concentrations was calculated by adding three standard deviations to the mean value of the background samples. The resulting value was then rounded to the next whole number. Multiples of this number were then taken to establish the concentration intervals of 2x, 3x, and greater than 3x background for each analyte. The range of background values for the Copper/Molybdenum Ratio was determined by taking the 95% confidence level around the mean. Also, the value of this ratio decreases as the molybdenum concentration increases. Therefore, 1/2x and 1/3x background values where established by dividing the mean value by 2 and, respectively, 3. Another bracket for this ratio was established for values that are higher than the background range (Table 9.1).

Background concentrations for the target analytes were also established for soils within the "hot zone" on USFS-administered land in the North Cave Hills by the Pioneer (2005) study. Background samples where taken along undisturbed outcrops of the mineralized zone. This zone occurs within a major lignite seam approximately 60-100 feet above the sediments underlying the soil horizons at the base of the bluffs and associated spoil piles. Therefore, the background data cited in the Pioneer (2005) are not representative for this study. Nevertheless, target analyte concentrations were similar to the ones obtained in this study, except for one sample with very high concentrations for all target analytes but thorium (Table 9.2). Selenium values for the Pioneer 1999 sampling event also appear very high when compared to the Portage 2004 sampling run and this study. The approach of the Pioneer (2005) study establishing background by calculating a mean value based on a small population of samples lacking a normal distribution appears questionable.

## 9.2 East-Side Spoils of Bluff B

The mine spoils on the east side of Bluff B are over-steepened and sparsely vegetated. Years of erosion has left these deposits deeply furcated, and in several places the once covered sandstone cliffs are reappearing. Runoff water from the barren expanses of the strip mine above is channeled into a few distinctive lows in the bench line where it is then discharged down slope across the spoils. Several deep gullies have developed at these places in the spoil deposits.

Below the major discharge point on the east side of Bluff B, the high volume of water combined with the abrupt flattening of the slope at the base of the spoil have carved out an up to 5m deep and 3m wide gully into the gently sloping talus deposits and in-situ Ludlow Formation at the base of the table of Bluff B (Figures 9.1 and 9.2). This gully shallows out to about knee-deep at the USFS-administered/private land interface (Figure 9.3), then deepens again to approximately 1.5m on the Gene Feist property and shallows out to near surface depth just before it reaches the fence line at Riley Pass Road (Figure 9.4).

Washover and splay deposits at the lower end of the Gene Feist property either represent an alternate course in the lower reach during bank-full flow or might be evidence of a previous course of the channel before entrenchment. The channel also appears to have been filled just above the fence line with one or more truck loads of gravel to cobble sized mine spoil material either to control erosion or to create a ford in the channel (Figure 9.4). Evidence of Incipient



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gullying also appears at several other sites on the Gene Feist property (Figure 9.5) and flow channeling can be connected to preferred discharge sites at the base of the spoils. Minor slumping and soil flow also form several sediment lobes at the base of the spoil piles. Wholesale sheet erosion of the spoils also creates silt to sand sized washover fans that cover the gentle slopes at the base of the bluff (Figure 9.6). Two of these lobes extend onto the Gene Feist property.

Four composite samples of soil cores penetrating the washover fans and 19 surface (scoop) samples were collected at the site (Table 9.3). Concentrations of copper, lead, selenium and thorium of all samples fall within the background range; the maximum vanadium concentration just exceeds the upper limit of the background. Therefore, these target analytes are not discussed further.

Most uranium concentrations were found below the background limit of 22 mg/kg, but generally decreased with increasing distance to the base of the mine spoils. Relatively higher concentrations were also associated with washover deposits and channel sediments. Uranium concentrations also reached 2x background concentrations at two sampling sites in the northwestern corner of the soil survey where washover sediments are derived from the northeastern most part of Bluff B. Both sampling locations are located on USFS-administered land (Fig. 9.7)

Arsenic concentrations generally follow the same pattern, but reach 2x background concentration (32-64 mg/kg) at several sampling locations, including some sites on private land. Site #8 at the western limit of the soil survey along Riley Pass Road reached 3x background, but actually represents drainage sediments. The one sample in the northwest corner of the survey associated with the highest uranium concentration also marginally exceeded 3x background (96 mg/kg) for arsenic (Fig. 9.8).

Molybdenum concentrations also display the same trends as the uranium and arsenic data. Only five samples exceeded background and were within the 2x background interval, however two of these barely exceeded the background limit. The second highest molybdenum concentration was associated with the drainage sediments at site #8. Nevertheless, the highest concentration occurred in the northwestern corner and is associated with the high uranium and arsenic values in washover deposits derived from the northeastern part of Bluff B and the associated mine spoils. Therefore, the higher molybdenum concentrations may be linked to sediments derived directly from the mine spoils. These high concentrations also resulted in very low values of the copper/molybdenum ratio in the 1/3x background range (0.25-0.5), further deteriorating the already marginal soil quality in the study area with regard to this parameter (Fig. 9.9).

### 9.3 North-East Side Spoils of Bluff H

A large mass of spoils and in-situ formation slid off at the north side of Bluff H. This landslide can be linked to the severe over-steepening of the slope profile with unconsolidated spoils during the mining operations. The large, rotated mass of the landslide forms a prominent hill below the head scarp and is partially located on private land (Rothenberger property). The entire mass appears to be relatively stable due to the relatively dense cover of shrubs and sod, and, therefore,



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only sheet erosion occurs at the toe of this mass. Nevertheless, continuous slow movement and soil creep is evident by the zigzagging of the fenceline which had to be re-positioned and repaired in the past (Bill Rothenberger, landowner, personal communication).

The head scarp of the slide forms a crater-like setting, and the water collecting there drains to the east through a well-defined erosional gully. The mouth of this gully is located on USFS-administered land, but a fan of silt to cobble sized washover sediments spreads out over the gently sloping soils at the base of the bluff onto private land.

Three soil cores were taken around the northeastern edge of the slide mass (Figure 9.10). Sample #13 was placed on the washover fan described above; sample #12 represents a hand auger sample taken in the drainage below and is presented in the figures for reference only. Target analyte concentrations are listed in Table 9.4. Similar to the soil survey results found below Bluff B, concentrations of copper, lead, selenium, vanadium and thorium for all soil samples below Bluff H did not exceed the background range. Uranium concentrations also were below the upper limit of the background (Fig. 9.10).

Arsenic and molybdenum concentrations were below the background range (<32 and <15 mg/kg, respectively) for the two samples collected at the front toe of the landslide. Only the sample located on the washover fan deposits had an arsenic concentration within the 2x background range (58.7 mg/kg). Although the molybdenum concentration of this sample was within the background range, the absolute value (12.4 mg/kg) was either double or triple of the other two sample results. This elevated molybdenum value degrades the already marginal values of the copper/molybdenum ratio for the background range (0.75-2) to about ½ of the value for the other two samples (Figs. 9.11 and 9.12). Therefore, the elevated arsenic concentration and marginally degraded copper/molybdenum ratio appear attributed to the mine spoils of Bluff H.

## 9.4 Comparison of Bluff B and H Soil Results to Pioneer (2005) Study

Soil sampling sites on bluffs A, B, C, D, E, F, G, H, and I1 and I2 of the Pioneer (2005) study where re-plotted over the base map used in this study, and the associated analytical data for uranium, arsenic, molybdenum and the copper/molybdenum ratio were re-contoured according to the background range established for this study. A second set of maps shows these values for Bluffs J – L and the background samples used collected for the Pioneer (2005) study (Figs. 9.13 - 9.20).

These maps show that the very high concentration for these elements are limited to a narrow band within the hot zone and are associated with the lignites exposed in the highwalls of the mining operations or in the spoils of bluffs A, B, C, D, F, and H. Background sample RP-SS-X, with anomalously high target analyte concentrations, might represent the pre-mining soil concentration of target analytes within the hot zone, but these high concentrations must have been limited to a narrow and laterally limited band along the outcrop of the uraniferous lignite. Due to the extensive mining operations, background concentrations of soils within the hot zone cannot be accurately determined. Nevertheless, the mining operations exposed these deposits and made them vulnerable to accelerated erosion. Uraniferous lignite and other sediments with high target analyte concentrations are also mixed in with the mine spoils. Target analyte



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concentrations in these samples are all above the 3x background range established for this study. Mixed-in mine spoils at the bluffs listed above are an order of magnitude higher, and lignite samples are even up to two orders of magnitudes higher than the sample concentrations observed in the soil surveys of this study.

All other background samples show uranium, arsenic and molybdenum concentration that are either within the background or the 2x background ranges established for this study. Mine spoils composed of pure overburden sediments show target analyte concentrations within the same range, even when they are located within the hot zone. Soil samples taken of the mine spoils of Bluffs J, K and L on the western side of the North Cave Hills all exhibit concentrations within the same range. Only the two lignite samples at Bluffs J and K are above 3x background for the target analytes.

The copper/molybdenum ratios of the background samples fall within or around the background range of this study. Many of the uncontaminated overburden sediments at the mine sites show even much higher values indicating favorable soil conditions with regard to this parameter (Figs. 9.19 and 9.20). Nevertheless, lignite and mixed spoils samples display very low values of this ratio well below the 1/3 background range. The low values are not due to lower copper, but to the very high molybdenum concentrations in these samples (Figs. 9.17 and 9.18).

These observations confirm that the lignites exposed in the highwalls of the abandoned mine sites and the associated spoils are a significant source of contaminated sediments covering the soils at the base of sites located along the eastern side of the North Cave Hills. On the western side, Bluffs J, K1 and K2 Bluff constitute only minor sources of contaminated sediments, and Bluff L does not appear to be a source for contaminated sediments. This signifies that bluffs containing contaminated sediments are also source areas for the migration of contaminated sediments within the local drainages.

## 10.0 Sediment Results

Map analysis according to the watershed approach described above led to the identification of 14 drainages that leave USFS-administered land and are potentially impacted by sediment transport from the mapped mine sites. Additionally, 4 drainages not impacted by mining and/or exploration activities were selected to represent various background conditions. A fifth drainage with extensive exploration, but no mining activities in its watershed was added to represent background conditions after checking the field and analytical data.

During phase I, sediment cores were taken in 12 of these drainages at or near the USFS-administered/private land interface to the depth of in-situ formation or to a maximum depth of 20 feet. Several holes did not reach in situ formation due to refusal (penetration limit of the direct–push probing equipment) due to hard underground. Two sites were limited to one-foot deep hand-auger samples because the track-mounted probe (Geoprobe™ DT6610) could not access the sites. The location of several sites originally surveyed late in 2005 for the SAP also had to be shifted up- or downstream away from the USFS-administered/private land boundary in several drainages due to the unusually wet conditions in late spring and early summer of 2006. Stock



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dams and ponds were filled to near maximum capacity and access was only possible in the uppermost reaches. Extensive marshes also had developed in some reaches and three sites in the upper Pete's Creek drainage selected for Geoprobe coring could only be sampled with the hand auger.

The Pete's Creek Drainage was sampled more extensively downstream beyond the USFS-administered/private land interface during phase II. Eight additional sediment cores and 25 hand-auger samples were collected. Results of both phases will be discussed in whole within the context of each drainage.

A stratigraphic relationship between the sediments of the various drainages could not be established. The transition from drainage sediment to weathered in-situ formation in the cores was based on the presence of lag deposits like gravel or coarse sand within the section that indicate the base of the channel. In some cores, a paleosol horizon was chosen to represent the transition zone. Nevertheless, this transition could not be determined in several cores because a clear lag deposit or paleosol horizon was missing, and the underlying in-situ sediments of the Ludlow or Hell Creek Formations were similar in grain size and appearance to the drainage sediments (see Table 10.1).

After retrieval of the core, the plastic sleeve was cut open, described in a core log, and the sediments were field-screened for the target analytes with a hand-held X-ray fluorescence spectrometer (XRF) by taking readings of each interval described in the core log or, at a minimum, at 1 ft intervals. Composite samples were then taken with a stainless steel lab spoon by removing a groove of equal dimensions along the side of the cut core sleeve. The length of each sampling interval was based on the XRF readings and stratigraphic observations such as grain size and color changes.

Hand Auger samples with a 0.5 inch diameter were sampled across their entire length unless except when a stratigraphic change was discernible. Field screening and analysis with the hand-held XRF unit was not possible due to the interference of the steel tube of the auger.

## 10.1 Background Concentration of Target Analytes

The following 5 drainages were selected to determine the background concentrations of the target analytes in drainage sediments on private land as they move off USFS-administered land in the North Cave Hills (Figure 10.1):

1. #20: Very small watershed (under 10 acres) along the eastern side without any documented mining or exploration activities, about one mile north of Bluff A. This drainage is potentially spring-fed and represents "pristine" conditions of one of the short easterly drainages and flows into Pete's Creek to the east;

2. #21: Smaller northwesterly drainage with an area of approximately 2/3 of one square mile fed by Cox Springs #'s 1 and 2. No mining or exploration activities are documented in this watershed. This drainage represents "pristine" conditions outside of the "hot zone" in the highly dissected northern part and flows to the west into



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Crooked Creek;

3. #24: Uppermost drainage of Campbell Creek draining almost exclusively private land with an area of approximately one square mile. This sample location is situated at the upper end of a stock dam. Any drainages coming off USFS administered land on the southwestern side enter Campbell creek below this point; this drainage represents "pristine" conditions on private land;

4. #26: Icebox Canyon and the drainage immediately to the west fed by Travers Spring #2 represent "pristine" conditions within the "hot zone" on the southwestern side. No mining or exploration activities are documented in this watershed. This is a relatively large side drainage (approximately one square mile) of Schleichart Draw and Campbell Creek. The sampling site is located at the upper end of a stock dam on State land;

5. #29: Very small (under 5 acres) ephemeral drainage with extensive exploration activity in its watershed; east of Bluff H, but not impacted by mining and just northeast of the "hot zone". Sampling site is located at the USFS-administered/private land interface.

Shortened versions of the core logs for these sites are presented in Table 10.1. Cores were taken in 5' long plastic sleeves, and, if part of the core was not recovered, the first described interval of each core section in the core log was adjusted to the top of this section (e.g. to 0' for the first section, to 5' for the second, etc.). The bottom of the channel sediments in core log of site #21 might have been picked at 13' or 16.5', but was not determined due to the lack of a clear boundary. Background concentrations for cores with more than one sampled interval were established by first weighting the concentrations according to the length of each interval with Equation 10.1 below:

$$\text{Total Concentration} = \left(\frac{IL_1}{IL_T} * C_1\right) + \left(\frac{IL_1}{IL_T} * C_2\right) + \bullet\bullet\bullet + \left(\frac{IL_n}{IL_T} * C_n\right) \quad \text{[Equation 10.1]}$$

Where:
$IL_1$ = interval length of sampling interval 1 [ft]
$IL_T$ = total length of core [ft]
$C_1$ = analyte concentration of sampling interval 1 [mg/kg]

The mean of the total concentrations was then calculated, and the background concentrations for each target analyte were established by the procedures described within the Soil Results section below (Table 10.2). Sediment samples representing in-situ formation were not included within these calculations, and the analytical results for these intervals are shown here for completeness only. Nevertheless, inclusion of these intervals into the background calculations would either elevate or decrease the upper limit of the background only slightly. Even the relatively high uranium and molybdenum concentrations of the coal seam sampled at the bottom of site #24 increased the background limit from 3 to 4mg/kg and from 5 to 6 mg/kg, respectively, after adjusting to a whole number (due to the short interval length and, therefore, small contribution to



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the concentration over the whole length of the core). To account for the possibility that these in-situ sediments contribute to the background concentration, the upper limit for uranium was raised to 4 mg/kg and for molybdenum to 6 mg/kg.

The calculated background concentrations are representative for the entire channel depth of the channel, and thus provide a historical of channel sediments. As a result, the background limits are appropriate for the evaluation of historical releases of contaminated sediments into the impacted drainages.

Background concentrations for the target analytes were also established for drainage sediments within the "hot zone" on USFS-administered land in the North Cave Hills by the Pioneer (2005) study (Table 10.3). Surface samples were collected in August 1999 in drainages undisturbed by mining activities. Each of these samples was paired with a soil sample that is located higher up in the same watershed. The background data (mean concentrations) cited in the Pioneer (2005) cannot be compared directly to the values established for this study due to the different sampling area and sampling strategy. Nevertheless, target analyte concentrations are similar to the values established for this study, with the exception of uranium (approximately 2x higher) and selenium (7x higher) when compared to background established for this study. Selenium values for the Pioneer 1999 sampling events within the drainage sediments also appear very high compared to both the Portage 2004 sampling results and this study.

A key finding from the Pioneer (2005) study was the rapid decrease in the uranium, arsenic, and molybdenum concentrations from soil sample RP-SS-X1 (Table 9.2) to the sediment sample RP-SE-XI (Table 10.3) collected within the drainage just below. The soil sample likely represents the only true "pristine" background conditions within the highly mineralized "hot zone". Nevertheless, just a few hundred meters down-gradient, the uranium and arsenic concentrations were diminished by over an order of magnitude and the molybdenum concentration by over two orders of magnitude. This shows that the sediment contributions to the drainage from this relatively narrow outcropping is not very high, and that the mixing and dilution with sediments derived from the un-mineralized section appears very effective in lowering contaminant concentrations in this natural setting undisturbed by any mining activities.

## 10.2 Contaminant Concentrations in Sediments

Analytical results for drainage sediments other than the background samples are presented in Table 10.4, including sampling intervals with in-situ formation. Statistical values for these samples are shown in Table 10.5. Core logs for the sites with Geoprobe cores can be found Appendix D. Concentrations for uranium, arsenic, and molybdenum, the three elements of most concern, and the copper/molybdenum ratio are also presented graphically within Figures 10.1 through 10.33. Analytical results for the other five target analyte are only presented in the Tables 10.4 and 10.5 and discussed below.

Concentrations for the upper background limits were only exceeded minimally in one sample for copper by less than 1 mg/kg and in two samples for lead by less than 2 mg/kg. Vanadium concentrations were 2x background in four drainage samples; the higher vanadium concentrations were associated with relatively high arsenic concentrations in these samples. One



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in-situ sample of a coal seam also was within the 2x background range for vanadium, but was associated with relatively high uranium and low arsenic concentrations. Table 10.5 also shows that the minimum, maximum, and average concentrations for these three elements were essentially the same for the drainage and the in-situ formation samples with regard to these three elements.

Selenium background concentrations exceeded the background in seven drainage samples in the upper Pete's Creek drainage. Nevertheless, only two of these samples exceeded the background by more than 2x. Both samples represent coarse grained sediments at the base of the channel at site #1 below sediment pond #2 and displayed very high selenium concentrations of 4x and 8x background, respectively. Selenium concentrations also exceed the background in five in-situ formation samples. Three of these samples were from the cores of sites #1 and #2, but the concentrations were only 2x and 3x background in the in-situ formation when compared to 5x and 8x higher values for the drainage sediments at the same location. Higher selenium concentrations of 2x and 4x background were also found in in-situ formation at site #25 in a side drainage of Campbell creek. The range and average of the concentration values (Table 10.5) also shows that concentrations for in-situ formation and drainage sediments were essentially the same except for the upper Pete's Creek drainage, especially at site #1.

Thorium concentrations only slightly exceed the background limit in three drainage samples and were associated with relatively high uranium concentrations. Nevertheless, high uranium concentrations are not necessarily associated with high thorium concentrations within all samples. Concentrations were 2x background level in samples representing in-situ formation, but only two of the three samples were associated with relatively high uranium concentrations. All samples with higher thorium concentrations originated from the upper Pete's Creek drainage.

Uranium, arsenic, and molybdenum concentrations of drainage sediment samples were much higher when compared to the in-situ formation samples (Table 10.5). With the exception of uranium, the average concentrations of the drainage sediment samples were twice as high. Therefore, these three elements were the target analytes of major concern. Copper/molybdenum (Cu/Mo) ratios are also presented because deteriorating values were a direct result of the high molybdenum concentrations; with a few exceptions, copper concentrations were relatively uniform throughout the study area. Concentrations of these elements and the Cu/Mo ratio are shown as bar graphs (Figs. 10.2, 10.4, 10.6, 10.8) plotted on a series of maps for all sediment samples including samples of the underlying in-situ formation. The upper Pete's Creek drainage was presented in a series of inset maps (Figs. 10.3, 10.5, 10.7, 10.9) because of the higher sample density in this area. Another series of maps at the end of this section (Figs. 10.14 through 10.17 and 10.22 through 10.25) is based on only the top intervals at each sampling location only and presents each sampled stream segment according to a color-code based on the concentration value. The upper Pete's Creek Drainage and Schleichart Draw are discussed in two separate sections.

### 10.2.1 Uranium Concentrations

Drainages potentially impacted by mining activities generally had uranium concentrations within



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the background limits at the USFS-administered/private land interface (Fig. 10.1). Background limits were exceeded only minimally by 0.1 mg/kg in Schleichart Draw and 0.4 mg/kg in the drainage below bluffs K1 and K2 (below confluence of Devils and Sawmill Canyons). Uranium concentrations also varied between background and 2x background. These variations may be attributed to either the scouring and random redistribution of more contaminated sediments within the stream channel or to sediment contributions from coal seam outcrops that may contain low-level uranium concentrations in the lower Pete's and Crooked Creek drainages.

Sediment samples of in-situ formation also were within the background range, except at sites #24 with >5x background (this interval was left out mistakenly on the maps, but is listed in Table 10.4) and #25 with >3x background (Fig. 10.2). Both intervals consisted of an in-situ coal seam at the bottom of the borehole.

The upper Pete's Creek drainage displayed the highest uranium concentrations (Fig. 10.3). Sediment samples with in-situ formation were in the upper or 2x background range and reach >3x and >4x background at sites #2 and #17, respectively, where the core penetrated a coal seam at the bottom of the borehole. Drainage sediments in the side drainages also exhibited concentrations in the upper or 2x background range except for the drainages connected to the mine spoils of Bluff B and Bluff H. The highest uranium concentrations occurred in the drainages below sedimentation ponds 1 and 2, the drainage connected to the gully below the northeast spoils of Bluff B, and, to a lesser degree, the drainages below the east and west sides of Bluff H.

### 10.2.2 Arsenic Concentrations

Sediment samples consisting of in-situ formation generally exhibited arsenic concentrations within the background range except for site #22 below the confluence of Devils and Sawmill Canyons where the concentration was 2x background (Fig. 10.4). Arsenic concentrations from in-situ formation samples in the upper Pete's Creek drainage were also within the background or 2x background range, even within the coal seams that contained elevated uranium concentrations (Fig. 10.5).

Arsenic concentrations of drainage sediments generally were within the background limits at the USFS-administered/private land interface except for site #23 below Bluff J with a concentration of 2 x background (Fig. 10.4) and in the upper Pete's Creek drainage (Fig. 10.5). This drainage showed the highest concentrations, and the highest arsenic concentrations of up to 5x background occurred in coarse mine spoils at the base of the channel below sedimentation pond 2. The highest uranium concentrations at this site were in finer-grained sediments at the top of the core. The higher concentrations of the lower intervals of the channel sediments at sites #34 and #35 downstream of pond 2 may be related to historical release of coarser-grained mine spoils from Bluff B. Other drainage sediments containing up to 3x background concentrations occurred in the side drainage linked to the gully below the east side of Bluff B and in the side drainage to the east of Bluff H.

Arsenic concentrations varied in the lower Pete's Creek and Crooked Creek drainages between



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the background and 2x background (Fig. 10.4). Site #31 is located at the lower end of a side drainage of Pete's Creek and connects to the west side of an abandoned uranium mine on private land near the town of Ludlow (Flat Top mine). Sediments at the base of the channel exhibited arsenic and molybdenum concentrations of 2x background which could indicate historic releases of contaminated sediments from the Flat Top mine on private property (Figs. 10.4 and 10.6). Nevertheless, the uranium concentration was within the background limit, and the sediment flux in this drainage is well checked by a series of large stock dams. It is more likely that the varying arsenic concentrations at this site and in the lower Pete's Creek and Crooked Creek drainages are due to the same reasons as for the varying uranium concentrations. Furthermore, crop farming increases in the lower part of these drainages, and contributions from non-point sources of arsenic related to the use of arsenic-containing pesticides could also be possible.

### 10.2.3 Molybdenum Concentrations

Molybdenum concentrations in sediment samples representing in-situ formation did not exceed the background limits except at site #22 with a concentration of 2x background (Fig. 10.6) and in the upper Pete's Creek drainage where concentrations varied from background to 2x background and to 3x background in the coal seam at site #2 (Fig. 10.7).

Drainage sediments had molybdenum concentrations in the background range except at site #22 (Fig. 10.6) with a 2x background concentration (this site also had arsenic in the 2x background range) and in the upper Pete's Creek drainage. The highest concentrations of up to 16x background occurred below sedimentation pond 2, >3x background in the drainage linked to the gully below Bluff B, and as high as 8x and 3x, respectively in the drainages flowing north from Bluff H. Molybdenum concentrations in the lower Pete's Creek and Crooked Creek drainages also varied between background and 2x background values for the same reasons inferred above for uranium and arsenic.

### 10.2.4 Copper/Molybdenum Ratio

Copper/molybdenum ratios deteriorated to below background values (lower values signify greater impairment) where the molybdenum concentrations were relatively high. This occurred at sites #22 and #23 where ratios of <1/3x or 1/2x background occurred (Fig. 10.8). Several sediment samples of sites from the lower Pete's Creek and Crooked Creek drainages also had values of 1/2x and 1/3x background with high molybdenum concentrations controlling the ration. Nevertheless, the lowest copper/molybdenum ratios were associated with the more highly contaminated sediments released from Bluff B and H in the upper Pete's Creek drainage (Fig. 10.9).

## 10.3 Sediment Contaminant Concentration and Source Distance

To determine the distance of the sampling sites to the potential sources of contaminated sediments, the affected drainages were digitized manually to the lowest possible stream order and highest accuracy recognizable on the digital aerial ortho-photos available for the study area. These calculated stream lengths were determined to be up to two times the thalweg length when



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compared to the hydrographic layer for the ortho-photos available from the USGS. The distance of each sampling site to its potential source areas (bluffs) was then plotted against the uranium, arsenic, and molybdenum concentrations and the copper/molybdenum ratio of the top interval of each sediment core or the hand auger samples. Distances for each sample to its potential sources are shown in Appendix A4. A particular sampling site might plot several times within the same graph at the same concentrations, but at different distances depending on the number of potential sources.

Figures 10.10 to 10.13 compare drainage sediment samples within the Pete's Creek to those within the Crooked Creek drainages. These graphs show that the potential sources within the upper Crooked Creek drainage (Bluffs J and K1 and K2) have uranium and molybdenum concentrations at or slightly above background and arsenic concentrations at or below 2x background. These low concentrations remain essentially unchanged within the lower part of the drainage at and below the confluence with Pete's Creek about 30 km downstream from the source area. Copper/molybdenum ratios behave slightly different where the ratios improve from very low in the source area to very high values in the downstream reaches.

Concentrations for these three contaminants in the Pete's Creek drainage show the highest values of all samples in the source area (Bluffs A-I), then drop to background values about 1 km downstream, but increase rapidly again over a short distance. Nevertheless, concentrations reduce again to background values 5 km downstream and remain at or slightly above background values to the confluence with Crooked Creek about 13 km downstream from the source area. Copper/molybdenum ratios behave similarly improving from generally very low values at the source area to relatively higher, but still considered low values in the downstream reaches. This clearly shows that only the bluffs in the upper Pete's Creek drainage contribute contaminant concentrations above background values to this drainage system.

The concentration ranges for each stream segment is also shown in a series of maps. These maps also display the drainage sampling sites and concentrations of the Pioneer (2005) study; concentrations also were re-categorized according to the background limits established for this study. The site numbers for this study contain numbers only on these maps, whereas the site numbers for the Pioneer (2005) study are designated by letters and numbers on these maps. Some caution applies, though, when comparing the Pioneer (2005) data to the data obtained for this study. Only scoop samples of surface sediments were taken during the 1999 and 2004 sampling runs in the Pioneer (2005) study, and sampling occurred under relatively wet conditions for this study in 2006.

These maps not only reconfirm the source areas determined in the previous figures in a more visual fashion, but also extend the drainages onto USFS-administered land by inclusion of the Pioneer (2005) data. Drainages in the upper Crooked Creek drainage on USFS-administered land close to the source areas of Bluffs J and K1+2 showed uranium, arsenic, and molybdenum concentrations at background or 2x background values (Figs. 10.14 through 10.16). These values remained essentially the same on the adjacent private land. Only the copper/molybdenum ratio deteriorated to <1/3x background on private land below Bluff J due to the relatively higher molybdenum concentrations (Fig. 10.17). The contaminant concentrations also remained low in the downstream reaches.



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Side drainages on USFS-administered land within the upper Pete's Creek watershed showed very high uranium concentrations in drainage sediments below every source area (Bluffs A-I). These very high concentrations were mostly limited to Bluffs C-H for arsenic and molybdenum. The contaminant concentrations rapidly diminished to background or 2x background values at the USFS-administered/private land interface in most side drainages. Contaminant concentrations on private land only remained elevated within side drainages connected to Bluffs B and H, but rapidly diminished to or close to background values within the main drainage of Pete's Creek.

Potential source areas in the upper Campbell Creek drainage were limited to Bluff L. Side drainages on USFS-administered land displayed contaminant concentrations and copper/molybdenum concentrations at background or 2x background and displayed background values only at the USFS-administered land/private land interface. Schleichart Draw will be discussed in a separate section.

## 10.4 Contaminant Concentrations in the Pete's Creek Drainage

This section discusses the various source areas (bluffs) and their potential contribution of contaminant sediments to the Pete's Creek drainage in more detail. Figure 10.18 shows that the highest uranium concentrations occured below sedimentations pond 1 and 2 and at a site in a drainage approximately 2 km below Bluffs H and I1+2. Neither of these bluffs showed high uranium concentrations upstream at the USFS-administered land/private land interface. Uranium concentrations subsequently fall off rapidly in the main Pete's Creek drainage below ponds 1 and 2 to background values just before the confluence with the side drainage connecting to the gully below the east side spoils of Bluff B. Uranium concentrations in this side drainage were initially at 3x background at the USFS-administered land/private land interface, and then reduced to background or slightly above background values before the confluence with the main Pete's Creek channel. Uranium concentrations increased again after the confluence.

The rapid decrease below ponds 1 and 2 is most likely due to the extensive marsh which developed in the drainages below ponds 1 and 2 under the wet conditions observed during the spring and summer 2006. This marsh most likely filters out (or adsorbs) the highly-contaminated sediments that pass through the sedimentation ponds. In contrast, the gully and the adjoining drainage below the west side spoils of Bluff B is mostly down-cutting, and very few, coarser-grained sediments remain in the channel. Nevertheless, a tremendous amount of sediments is passing through this channel at higher discharges, which are subsequently deposited into the main channel of Pete's Creek. These sediments have filled up the main drainage to such a degree, that backflow sediments consisting primarily of mine spoils are deposited upstream in the main channel during high flows. It is highly likely that this gully will eventually develop into the main channel in the future due to the retaining action of the two sedimentation ponds in the old channel. Therefore, it is not surprising that the concentrations increase again at this location within Pete's Creek.

Arsenic and molybdenum concentrations and the copper/molybdenum ratio behave in a similar manner (Figs 10.19 through 10.21). Of interest, arsenic did not have the highest concentrations below Bluff H and I1+2 or below ponds 1 and 2, but instead within the side drainage connecting



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to the gully on the east side of Bluff B. Nevertheless, when drainage sediments at lower core intervals are considered, the highest arsenic concentrations still occurred below ponds 1 and 2.

Sampling sites in side drainages joining Pete's Creek in its lower reaches with no identified source were arbitrarily set at a distance of 0.5 km. None of these drainages exhibited contaminant concentrations above background, and the copper/molybdenum ratios were also relatively high.

A series of maps of the upper Pete's Creek drainage also confirms these results (Figs. 10.22 through 10.25).

## 10.5 Contaminant Concentrations in Schleichart Draw

Schleichart Draw drains the western part of the central North Cave Hills and its upper reaches connect to the west side of the Bluff B spoils and to Bluff C. Schleichart Draw leaves USFS-administered land in its lowermost reach and then joins Campbell Creek which reenters USFS-administered land again about 1 km below the confluence.

The figures presented within this section include results from the 1999 sediment sampling by Pioneer (2005) within the upper reaches of Schleichart Draw and from this study containing the lower reach of Schleichart Draw. It is important to reiterate that the two data sets represent two different points in time (summers of 1999 and 2006). Samples collected during this study consist of core and hand auger samples and, therefore, represent drainage sediments accumulated over a certain span of time, rather than the scoop samples of the Pioneer (2005) study which likely only characterize the time span between two major flooding events.

Copper, lead, and vanadium concentrations for Schleichart Draw sediment samples on USFS–administered land collected during the Pioneer (2005) study ranged from above background to below 2x background values established for this study and showed no trend (neither increased or decreased concentration) with distance from the source bluffs. For this study, contaminant concentrations within the lower Schleichart Draw drainage on private land all were below background for these three contaminants (Table 10.4).

Selenium concentrations in the Pioneer (2005) study did not show a definitive trend, but did have exceptionally high concentrations ranging from >12x to 30x background. As stated previously, the high selenium concentrations reported contradict all other data sets cited in the Pioneer (2005) or within this study, and thus appear to be due to analytical error. Selenium concentrations for the two sampling locations of this study in lower Schleichart Draw all were below or slightly above background (Table 10.4).

Uranium concentrations ranged from >5x to 15x background and decreased with distance from the source in upper Schleichart Draw (Fig. 10.26). Concentrations markedly increased below Pond 3 and below Pond 5 (Figs. 10.26 and 10.30). This increase may be attributed to inconsistencies with sampling locations (such sampling pond inflow versus outflow) for the ponds or reservoirs, or from breaching and subsequent overflow of the ponds or reservoirs during flood events. The increase measured below Pond 5 may have also been caused by sediment



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loading from unchecked side drainages connecting to Bluffs C, E, and I1. Samples collected during this study were just above background at the USFS-administered land/private land interface (Sample #27), and below background below the Brown Reservoir (Sample #30; Figs 10.26 and 10.30; Table 10.4) within Schleichart Draw.

Arsenic concentrations within the upper Schleichart Draw ranged from slightly above background to below background, and generally decreased with distance from source (Fig. 10.27). Arsenic concentration increased below Pond 3, however arsenic did not increase below Pond 5 as did uranium (Figs. 10.26). For samples collected below the USFS administered land/private land interface in lower Schleichart Draw, arsenic concentrations increased, however they were all below background concentrations (Figs. 10.27 and 10.31). The slight increase in arsenic observed may be attributed to localized lignite particles collected within the sample below Brown Reservoir (Sample #30).

Molybdenum concentrations within upper Schleichart Draw all were below background, and slightly increased with distance from source (Figs.10.28 and 10.32). Molybdenum concentrations below the USFS administered land/private land interface were below background, and increased slightly with distance from the source.

Copper/molybdenum ratios were favorable in the upper Schleichart Draw with values of over 5, but decreased to below 3 as a result of increased molybdenum concentrations (Figs.10.29 and 10.33). All values were above background (favorable) within the upper Schleichart Draw. Copper/molybdenum ratios in lower Schleichart Draw continued to deteriorate to below background (unfavorable) below Brown Reservoir due to the relative increased molybdenum concentrations compared to copper.

## 10.6 Sedimentation Pond Failure

Sedimentation Ponds #1 and 2 are located east of Riley Pass below the spoil piles of Bluff B. The two ponds are part of a series of 5 sedimentation ponds constructed in 1987 to control runoff from Bluff B spoil piles in the upper Pete's Creek and Schleichart Draw drainages. Contaminant concentrations of the sediments and the surface water contained within in the two ponds were found to be many times higher than background concentrations for both the Pioneer 2005 and this study.

Two major problems related to the operational design of the two ponds were observed during the surface water and sediment sampling events of 2006:

1. During low flow conditions following a major discharge event (e.g., sediment pond water not visibly overflowing into the standpipe), there was viable discharge from both the standpipe outflow and the earthen material surrounding the standpipe. Water appears to be channeling or flowing around the horizontal standpipe located at the base of the pond, and infiltrating into the standpipe from rusted or otherwise defective sections of the pipe. Water was visibly entering the standpipe through holes where rivets were missing (Figs. 10.34 and 10.35). As a result, water levels within the ponds had adjusted to a level below overflow elevation, decreasing the overall detention time within the pond. (Fig. 10.36).



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If the rivets were replaced within the standpipe, the pond water elevation would rise and would subsequently increase the pore water pressure surrounding the standpipe. These conditions would likely result in increased discharge from the soil surrounding the standpipe, and could potentially undermine the earthen retaining structure and the road crossing above.

2. Runoff water from the spoil piles after rainfalls was heavily laden with sediments before entering the sedimentation ponds, and sand- and silt-sized sediments (consisting mainly of quartz) appeared to readily settle out within the ponds. However, clay-sized particles mostly remained suspended within the water and were not retained by the sedimentation ponds. The very visible and pronounced dispersion of the clay particles in the water flowing from the ponds (Fig. 10.37) was likely due to the relatively high sodium and/or potassium concentrations of the eroding soils and mine spoils (see Pioneer 2005 results). Sediment cores collected at sampling sites #1 and 2 below the two sedimentation ponds showed evidence of sand sized lignite particles enriched with silt and clay, suggesting that less dense lignite particles may float through the ponds and settle out in the marshy areas below the ponds.

## 11.0 Data Validation

This section describes the quality assurance for the analytical results presented within this study. The analytical results presented were collected and analyzed based upon four general data levels established at the beginning of the project. The data levels were distinguished by the types of technology available, documentation, and degree of sophistication.

- **Level IV (Litigation Quality):** Laboratory analysis characterized by rigorous QC/QA protocols and documentation providing qualitative and quantitative analytical data. For this study, all Level IV analyses were performed by Energy Laboratories Inc. (ELI), a National Environmental Laboratory Accreditation Conference (NELAC) certified laboratory using standard EPA methods;
- **Level III (Investigative Quality):** - Laboratory analysis following published EPA methods by an academic laboratory facility [SDSM&T Environmental Mining Experiment Station (EMES) laboratory] that is not certified by NELAC or other organizations. A minimum of 10% of the total number of samples collected were analyzed as duplicate samples by ELI for validation of all Level III data. Level III data represent the majority of the data presented within this study;
- **Level II (Portable Instruments of Investigative Quality):** Field measurements using portable analytical instrumentation including documentation of instrumentation standards and calibrations within field notes;
- **Level I (Screening Quality):** Field screening using portable instrumentation that provided real-time data to assist in the optimization of sampling and for on-site health and safety evaluations.

A summary of the target analytes, analytical methods, data levels, sample media, and data use is presented in Table 11.1. In general, target analytes and analytical methods used for sample



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analysis for this study were similar to those targeted in previous site investigations within the North Cave Hills (Denver Knight Piesold, 1991; Pioneer 2002, 2005). Additional analysis performed within the context of this study included: nitrate/nitrate, sulfate, and phosphate within select surface water samples allowing better under standing of surface water chemistry as related to contaminant fate and transport; and a comprehensive groundwater analysis of domestic and stock wells that had not been previously studied in the North Cave Hills region. A comprehensive list of analytical analysis parameters for the groundwater study is presented in Table 7.1.

## 11.1 Sampling Procedures

Samples were collected and analyzed in accordance to the Sampling and Analysis Plan (SAP; SDSM&T, 2006) and Standard Operating Procedures (SOP; SDSM&T, 2006) developed for this project. The SAP procedures were developed in accordance with EPA accepted protocols. Provided below is discussion regarding project sampling procedures.

### 11.1.1 Sample Index

Several surface water and sediment and soil sampling locations initially listed in the SAP were based on topographic maps, and several sites were subsequently moved based upon local field conditions encountered. Missing sample numbers within the surface water sample sequence were due to the absence of flowing water within the drainage during sampling.

Sample IDs for groundwater (GW) samples were changed in accordance with SAP naming protocol. The original IDs appear on the ELI analytical reports provided in Appendix B2. New and corresponding old sample IDs are shown in Appendix A2.

Aerosol dust samples were collected using a portable wind tunnel (WT) and/or a soil scoop at each sampling site listed in this report. Sample numbers listed and discussed within this report are only a portion of the total samples collected. Additional samples were collected as part of a separate, on-going study comparing grain size and metals concentrations, and these results have not been included within this report.

Sediment sample ID NCH-SE-37-0/1 was reassigned to NCH-SE-9-0/1 due to a recording error; this error was not corrected on the sample jar ID or the chain-of–custody form. The change was documented in the field book and within the spreadsheet provided in Appendix B4.

Sediment sample ID NCH-SE-62-0/0.3 was mis-interpreted as NCH-SE-52-3 by ELI. The error was corrected on the copy of the original ELI reports provided in Appendix B2.

### 11.1.2 Field Books

A copy of the field notes for each investigation phase (i.e., surface water, groundwater, air particulates, and sediments and soils) is provided in Appendix C. The field books appear complete, and all data, observations, field equipment calibrations, standard certificates, and



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sample IDs appear to be recorded.

### 11.1.3 Core Logs

Core logs were checked for completeness and accuracy. Logs are only available for sediment and soil sampling sites where cores were collected using either the Geoprobe equipment or the hand auger sample. Logs appear complete and are provided in Appendix D. Errors found within the original core logs were correctly transcribed within the spreadsheet logs (indicated by red font). Spelling errors were also corrected in the transcription.

### 11.1.4 Safety Meeting Forms

Safety meetings were held with the drilling crew for each field day that included sampling activities with the Geoprobe equipment according to the Health and Safety Plan (HSP; SDSM&T, 2006). Each member of the crew acknowledged to have read and understood the HSP. All forms are present and complete, and are provided in Appendix E.

### 11.1.5 Sampling Location Coordinates

Coordinates for all sampling locations were confirmed by visually plotting their location on maps provided within this report. All sampling locations appear to be correct. Coordinates were recorded in Universal Transverse Mercator (UTM) or Latitude/Longitude formats in the field. The data are listed in the originally recorded formats in Appendix F.

Sediment to source distances provided in Appendix A4 were measured using Geographical Information System (GIS) base maps developed for this report. The distances were checked visually on these maps and appear to be complete and correct.

### 11.1.6 Sampling Completeness

Surface water samples were collected at 43 (75%) of a total of 57 locations specified in the SAP; all samples were analyzed for total metal concentrations. Only 32 (56%) were analyzed for dissolved metals. All groundwater, air particulate (wind tunnel) and sediment and soil sampling locations specified in the SAP were sampled.

### 11.1.7 Field Duplicates

For surface waters samples collected, three (3) field duplicates out of a total of 47 samples were collected at the required frequency of 1 sample per every 20 samples as specified in the SAP. Groundwater sampling also complied with the required frequency with 2 field duplicates out of a total of 37 water well samples.

Another set of samples for surface water, air particulates (wind tunnel), and sediments and soils was collected in the field and sent to ELI at a minimum frequency of 1 in 10 samples (10%) for



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external QC specified within the SAP. Three (3) of a total of 32 (9%) samples analyzed for surface water dissolved metals were sent to ELI; this number is only slightly below the required minimum and was accepted for data validation purposes. For surface water total metals, 13 of 47 (28%) samples were analyzed by ELI.

Sediment and soil samples were dried and pulverized at the SDSM&T EMES lab and then split in four equal parts. Each aliquot was then stored in a relabeled sample jar. Jar 1 was analyzed for every sample; jar 2 was used for lab duplicate samples at the required sample frequency (1 lab duplicate per digestion batch); jar 4 served as a back-up sample. Jar 3 was sent to ELI for external QC analysis as needed.

Wind tunnel (WT) samples consisted soil materials and followed a similar protocol as the SE (sediment) samples. Three (3) of a total of 35 (9%) were analyzed by ELI; this number is below the required minimum, but was accepted for data validation.

For the overall project, a total of 30 of 128 samples (23%) were analyzed by ELI for external QC.

#### 11.1.8 Equipment Rinsate Blanks

An equipment rinsate blank consisted of de-ionized water poured through decontaminated field equipment, if non-disposable equipment was used. Equipment rinsate blanks were prepared at a minimum frequency of 1 per 20 sampling sites on sampling equipment that was used and decontaminated for reuse (see Appendix B4). Equipment rinsate blanks were used to assess representativeness of samples collected by that specific equipment. Overall, 3 rinsate samples were collected and analyzed for 31 coring sites, and 3 additional rinsate samples were collected and analyzed for 31 hand auger sites, meeting the required frequency specified within the SAP.

No contaminants were detected in a rinsate sample of the stainless steel spatula that was used for collecting sample from the collected cores.

Uranium, lead, selenium, vanadium, and thorium were not detected in any of the rinsate samples. However, 5 of the 7 samples contained arsenic ranging from 0.00775 to 0.01516 mg/L, exceeding the detection limit by 1.5 to 3x. These values were most likely due to errors associated with arsenic correction factors applied for SDSM&T EMES analysis (see Level III discussion below). A molybdenum concentration at the detection limit was reported for NCH-RI-1. Much higher values of molybdenum of 0.0873 mg/kg (18x detection limit) and copper of 0.05265 mg/kg (10x detection limit) were reported for NCH-37-1. This rinsate sample was collected from the Geoprobe coring assembly without the plastic sleeve that collects the soil core, and it is highly probable that the high concentrations reported were caused by remnant acid wash solution found within the metal casing. Samples typically do not contact the metal casing under normal procedures, but instead are collected and protected within a plastic sleeve. Thus this rinsate sample likely does not accurately represent a pathway for sample contamination during normal operating procedures.



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A comparison of arsenic, molybdenum, and copper results immediately preceding, and following a rinsate sample is provided in Table 11.2. By comparing the sediment and associated rinsate results, arsenic, molybdenum and copper concentrations were not appreciably higher in cases where the rinsates showed detectable levels. The field QC assessment for rinsate samples suggest that the decontamination procedures may have been marginally completed for one sample. The low levels reported for the three contaminants found within the rinsate blanks were deemed to be insignificant and would not affect sediment and soil results reported. From a mass balance perspective, the contaminant masses found within the sediments were typically several orders of magnitude greater than concentrations reported from the rinsate samples collected.

Soil samples NCH-SE-63-0 to NCH-SE-81-0 represent soil surface samples collected using disposable plastic scoops that are manufactured specifically for environmental sampling. Therefore, no rinsate blank samples were collected.

#### 11.1.9 Field Blanks

Field blanks were prepared by pouring de-ionized water into the appropriate sample containers and adding any required preservative chemicals. A field blank was prepared at a minimum frequency of 1 per 20 samples for the water media only because contamination introduced by improper field activities may be more easily detected in a water matrix. Field blanks provide a measure of potential errors that can be introduced from sources other than the sample, and were used to assess representativeness.

#### 11.1.10 Sample Custody

All groundwater and a several surface water samples were hand delivered directly from the field to ELI. The remaining surface water samples and all sediment, soil, and air particulate samples were delivered directly to SDSM&T EMES lab from the field. After processing, duplicates of solid samples were then sent from the SDSM&T EMES lab to ELI. Several water samples were initially refrigerated and stored at SDSM&T EMES, and then delivered to ELI. Samples collected for analysis are listed in the field notes (see Appendix C) and the chain-of-custody (COC) forms (see Appendix E). The COC forms were checked and appear to be complete.

#### 11.1.11 Sampling Holding Times

All samples were analyzed within the 6 months maximum holding time specified within EPA Method 200.8 for the target analytes. Several surface water sample volumes were insufficient for the completion of the dissolved metals analysis, and several dissolved metals samples were stored for approximately 5 months without acid preservation (see appendix B1). ELI analysis of surface and groundwater samples were analyzed within the holding times specified by the specific analytical methods employed.

### 11.2 Level IV (Litigation Quality) Data Validation

All groundwater (GW) samples were submitted to and analyzed by ELI, a NELAC certified lab



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located in Rapid City, South Dakota. All analysis followed EPA protocol and yielded Level IV (Litigation Quality) data. All QC samples passed the internal QC limits criteria established by ELI, and all data passed ELI QC assessment. Results of all Level IV data are shown in Appendices A1, A2, B1 and B2. It should be noted that assigned GW sample IDs were changed after analysis by ELI; thus "New" and "Old" sample IDs have been provided in Appendix A2.

External QC duplicate samples (surface water, air particulates, and sediment and soils) as part of SDSM&T Level III data analysis were also submitted to and analyzed by ELI during this study. These results are also classified as Level IV data.

## 11.3 Level III (Investigative Quality) Data Validation

This section discusses the data validation methodology for all Level III (Investigative Quality) samples analyzed by SDSM&T's EMES lab during November and December 2006. Level III analyses includes surface water (total and dissolved metals), air particulate, and sediment/soil results. The discussion below is organized based upon sample medium classification and internal (SDSM&T EMES lab analysis) and external (comparison between SDSM&T EMES and ELI analytical results) data assessment.

### 11.3.1 Data Qualifiers

A list of data qualifiers, or "flags" used to qualify all Level III data within this study are presented in Table 11.3. Discussion regarding the various data qualifiers used to describe the integrity of the data has included within the data validation sections below.

### 11.3.2 SDSM&T EMES Lab Metal Analysis Quality Assurance

The EPA Method 200.8 digestion procedure for analysis of metals using Inductively Coupled Mass Spectrometry (ICP-MS) was followed to the best of the ability of the SDSM&T EMES laboratory staff for all sample preparation. Logs were kept for all phases of the sample preparation and analysis and will be archived at SDSM&T EMES lab.

The following quality assurance procedures were employed by the SDSM&T EMES lab:

- The Agilent ICP-MS was tuned to optimum performance using a certified tuning solution and the Agilent auto-tune software prior to the start of analyses. The tuning process was repeated whenever instrument maintenance was performed;
- Certified reference standards were used to calibrate and verify the analyses;
- An initial calibration was performed for each batch of samples (containing no more than 25 samples) using at least three data points for each element. Correlation coefficients for all initial calibrations were required to be $\geq 0.99$. Printouts of the calibration curves for each element were stored with the original instrument analysis printouts and hardcopies have been archived at the SDSM&T EMES lab;
- Immediately after the initial calibration, an initial calibration verification sample (ICV) and initial calibration blank (ICB) were analyzed. If the ICV or ICB failed to meet QC



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standards, the calibration was repeated;

- Continuing calibration verification (CCV) and continuing calibration blank (CCB) samples were analyzed for each 10 samples. If the CCV or CCB failed to meet QC standards, the calibration and analysis of the affected samples were repeated;
- A second source check sample was analyzed immediately following the initial calibration verification and initial calibration blank samples to confirm the accuracy of the initial calibration;
- One duplicate sample, one spiked duplicate sample, one laboratory blank sample, and one spiked laboratory blank sample were analyzed for each batch of samples. If any of these failed to meet QC standards, the data was rejected or flagged at the discretion of the project QA manager;
- To determine the realistic detection limits (i.e., reporting limits), the SDSM&T EMES personnel created a calibration curve using standard solutions at 1 ppb (µg/L), 5 ppb, and 10 ppb, then analyzed the 1 ppb and 5 ppb solutions as samples. Using this data, the lab determined the point at which the analyte signal could be accurately separated from the background signal (noise);
- Acceptable recovery for all spike samples was $\pm$ 30% for all samples (water and soil). Any spikes with recoveries outside this range were considered to have failed QC;
- Acceptable variation between duplicate samples was $\pm$ 30% for all samples (water and soil). Any duplicates with variation outside this range were considered to have failed QC;
- All data, including data from analyses with failed quality assurance samples were evaluated by the project quality assurance manager and either accepted, accepted with qualifications, or rejected at his discretion;
- In recording the data, all quality assurance failures were noted and identified. The notation "QAF" (Quality Assurance Failure) was assigned to the data for each sample affected by the quality assurance failure. In addition, the failed QA sample was identified. For example, any sample for which the continuing calibration verification fell outside the acceptable range was marked, "QAF - CCV". If the CCV and CCB were outside acceptable limits, the notation "QAF – CCV, CCB" was used.

The argon supply gas used during normal ICP-MS operations forms argon chloride ions within the ICP-MS plasma chamber. These ions are known to interfere with the quantification of arsenic and selenium. ELI corrects for these interferences per correction factors/equations listed within EPA 200.8 methods. The SDSM&T EMES lab only corrected for arsenic concentrations by subtracting the arsenic concentration in the lab blank from the arsenic sample concentrations found within the same digestion batch. Nevertheless, the arsenic concentrations in several lab blanks were found to be below the detection limits, and thus no correction was applied to these samples. The correction factors resulted in negative arsenic concentrations for several samples containing low arsenic concentrations. In addition, several digestion batches met QC criteria for uncorrected data, however corrected data did not meet QC criteria. As a result, all Level III arsenic concentrations reported were qualified with a "CF"-flag due to inherent errors associated with the correction factors applied. The correction factor used for arsenic and the lack of correction for selenium concentrations help explain the occurrence of QC failures for low arsenic and selenium concentrations within this study.



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The detection limits in water and soil matrices reported by SDSM&T EMES and ELI for all Level III data is presented in Table 11.4. ELI reporting limits varied between analytes due to matrix interferences. SDSM&T EMES detection limits were generally higher than ELI detection limits, with the exception of copper and lead in water medium. SDSM&T EMES detection limits were up to 20x higher than ELI for vanadium and thorium. These inter-lab detection limit differences may account for many "not-detected" (ND) metal concentrations reported by SDSM&T EMES when compared to ELI, and vice versa. As a result, metal concentrations that were reported close their corresponding detection limit could not be used for external quality control purposes (e.g., inter-lab data comparison).

Inter-lab data comparisons were performed as part of the external data quality control (QC) process. The failure criteria for inter-lab external QC comparisons were set to the following limits (Table 11.5):

- Error between two corresponding QC samples did not exceed $\pm$30%. These were the same limit criteria established internal QC lab and field duplicate analysis;
- The square of the regression coefficient ($R^2$) was < 0.9000 for the regression analysis;
- The y-intercept of the trendline was 2x higher or lower that the highest detection limits of the eight analytes in water or soil;
- The slope of the trendline was not lower than 0.8 (signifying unacceptable low bias) or higher than 1.2 (signifying unacceptable high bias).

### 11.3.3 Surface Water Data Validation

All QC data and figures for surface water samples discussed below are provided within Appendix B1 materials.

#### 11.3.3.1 Dissolved Metals Internal QC Assessment

Spike Sample Recovery QC:

- All target analytes passed internal QC assessment, however a spike recovery sample was missing for the analytical run performed on 12/11/2006 (undigested samples).

Lab Duplicate QC:

- All target analytes passed internal QC criteria.

Blank Spike Recovery QC:

- Arsenic and selenium exceeded QC limits by +4% and +3%, respectively, for the digested samples. These differences suggest minor problems with the recovery of these analytes for the digested samples analyzed on 11/30/2006, however the QC failures were only slightly greater than the QC limits (i.e., nearly insignificant);
- Thorium and lead exceeded QC limits by +12% and +15%, respectively, for the digested

samples. These differences suggest problems associated with the digested samples analyzed on 11/30/2006;

- A blank spike sample was missing for the analytical batch performed 12/11/2006 (undigested samples).

Lab Blanks QC:

- All target analytes passed internal QC criteria.

Field Duplicate QC:

- Two out of three lab duplicates passed internal QC criteria;
- The sample not passing QC was NCH-SW-57-2 (field duplicate). The sample remained un-acidified after collection for 5 months, and was ultimately compared to NCH-SW-57-1, a sample which was acidified immediately after collection. The comparison resulted in a pronounced low bias for this duplicate sample. True analytical concentrations for sample NCH-SW-57-2 may be approximately 20% higher than reported for U; 30% higher for Mo; 50% higher for As and Cu; and 100% higher for V due to the extended non-acidified holding time of the duplicate sample. Se, Pb and Th percentages were not estimated, but would likely exhibit low bias. This sample was labeled "Sample not acidified for 4-5 months" within spreadsheets found within Appendix B1.

Field Blank QC:

- All target analytes passed internal QC criteria .

11.3.3.2 Dissolved Metals External QC Assessment

The error and the regression analysis for the dissolved metals external QC sample pairs (SDSMT EMES and ELI) is provided in Table 11.6. The following data quality assessments were made:

- Uranium and arsenic passed external QC criteria;
- Molybdenum exceeded the external QC criteria for the y-intercept and the slope, and 1 out of 3 samples failed the external QC limits $\pm$30% by +10%. The slope and the high error associated with the highest concentration indicated a positive bias and molybdenum concentrations were qualified with a "J+" flag, and thus the values may only be used for estimating purposes;
- Copper regression analysis was not possible due to the "not-detect" concentrations reported by ELI. SDSM& EMES results were an order of magnitude higher than the reported detection limit. This indicates a high bias and, as a result, the data were qualified with an "R"-flag signifying the data was rejected;
- Lead exceeded (slightly) the external QC criteria for $R^2$, and 4 of 30 samples (13%) exceeded the error limits of $\pm$30% by up to -3.3%. Lead passed external QC criteria despite an overall slightly negative bias;
- Selenium, vanadium and thorium had many "non-detect" concentrations, and thus could



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not be used for external QC. Results for these analytes thus may be only used as estimates and were qualified by a "J"-flag.

As an overall assessment, the dissolved metal concentrations should only be used as estimates for the analyte concentrations due to due to frequent internal and external QC failures.

11.3.3.3 Total Metals Internal QC Assessment

Spike Sample Recovery QC:

- All target analytes passed internal QC criteria.

Lab Duplicate QC:

- Arsenic failed the internal QC limits by an additional -27% for the 1st digestion, which could be attributed to either a problem with the analytical methods or error associated with the correction factor used for arsenic;
- All other target analytes passed internal QC criteria.

Blank Spike Recovery QC:

- Uranium exceeded the internal QC limits by +8% for the 1st and by +1% for the 2nd digestion. This could indicate a problem associated with analytical methods for 2 of 3 sample digestion batches, however the overall low percentage errors were deemed acceptable and thus passed internal QC criteria;
- Arsenic exceeded the internal QC limits by and additional +1% in the 2nd digestion, however this overall low error was deemed acceptable and thus passed internal QC criteria;
- Lead exceeded the internal QC limits by +11% in the 1st and by +2% in the 2nd digestion. This could indicate a problem associated with analytical methods for 2 of 3 sample digestion batches, however the overall low percentage errors were deemed acceptable and thus passed internal QC criteria;
- Thorium exceeded the internal QC limits by an additional +11% in the 1st digestion, however this overall low error was deemed acceptable and thus passed internal QC criteria.

As a result, all Blank Spike samples passed internal QC assessment.

Lab Blanks QC:

- All target analytes passed internal QC criteria.

Field Duplicate QC:

- All target analytes passed internal QC criteria.



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Field Blank QC:

- One of two field blank samples [NCH-SW-21-2 (Blank)] contained a total thorium concentration at 1.5x the detection limit. This result could be classified as a false positive, however the concentration reported is very close to the detection limit. The elevated or residual thorium concentration was likely due to thorium carry-over from the 1st sample digestion and likely represented an artifact. Therefore, the field blanks passed internal QC criteria.

11.3.3.4 Total Metals External QC Assessment

The error and the regression analysis for the total metals external QC sample pairs (SDSMT EMES and ELI) is provided in Table 11.7. Based upon these results, the following data quality assessments were made:

- Uranium passed the external QC limits for $R^2$ and slope. Two (2) of 13 samples were "non-detect" and were not be used for regression analysis. Four (4) of 11 samples (36%) exceeded the error limits of ±30% by additional percentages ranging from -2.5% to +24% with an average error of -3.9%. As a result, uranium was considered passing external QC criteria;.
- Arsenic passed the external QC limits for $R^2$ and slope, and only slightly exceeded the y-intercept limit. Two samples were "non-detect" and were not used for regression analysis. Six (6) of 13 samples (46%) exceed the error limits ±30% by additional percentages ranging from only -7.9% to +52% with an average error of -3.9%. As a result, arsenic was considered passing external QC criteria;
- Molybdenum failed the external QC limits for $R^2$ and y-intercept criteria. Seven (7) of 13 samples were "non-detect" and were not used for regression analysis. Five (5) of 11 samples (45%) exceed the error limits of ±30% by additional percentages ranging from -26% to +26% with an average error of 7.7%. As a result, molybdenum did not pass external QC criteria and concentrations were qualified with a "J" flag. The molybdenum results reported should only be used as estimated concentrations;
- Copper failed the external QC limits for slope and y-intercept. Seven (7) of 13 samples were "non-detect" and were not used for regression analysis. SDSM&T EMES reported copper concentrations were 10x higher than the detection limit for 4 of the seven 7 "non-detect" samples analyzed by ELI. Five (5) of 6 samples (83%) exceed the error limits of ±30% by additional percentages ranging from +41% to +164% with an average error of 94.5%. As a result, copper did not pass external QC criteria and concentrations were qualified with a "J" flag. The copper results reported should only be used as estimated concentrations;
- Lead passed the external QC limits for and the $R^2$ and slope, but exceeded the intercept limits. Seven (7) of 13 samples were "non-detect" and were not used for regression analysis. Two (2) of 5 samples (40%) exceed the error limits of ±30% by additional percentages ranging from +36% to +49% with an average error of +17%. As a result, lead did not pass external QC criteria and concentrations were qualified with a "J" flag. The



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lead results reported should only be used as estimated concentrations;

- Selenium passed external QC limits for $R^2$ and slope. Nine (9) of 13 samples were "non-detects and were not used for regression analysis. Two (2) of 4 samples (50%) exceed the error limits of ±30% by additional percentages ranging from +6% to +22% with an average error of 28.4%. Also, the highest errors occurred at high concentrations. As a result, selenium did not pass external QC criteria and concentrations were qualified with a "J" flag. The selenium results reported should only be used as estimated concentrations and may be biased high;
- Vanadium failed the external QC criteria for $R^2$ and slope (negative slope). Three (3) of 4 samples (75%) exceeded the error limits of ±30% by an additional percentage ranging from -20% to +143% with an average error of +71%. Nine (9) of 13 samples were "non-detect" and were not used for regression analysis. The vanadium results were rejected due to failure meeting external QC assessment, and were qualified with an "R" flag;
- Thorium failed the external QC criteria for $R^2$ and slope. Four (4) of 5 samples (80%) exceeded the error limits of ±30% by an additional percentage ranging from -7% to +100% with an average error of +42%. Seven (7) of 13 samples were "non-detect" and were not used for regression analysis. The thorium results were rejected due to failure meeting external QC assessment, and were qualified with an "R" flag.

As an overall assessment, uranium and arsenic results passed both internal and external QC criteria despite minor QC failures. Molybdenum and lead results may only be used as estimated quantities or approximations. Copper and selenium may also only be used as estimated quantities, however the results may be biased high. Vanadium and thorium results failed the QC criteria and were rejected, and thus may have limited value.

### 11.3.4 Air Particulate Data Validation

All QC data and charts for air particulate samples discussed below are provided in Appendix B3 materials. Only evaluation of wind tunnel (WT) samples has been presented.

#### 11.3.4.1 Wind Tunnel Internal QC Assessment

Spike Sample Recovery QC:

- Only copper exceeded internal QC limits by only +1% in the 1st digestion. The small margin of the QC failure in 1 of 2 batches was deemed acceptable.

Lab Duplicate QC:

- All target analytes passed the internal QC criteria.

Blank Spike Recovery QC:

- Only copper exceeded internal QC limits by only +1% in the 1st digestion. The small margin of the QC failure in 1 of 2 batches was deemed acceptable.

Lab Blanks QC:

- All target analytes passed the internal QC criteria..

11.3.4.2 Wind Tunnel External QC Assessment

The error and the regression analysis for the wind tunnel external QC sample pairs (SDSMT EMES and ELI) is provided in Table 11.8. Based upon these results, the following data quality assessments were made:

- In general, two factors hindered an accurate assessment of external QC wind tunnel samples:

    1. Concentrations were generally low and varied little amongst sample population. As a result, small differences between concentrations within sample pairs led to relatively large errors and failure of $R^2$ and slope criteria;
    2. The small number of samples (3);

- Uranium failed the external QC limits for $R^2$, and 1 of 3 samples (33%) exceeded the error limits of $\pm$30% by an additional -2%. All error values were negative with an average error of -21%. As a result, uranium results were qualified with a "J-"flag, and the uranium results reported may subsequently be used only as estimated concentrations, and may be biased low;
- Arsenic failed the external QC limits for the trendline, and 1 of 3 samples (33%) exceeded the error limits of $\pm$30% by an additional -35%. All error values were negative with an average error of -25%. As a result, arsenic results were qualified with a "J-"flag, and the arsenic results reported may subsequently be used only as estimated concentrations, and may be biased low;
- Molybdenum failed the external QC limits for slope, and 1 of 3 samples (33%) exceeded the error limits of $\pm$30% by an additional -35%. All error values were negative with an average error of -38%. As a result, molybdenum results were qualified with a "J-"flag, and the molybdenum results reported may subsequently be used only as estimated concentrations, and may be biased low;
- Copper failed the external QC limits for $R^2$ and the y-intercept, and 3 of 3 samples (100%) exceeded the error limits of $\pm$30% by an additional -4% to -18%. All error values were negative with an average error of -39%. As a result, copper results were qualified with a "J-"flag, and the copper results reported may subsequently be used only as estimated concentrations, and may be biased low;
- Lead slightly failed the external QC limits for slope, and all errors were within the limits of $\pm$30%. As a result, lead passed external QC criteria;
- Selenium concentrations were reported as near or at analytical detection limit. SDSM&T EMES result were "not-detects" for all 3 samples, whereas ELI results were up to 3x the SDSM&T EMES detection limit. Therefore, error and regression analysis was not possible. Selenium concentrations were qualified with a "J-"flag, and selenium results



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reported may subsequently be used only as estimated concentrations, and may be biased low and may yield false negatives;

- Vanadium failed the external QC limits for $R^2$, and 3 of 3 samples (100%) exceeded the error limits of ±30% by an additional -18% to -36%. All error values were negative with an average error of -54%. As a result, vanadium results were qualified with a "J-"flag, and the vanadium results reported may subsequently be used only as estimated concentrations, and may be biased low.
- Thorium failed the external QC limits for the slope, and 3 of 3 samples (100%) exceeded the error limits of ±30% by an additional -23% to -29%. All error values were negative with an average error of -57%. As a result, thorium results were qualified with a "J-"flag, and the thorium results reported may subsequently be used only as estimated concentrations, and may be biased low.

As an overall assessment of the wind tunnel data, all metals displayed a negative or low bias. All metals but lead failed external QC criteria and were qualified with a "J-"flag. Thus, these results should only be used as estimates.

### 11.3.5 Sediment and Soil Data Validation

All QC data and charts for sediment and soil samples discussed below are provided in Appendix B4 materials.

#### 11.3.5.1 Sediment and Soil Internal QC Assessment

Lab Blanks QC:

- Lab blanks in the 1st to the 5th digestion reported vanadium concentration below the detection limit. The samples passed internal QC criteria;
- The lab blank of the 6th digestion showed a residual selenium concentration at 1.5x the detection limit. As a result, the selenium concentrations in this digestion batch were only thought to affect concentrations close to the detection limit, and the sample passed internal QC criteria;

Sample and Blank Spike Recoveries QC:

- Arsenic, copper, selenium, thorium, and vanadium exceeded QC limits by additional percentages of -1% to -5% in one to two digestions. n the in one or two digestions only. This could indicate a problem associated with analytical methods for the sample digestion batches, however the overall low percentage errors were deemed acceptable and thus passed internal QC criteria;.
- Thorium exceeded the external QC limits by an additional percentage of -8% in the 8th digestion. This could indicate a problem associated with analytical methods for this sample digestion batch, however the overall low percentage errors were deemed acceptable and thus passed internal QC criteria;



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Lab Duplicate QC:

- Thorium failed external QC limits by an additional -4% in the 4th digestion. This indicates a low bias for the concentrations, but this failure is relatively small for only one out of 8 digestion batches, and these samples were deemed to pass internal QC criteria;

11.3.5.2 Sediment and Soil External QC Assessment

The error and the regression analysis for the sediment and soil external QC sample pairs (SDSM&T EMES and ELI) is provided in Table 11.9. Based upon these results, the following data quality assessments were made:

- Uranium passed the external QC criteria;.
- Arsenic (slightly) failed the external QC limits for $R^2$, and only 3 out of 30 samples (10%) exceeded the error limit of $\pm$30% by an additional +0.5% and -4.2%, respectively. As a result, arsenic passed the external QC criteria;
- Molybdenum (slightly) failed the external QC limits for the y-intercept, and only 4 out of 30 samples (13%) exceeded the error limit of $\pm$30% by an additional percentage ranging from -1.2% to +3.9%. As a result, molybdenum passed the external QC criteria;
- Copper (slightly) failed the external QC limits for $R^2$, and only 5 out of 30 samples (17%) exceeded the error limit of $\pm$30% by and additional percentage of up to -6.3%. As a result, copper passed the external QC criteria despite an overall slight negative bias;
- Lead (slightly) failed the external QC criteria for $R^2$, and only 4 out of 30 samples (13%) exceeded the error limits of $\pm$30% by an additional percentage of up to -3.3%. As a result, lead passed the external QC criteria despite an overall slight negative bias;
- Selenium concentrations were generally low and slightly above the reported detection limit. Therefore, only small differences in concentrations resulted in a large error between the QC sample pairs. Selenium passes the external QC criteria for the regression analysis, but 7 out of 30 samples (23%) exceed the error limits of $\pm$30% by an additional percentage ranging from -25.2% to +53.6%. The large errors were generally positive and were associated with very low concentrations slightly above the detection limits. As a result, selenium passed the external QC criteria;
- Vanadium failed the external QC criteria for $R^2$ and slope, 22 out of 30 samples (77%) exceeded the error limits of $\pm$30% by an additional percentage ranging from -6.2% to -58.6%. Vanadium displayed a strong negative bias, and as a result, vanadium did not pass external QC criteria. Vanadium concentrations were qualified with a "J-" flag, and the values may only be used as estimates;
- Thorium failed the QC criteria for $R^2$ and slope, and 16 out of 30 samples (77%) exceeded the error limits of $\pm$30% by an additional percentage of up to -58.6%. The largest errors were associated with very low concentrations close to the detection limit. Thorium displayed a strong negative bias and, as a result, thorium did not pass external QC criteria. Thorium concentrations were qualified with a "J-"flag and the values may only be used as estimates.

As an overall assessment of the sediment and soil data, all metals but selenium and molybdenum



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displayed a more or less pronounced negative bias. Despite minor internal and external QC failures, arsenic, molybdenum, copper, lead, and selenium passed the overall QC evaluation. Only vanadium and thorium failed overall QC evaluation; these data display a pronounced negative bias and can only be used as estimates.

### 11.4 Level II (Portable Instruments of Investigative Quality) Data Validation

Data validation of field data using portable instrumentation (i.e., pH meter and ORP meter) was not possible due to limited statistical control limitations associated with these measurements. Professional judgment was used to assess the field QC for purposes of this study. Calibration standard labels were documented within the field notes (Appendix C1). A summary of the field measurements is provided in Appendix A1 and is deemed correct and complete.

### 11.5 Level I (Screening Quality) Data Validation

This level is characterized by the use of portable instruments that provided real-time data to assist with optimizing field sampling, and for on-site health and safety evaluations. A hand-held scintillometer was used for sediment and soil radiation measurements. The instrument performs an internal calibration check every time it is turned on, and only functions if the calibration check passed the internal standard. A partial log of scintillometer field measurements has been provided in the field notes in appendix C4 and appears correct and complete. The second set of scintillometer logs was recorded by the drilling crew in a separate field book, however copes of these notes have not been provided within the Appendix. None of the radiation measurements recorded in the field notes were higher than the level of concern specified in the Health and Safety Plan.

Sediment and soil samples were also screened in the field using a hand-held X-Ray fluorescence spectrometer (XRF) for all target analytes except thorium. The XRF requires calibration each time it is turned on or if the instrument internally detects a change in calibration. Measurements and calibrations are provided in Appendix B4 and appear to be complete. Note several measurements do not have the correct date and/or time stamp due to errors associated with instrument settings.

## 12.0 Conclusions and Recommendations

The primary objective if this study was to determine the extent of heavy metal and radionuclide contamination found on private property that may be attributed to historical mining operations within the North Cave Hills complex. Of the eight target analytes, only uranium, arsenic, and molybdenum concentrations were found to be above the established background within surface water, drainage sediment, and soil samples collected on private property; vanadium and copper concentrations were reported above established background only within select surface water samples.

Contaminant concentration levels within the Crooked Creek and Campbell Creek drainages within the northern North Cave Hills complex generally were at background or 2x background



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levels at the USFS-administered/private land interfaces, and contaminant concentrations did not decrease at distances further downstream. For the Schleichart Draw drainage flowing from the southern portion of the North Cave Hills complex into Campbell Creek, uranium concentrations within the surface water was above 3x background, and decreased to less than 2x background within Campbell Creek below the Brown Reservoir.

Results from this study show the highest contaminant concentrations (greater than 3x background) were generally limited to the upper Pete's Creek drainage. Several sources of contaminant loading within the Pete's Creek drainage have been identified, and include:

1. Large volumes of runoff water and spoilage sediments channeling through an un-named tributary of Pete's Creek below the northern reaches of Bluff B. This channeling has resulted in extensive sedimentation of mine spoils within the main channel of Pete's Creek. This un-named tributary appears to be the largest source of contaminant loading in surface water and drainage sediments within the entire Pete's Creek watershed with contaminant concentrations exceeded 3x background;
2. Operational failure of Sedimentation Ponds #1 and 2 below Bluff B resulting in discharging surface water and sediments containing contaminant concentrations greater than 3x background;
3. Surface water runoff and drainage sediments from Bluffs F, G, H, I1, and I2 yielding contaminant concentrations greater than 3x background for most contaminants analyzed;
4. Surface water runoff and drainage sediments from a tributary draining the Flint Hills area south of Tufte Road. The Flint Hills area includes potential runoff from the Flat Top minesite located northeast of Ludlow on private property. Contaminant concentrations of surface water and sediments within this tributary were generally below 2x background, and thus this drainage does not appear to be a significant source of contaminant loading within the Pete's Creek drainage.

Contaminant concentrations for surface water in Pete's Creek were less than 3x background approximately 15-20 km downstream from the source areas, while drainage sediments were at background approximately 5-10 km downstream from the source areas. These results imply that natural contaminant attenuation is actively occurring within the entire reach of Pete's Creek.

Mine spoils have migrated from Bluffs B and H onto private land through slumping and sliding movement actions (area north of Bluff B and northeast of Bluff H), and through sheet erosion and development of washover fans (area northeast of Bluff B). Contaminant concentrations of these sediments on private land were generally at or below background concentrations. However, arsenic and molybdenum concentrations near Bluff B were 2x background, and were 2x and 3x background, respectively, near Bluff H. Contaminant concentrations of sediments collected on USFS-administered lands were generally much higher, and thus continued migration of mine spoils may result in increased sediment contaminant concentrations on private land in the future.

Other findings and recommendations as a result of this study include:

1. Evidence of arsenic and uranium mobility and attenuation within the Pete's Creek



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watershed varied considerably. Arsenic attenuation readily occurred within the upper reaches of Pete's Creek, and was likely attributable to the highly oxidative (positive oxidation/reduction potential suggesting oxygen rich) conditions observed. These geochemical conditions promote the formation of insoluble and likely less mobile arsenate [As(V)] species as compared to the more soluble and highly mobile arsenite [As(III)] species common under reducing conditions. Conversely, oxidative conditions typically result in the preferential formation of mobile uranyl [U(VI)] species versus immobile uraninite [U(IV)] species. These complex (bio)geochemical relationships as related to contaminant fate and transport are currently being investigated through graduate student research at SDSM&T;

2. Sedimentation ponds #1 and 2 are currently not effective in capturing surface water and sediment loading from Bluff B spoils. The relatively low dissolved metal concentrations (such as arsenic and uranium) compared to their corresponding total metal concentrations and contaminant concentrations found within the drainage sediments collected immediately downstream of the ponds suggest that a significant mass of sediment (at size fraction <0.45 μm) is effectively passing through these engineered structures. High alkali metal concentrations found within the runoff water entering the ponds appears to disperse suspended clay particles and prevents these particles from settling out within the pond. Suspended coal particles also appear to float through the structure without being removed. In addition, sediment pond water appears to be channeling around the outflow standpipes. These structures appear to be engineered to retain only the coarse fraction of the sediment load and, thus the fine sediment fraction appears to pass through the ponds through the pond outflow. The fine sediment fraction and the coal particles likely contribute to the greatest percentage of down-gradient contaminant loading compared to the coarser silt to cobble sized siliciclastic sediments. Consequently, the sedimentation ponds appear ineffective at reducing or controlling contaminant loading into the upper Pete's Creek watershed. A significantly re-vamped approach to mitigate the environmental effects from Bluff B surface water runoff, such as the use of constructive wetlands for enhanced contaminant remove, is recommended. Studies investigating the relationship between grain size and contaminant concentrations are currently ongoing at SDSM&T as part of graduate student research, and these research findings would be beneficial for the re-design of the sedimentation ponds;
3. The design of the proposed sedimentation pond to be located below the northeastern spoils of Bluff B should be sized to provide sufficient detention time for sediment settling (i.e., removal) under high flow conditions. This design should also include mechanism(s) to retaining the fine sediment fraction lignite particles. The design should also account for the expected runoff water geochemistry for the maximization of contaminant removal. The use of constructed wetlands, as recommended for Ponds #1 and 2 above, should also be considered;
4. Numerous exposed lignite outcroppings are found within the drainages and sub-drainages of the North Cave Hills. These lignite seams are stratigraphically lower (i.e., appear to contain less uranium) than the uraniferous lignite mined in the area, and thus do not appear to be a significant source of contaminant loading within the drainages;
5. The relatively high molybdenum concentrations associated with the mine spoils, as compared to copper concentrations, appears to cause the pronounced deterioration of the copper molybdenum ratios within the North Cave Hills. Thus molybdenum affects the



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overall quality of the surface water, soils, and drainage sediments.

Results from the groundwater study suggest that the metals and radionuclides are natural components of the groundwater systems within area surrounding the North Cave Hills region. Further, the distribution of contaminates found within collected samples suggest they are from natural sources and are ubiquitous in occurrence, particularly with respect to gross alpha and zinc. At this time, it is indeterminate whether the abandoned uranium mines in the North Cave Hills contribute to the metals content of the water without more extensive studies.

Trace amounts of aerosol sized dust were found to exist within the soils surrounding the North Cave Hills. Soil particle laser sizing results suggest the North Cave Hills contain <1% $PM_{10}$ and range between 0.11 and 1.1% with an average of 0.55%. Thus, soils in the study area contain low amounts of aerosol particulates and appears to be less susceptible to air entrainment.

Uranium airborne dust contaminant results show the highest correlation to the abandoned mine sites and the prevailing wind direction forming a northwest to southeast plume for the North Cave Hills region. However, the uranium distribution does not correlate with the other metal contaminants, and thus airborne contaminant transport appears only partially responsible for dust contaminant transport and deposition for the North Cave Hills region.

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ORIGINAL ARTICLE

# Chemical composition of bottom sediments within black hills region reservoirs of South Dakota and Wyoming

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**Abstract** The objectives of this study were to determine the effect of heavy metals transported from mining areas due to historical mining activities within the Black Hills region of South Dakota and Wyoming US, and to evaluate the presence of major and trace elements resulting from influence of provenance, weathering, erosion, and sediment sorting within reservoir sediments. Soil core samples were collected from both inflow and outflow of the reservoirs. X-ray florescence analyses were performed to determine the presence of major and the trace elements concentration. Pactola and Sheridan Lakes had the highest concentration of As, Fe, Mn, and Rb/Sr ratios, while the Belle Fourche Reservoir had the highest U concentration. Spatial and temporal patterns of Rb/Sr ratio of the reservoir sediments were used to determine the weathering intensity of the catchment areas. With the exception of Angostura and LAK reservoirs, all Black Hills reservoirs were dominated by physical weathering processes within their respected watersheds. Immobile high field strength elements from within the reservoir sediments were higher compared to upper continental crust (UCC) concentrations, and further suggest the dominance of physical weathering processes for all reservoirs except LAK. Spider diagrams normalized to UCC concentrations indicate that Black Hills regional reservoirs were elevated in Zr, Hf, and U, further supporting the dominance of physical or mechanical weathering influences from their watersheds. Watersheds dominated by physical weathering processes are commonly subjected to high erosion, anthropogenic activities, and/or high precipitation processes.

**Keywords** Geochemistry · Reservoir sediment · Uranium · Mineralogy · Weathering

## Introduction

Mining-related activities in the Black Hills region of South Dakota (SD) and Wyoming (WY) US began with the European settlement in the region in the late 1800s. Black Hills region is the only region in SD which provides the geophysical setting for the precious mineral deposits. The past mining activities in the Black Hills can be divided into three groups: the northern hills with primarily gold mines, the central hills with pegmatite and gold mines, and the southern hills near Edgemont with U mining (Webb et al. 1998). Gold was discovered in 1874, and initial mining activity was limited to the placer mining in Custer, SD (Webb et al. 1998), followed by silver (Ag), base metals, pegmatite, oil and gas, sand and gravel, gypsum, and molybdenum (Mo). Most of these placer deposits were Proterozoic to Quaternary age (DeWitt et al. 1989). Hardrock mining of ore formations began in 1876, after the discovery of gold-bearing deposits. DeWitt et al. (1989) classified 1084 mines in 85 metallic mineral district in the Black Hills. The Homestake mine in Lead, SD was the largest gold producing mine in North America before it closed down in 2002. Uranium (U) mining also has a long history in the southern Black Hills region starting in 1951 (Page and Redden 1952). Nearly 1 million tons of $U_3O_8$

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were mined during the following 13 years, commonly without erosion controls or reclamation pursuant to mining laws of that time (e.g., Act of 1872 and 30 USC 541, 1955). As a result, there has been extensive environmental degradation from these mining and post-mining operations.

Environmental hazards associated with mining in the Black Hills includes acid mine drainage (AMD) and arsenic contamination in the northern Black Hills, and contamination associated with abandoned U mines and tailings in the southern Black Hills. There have been several investigative studies conducted on AMD and As contamination in the northern Black Hills. A report by Ecology Environment LLC (2004) concluded that the concentration of As, Be, Ca, Ag, Mn, Hg, and Se in the soil and sediment samples collected from the Gold Mountain mine site was 3 times background, with the highest concentration of As in soil and sediment samples were 159 and 787 mg/kg, respectively. Gold mining in the northern Black Hills region of SD has been a continual source of mining tailings discharge into the Whitewood Creek and transported into the Belle Fourche (BF) River and thence to the Cheyenne River. Horowitz et al. (1988) concluded that the high concentration of As in core sediments was likely transported from the banks or floodplains of Whitewood Creek and the BF River.

There is limited knowledge regarding the status, size, and locations of historical U mines at the Black Hills region. The U mining district north of Edgemont SD (Fall River County) has been well documented (Hall 1982; Davis et al. 1999; Rahn et al. 1996; Webb et al. 1998) with 24 abandoned U mines documented within the Edgemont district. Rahn et al. (1996) reported that dissolved uranium was detected at 2.6 ppm in water samples collected from standing water in several mines from the Edgemont district, while Davis et al. (1999) evaluated water-quality impacts from abandoned mines within the Bear Butte Creek basin of the northern Black Hill, and the headwaters of the Driftwood Creek basin within the uranium mining district of the southern Black Hills. They reported that water-quality impacts were limited to the Strawberry Creek and the Bear Butte Creek, while for Driftwood Creek, surface water-quality impacts were limited to a stock pond own-gradient from abandoned U mines. Webb et al. (1995) reported that mine pit waters contained 2 mg/L U within this same region (Rahn et al. 1996).

The accumulation of heavy metals and radionuclides within reservoir bottom sediments has been used to better understand historical pollution trends from mining-impacted watersheds (Rauch et al. 2006; Spliethoff and Hemond 1995). Factors known to influence metal transport to sediments include climate, chemical and physical properties of host materials, weathering processes, sediment transport energy, and anthropogenic activities (Das and Haake 2003; Reynolds et al. 2010). Reservoir bottom sediment profiles can provide a comprehensive understanding of source material transport phenomena and chronology for understanding the history of the environmental impacts incurred. The objective of this research was to determine the watershed impacts due to soil and water erosion from abandoned mining sites on and adjacent to US Forest Service (USFS) administered lands within the Black Hills region using major and trace element geochemistry signatures, and comparing those to known physical and chemical transport process signatures to elucidate potential transport processes within the potentially mining-impacted watersheds.

## Geology and climate

The Black Hills region has a unique geological record. The oldest rocks in the Black Hills are Precambrian of metamorphic and igneous origin, found in the central hills of the eroded dome, and are the only exposed Precambrian rocks of Trans-Hudeon orogeny in the northern US (Roddy et al. 1991). The central part of the Black Hills is encircled by the younger Cambrian Deadwood Formation and the Jurassic Morrison Formation. Mineral deposits are limited to Precambrian rocks in the northern and central Black Hills and tertiary intrusions in the northern Black Hills (Webb et al. 1998). The metamorphic rocks of Precambrian age are mostly slates and quartzite. Rich (1981) divided Precambrian rocks of Black Hills into Archean, Oldest Early Proterozoic, Older Early Proterozoic, and Younger Early Proterozoic units. Archean metasedimentary rocks and Oldest Early Proterozoic rocks have limited exposures in the Little Elk Creek area and at Bear Mountain and Nemo area, respectively. Older Early Proterozoic unit chiefly contain conglomerate and quartzite. The source of these rocks is mainly Oldest Early Proterozoic unit, but Estes Formation with abundant feldspar and quartz clasts indicate Little Elk Granite source of Late Archean. Estes Formation in Nemo area consists of arkose, quartzite, and pelite. Nemo area also consists of dolomite and silty pelite of carbonate origin. Carbonate rocks at the west Nemo overlain by theoleiitic pillow basalt and maffic tuff and shale. Theoleiitic basalt without pillow structure is also exposed within Harney Peak Granite. Pillow basalt is overlain by ferruginous metachert unit in some parts of Nemo and Pactola Reservoir (PAC) dam. Older Early Proterozoic rocks are overlain by the Younger Early Proterozoic units in the east-central part of the Black Hills region. These rocks consist of conglomerate, debris flow, quartzite, banded iron formation, and alkali basalt. In most of the Black Hills area, Precambrian rocks are overlain by the younger Cambrian Deadwood Formation where it thins out in the southern part of the hills. Deadwood Formation is composed of glauconitic sandstone, shale, limestone, and the discontinuous basal conglomerate (Rich



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1981; Strobel et al. 1999). Deadwood Formation is overlain by the Upper Devonian and Lower Mississippian Englewood limestone along the northwestern side of Wind Cave. Mississippian-age Englewood limestone is underlain by Mississippian-age Madison Limestone. Madison Limestone consists of reddish brown sandstone and massive limestone with upper portion mark by karst topography (Rich 1981; Strobel et al. 1999). Due to regional disconformity along the underlain Formations, the thickness of Madison Limestone increases from almost zero in the south to 305 meter (m) in the north (Rahn 1985). The Madison Limestone is unconformably overlain by the Pennsylvanian and Lower Permian Minnelusa Formation. Thickness of Minnelusa Formation increases from less than 120 m in the north to 350 m in the south. Minnelusa Formation consists of cross-stratified sandstone, limestone, dolomite, and shale (Strobel et al. 1999). The upper part of the Minnelusa Formation consists of breccias formed from gypsum and anhydrite (Braddock 1963). Jurassic age Morrison Formation, Unkpapa Sandstone, Sundance Formation, and Gypsum Spring Formation consist of sandstone, siltstone, shale, claystone, and Limestone. Morrison Formation and Unkpapa Sandstone increase in thickness along the eastern side of the Black Hills.

The Inyan Kara Group consists of Lower Cretaceous age sandstone of Lakota and Fall River Formations which form a major hogback surrounded Black Hills. For the southern Black Hills, commercial grade U was produced from the Inyan Kara Group (Webb et al. 1995) composed of sandstone, siltstone, and shale of marine and non-marine units of Lower Cretaceous age. Lakota Formation is overlain by Fall River Formation, and unconformably overlies the Morrison Formation. Lakota Formation is composed of cross-bedded channel-fill sandstone, shale, and limestone having maximum of 152 m, while the Fall River Formation consists of well bedded, fine-grained sandstone, with some siltstone and claystone with maximum thickness of about 61 m (Rich 1981). Outside the hogback, the trace deposits of sand and gravel cover the bottom of the stream valleys at different elevations.

The climate of Black Hills region consists of four seasons, with cold winters and hot summers. The precipitation is relatively low, with the average annual precipitation between 1971 and 2000 in the northern and central part of Black Hills ranges between 61 and 68 centimeter (cm), whereas, it is less than 43 cm in the southern part.

## Materials and methods

### Sample locations and collection

This study consists of bottom sediments collected from seven reservoirs within the Black Hills region of SD and WY (Fig. 1), including Angostura (ANG), Belle Fourche (Orman) Dam (OD), Deerfield (DF), Keyhole (KR), LAK, Pactola (PAC), and Sheridan (SH). Below are geographic and geologic descriptions for each of the reservoirs, while specific sampling location is provided in Fig. 2.

ANG Reservoir is located on the Cheyenne River, at the southeastern edge of the Black Hills. It was completed in 1949 for irrigation purposes, and has a catchment area of approximately 9100 $km^2$ from the Cheyenne River of predominantly semi-arid plains across southwest SD, northwest NE, and east-central WY (Green 1990). Rocks of Paleozoic strata, primarily limestone, inter-bedded sandstone and shale are exposed in the northern watershed, while Mesozoic rocks of Fox Hill sandstone, Pierre Shale, Carlile Shale, Greenhorn Limestone, Skull Creek Shale and Inyan Kara Group, Sundance Formation and Spearfish Formation are exposed primarily in the southern edge of the Black Hills. Horsehead Creek is second major source of inflow into the reservoir which mostly drains Pierre Shale and is known source of Se in the region (Green 1990). Samples were collected near the reservoir spillway (ANG 1–1), Cheyenne River inlet (ANG 3–3), and Horsehead Creek Arm (ANG 2–3).

OD Reservoir (906 m elevation) is located at the terminus of Owl Creek, 13 km east of Belle Fourche, SD constructed in 1914 for irrigation purposes. The reservoir periodically collects diversion water from the BF River during high flows. The catchment area is approximately 442 $km^2$ for Owl Creek and 1664 $km^2$ above the BF Diversion. The topography of the catchment area is characterized by broad, shallow valleys and gently sloping hills (Roddy et al. 1991). The catchment contains rock exposures from the Hell Creek Formation, Fox Hills Sandstone, Niobrara Formation, Carlile Shale, Greenhorn Limestone, BF and Mowry Shales, and Skull Creek Shale and Inyon Kara Group (Roddy et al. 1991). Samples were collected near the Belle Fourche Reservoir Diversion (OD 2–1) and Owl Creek inlet (OD 1–1).

The DF Reservoir (1802 m elevation) is located 40 km west of Rapid City on Castle Creek. The dam on Castle Creek was constructed in 1947. Deerfield Reservoir has a surface area of 1.68 $km^2$ and average depth of 9 m. Deerfield Reservoir is nested between two bluffs composed of phyllite and quartz mica schist of Precambrian core in the southeastern portion of the Black Hills. Samples were collected adjacent to the reservoir spillway (DR 1–1), Goldrun Creek inlet (DR 2–1), and Castel Creek Arm (DR 3–1).

KR Reservoir (1258 m elevation) is located within the upper BF River near Moorcroft, WY, USA. Constructed in 1952, the reservoir has a catchment area of 5850 $km^2$. The catchment lithology is composed of three Cretaceous age geological units, including Lakota sandstone, Fuson shale,



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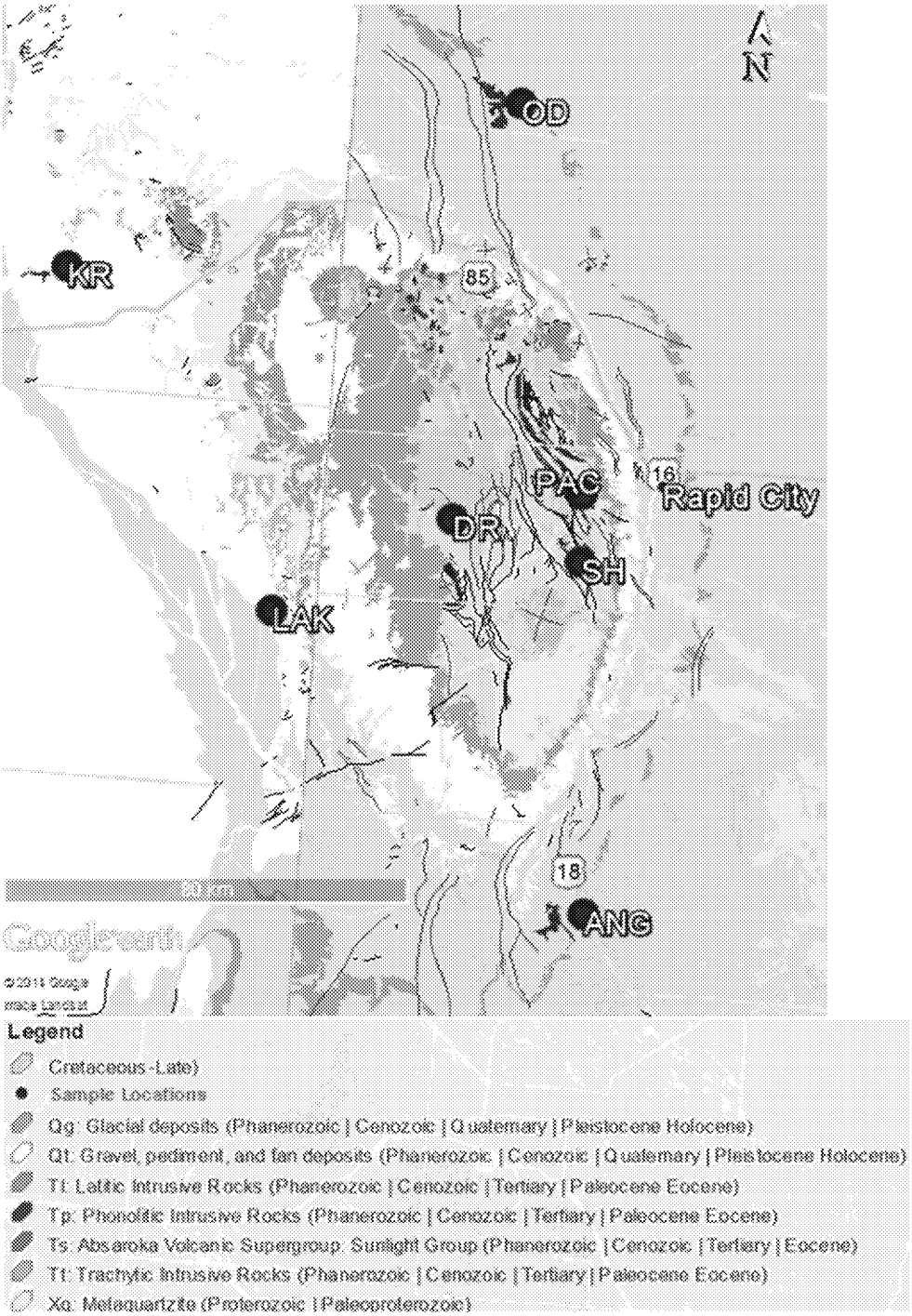


**Fig. 1** Locations with Geological map of seven reservoirs: *ANG* angostura, *Orman* Belle Fourche *OD* dam, *DF* deerfield, *KR* keyhole, *PAC* LAK, Pactola, and *SH* Sheridan in the Black Hills region of South Dakota and Wyoming

and Dakota sandstone. Samples were collected at the Eggie Creek Bay (KR 1–1), BF Mull Creek Bay (KR 2–1), and River inlet (KR 3–1).

LAK Reservoir (1335 m elevation) is located on the Stockade Beavercreek on private land, 8 km southeast of Newcastle, WY. The reservoir was constructed in the 1940s. The LAK Reservoir is located on the western edge of the Black Hills in a narrow canyon with steep cliffs. The rocks in the catchment are composed of sandstone and limestone of Minnelusa Formation of Permian age, Minnekahta Limestone and Opeche Shale of Phanerazoic, Paleozoic, and Permian ages and shale, siltstone and gypsum of Spearfish Formation of Paleozoic, Mesozoic age. Samples were collected from the spillway (LAK 1–1).

PAC Reservoir (1388 m elevation) is located on Rapid Creek, 17 km north of Hill City, SD, USA. The dam on the Rapid Creek was constructed in 1956. The normal operating depth at dam is 60.8 m. PAC Reservoir has a surface



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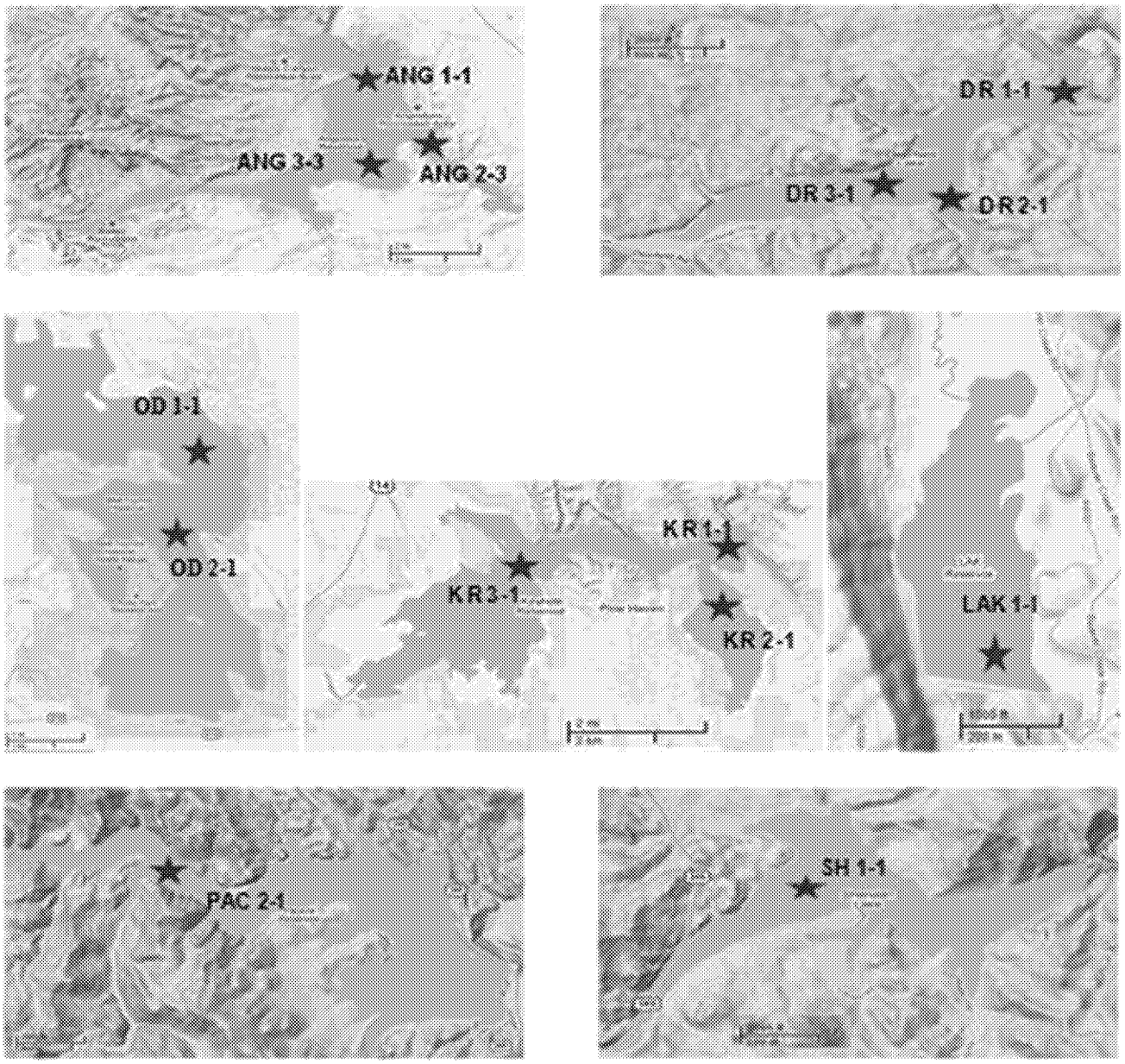


**Fig. 2** Sampling location of seven reservoirs: *ANG* angostura, *Orman* Belle Fourche *OD* dam, *DF* deerfield, *KR* keyhole, *PAC* LAK, *PAC* Pactola, and *SH* Sheridan in the Black Hills Region of South Dakota and Wyoming

area of over 5 $km^2$ at spillway crest level and the catchment area is approximately 86 $km^2$ for Rapid Creek. Rocks of metamorphosed shale and meta-basalt of Proterozoic age are present in the catchment area of PAC Reservoir watershed. Many small quartz veins and minor pyrrhotite, arsenopyrite, gold mineralization were noted along the Right-Lateral Silver City fault northwest of PAC Reservoir (Redden and DeWitt 2008). One sample was collected from the Rapid Creek inlet (PAC 2–1).

SH Lake (1409 m elevation) is located on the Spring Creek, 9 km northeast of Hill City, SD. The dam on Spring Creek was constructed in the 1930s. Sheridan Lake is located 6 miles south of PAC Reservoir. Spring creek drains approximately 101 $km^2$ above Sheridan Lake. The geology of the catchments of both SH and PAC is similar due to their close proximity. Sheridan Lake catchment has exposed Alluvium rocks of Phonerozoic, Cenazoic, and Quaternary ages that have clay to bolder size clasts with some organic matter which are absent in PAC Reservoir catchment area. One sample was collected from the Spring Creek inlet (SH 1–1).

Fourteen bottom reservoir sediments were collected from seven reservoirs in the Black Hills region in January and February 2011, with selection based upon previous uranium mining locations and effected watershed locations.



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Sediment cores were generally collected from the channel inflow and outflow, and the deepest parts of the reservoirs where the sediment rate was higher and sediments were considered undisturbed from wind. To collect core samples, separate 20 cm diameter holes were drilled into the ice using a gas-powered auger. Water depths were determined using sonar depth locator. One water sample was collected from a separate drill site using 500 mL surface water grab sample (Wildco bomb sampler, Wildlife Supply Company, Yulee, FL) to minimize consolidation of local sediments. Water sample was collected 30 cm above reservoir bed from each sediment core location prior to sampling. After collecting each sample, water-quality parameters were noted including dissolved oxygen (DO), temperature, pH, and conductivity. Two sediment cores were collected from each location (from separate sampling sites) using a 122 cm length suction coring device (Wildco 2400-B20 KB), with cores collected within internal 4.31 cm diameter plexiglass tube. Core samples were sliced into 2–3 cm segments and placed in a 120 mL whirl–pak bags within 24 h of collection, and stored at 0 °C prior to analysis.

### Laboratory analysis

One mm diameter pellets were prepared with 0.9 mm of sample powder mixed with 0.1 mm of ultra-bind. Pressed powder pellets were prepared for all fourteen core samples and were analyzed for major and trace elements (Ag, As, Ca, Cr, Cu, Fe, Mn, Mo, Ni, Pb, Rb, $SiO_2$, Sr, Ti, U, V, and Z) using a Bruker Tracer III-SD hand-held X-ray fluorescence spectrometry (XRF) instrument. Organic matter content was determined by Loss on Ignition (LOI) method following Heiri et al. (2001) procedures:

$$\mathrm{LOI} = 100 \times (\text{Mass loss})/(\text{Sample weight prior to firing}) \quad (1)$$

All 11 water samples were analyzed for total metal analysis (Ag, Al, As, Ca, Cd, Cr, Cu, Fe, K, Mg, Mn, Mo, Na, Ni, Pb, Rb, Se, Sr, Th, U, V, and Zn) following EPA 200.7 and 200.8 methods.

### Statistical methods

Inter-core element correlations were determined using Pearson correlation $r$ representing statistical relationship between two elements (SigmaPlot, Systat Software, San Jose, CA, USA). Values approaching +1 indicate a strong positive correlation, while values approaching −1 indicate a strong negative correlation. Significance of 95 % confidence interval and approach +1 or −1 was assumed for $p$ values <0.04.

## Results

### Reservoir sediment metal concentrations

While an increase in reservoir heavy metal concentration may be considered an indicator of anthropogenic pollution, metal loading may also be introduced by geologic weathering processes within the catchment. Down-core pattern of chemical concentrations of reservoir sediments is considered helpful in understanding the distribution of elements in samples collected from different reservoir locations. For this study, locations were chosen to investigate contributions in metal concentration emanating via stream flows through diverse geologic sequences. To clarify the elemental downcore pattern elemental concentration data including LOI, five major elements (Ca, Fe, Mn, $SiO_2$, and Ti), twelve trace elements (Ag, As, Cr, Cu, Mo, Ni, Pb, Rb, Sr, U, V, and Zn), and Rb/Sr ratio were graphed as a function of depth for all Black Hills sampling locations (Figs. 2, 3 ESM).

Reservoir sediment LOI was highest (2.71–20.69 %) at the surface and variable between cores. LOI concentrations in the bottom sediment cores ranged between 1.19 and 29.47 %. The wide range of LOI in the sediment samples suggests that differing source materials were present within the reservoir watersheds. Samples collected from PAC and SH had the highest LOI concentration. PAC and SH also had the highest concentrations of As, Fe, Mn, Ni, Pb, Ti, and Zn. The concentrations of As and Cr were higher in shallow depths compared to the deeper sediments collected from PAC. Both PAC and SH watersheds have a long history of mining activities.

Silica-rich sand with low LOI, Cu, Fe, Mn, Rb, Ti, U, and Zn was present within the Horsehead Creek Arm and the Cheyenne River inlet samples collected within ANG Reservoir. These silica-rich sands ranged from fine to coarse grained and were present at the bottom of the sample cores. The Cheyenne River inlet results were generally lower values compared to spillway samples. The mineralogy of the spillway sediments might be influenced by the streams that drain from the north into ANG reservoir.

Iron and Mn exhibited strong inter-core relation for all samples except those collected near the spillway of ANG and DF Reservoir, and Spring Creek from SL. Iron and Mn generally exhibit similar redox geochemical behavior (Singh and Nayak 2009). Rb/Sr trends may describe weathering intensity within the catchment because mineralization of Rb and Sr shows different preferences depending upon their mineral structure (Xu et al. 2010; Zhangdong et al. 2001). During weak chemical weathering, Rb tends to stay behind, resulting in Rb formation



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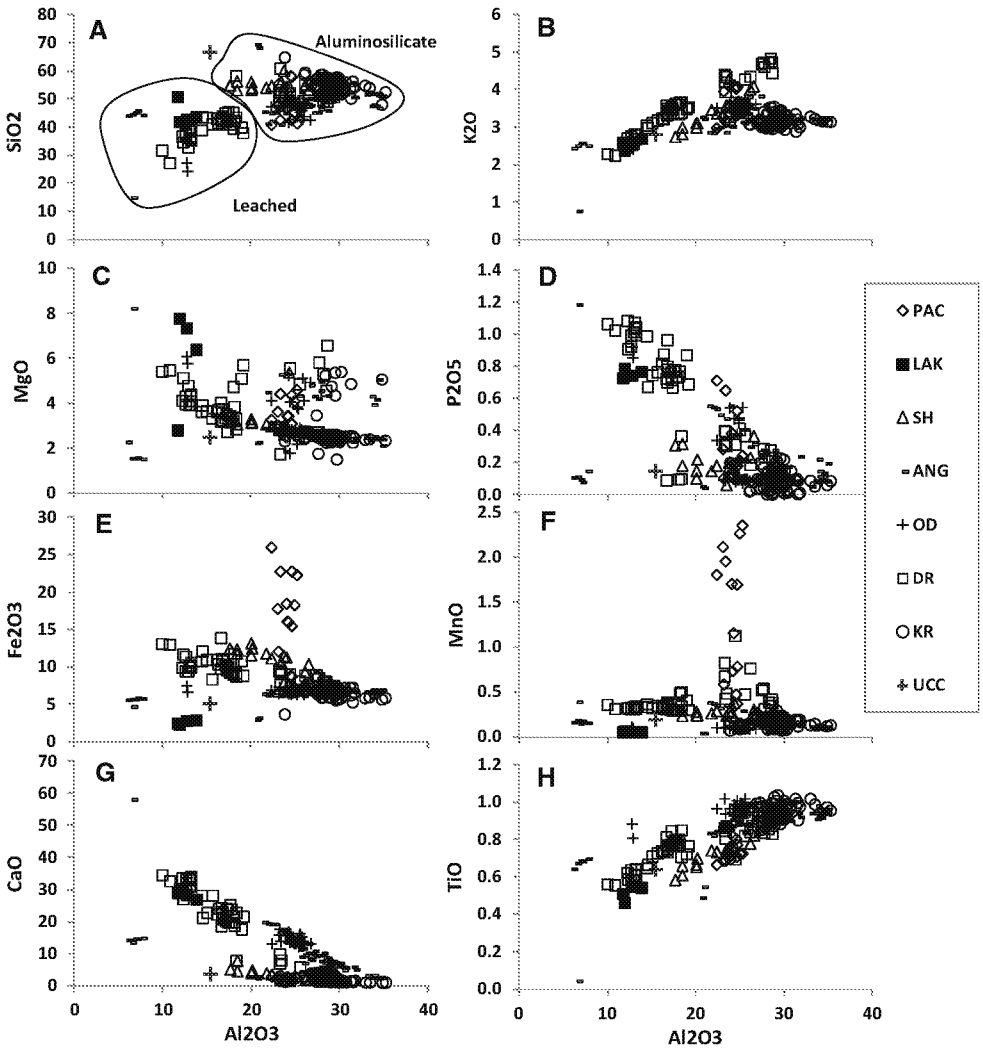


**Fig. 3** Chemical variation diagrams for **a** $SiO_2$, **b** $K_2O$, **c** MgO, **d** $P_2O_5$, **e** $Fe_2O_3$, **f** MnO, **g** CaO, and **h** $TiO_2$ compared to $Al_2O_3$ of reservoir sediments. Upper continental crust (UCC) from Rudnick and Gao (2003)

enrichment. With the exception of the KR Reservoir and BF River arm, all samples had elevated Rb/Sr values at depth, suggesting weak chemical weathering of these sediments within these watersheds (Xu et al. 2010; Zhangdong et al. 2001). Strontium and Ca also exhibit similar trends except in samples collected from the spillway in DF Reservoir and SH Lake, and appear attributed to Sr partitioning into Ca-rich minerals (Chen et al. 1999). Calcium peaked at 20 cm depth (7.9 ppm) in SH Lake, while the spillway in DF Reservoir Ca peaked at 5 cm depth whereas Sr remained consistent. The elevated sediment Ca may be attributed to the precipitation of carbonate with low Sr distribution coefficients (Singer and Navrot 1973). Silver, Mo, Pb and U trends were similar for all samples, with U intermittently elevated. For LAK reservoir, there were no significant trends primarily due to low core recovery.

## Reservoir sediment spatial distribution

Average compositions of all reservoir sediments are presented in Table 1. Bottom sediments from PAC reservoir and SH Lake were markedly enriched in Mn, Cu, Cr, V, Fe, As, and Rb/Sr ratios. High Fe and As in PAC Reservoir and SH Lake sediments correlated with high pyrrhotite, arsenopyrite in Precambrian rocks of catchment area. The OD sediment samples contained elevated U as compared to other reservoir sediment samples, and appear correlated with major U deposits contained within sandstones and from Inyan Kara Formation of the Powder River basin. Sediment samples from DF and LAK Reservoirs were distinctly enriched in Ca, which may be associated with the limestone of Minnelusa Formation of Permian age. LAK Reservoir contained the lowest metal concentrations for the Black Hills region. LAK Reservoir drains the western part



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**Table 1** Average sediment compositions from the seven reservoirs in ppm

| | ANG | DF | KH | OD | SH | PAC | LAK |
|---|---|---|---|---|---|---|---|
| Catchment area ($km^2$) | 9100 | 33 | 5850 | 2106 | 101 | 86 | 152 |
| Geology | Paleozoic Ls, Ss, and Sh | Precambrian Phy and Sch | Cretaceous Ss and Sh | Cretaceous Ss and Sh | Alluvium | Proterozoic meta Sh | Permian Ss and Ls |
| Si02 | 444,431 | 710,633 | 923,451 | 781,513 | 526,800 | 609,692 | 519,000 |
| Ca | 49,018 | 113,741 | 14,078 | 90,527 | 19,323 | 15,978 | 156,500 |
| Ti | 3213 | 2568 | 4041 | 3323 | 2834 | 3858 | 1350 |
| V | 124 | 163 | 115 | 124 | 183 | 287 | 152 |
| Cr | 77 | 104 | 88 | 86 | 137 | 356 | 27 |
| Mn | 562 | **1455** | 665 | 307 | **1137** | **6921** | 124 |
| Fe | 24,210 | **31,659** | 26,106 | 23,530 | **38,680** | **62,223** | **7330** |
| Ni | 13 | 13 | 12 | 16 | 13 | 33 | 12 |
| Cu | 37 | 52 | 36 | 40 | 56 | 63 | 24 |
| Zn | 71 | 62 | 72 | 69 | 89 | 181 | 18 |
| As | 7 | 6 | 7 | 10 | **86** | **85** | 7 |
| Sr | 244 | 108 | 148 | 338 | 98 | 95 | 165 |
| Mo | 67 | 81 | 61 | 87 | 71 | 84 | 49 |
| Ag | 20 | 33 | 19 | 31 | 27 | 26 | 13 |
| Pb | 24 | 34 | 21 | 34 | 34 | 40 | 18 |
| U | 45 | 46 | 41 | **60** | 41 | 49 | **9** |
| Rb | 96 | 90 | 101 | 102 | 96 | 95 | 37 |
| Rb/Sr | 0.46 | 0.84 | 0.70 | 0.35 | **0.99** | **1.01** | 0.23 |

Values in bold represent elevated concentration

*Ls* limestone, *Ss* sandstone, *Sh* shale, *Phy* phylite, *Sch* schist

of the Black Hills and is a relatively smaller catchment compared to others from this study.

Elemental concentrations relative to $Al_2O_3$ are present in Fig. 3. Changes in Ca and organic matter can be evaluated using elemental concentration normalized with Al. It is suggested that the concentration of Al in sediments does not change over 10,000 years (Bertine and Goldberg 1977). Higher ratio of $SiO_2/Al_2O_3$ is noted in shallow sediments from the samples collected near the spillway in ANG Reservoir, LAK Reservoir, and SH Lake and bottom sediment sample collected from the Cheyenne River arm in ANG Reservoir. Higher ratio of $SiO_2/Al_2O_3$ ratios in these sediments is likely due to low Al-rich minerals and feldspar and high quartz. All other reservoir samples had relatively constant $SiO_2/Al_2O_3$ suggesting dilution of minerals like hematite, calcite, or opaque minerals with little or no $SiO_2$ and $Al_2O_3$ (Cullers 2000). Samples collected near spillway and from Cheyenne River arm in ANG Reservoir mostly have low $SiO_2/Al_2O_3$ ratio relative to other samples. This can be linked to enrichment of Al-rich minerals like Koalinite and Illite relative to quartz in these sediments.

## Reservoir water quality

Although trace elements such as As, Pb, Cd, and Cr are minimally present in natural waters, they are very important factor in water-quality viewpoint. Results of water samples collected from the water column immediately above the bottom sediments from the reservoirs in the Black Hills region are presented in Fig. 4. If the pH of an aqueous solution is known, the stability of minerals in contact with the water may be determined. For example, Cu, Ni, Hg, and Ca are highly stable in natural waters and can adversely affect water quality of the reservoirs (Förstner 1976). The pH of water samples ranged from 7.35 collected near spillway of ANG to 8.2 from the Castel Creek arm in Deerfield Reservoirs. The water sample collected near spillway in Keyhole Reservoir has the lowest DO concentration, and could be due to the number of factors such as lack of inflowing water, temperature, and extensive ice cover (Guenther and Hubert 1991). Uranium concentrations were all below the mean contaminant levels (MCL) of 30 μg/L (EPA 2011). Arsenic (8.89 μg/L) was only detected in SH Lake, while Fe, Ni, and Th were not detected in any lakes.



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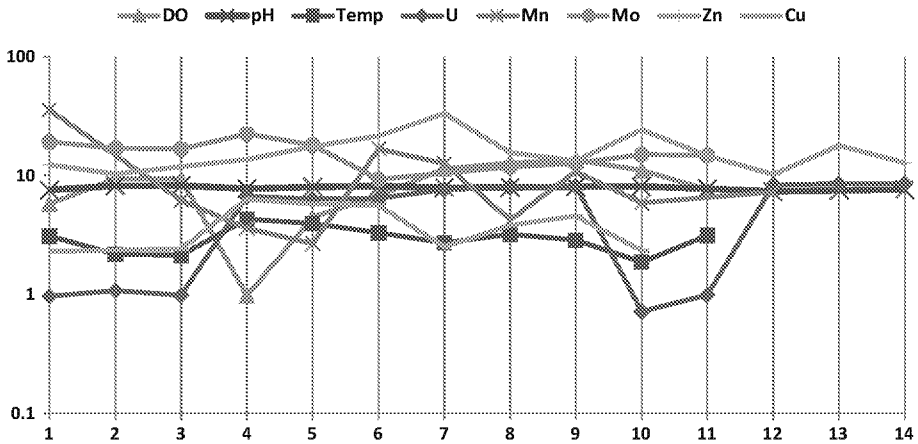


**Fig. 4** Dissolve oxygen (mg/L), pH, temperature (°C) and concentrations of U, Mn, Mo, Zn, and Cu (μg/L) for water samples collected. *1* DR 1, *2* DR 2, *3* DR 3, *4* KR 1, *5* KR 2, *6* KR 3, *7* LAK 1, *8* OD 1, *9* OD 2, *10* PAC 2, *11* SH 1, *12* ANG 1, *13* ANG 2, *14* ANG 3

## Discussion

### Major elements

Major oxide values are used to classify the rock types and construction of chemical variation diagrams, with the latter commonly used to present the relationship between elemental data and geochemical processes. In Fig. 3, $Al_2O_3$ shows the most chemical variation among all oxides ranging from 5.9 to 35.2 wt%. Due to Al high abundance and its relatively small inputs from anthropogenic source, it was plotted on the horizontal axis vs other major oxides on the vertical axis, and compared to reservoir sediments and the estimated averages of the upper continental crust (UCC) (Rudnick and Gao 2003). $Al_2O_3$ in sediments increased towards finer grain (clay) and $SiO_2$ increases towards coarse grains (sand) (Das and Haake 2003; Vital and Stattegger 2000). Similarly, other elements that exhibited similar behavior are $Fe_2O_3$, $TiO_2$, MgO, and $K_2O$. If sediment has grain size effects from sand to mud, it shows smooth trends. Variation diagrams of major oxides of present study show that $Fe_2O_3$ and MgO did not indicate smooth trends againstBlack Hills sampling locations $Al_2O_3$, while $SiO_2$ and $Al_2O_3$ show differing patterns which suggest that there was no grain size effect from sand to mud in these sediments. In mud, CaO is negatively correlated with $Al_2O_3$ (Vital and Stattegger 2000). The results suggest that samples collected from reservoirs of Black Hills region consist primarily of clay minerals.

Inter-core element correlations were determined using Pearson correlations (Table 2 ESM). With the exception of LAK, U generally had strong correlations with Mo (0.805–0.954), Ag (0.477–0.882), and Pb (0.642–0.889) in all reservoirs. The strong negative correlation of Rb/Sr to Ca (−0.928 and −0.851) and strong positive correlation of Rb/Sr to Rb (0.748 and 0.917) in ANG and OD sediments, respectively, indicate chemical weathering and sorting. Further, the correlation between $SiO_2$ and Rb (0.528) determined within OD sediments suggests chemical weathering in the catchment area. Strong correlation of As to Fe (0.787) in PAC Reservoir and 0.805 in SH Lake suggests the presence of similar mineral phase such as arsenopyrite. Positive correlation of Zn to Ti (0.451–0.695) and Fe (0.467–0.911) in ANG, OD, and KR sediment samples indicates the presence of Ilmenite group of minerals. Similarly, strong positive correlation of Sr to Ca (0.880–0.982) in ANG, OD, and KR sediment samples suggests calcite mineral phase controls and potential of chemical weathering. For SH Lake, a strong negative correlation of Fe to Mn of −0.612 suggests that differing geological sources may exist in the catchment (Larson and Stone 2011). Vice-a-versa, a strong positive correlation of Fe to Mn of 0.808 and 0.694 in PAC and Keyhole Reservoirs, respectively, indicates similar source or post-depositional behaviors (Singh and Nayak 2009).

The $Fe_2O_3$ and MnO to $Al_2O_3$ comparisons (Fig. 3e) from PAC suggest that excess $Fe_2O_3$ and MnO were present, and could be attributed to enrichment of biotite and ferromagnesium minerals. In addition, there appears to be contribution from high arsenopyrite in Precambrian rocks common within the PAC catchment (Table 1). LAK, DF, and sediment at depths of 18–22 cm from BF inlet of OD Reservoir samples contained relatively low $SiO_2$ and $Al_2O_3$, and high CaO. These sediments also had relatively high Ca and MgO. This is consistent with the calcite and Mg found within the Minnelusa Formation and calcite in Minnekahta Limestone common to these catchment areas. Variation diagrams in Fig. 3 indicate that, as $Al_2O_3$ increased, $TiO_2$ and $K_2O$ increased, whereas $P_2O_5$ and CaO decreased. MnO, $Fe_2O_3$, $SiO_2$, and MgO remained consistent, while the linear trends of $TiO_2$ and $K_2O$ against $Al_2O_3$ appear attributed to the presence of clay minerals. $P_2O_5$ and CaO showed negative trends against $Al_2O_3$, which may be attributed to the presence of minerals like



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apatite and epidote and depletion of detrital clay minerals in LAK and some OD 2–1 samples. The major oxide concentrations of reservoir sediments of Black Hills region were generally higher compared to UCC. This could be due to the loss during sedimentary processes and strong physical weathering of rocks in the catchment area (Borges et al. 2008). For the $SiO_2$ vs $Al_2O_3$ comparisons (Fig. 3a), most samples were depleted in $SiO_2$ compared to UCC indicating the presence of carbonate minerals. $Al_2O_3$ in reservoir sediments indicates two differing trends when compared to UCC. LAK, sample collected near spillway from DR, and select sediments from BF River inlet, and near spillway and Horsehead Creek inlet from ANG were depleted in $Al_2O_3$ compared to UCC, suggesting the loss of Al-rich clay minerals and feldspar (Borges et al. 2008; Cullers 2000).

The major elements determined in the reservoir sediments reflect the type of rocks in the catchment area. $Fe_2O_3/K_2O$ vs $SiO_2/Al_2O_3$ ratio (Herron 1988) diagrams are commonly used to describe the sedimentary rocks, which present index of chemical maturity and measures mineral stability in the sediment. Herron's classification diagram has been successfully applied to the modern unconsolidated sediments (Vital and Stattegger 2000). The diagram scheme from Herron (1988) has been applied to the reservoir sediments from Black Hills region (Fig. 5a). Sediments at depths of 0–10 cm collected from Horsehead Creek arm of ANG Reservoir and 2–4 cm from LAK Reservoir may be classified as litharenite and wacke, respectively. Herron diagram is effective in distinguishing Fe-rich PAC, SH, and DF Reservoirs sediments. The Black Hills reservoir sediments generally lie within the shale range which is consistent with black shale common to the region. Sediments collected from LAK Reservoir have comparatively higher CaO than sediments collected from the other reservoirs (Fig. 5b), which is consistent with the calcite found within the Minnelusa Formation and Minnekahta limestone common to that catchment. All other reservoir sediments were generally consistent with the Pierre Shale and UCC.

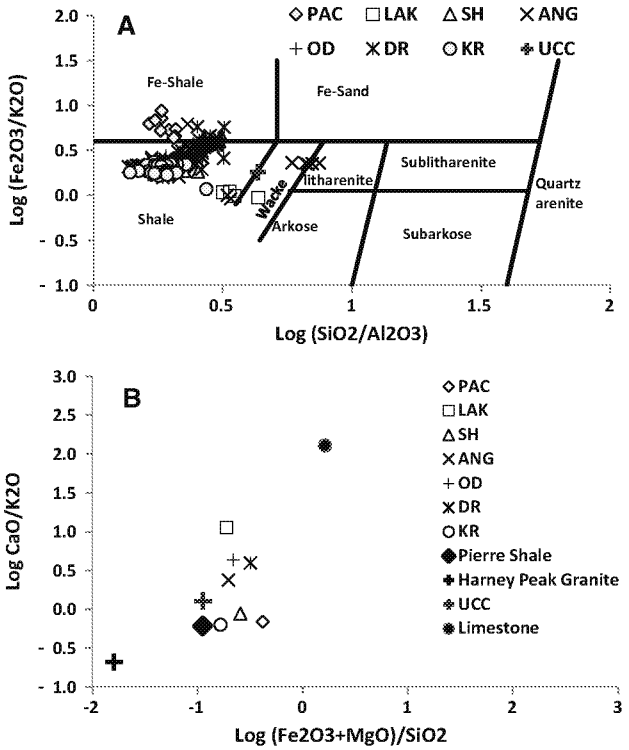


**Fig. 5** **a** Chemical maturity and measures mineral stability (Herron 1988), and **b** geochemical view of origin of sediments in the reservoir sediments (Railsback 1993). Geochemistry of Harney Peak granite from (Duke et al. 1992). Data sources for Upper continental crust (UCC) (Rudnick and Gao 2003), Pierre Shale (Tourtelot 1962), limestone (Clarke and Washington 1924)

## Minor elements

Trace element ratios may be more informative than concentration when comparing reservoir sediments with catchment geology. Clay-rich sediments generally have higher concentration of trace elements resulting from the influence of provenance, weathering, and grain size sorting. For this reason, many reservoir sediment studies have successfully utilized clay and heavy metal profiles for provenance determination (Vital et al. 1999; Vital and Stattegger 2000). This is especially true since high-field strength elements (HFSE) such as Zr, Hf, Ti, Pb, and U, and transition elements such as Cr, Mn, Fe, Ni, Cu, and Zn are relatively immobile and exhibit low solubility. Their low solubility attributes suggest that they may be transported as suspended particles and, therefore, the geochemistry of the source rock remains present. For example, immobile La and Th are more abundant in felsic rocks, while Sc and Co are more abundant in basic rocks (Nyakairu and Koeberl 2002). Large ion lithosphere elements (LILE) such as Rb and Sr, while typically fluid mobile, are subject to weathering. The average sediment values for our study are presented on UCC-normalized spider diagrams in Fig. 6. With the exception of PAC and LAK Reservoirs, spider diagrams show anomalies within Cu, Sr, Zr, Hf, Ti, Pb, and U for all samples. All samples were more enriched in HFSE and strongly depleted in Ni. Chromium, Mn, Fe, and Sr were depleted in most samples. HFSE shows similar patterns for all samples, except for LAK Reservoir which had relatively slightly low abundance of Ti and U, consistent with the limestone of Minnelusa Formation of that catchment. Zr, Hf, and U were associated with heavy elements which are resistant to the weathering like zircon. All samples demonstrated enrichment of Zr, Hf, and U compared to the UCC. Enrichment of U in particular suggests



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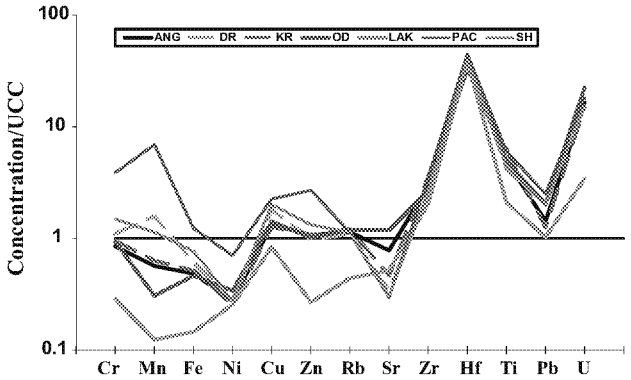


**Fig. 6** Upper continent crust normalized spider diagram of reservoir sediments

weak chemical weathering (Singh and Nayak 2009), while enrichment of Hf and Zr could be due to the presence of zircon in the source rock.

The negative correlation between Sr and Rb/Sr suggests chemical weathering in the catchment area of the ANG Reservoir (Fig. 7a). In similar fashion, the shallow depth sediments collected near spillway from ANG Reservoir had low Rb/Sr ratio and higher Sr concentration compared to UCC, suggesting strong chemical weathering within the catchment area. However, the bottom sediments collected near spillway from ANG Reservoir had high Rb/Sr ratio and low Sr concentration compared to UCC, suggesting strong physical weathering in the catchment area. These differences may be attributed to seasonal variations such as

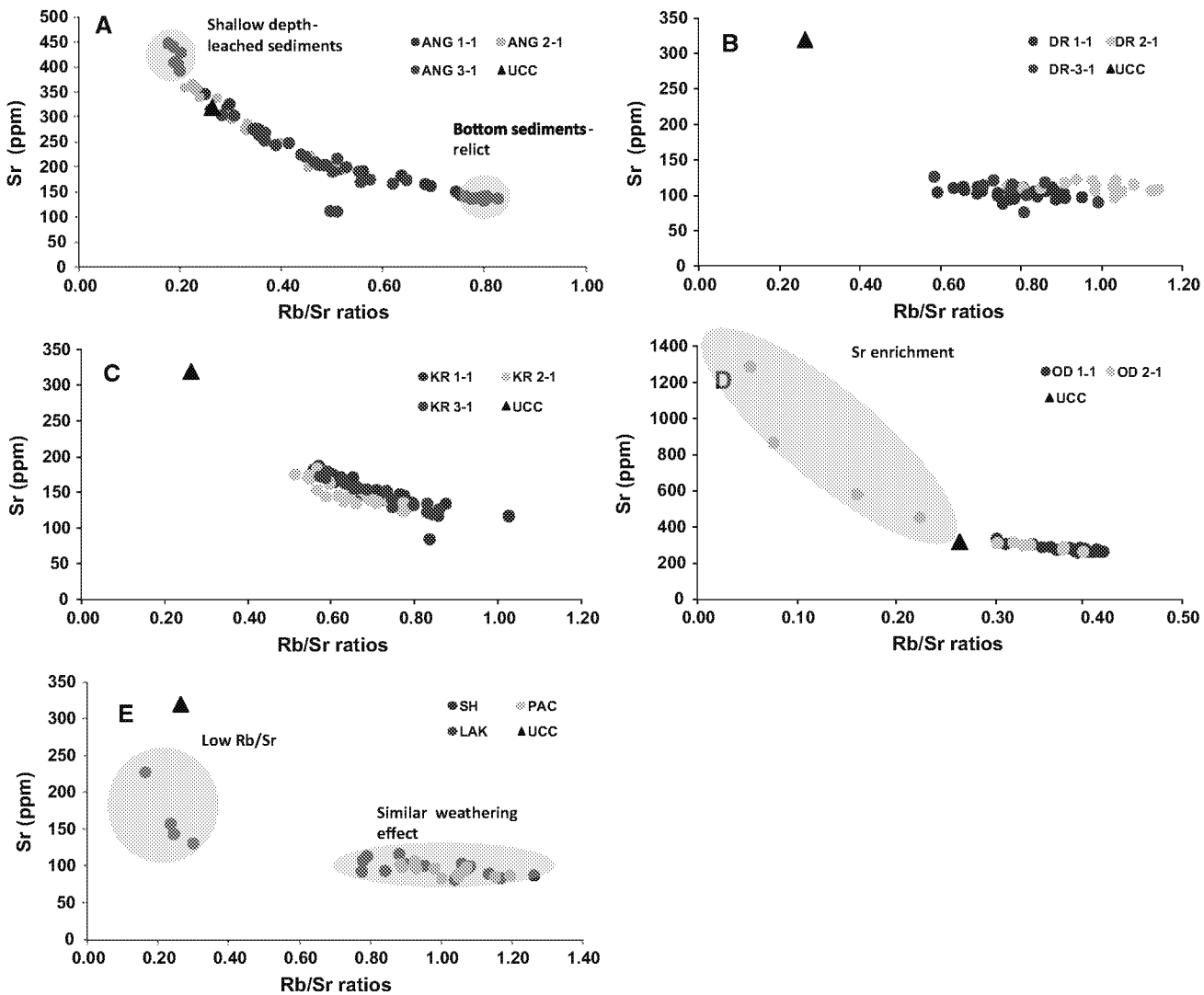


**Fig. 7** Rb/Sr ratio of the reservoir sediments at **a** ANG, **b** DR, **c** KR, **d** OD, **e** SH, PAC and LAK compared to UCC. UCC from (Rudnick and Gao 2003). *Gray* shading indicates weathering effects



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transport of coarse sediments as bed load from rapid snowmelt and/or flooding, and fine sediments reflect suspended transport resulted in summer rainfall.

Sediment sample collected from BF inlet of OD Reservoir had lower Rb/Sr ratio and high Sr of bottom sediment suggesting strong chemical weathering of these sediments (Fig. 7d), while the Owl Creek arm of OD Reservoir shows weak chemical weathering. KR Reservoir sediments have intermediate to low Sr and high Rb/Sr ratio compared to the UCC, and exhibited a negative correlation with Rb/Sr ratio suggesting combination of both physical and chemical weathering in catchment area (Fig. 7c). DF Reservoir sediments had low Sr and high Rb/Sr ratio compared to UCC (Fig. 7b), while there was no change in Sr as Rb/Sr ratio increased suggesting strong physical weathering in catchment area of DF Reservoir. The negative correlation between Rb and Rb/Sr suggests strong physical weathering in the catchment area of PAC Reservoir and SH Lake (Fig. 7e), while LAK Reservoir had low Rb and Rb/Sr ratio suggesting that chemical weathering processes were dominant.

## Conclusion

The reservoir sediment metal results show that Ag, Mo, Pb and U generally exhibit similar trends across all Black Hills region reservoirs. PAC Reservoir and SH Lake had the highest As, Fe, Mn, and Rb/Sr ratios. OD Reservoir had the highest U concentration compared to all other reservoirs, while LAK Reservoir generally had the lowest metal concentrations. With the exception of ANG and LAK Reservoirs, all Black Hills reservoirs appear dominated by physical weathering processes from within their respected watersheds, while all reservoir samples except LAK that exhibited higher HFSE compared to UCC. HFSE are considered relatively immobile and least soluble trace elements suggesting that physical transport via suspended particulates may be the dominant transport mode. These trends are consistent with the detrital component of the sediments transported from the source areas. The anthropogenic activities such as historic gold mining in the north and central Black Hills, and U mining in the southern Black Hills may contribute to the physical transport of contaminant loading to the reservoirs; however, the relative magnitude of contaminants determined within the sediments is minor. Aqueous U was consistently below the drinking water mean contaminant levels (MCL) of 30 μg/L (EPA 2011), while As (8.89 μg/L) was only detected within SH Lake. Results suggest that the reservoir sediments and waters sampled from the Black Hills region appear largely unaffected by the abandoned mines located within the reservoir catchments.

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Hi, Valois --

I'm going to send you some files with articles that are cited in my long comments, which will be sent tomorrow. If there are any others you want to see, let me know. Some things I only have on paper.

Thanks --

Lilias

Environ Earth Sci (2016) 75:823
DOI 10.1007/s12665-016-5522-8

ORIGINAL ARTICLE

# Stream sediment geochemistry of the upper Cheyenne River watershed within the abandoned uranium mining region of the southern Black Hills, South Dakota, USA

**Rohit K. Sharma[1] · Keith D. Putirka[2] · James J. Stone[1]**

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**Abstract** Abandoned uranium (U) mine workings and tailings deposits are found throughout the southern Black Hills of South Dakota. The close proximity of the mine sites to the Cheyenne River (CR) appears to promote elevated metal and radionuclide transport within the watershed, however, the extent of their contribution is unknown. Sixty sediment and soil samples were collected from potentially impacted locations within the watershed to elucidate contaminant occurrence and transport mechanisms. The degree of sediment contaminant impacts were assessed by establishing enrichment factors (EF) and pollution load indices (PLI) criterion as compared to non-mining impacted reference sites. Herron classifications suggest that the sediments collected from the southern Black Hills are immature, consistent with the presence of detrital feldspar. Generally, sediment Sr content were found depleted and intermittently enriched in Rb/Sr ratios compared to upper continental crust concentrations, suggesting physical weathering mechanisms predominate within the CR catchment up gradient of the Angostura Reservoir. Increasing EF and PLI indices coupled with low strontium (Sr) values suggest sediment contamination found along the CR and Angostura Reservoir delta appear attributed to anthropogenic activities and not natural weathering processes.

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**Keywords** Geochemistry · Stream sediments · Uranium · Mineralogy · Chemical weathering · Enrichment factor · Pollution load index

## Introduction

History of uranium (U) mining in the southern Black Hills of South Dakota US dates to the 1950s. Uranium deposits were found and mined from four primary areas: Edgemont area, Carlile area, Hulett Creek area, and Elkhorn Creek area (Fig. 1). Uranium deposits were discovered in the Black Hills in Craven Canyon north of Edgemont, South Dakota (Robinson and Gott 1958), with U production in the Edgemont area the highest among all the areas combined. There are an estimated 142 abandoned U mine and prospect sites in the Edgemont area of South Dakota (SD) (Braddock 1955). These U deposits are present in the rocks of Inyan Kara Formation as a carnotite, tyuyamunite, metatyuyamunite, corvusite, and associated secondary U and vanadium (V) minerals. These minerals are deposited as a mineralizing solution through the permeable Inyan Kara Group (Robinson and Gott 1958). Uranium and V are accumulated as front roll deposits in the Cretaceous rocks and formed in reducing environment close to the surface (DeWitt and Buscher 1988). Most of the openings at the mine site are shaft, open pit, and trench (DeWitt and Buscher 1988). To date, very little reclamation has been done in these mined areas. Abandoned U mines are scattered throughout the Edgemont U district with mine tailings still found adjacent to mined areas. These tailings are a continued source of radiological elements, while the close proximity of these tailings to the Cheyenne River may promote the contaminant migration into the southern Black Hills watersheds.



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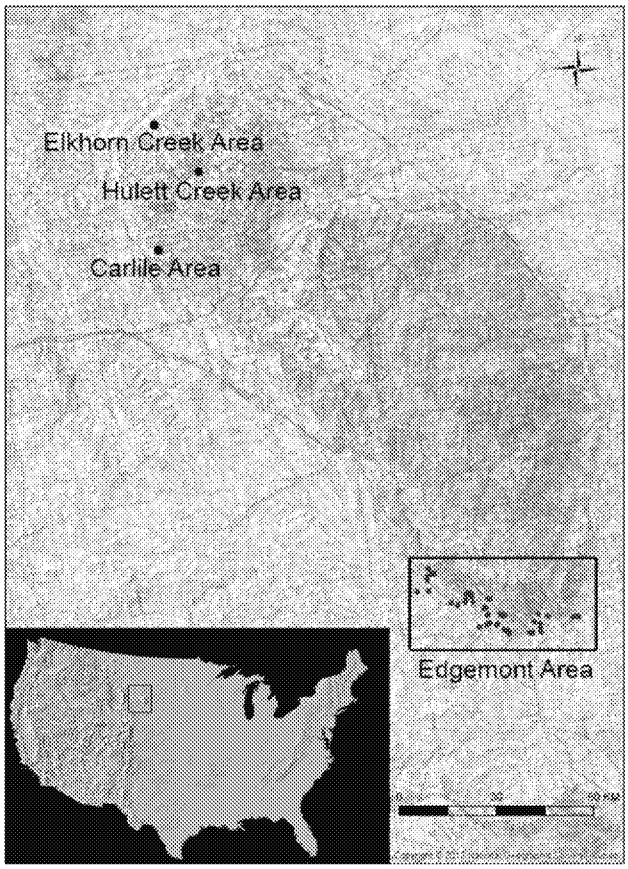


**Fig. 1** Location map showing study area (*boxed*) and principle uranium mining areas within the Black Hills of SD: Edgemont, Carlile, Hulett Creek, and Elkhorn Creek

Several studies have evaluated the environmental hazard of abandoned mines in the U mining district north of Edgemont (Davis and Webb 1999; Hall 1982; Webb et al. 1995, 1998). Rahn and Hall (1982) and Hall (1982) documented 24 abandoned U mines within the Edgemont district. Rahn et al. (1996) focused on water quality impacts relating to abandoned mining in the region, and reported dissolved uranium exceeding 2.6 mg/L at several sites. In a similar study employing a watershed approach, Davis and Webb (1999) evaluated water-quality impacts from abandoned mines within the Bear Butte Creek basin of the northern Black Hills, and the headwaters of the Driftwood Creek basin within the uranium mining district of the southern Black Hills. Their study reported water-quality impacts were limited to the Strawberry Creek and the Bear Butte Creek, while for Driftwood Creek, surface water-quality impacts were limited to a stock pond downgradient from abandoned U mines. Webb et al. (1995) reported 2 mg/L U found within mine pit waters of the southern Black Hills region.

Transport of metals within a river system may occur due to physical or chemical transport processes. In the Black Hills region, solid phase sediments are primarily composed of silicate and secondary clay minerals, such as aluminosilicate clay minerals. Metals in solid phase are present in the river sediments in very low concentrations and typically bound within these aluminosilicate clay minerals, and as a result, may show little fractionation during weathering processes (Windom 1988). Furthermore, when metals in solution come in contact with the stagnant water bodies such as lakes and reservoirs, they are quickly removed from the water column via sedimentation, and often concentrated within lake and reservoir bottom sediments. Pollution from the abandoned mines is of paramount environmental concern in the Black Hills region, as the heavy metals may be transported from the mining areas to the water resources down gradient, leading to environmental degradation.

The objectives of this study were (1) to determine the presence of heavy metals and radionuclides that may have been transported from abandoned U mining areas of the southern Black Hills, specifically within the Cheyenne River watershed above the Angostura Reservoir; (2) to elucidate transport mechanisms of the contaminants; and (3) to assess the degree of potential contamination within the watershed soils and sediments.

## Study area

The study area is situated in the southern Black Hills of South Dakota. The U mining area is commonly referred to as the 'Edgemont U district' located 25 km north of Edgemont in Fall River County (Fig. 1). The sampling area lies south of Dewey-Minnekahta road, north of Edgemont, and west of Angostura Reservoir. The land use of study area is mostly grazing, wilderness, and outdoor recreation. The town of Edgenont is approximately 30 km west of the Angostura Reservior. The Black Hills Wild Horse Sanctuary is approximately 12 km west of the Angustora Reservior.

The Cordilleran foreland basin in the North America is considered as one of the major basement deformation along the orogenic belt in the world. It is located between south of the Colorado Plateau and the Rocky mountain in south Canada. The western part of the basin is bounded by large scale uplifts of deep basement. High angle normal fault and reverse fault are predominant structures within the Black Hills tectonic unit of Cordilleran foreland basin, which resulted from the vertical movement of Precambrian basement blocks (Osterwald and Dean 1961). The Black Hills uplift in western South Dakota consists of central Precambrian basement surrounded by sedimentary rocks of Paleozoic and Mesozoic ages. The Precambrian core in Black Hills is granitic in center and metamorphic around its



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margin (Sales 1968). Uranium deposits in Black Hills are close to the igneous structures (Osterwald and Dean 1961). Numerous studies have identified sources of U in the black shale in Black Hills region. Finnell and Parrish (1958) suggested that U deposits may have been influenced by igneous intrusions and characteristic of host rocks. The host rock of these U deposits are Lakota and Fall River Formations of the lower Cretaceous age Inyan kara Group. These formations consist of intermediate carbon rich sedimentary rocks with thinly bedded mudstone and shale. The U deposits in the Inyan kara Group are considered roll-front deposits, formed by the introduction of U rich oxidizing groundwater into reduced sediment beds along basin margins (IAEA 1985).

Geology of the study area consists of sandstone of the Lakota and Fall River Formations of early Cretaceous age Inyan Kara Group, which forms a major hogback surrounding Black Hills. I Dead Canyon, Dewey Mines, and Chilson Canyon nyan Kara Group also consists of intermediate carbon rich sedimentary rocks. In the southern Black Hills, according to Robinson and Gott (1958), the Inyan Kara Group dips gently away from the core of the uplift where faults are rare. The Lakota Formation is overlain by the Fall River Formation, and unconformably overlies the Morrison Formation. The Lakota Formation consists of lenticular beds of sandstones including conglomerate, sandy claystone, and carbonaceous shale and ranges in thickness between 30.5 and 152 m. The Fall River Formation consists of well bedded, fine-grained sandstone, with some siltstone and claystone with a maximum thickness of about 61 m (Rich 1981). The Fall River Formation and Lakota Formation are separated from each other by a sharp lithological break (Robinson and Gott 1958).

## Methods

### Sample collection

Three groups of samples were considered for this study: mine tailings, river drainages, and Angostura Reservoir. Mine tailings samples were collected from several abandoned U mines located within the southern Black Hills region. River sediment samples were collected from the major drainages containing abandoned U mines and prospects. Angostura Reservoir samples were shallow depth samples collected from the Cheyenne River delta. The delta samples were collected from a depth of about 1 m below the water column where sediment accumulation is considered greater. A total of 60 soil and sediment samples were collected from various locations from the Cheyenne River (CR) (19 samples) and its drainages, namely Red Canyon (RC) (nine samples), Sheep Canyon (SC) (two samples), Chilson Canyon (CC) (four samples), Dead Canyon (DC) (12 samples), various abandoned U mines (Mines) (seven samples), five soil samples, and Angostura Reservoir delta (ANG) (three samples), in the southern Black Hills (Fig. 2). Three bottom lake delta sediments were collected from Angostura Reservoir using a 122 cm length suction coring device (Wildco 2400-B20KB), with cores collected within internal 4.31 cm diameter plexiglass tube. Sediment cores were collected near channel inflow where the sedimentation rate was considered higher. Core samples were sliced into 2–3 cm segments.

Fifty-seven soil and sediment samples were collected within the Cheyenne River catchment above Angostura Reservoir to understand contaminant transport mechanism of the watershed. Samples were collected from within the channel where sediment accumulation was considered high. Soil and sediment samples were collected using a hand auger. All samples were placed in a 120 mL whirl–pak bags and stored at 4 °C prior to analysis.

### Laboratory analysis

All samples were screened in the laboratory and any cobble were removed manually. Organic matter content was determined by loss on ignition (LOI) method following Heiri et al. (2001). Pellets of 1 mm in diameter were prepared with 0.9 gm of sample (soil, sediment, and core slices) that were individually ground using mortar and pestle, and mixed with 0.1 gm of ultra-bind. Pressed powder pellets were analyzed for major and trace elements (Ag, As, Ca, Cr, Cu, Fe, Mn, Mo, Ni, Pb, Rb, $SiO_2$, Sr, Ti, U, V, and Z) using a Bruker Tracer III-SD hand-held X-ray fluorescence spectrometry (XRF) instrument.

### Statistical methods

Inter-element correlations were determined using Pearson moment correlations (SigmaPlot, Systat Software, San Jose, CA). The significance of statistical test was set at $p < 0.04$.

### Evaluation methods

Heavy element accumulation in river sediments can be influenced by factors such as geology, sediment transport, and anthropogenic activity. The degree of contamination found within sediment samples collected was determined using enrichment factor (EF) (Zoller et al. 1974; Sinex and Helz 1981) and pollution load index (PLI) (Tomlinson et al. 1980). EF is expressed by the following equation

$$\mathrm{EF} = \frac{\left(\frac{X}{\mathrm{Al}}\right)\ \mathrm{Sample}}{\left(\frac{X}{\mathrm{Al}}\right)\ \mathrm{Pierre\ Shale}}, \quad (1)$$



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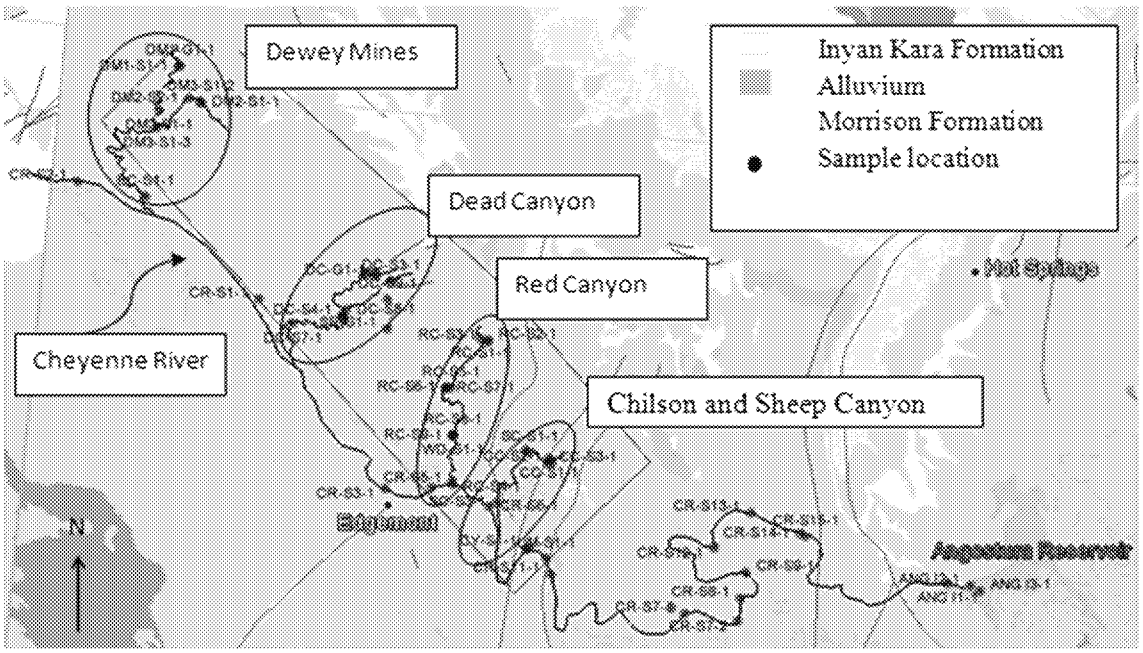


**Fig. 2** Sampling location Dewey Mines (DM), Cheyenne River (CR), Red Canyon (RC), Chilson Canyon (CC), Sheep Canyon (SC), and Angostura Reservior (ANG) and primary geologic formations of southern Black Hills region. *Black dots* represent sampling locations for study

where $X$ is the elemental concentration compared to Al used as a reference element because of it's an immobile element and a major constituent of clay mineral. Pierre Shale value was from Schultz et al. (1980). The EF classification consists of five groups describe as follows (Mmolawa et al. 2011):

<2 = depleted;
2–5 = moderately enrichment;
5–20 = significant enrichment;
20–40 = very high enrichment;
>40 = extremely enrichment.

PLI proposed by Tomlinson et al. (1980) was used as an indicator of pollution caused by anthropogenic activities. PLI is determined by:

$$\mathrm{PLI} = (\mathrm{CF1} \times \mathrm{CF2} \times \mathrm{CF3} \times \cdots \times \mathrm{CFn})1/n, \quad (2)$$

where CF is contamination factor and $n$ is number of heavy metals. Contamination factor is defined as metal concentration in sediments divided by the background values of metal within Pierre Shale (Schultz et al. 1980). The PLI value less than 1 indicates minor pollution while PLI greater than 1 indicates pollution.

## Results and discussion

### Major elements

Major oxide determination is helpful to classify the rock types and construct of a chemical variation diagram. Bulk elemental geochemistry of major elements was plotted against $Al_2O_3$ which shows the most chemical variation among all oxides ranges from 9.3 to 35.9 % in the variation diagram (Fig. 3). Pierre Shale (Schultz et al. 1980) and Harney Peak Biotitic Granite (HPBG) (Duke et al. 1992) values were included within the variation diagram as representative comparisons. Bottom sediments collected from Angostura delta were low in $SiO_2$ and varied from 44.5 % (27–30 mm) to 62 % (30–33 mm), with higher concentrations at deeper depths. This is indicative of sediment fractionation within the water column, with enrichment of phyllosilicates at shallow depths and sand rich at depth (Das et al. 2006) (Fig. 3). Cheyenne River sediments were comparatively low in $Al_2O_3$ than other samples collected from Angostura watershed, while upstream sediments of Cheyenne River were low in CaO, $P_2O_5$, and $K_2O$, and higher in $Fe_2O_3$ and $TiO_2$. $SiO_2$ was depleted and $K_2O$, MgO, $Fe_2O_3$, and $TiO_2$ were enriched in most samples compared to Pierre Shale and HPBG. It has been suggested that the $Al_2O_3$ in sediments increases towards finer grain and $SiO_2$ towards coarse grains (Das and Haake 2003; Vital and Stattegger 2000) (Fig. 3). Elements like $Fe_2O_3$, $TiO_2$, and $K_2O$ exhibit behavior similar to $Al_2O_3$, suggesting a tendency to be enriched in finer grains. The smoothing trends for (−ve), Fe2O3 (+ve), CaO (−ve), and TiO2 (+ve) with $Al_2O_3$ indicate the presence of clay minerals in sediments, while correlations between $Fe_2O_3$ and $TiO_2$ to $Al_2O_3$ appear due to biotite enrichment. In clay sediments CaO was negatively correlated with $Al_2O_3$ due to Ca removal during sediment transport. During chemical and



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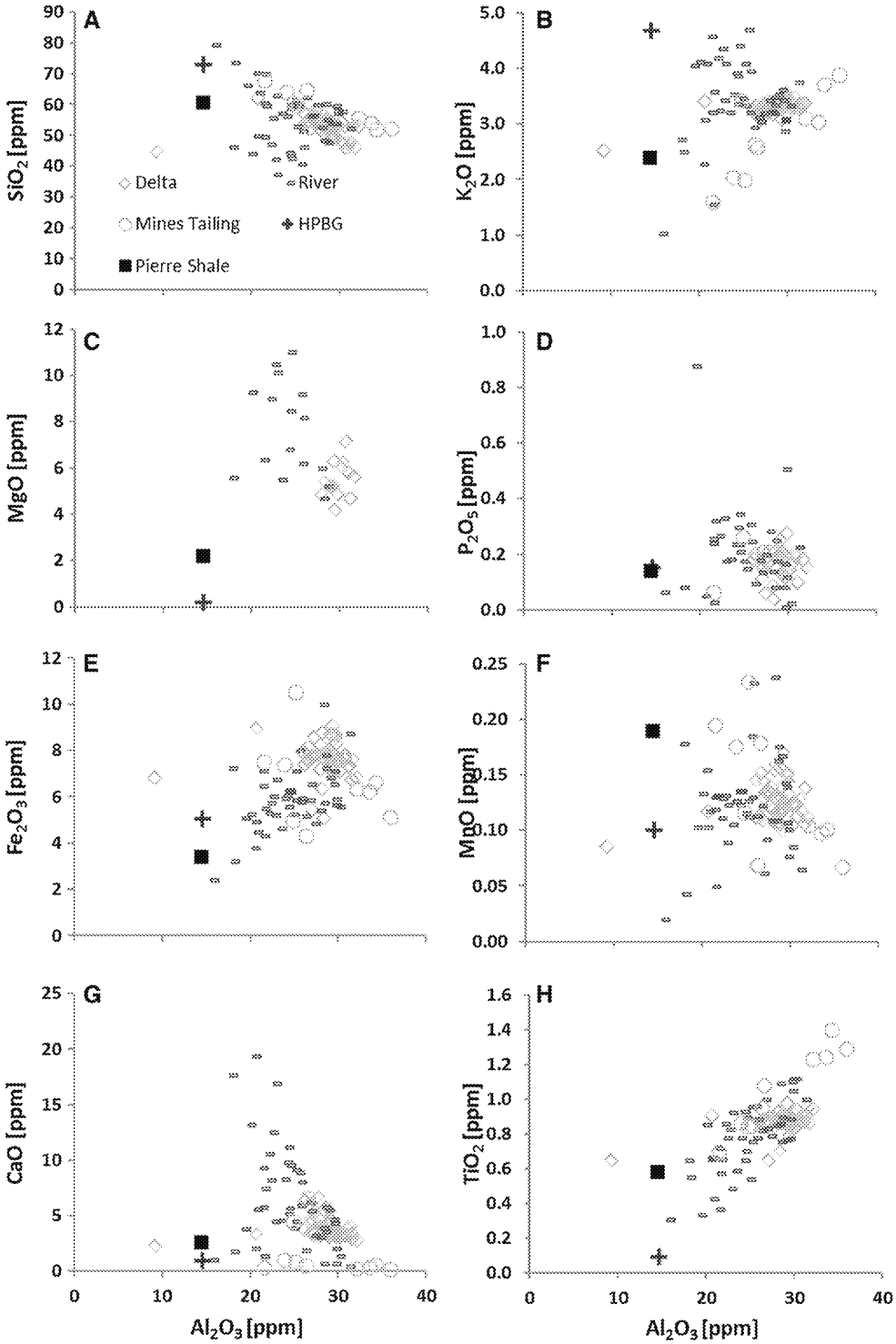


**Fig. 3** **a** $SiO_2$, **b** $K_2O$, **c** MgO, **d** $P_2O_5$, **e** $Fe_2O_3$, **f** MnO, **g** CaO, **h** $TiO_2$ compared to $Al_2O_3$ for the study samples. *Red* "+" reference Harney Peak Biotitic Granite (HPBG)

physical weathering, the breakdown of source rocks where sorting of sediment particles during transportation often leads to enrichment of specific minerals (Sensarma et al. 2008; Whitmore et al. 2004). Samples collected between Dead Canyon and Red Canyon exhibited relatively low $SiO_2$ and $Al_2O_3$, and relatively high Ca and MgO, consistent with the calcite and Mg common to the in Minnelusa Formation and Minnekahta Limestone common to the southern Black Hills.

The ratio of log $Fe_2O_3/K_2O$ and log $SiO_2/Al_2O_3$ can discern source mineralogy as well as differentiate between mature and immature unconsolidated sediments (Herron 1988). As shown in Fig. 4 (A) most soil and sediment samples were consistent with the black shales of the Black



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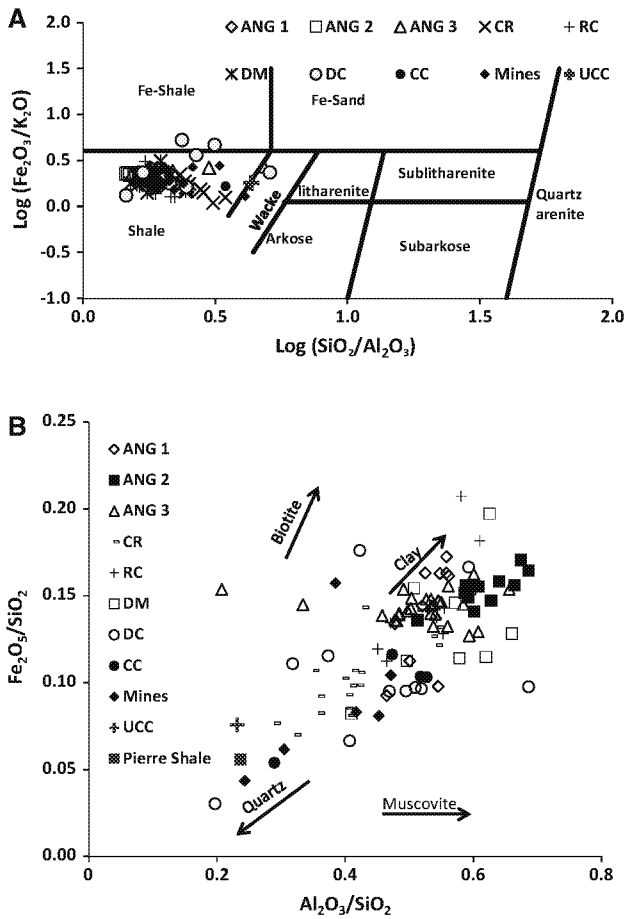


**Fig. 4** Chemical maturity and mineral stability (Herron 1988) of the sediments collected from the southern Black Hills region **a** $Al_2O_3/SiO_2$ versus $Fe_2O_3/SiO_2$ for soil, Cheyenne River, and Angostura Reservoir delta sediments. Linear trend represent mineralogical sorting. **b** Geochemistry of the sediments collected from the southern Black Hills region compared to UCC and Pierre Shale

Hills region with the exception of Dead Canyon (DC) samples classified as "wacke". Herron's classification also effectively distinguished Fe rich sediments from Dead Canyon. Sediments with lithic particles are commonly referred as immature, consistent with southern Black Hills samples containing the presence of detrital feldspar (Wang et al. 1990). Comparisons with $Fe_2O_3/SiO_2$ and $Al_2O_3/SiO_2$ ratios in upper continental crust (UCC) following Galy and France-Lanord (2001) and Pierre Shale from Schultz et al. (1980) (Fig. 4b) indicate Angostura Reservoir delta sediments were enriched in Al and Fe, and depleted in Si compared to Cheyenne River (CR) sediments, UCC and Pierre Shale (PS). This is consistent with the sorting of minerals during transport where base flow sediments become enriched in quartz minerals while suspended sediments become enriched in phyllosilicates. Therefore, it is concluded that the bottom sediments collected from Angostura Reservoir delta generally consist of suspended load from the Cheyenne River and sediment samples collected from Cheyenne River and its drainages were base flow sediments.

## Inter-element relations

Pearson correlation results for data for composited Angostura Reservoir delta sediments, Cheyenne River sediments, and abandoned U mine locations and drainages are presented in Table 1. Manganese and Fe are considered emanating from similar geologic media (Singh and Nayak 2009), and exhibit strong inter-correlations (0.597–0.806) for all samples. Similarly, Sr and Ca exhibited strong inter-correlation (0.665–0.801), and appears due to Sr partitioning behavior into calcite-enriched mineral phases (Chen et al. 1999). Angostura Reservoir delta sediments and abandoned U mine locations showed U correlations with V (0.472–0.513), Rb (0.576–0.632), and Mo (0.867–0.948). Uranium was also correlated with $TiO_2$ in abandoned U mine sites. These correlations may be attributed to the historical mining of carnotite (sandstone type U deposits), corvusite, tyuyamunite, and rauvite deposits within the Edgemont district (Robinson and Gott 1958). For the Cheyenne River sediments, U was correlated with Al (0.639), Mn (0.739.), Fe (0.776), Co (0.798), Zn (0.579), Rb (0.758), and Mo (0.883). A strong correlation of Fe, Ti, Mn, and U with $Al_2O_3$ found within the Cheyenne River sediments suggests the presence of phyllosilicates, while a Fe and U affinity appears due to the presence of brannerite and samarskite minerals. For the U minesites, a strong negative correlation existed between Sr and $SiO_2$ and Zr suggesting quartz mineral deficiency, consistent with the mineral sorting of source materials weathering and transport processes.

## Trace elements

Base flow sediments generally have high concentrations of trace elements resulting from source rock composition, weathering, and grain size sorting, amongst others (Ayers et al. 2000). Metal pollution assessment of river sediment has utilized heavy metals signatures for provenance determination (Vital and Stattegger 2000; Vital et al. 1999). High field strength elements (HFSE) Zr, Hf, Ti, Pb, and U and transition elements Cr, Mn, Fe, Ni, Cu, and Zn are considered relatively immobile and least soluble trace elements in fairly neutral waters, and if transported as suspended particles, may effectively provide a geochemical signature of the geologic origin.

Average values of soil and sediments collected from the southern Black Hills region were plotted on a Pierre Shale-normalized spider diagram (Fig. 5). These results show similarities for all elements with the exception of



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**Table 1** Pearson correlation coefficient of chemical data for (A) Angostura Reservoir delta bottom sediments, (B) Cheyenne River bed sediment, and (C) abandoned U mines spoils and drainages sediments

**A**

| | $Al_2O_3$ | $SiO_2$ | $P_2O5$ | $K_2O$ | CaO | $TiO_2$ | MnO | $Fe_2O_3$ | V | Co | Cu | Zn | As | Rb | Sr | Zr | Mo | U |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| MgO | 0.338 | -0.579 | -0.098 | -0.192 | -0.218 | -0.176 | -0.065 | -0.038 | -0.489 | 0.068 | -0.320 | -0.148 | -0.148 | -0.054 | -0.078 | -0.071 | 0.080 | 0.235 |
| $Al_2O_3$ | | -0.106 | 0.065 | 0.704 | 0.026 | 0.507 | 0.261 | 0.015 | -0.022 | -0.322 | -0.184 | -0.011 | -0.313 | 0.116 | -0.118 | -0.003 | 0.012 | 0.046 |
| $SiO_2$ | | | -0.092 | 0.280 | 0.213 | 0.179 | 0.105 | 0.157 | 0.077 | -0.218 | 0.146 | -0.019 | -0.141 | -0.152 | 0.111 | 0.124 | 0.052 | 0.067 |
| $P_2O5$ | | | | 0.093 | 0.123 | -0.006 | -0.366 | -0.262 | 0.304 | -0.244 | 0.267 | -0.222 | -0.606 | -0.061 | -0.042 | -0.013 | 0.187 | 0.171 |
| $K_2O$ | | | | | 0.027 | 0.723 | 0.337 | 0.503 | 0.133 | -0.250 | 0.116 | 0.072 | -0.220 | 0.362 | 0.061 | -0.060 | 0.231 | 0.286 |
| CaO | | | | | | 0.077 | -0.129 | -0.084 | 0.090 | 0.040 | 0.223 | -0.109 | -0.319 | -0.253 | 0.801 | 0.043 | 0.004 | -0.046 |
| $TiO_2$ | | | | | | | 0.099 | 0.398 | 0.073 | -0.133 | 0.380 | 0.188 | -0.016 | 0.595 | 0.232 | -0.009 | 0.142 | 0.276 |
| MnO | | | | | | | | 0.597 | -0.060 | -0.224 | 0.533 | 0.171 | 0.258 | 0.076 | -0.050 | -0.078 | -0.043 | -0.049 |
| $Fe_2O_3$ | | | | | | | | | 0.191 | 0.042 | 0.065 | 0.381 | 0.210 | 0.593 | 0.297 | -0.372 | 0.264 | 0.328 |
| V | | | | | | | | | | -0.072 | 0.119 | 0.061 | -0.130 | 0.238 | 0.207 | 0.096 | 0.591 | 0.513 |
| Co | | | | | | | | | | | 0.207 | 0.088 | 0.288 | 0.119 | 0.201 | 0.108 | 0.216 | 0.104 |
| Cu | | | | | | | | | | | | -0.029 | -0.229 | 0.366 | 0.405 | -0.195 | 0.098 | 0.156 |
| Zn | | | | | | | | | | | | | 0.227 | 0.444 | 0.067 | -0.280 | -0.030 | 0.025 |
| As | | | | | | | | | | | | | | 0.184 | -0.054 | 0.212 | 0.039 | 0.049 |
| Rb | | | | | | | | | | | | | | | 0.233 | -0.423 | 0.433 | 0.576 |
| Sr | | | | | | | | | | | | | | | | -0.112 | 0.248 | 0.270 |
| Zr | | | | | | | | | | | | | | | | | 0.100 | 0.017 |
| Mo | | | | | | | | | | | | | | | | | | 0.948 |

**B**

| | $Al_2O_3$ | $SiO_2$ | $P_2O5$ | $K_2O$ | CaO | $TiO_2$ | MnO | $Fe_2O_3$ | V | Co | Cu | Zn | As | Rb | Sr | Zr | Mo | U |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| MgO | -0.863 | -0.097 | 0.989 | -0.737 | 0.888 | -0.333 | -0.397 | 0.235 | 0.000 | -1.000 | 0.809 | 0.726 | -- | 0.763 | 0.888 | 0.925 | -1.000 | -1.000 |
| $Al_2O_3$ | | -0.458 | -0.595 | -0.255 | -0.400 | 0.711 | 0.734 | 0.680 | 0.008 | 0.575 | -0.055 | 0.177 | -0.159 | 0.179 | -0.208 | -0.155 | 0.380 | 0.639 |
| $SiO_2$ | | | 0.513 | 0.556 | -0.472 | -0.778 | -0.588 | -0.589 | -0.336 | -0.293 | -0.351 | -0.487 | 0.128 | -0.461 | -0.588 | -0.205 | -0.060 | -0.346 |
| $P_2O5$ | | | | 0.459 | -0.099 | -0.581 | -0.272 | -0.288 | -0.152 | -0.021 | -0.096 | -0.147 | 0.583 | -0.132 | -0.032 | 0.013 | 0.036 | 0.012 |
| $K_2O$ | | | | | -0.334 | -0.660 | -0.092 | -0.067 | 0.034 | 0.124 | -0.159 | -0.271 | 0.016 | -0.057 | -0.325 | -0.215 | 0.031 | -0.040 |
| CaO | | | | | | 0.117 | -0.188 | -0.199 | 0.034 | -0.337 | 0.166 | 0.136 | 0.046 | 0.068 | 0.665 | 0.246 | -0.375 | -0.335 |
| $TiO_2$ | | | | | | | 0.671 | 0.619 | 0.139 | 0.419 | 0.317 | 0.524 | 0.097 | 0.443 | 0.332 | 0.303 | 0.130 | 0.486 |
| MnO | | | | | | | | 0.806 | 0.271 | 0.647 | 0.299 | 0.452 | 0.090 | 0.495 | 0.131 | 0.105 | 0.446 | 0.739 |
| $Fe_2O_3$ | | | | | | | | | 0.034 | 0.778 | 0.346 | 0.474 | -0.011 | 0.599 | 0.220 | 0.109 | 0.538 | 0.776 |
| V | | | | | | | | | | 0.028 | 0.161 | 0.006 | 0.146 | 0.093 | 0.029 | 0.014 | 0.359 | 0.237 |
| Co | | | | | | | | | | | 0.701 | 0.532 | -0.220 | 0.781 | -0.025 | 0.155 | 0.589 | 0.798 |
| Cu | | | | | | | | | | | | 0.907 | 0.852 | 0.910 | 0.796 | 0.884 | -0.076 | 0.582 |
| Zn | | | | | | | | | | | | | 0.823 | 0.934 | 0.784 | 0.828 | -0.083 | 0.579 |
| As | | | | | | | | | | | | | | 0.709 | 0.615 | 0.797 | -0.523 | -0.081 |
| Rb | | | | | | | | | | | | | | | 0.751 | 0.792 | 0.113 | 0.758 |
| Sr | | | | | | | | | | | | | | | | 0.770 | -0.322 | 0.027 |
| Zr | | | | | | | | | | | | | | | | | -0.216 | 0.377 |
| Mo | | | | | | | | | | | | | | | | | | 0.883 |

**C**

| | $Al_2O_3$ | $SiO_2$ | $P_2O5$ | $K_2O$ | CaO | $TiO_2$ | MnO | $Fe_2O_3$ | V | Co | Cu | Zn | As | Rb | Sr | Zr | Mo | U |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| MgO | -0.270 | -0.729 | 0.744 | 0.866 | 0.430 | 0.467 | -0.363 | -0.379 | -0.275 | -0.542 | -0.512 | -0.378 | -0.555 | 0.246 | 0.421 | 0.037 | 0.123 | 0.263 |
| $Al_2O_3$ | | -0.188 | 0.185 | 0.294 | -0.466 | 0.889 | -0.109 | 0.281 | 0.387 | 0.186 | 0.258 | 0.561 | -0.138 | 0.727 | -0.188 | 0.082 | 0.264 | 0.427 |
| $SiO_2$ | | | -0.661 | -0.852 | -0.732 | -0.400 | -0.401 | -0.463 | 0.018 | -0.163 | -0.439 | -0.560 | 0.337 | -0.655 | -0.754 | 0.387 | -0.073 | -0.287 |
| $P_2O5$ | | | | 0.641 | 0.612 | 0.310 | 0.207 | 0.262 | -0.212 | 0.051 | 0.176 | 0.437 | -0.360 | 0.551 | 0.562 | -0.364 | 0.207 | 0.465 |
| $K_2O$ | | | | | 0.545 | 0.468 | 0.121 | 0.178 | -0.042 | -0.170 | 0.248 | 0.584 | -0.371 | 0.773 | 0.621 | -0.273 | 0.037 | 0.312 |
| CaO | | | | | | -0.186 | 0.316 | 0.132 | -0.274 | -0.064 | 0.233 | 0.073 | -0.178 | 0.111 | 0.771 | -0.440 | -0.112 | -0.027 |
| $TiO_2$ | | | | | | | 0.009 | 0.318 | 0.402 | 0.216 | 0.261 | 0.503 | -0.298 | 0.756 | -0.027 | 0.121 | 0.337 | 0.549 |
| MnO | | | | | | | | 0.682 | 0.003 | 0.604 | 0.396 | 0.231 | -0.358 | -0.030 | 0.144 | 0.080 | 0.030 | -0.013 |
| $Fe_2O_3$ | | | | | | | | | -0.059 | 0.818 | 0.586 | 0.481 | -0.333 | 0.323 | 0.251 | -0.124 | 0.190 | 0.225 |
| V | | | | | | | | | | -0.040 | 0.002 | -0.186 | 0.115 | 0.195 | -0.458 | 0.162 | 0.466 | 0.472 |
| Co | | | | | | | | | | | 0.486 | 0.216 | -0.189 | 0.031 | 0.027 | 0.129 | 0.280 | 0.179 |
| Cu | | | | | | | | | | | | 0.534 | -0.227 | 0.385 | 0.307 | -0.256 | 0.003 | 0.090 |
| Zn | | | | | | | | | | | | | -0.214 | 0.706 | 0.365 | -0.334 | -0.105 | 0.106 |
| As | | | | | | | | | | | | | | -0.280 | -0.112 | -0.065 | -0.103 | -0.234 |
| Rb | | | | | | | | | | | | | | | 0.336 | -0.312 | 0.288 | 0.632 |
| Sr | | | | | | | | | | | | | | | | 0.512 | -0.163 | -0.008 |
| Zr | | | | | | | | | | | | | | | | | 0.064 | -0.149 |
| Mo | | | | | | | | | | | | | | | | | | 0.867 |

Values shown in gray highlight indicate significant correlation at the 0.05 level

Angostura delta sediments (ANG 2) which had a relatively higher abundance of Hf. All samples were enriched in HFSE and strongly depleted in Ni and Sr, while Cr and Zn were depleted within most samples. These patterns are consistent with the detrital component of sediments transported from source areas, possibly due to anthropogenic processes such as mining. Transport mechanisms of reservoir sediments can alter the composition of immobile



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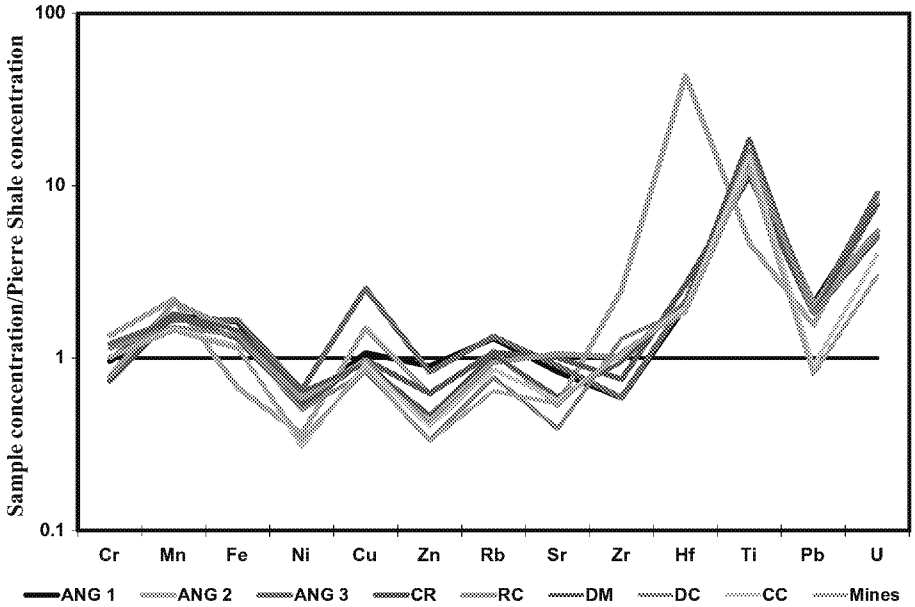


**Fig. 5** Pierre Shale-normalized spider diagram of reservoirs in the southern Black Hills region. Sample locations arranged from closest to the Angostura Reservoir (ANG) to the farthest away (mines)

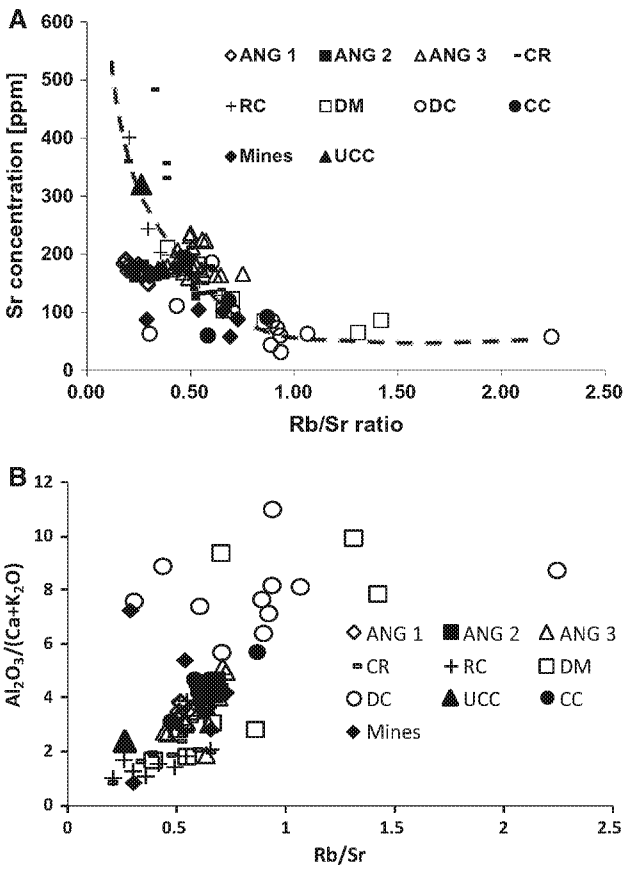


**Fig. 6** **a** Rb/Sr ratio of the sediments of southern Black Hills region. *Dashed line* present Sr enrichment zone and **b** comparison between Rb/Sr ratio and $Al_2O_3/(CaO + K_2O)$ the sediments of southern Black Hills region

trace elements; however, inter-elemental ratios are largely controlled by the source material signatures (Borges et al. 2008).

The Rb/Sr ratios of the sediments have been effectively used to describe weathering intensities from a catchment (Walther 2009; Chen et al. 1999; Jin et al. 2006; Rasbury et al. 2012; Xu et al. 2010), and provide a mechanism to understand metal transport mechanisms. Large ion lithosphere elements (LILE) such as Rb tend to have differing relations and mineral structures compared to Sr, typically considered fluid-mobile and subject to weathering (Walther 2009). For example, Rb substitutes for K in the K-feldspar, resulting in increasing the Rb/Sr ratio of the residue (Walther 2009). Similarly, when plagioclase crystallizes, Ca becomes incorporated into Sr, resulting in decreased Rb/Sr ratio. Rubidium generally coexists with K-rich minerals and Sr incorporated in Ca and Na-bearing minerals (Chen et al. 1999; Xu et al. 2010). Calcium and Na minerals are more reactive to the weathering then K-rich minerals, where weathering readily removes Ca and Na bearing minerals from paleosols leading to residues enriched in Rb but depleted in Sr. Low Sr concentration commonly result in high Rb/Sr ratios, suggesting weak chemical weathering, while high Sr (low Rb/Sr) may be indicative of strong chemical weathering. Shale rock has relatively higher Rb/Sr ratio compared to weathered rock (Rasbury et al. 2012).

The Sr concentration in sediments was generally depleted compared to UCC, suggesting physical weathering was a dominant factor within the study area (Fig. 6a).



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**Table 2** Average concentration (ppm) (A) and standard deviation (B) of heavy metals for the study sites

| | V | | Cu | | Zn | | As | | Zr | | Mo | | U | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | A | B | A | B | A | B | A | B | A | B | A | B | A | B |
| ANG 1 | **112.1** | 92.57 | 35.2 | 5.96 | **81.1** | 19.74 | 10 | 5.93 | 138 | 51.48 | 67.6 | 30.24 | **46.5** | 20.68 |
| ANG 2 | **130.9** | 71.43 | 36.5 | 5.43 | **95.2** | 31.22 | 8.1 | 4.64 | 113.5 | 8.47 | 64.6 | 21.48 | **45.5** | 13.08 |
| ANG 3 | **129.2** | 76.89 | **86.3** | 23.94 | **88.1** | 5.38 | 7.2 | 4.37 | 114 | 8.81 | 70.9 | 22.23 | **52.4** | 14.49 |
| CR | 67.1 | 41.77 | 33.3 | 17.27 | **66.2** | 41.25 | 9.7 | 8.65 | 145.7 | 71.11 | 47.9 | 25.19 | 29.5 | 16.23 |
| RC | 41.7 | 44.23 | 33 | 6.56 | 44.6 | 13.92 | 7.1 | 4.98 | **196.1** | 39.87 | 55.1 | 22.37 | 31.7 | 14.35 |
| DM | **108** | 91.06 | 31.4 | 3.69 | 49.6 | 17.00 | 5.2 | 3.60 | **183** | 24.27 | 71.1 | 29.05 | **44.7** | 29.23 |
| DC | 81.4 | 48.46 | 28.2 | 5.84 | 35.4 | 12.04 | 6.3 | 4.79 | **250.6** | 69.08 | 59.4 | 18.75 | 30.7 | 20.81 |
| CC | 40.8 | 43.58 | 31.5 | 3.11 | 42.5 | 12.34 | 11.3 | 8.39 | **204.8** | 67.01 | 50.8 | 3.77 | 23.3 | 12.76 |
| Mines | **108** | 77.36 | 29.1 | 5.34 | 35.1 | 14.09 | 13.3 | 12.99 | **210.4** | 54.61 | 49.4 | 3.99 | 17.4 | 8.50 |

Values shown in bold highlight present elevated concentration

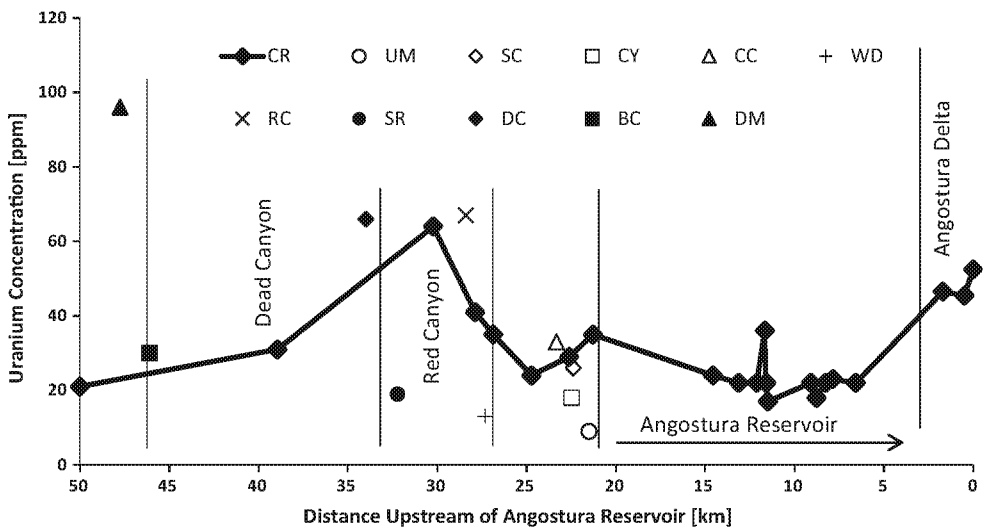


**Fig. 7** Uranium concentration as a function of distance upsteam of Angostura Reservoir along the Cheyenne River

Few Cheyenne River sediments exhibited high Sr content suggesting a strong chemical weathering signature from sedimentary sorting occurred. Shallow depth sediments collected from Angostura Reservoir delta (ANG 1) have low Rb/Sr ratio and higher Sr concentration compared to UCC, further suggesting a strong chemical weathering signature for the catchment. Samples collected from Dead Canyon (DC), Dewey Mines (DM), and Chilson Canyon (CC) exhibited high Rb/Sr ratios and low Sr concentrations compared to UCC, suggest a strong physical weathering signature. The average Rb/Sr ratios for the Angostura Reservoir delta bottom sediments was 0.37, which was higher than the average Rb/Sr ratio of UCC (0.26); however, it was lower than average Rb/Sr ratio for the Cheyenne River catchment sediments (0.49). These findings suggest the Cheyenne River sediments were leached more during transportation processes (Xu et al. 2010), and having undergone a weak chemical weathering process in arid and cold climate (Zhangdong et al. 2001).

The ratio of $Al_2O_3/(CaO + K_2O)$ is an alternative way to describe the weathering intensity in a watershed. This ratio is calculated by normalizing immobile $Al_2O_3$ with mobile elements CaO and $K_2O$. Comparison between Rb/Sr and $Al_2O_3/(CaO + K_2O)$ show a linear trend which shows a correlation between these two ratios (Fig. 6b). Samples collected from the Mines, Dead Canyon, Dewey Mines, and Chilson Canyon have higher $Al_2O_3/(CaO + K_2O)$ and a Rb/Sr ratio depicting weak chemical weathering in the mining areas.

## Assessment of metal contamination

Average composition and standard deviation of heavy metals concentrations for all soil and sediment samples



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**Table 3** Enrichment factors (EF) of heavy metals in the southern Black Hills region

| Sample | Mn | Fe | Cu | Zn | Rb | Sr | Zr | U |
|---|---|---|---|---|---|---|---|---|
| DM | 0.70 | 0.30 | 0.60 | 0.40 | 0.56 | 0.20 | 0.51 | 8.88 |
| DC | 0.62 | 0.29 | 0.58 | 0.30 | 0.44 | 0.14 | 0.74 | 6.49 |
| RC | 0.99 | 0.32 | 0.77 | 0.43 | 0.61 | 0.44 | 0.66 | 7.62 |
| CC | 0.63 | 0.25 | 0.67 | 0.37 | 0.51 | 0.22 | 0.63 | 5.09 |
| Mines | 0.69 | 0.27 | 0.69 | 0.35 | 0.43 | 0.23 | 0.73 | 4.30 |
| CR | 0.82 | 0.35 | 0.76 | 0.63 | 0.69 | 0.41 | 0.48 | 6.98 |
| ANG 3 | 0.67 | 0.33 | 1.72 | 0.73 | 0.74 | 0.32 | 0.33 | 10.83 |
| ANG 2 | 0.65 | 0.31 | 0.67 | 0.73 | 0.67 | 0.27 | 0.30 | 8.65 |
| ANG 1 | 0.77 | 0.32 | 0.68 | 0.65 | 0.65 | 0.29 | 0.39 | 9.31 |

collected are presented in Table 2. Delta sediments of Angostura Reservoir were markedly enriched in V, Zn, and U. Uranium was also elevated from the mine spoil and drainages at near U Mines sampled near Dewey (Fig. 2). Uranium concentrations in sediment samples collected from the Cheyenne River catchment were generally higher (22 ppm average) in the upstream sediments compared to those nearest Angostura Reservoir (14 ppm average) (Fig. 7). Molybdenum was enriched (47.9–71.1 ppm) for all samples compared to the HPBG (3.2 ppm), and correlate to known carbonaceous and pyritic shale concentration (100 ppm) (Kuroda and Sandell 1954). Molybdenum concentrations were variable, likely attributed to adsorption by Fe in deeper sediments where concentration of dissolved sulfide is higher, and thus is difficult to estimate Mo within sedimentary rocks (Chappaz et al. 2008). With the exception of Zn, all sediment samples collected from Cheyenne River were comparable to UCC (67 ppm) range, however, were enriched compared to HPBG (27.5 ppm). Zirconium was elevated from abandoned U mine regions, Dead Canyon, and Chilson Canyon. Placer deposits of U bearing minerals are known to have elevated Th and Zr (Butler 1952), consistent with the presence of Carnotite minerals common to the Inyan Kara formations of the southern Black Hills. Generally, elevated heavy metal concentration existed in both the upper and lower reaches of the Cheyenne River catchment, with higher concentrations within the upper reaches indicative of rapid sedimentation processes. Episodic flooding events appear to transport contaminated sediments from the minesites and surrounding areas effectively, with very little accumulation or contaminant signature existing along the intermediate watercourse.

## Enrichment factors and pollution load indices

The major source of heavy metal concentration in the aquatic system is typically river sediments derived from the weathering of rocks and soils within a drainage basin. Other common sources may include anthropogenic factors such as mining activities, waste water discharge, agriculture activities, and urban/suburban stormwater runoff. Suspended sediments are the predominant source of heavy metal loadings within aquatic system (Chakravarty and Patgiri 2009). The geochemistry of river and delta sediments assists with quantifying and understanding pollution trends in water systems. One valuable method of

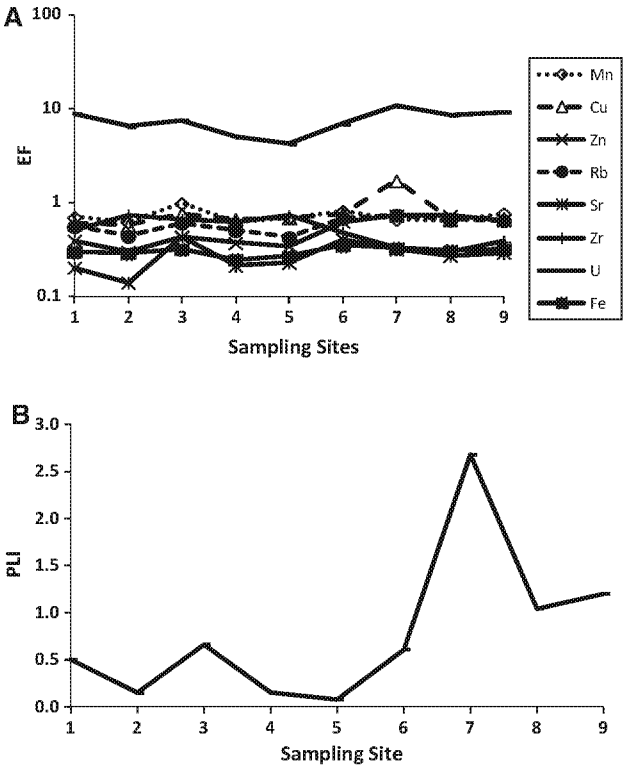


**Fig. 8** **a** Enrichment factor of sediment elements, and **b** pollution load index for the study sites. Sample sites: *1* DM, *2* DC, *3* RC, *4* CC, *5* mines, *6* CR, *7* ANG 3, *8* ANG 2, *9* ANG 1, where sample number 9 being the closest to the Angostura Reservoir and sample 1 the farthest upstream

**Table 4** Contamination factors (CF) and pollution load index (PLI) signifying degree of sediment contamination for the study sites

| Sample | Mn | Fe | Cu | Zn | Rb | Sr | Zr | U | PLI |
|---|---|---|---|---|---|---|---|---|---|
| DM | 1.31 | 0.54 | 1.12 | 0.74 | 1.04 | 0.38 | 0.95 | 16.56 | 0.50 |
| DC | 1.09 | 0.49 | 1.01 | 0.53 | 0.77 | 0.25 | 1.30 | 11.36 | 0.15 |
| RC | 1.52 | 0.48 | 1.18 | 0.67 | 0.94 | 0.68 | 1.02 | 11.73 | 0.66 |
| CC | 1.06 | 0.42 | 1.13 | 0.63 | 0.86 | 0.36 | 1.06 | 8.61 | 0.15 |
| Mines | 1.04 | 0.39 | 1.04 | 0.52 | 0.64 | 0.35 | 1.09 | 6.46 | 0.08 |
| CR | 1.28 | 0.54 | 1.19 | 0.99 | 1.08 | 0.64 | 0.76 | 10.91 | 0.61 |
| ANG 3 | 1.20 | 0.58 | 3.08 | 1.32 | 1.34 | 0.58 | 0.59 | 19.42 | 2.68 |
| ANG 2 | 1.27 | 0.59 | 1.30 | 1.42 | 1.30 | 0.53 | 0.59 | 16.84 | 1.04 |
| ANG 1 | 1.43 | 0.58 | 1.26 | 1.21 | 1.20 | 0.55 | 0.72 | 17.22 | 1.20 |



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impairment assessment is the determination of enrichment factors (EF). The EF were determined for Mn, Fe, Cu, Zn, Rb, Sr, Zr, and U in this study (Table 3; Fig. 8). With the exception of Cu in ANG 3 (1.72) sediments and U in all soil and sediment samples, all samples indicated EF depletion (<1). With the exception of Mines samples, most downstream sediments were enriched in U further signifying pollution migration from the upper catchment reaches.

Pollution load index (PLI) is another accepted sediment environmental impacts assessment methodology for quantifying anthropogenic activities (Tomlinson et al. 1980). All sediment and soil samples exhibited low PLI with the exception of sediments from the Angostura Reservoir (ANG 3) which were relatively high (2.68) (Table 4). There was generally an increase in PLI as one travels downstream of the Cheyenne River (Fig. 8) and appears to coincide sediment (and pollution) transport from the upper catchment mine sites. Contamination factors for U was elevated for all sites, including the Dewey U Mines (16.56), Cheyenne River (10.91), and Angostura delta (16.84–19.42). These findings further support that Angostura Reservoir U loading appears attributed to suspended particle transport from the upper Cheyenne River catchment, including areas impacted by historical U mining activities in the region.

## Conclusion

Geochemical analysis of bottom sediments, sediment, and soil samples from Angostura Reservoir delta, Cheyenne River, and abandoned U mine regions indicate that U concentration found within these locations were elevated compared to regional Pierre Shale concentrations. The highest U concentrations were found in the abandoned U mine areas, and within the Angostura Reservoir delta samples. The highest PLIs determined for the study were those associated with Angostura Reservoir delta sediments (ANG 3), suggesting that the Cheyenne River is an effective transporter of contaminants from the upper catchment reaches. There was little evidence of contaminant accumulation within Cheyenne River reaches, and instead the mobile contaminants appear effectively conveyed the Angostura Reservoir. Heavy metals appear to remain as suspended load within the Cheyenne River, as evident of increasing EF and PLI values within its reach. Anthropogenic activities such as historic U mining appear to be a significant contributor to contaminant loading within this historical mining area catchment.

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# ANALYSIS OF AQUIFER TESTS CONDUCTED AT THE PROPOSED BURDOCK URANIUM MINE SITE BURDOCK, SOUTH DAKOTA

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WATER SYSTEMS DEVELOPMENT BRANCH
NORRIS, TENNESSEE

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Tennessee Valley Authority
Office of Natural Resources
Division of Water Resources
Water Systems Development Branch

# ANALYSIS OF AQUIFER TESTS CONDUCTED AT THE PROPOSED BURDOCK URANIUM MINE SITE BURDOCK, SOUTH DAKOTA

Report No. WR28-1-520-109

Prepared by

J. M. Boggs
and
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Norris, Tennessee
May 1980

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## ABSTRACT

Separate aquifer tests were conducted in two aquifers which may be affected by TVA's proposed uranium mining operation near Burdock, South Dakota. In April 1979, a constant-discharge test was conducted in the Chilson member of the Lakota formation which comprises the principal ore body and an aquifer of regional importance. The hydraulic properties of both the Lakota (Chilson) aquifer and the overlying Fuson shale aquitard were determined. A second test was conducted in July 1979 in the Fall River aquifer which overlies the Fuson. The hydraulic characteristics of the Fall River aquifer and a second estimate of the Fuson aquitard properties were obtained from the test. The test results indicate that the two aquifers are hydrologically connected via (1) general leakage through the Fuson shale, and (2) direct pathways, probably in the form of numerous old (pre-TVA) unplugged exploration boreholes.

The hydraulic properties of the Fall River, Fuson and Lakota units obtained from the aquifer test analyses were incorporated into a computer model of the site geohydrologic system. These parameters were refined in a calibration process until the model could reproduce the drawdown responses observed during the Lakota aquifer test. Results indicate the transmissivity and storativity of the Lakota (Chilson) aquifer are approximately 1400 gallons per day per foot (gpd/ft) and $1.0 \times 10^{-4}$, respectively. The Fall River aquifer has an estimated transmissivity of 400 gpd/ft and a storativity of about $1.4 \times 10^{-5}$. The hydraulic conductivity of the Fuson aquitard is estimated at approximately $10^{-3}$ foot per day. The specific storativity of the Fuson was not measured but is assumed to be about $10^{-6}$ feet $^{-1}$.




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# INTRODUCTION

This report describes the aquifer testing program conducted at the proposed uranium mine site in Burdock, South Dakota. The purpose of the program was to determine the hydrogeologic conditions in the mining area in order to predict mine dewatering requirements and impacts.

The Fall River formation and the Chilson member of the Lakota formation comprise the principal aquifers in the vicinity of the proposed mine. These aquifers are separated by the Fuson shale member of the Lakota formation which acts as an aquitard. The uranium deposits to be mined lie within the Chilson unit.

Two unsuccessful aquifer tests were conducted at the site prior to those described in this report. The first test was conducted at the Burdock test well in February 1977. Pumping took place from both the Fall River and Lakota aquifers during the 14-day test. The test results were invalidated by questionable well discharge measurements and by mechanical difficulties with a deep-well current meter used to measure the quantity of water pumped from each aquifer. A second test lasting three days was performed in November 1977. Pumping was restricted to the Lakota aquifer during the test in order to determine the potential for leakage through the Fuson shale from the overlying Fall River aquifer. The results of the test were inconclusive because (1) five observation wells used in the test were subsequently found to be improperly constructed and (2) pressure gauges used to monitor pumping response at several wells malfunctioned during the test.

The problems associated with the two earlier tests were corrected for the tests described in this report. The defective observation wells were pressure sealed with cement grout and replaced with properly constructed wells. More reliable instrumentation for monitoring potentiometric heads in observation wells was used in subsequent tests.

# HYDROGEOLOGY

## Regional Setting

The proposed mine site is located in the northwestern corner of Fall River County, South Dakota, less than one mile southeast of the community of Burdock. Geologically, the site is situated on the southwest flank of the Black Hills Uplift (see Appendix, Figure 1). The stratigraphy of the region consists of a sequence of rocks ranging in age from Precambrian to Recent which crop out peripherally to the Black Hills. The Precambrian rocks crop out near the center of the Black Hills, and progressively younger rocks crop out to the southwest. Surficial rocks in the site area range in age from lower Cretaceous to Recent. A generalized stratigraphic column for the site is shown in Table 1.

The major structural features of the region are the southwesterly-trending Dewey and Long Mountain structural zones. Faults, fractures and breccia pipes in these zones are believed to affect the ground-water water regime.

## Aquifers

The principal aquifers in the region are the alluvial deposits associated with the Cheyenne River and its major tributaries, the Fall River formation, the Lakota formation, the Sundance formation, and the Pahasapa (or Madison) formation. Except for the alluvium, these aquifers crop out peripherally to the Black Hills where they receive recharge from precipitation. Ground-water movement is in the direction of dip, radially from the central Black Hills. In most instances, ground water in these aquifers is under artesian conditions away from the

# TABLE I: GENERALIZED STRATIGRAPHIC COLUMN FOR SITE REGION (FROM KEENE, 1973)

| PERIOD | FORMATION NAME | SYMBOL | COLUMN | LITHOLOGIC DESCRIPTION | THKNS. IN FEET | HYDROLOGIC CHARACTERISTICS |
|---|---|---|---|---|---|---|
| Quaternary | Alluvium | Qal | | Gravel, sand, and silt floodplain deposits. Alluvial terraces and windblown material. | 1-30 | Good to excellent aquifer along floodplains; terraces generally non-productive except for scattered springs. |
| Cretaceous | Pierre Fm. | Kp | | Dark gray shale, weathering brown or buff and containing many fossiliferous concretions.<br>Scattered concretions which form "teepee buttes"<br>Black fissile shale, cone-in-cone concretions. | 1000+ | Relatively no value as an aquifer; locally large diameter wells in stream valleys may yield small amounts of highly mineralized water during wet seasons. |
| | Niobrara Fm. | Kn | | Gray calcareous shale, weathering yellow and impure chalk with Ostrea Congesta. | 100-225 | No known wells. |
| | Turner sand<br>Carlile Fm.<br>Wall Creek sand | Kcr | | Light gray shale with large concretions.<br>Gray shale with thin sandstone layers.<br>Bed of impure limestone.<br>Thin sandstone. | 520-540 | Relatively impermeable; possible small yields from Turner and Wall Creek sands. |
| | Greenhorn Lms. | Kg | | Thin bedded hard limestone, weathering creamy white, contains Inoceramus Labiatus. | 50 | Too thin and dense to be an aquifer. |
| | Belle Fourche Fm.<br>Mowry Shale<br>Graneros Group<br>Newcastle sand<br>Skull Creek Shale | Kgs | | Light gray shale, bentonite, large concretions.<br>Light gray siliceous shale.<br>Thin brown-to-yellow sandstone.<br>Black shale. | 870 | Newcastle sand may yield water, permeability is variable. |
| | Fall River Fm. | Kfr | | Interbedded red-brown massive sandstone and carbonaceous shales. | 30-165 | Largest producer in the area. Yields up to 60 gpm of highly mineralized water (flow). Water quality generally poor, sometimes yields hydrogen sulfide. |
| | Fuson Shale<br>Minnewasta Lms.<br>Lakota Fm. | Klk | | Gray-to-purple shale, thin shales.<br>Light gray massive limestone.<br>Coarse, hard, cross-bedded sandstone, buff-to-gray, coal beds locally near base. | 0-180<br>0-25<br>130-230 | Relatively good aquifer from the lower Chilson member, up to 30 gpm artesian flow. |
| | Morrison Fm. | Km | | Green-to-maroon shale, thin sandstone. | 0-125 | No known wells, possible aquifer. |
| Jurassic | Unkpapa Fm. | Ju | | Fine grained, massive, vari-colored sandstone. | 0-240 | No known wells, possible aquifer. |
| | Sundance Fm. | Jsd | | Alternating beds of red sandstone and red-to-green marine shales. | 250-450 | Produces small amounts of water from the sands suitable for domestic use. |
| Triassic | Spearfish Fm. | Rs | | Red silty shale, limestone, and anhydrite near the top.<br>Redbeds.<br>Gypsum locally near the base. | 400 | Poor producer, small yields of sulfate water. |
| ? | Minnekahta Lms. | Cmk | | Pale brown, to gray dense, crystalline limestone. | 50 | Locally secondary fracture porosity. |
| Permian | Opeche Fm. | Co | | Red thinly bedded sandstones and shales, purple shale near top. | 100 | No known wells |
| ? Pennsylvanian | Minnelusa Fm. | Cml | | Converse sand, red-to-yellow cross bedded sand.<br>Red marker, thin red shale near middle.<br>Leo sands, series of thin limestones.<br>Dolomite at bottom with basal laterite zone. | 755-1040 | Permeability variable; tremendous flows of warm mineralized water recorded near the periphery of the Black Hills. Excellent potential. |
| Mississippian | Pahasapa Fm. | Cps | | Massive, light colored dolomite and limestone, cavernous in upper 100 feet. | 165-465 | Most promising aquifer in the area. The 2 wells in this aquifer produce large amounts of water suitable for domestic use. |
| Precambrian | Metamorphic and igneous rocks | P€ | | Granite, schists, quartzite, and slates. | --- | No potential. |

outcrop area, and water flows from numerous wells in the area at ground surface.

The Fall River and Lakota formations which form the Inyan Kara Group are the principal aquifers in the region. The alluvium is used locally as a source of domestic and stock water. The Sundance formation is used near its outcrop area in central and northwestern Fall River County. The Pahasapa (Madison) formation is locally accessible only by very deep wells and is the source for five wells in the city of Edgemont.

The Fall River and Lakota aquifers are of primary concern because of the potential impact of mine dewatering on the numerous wells developed in these aquifers in the vicinity of the mine. At the proposed mine site, the Fall River consists of approximately 120 feet of interbedded fine-grained sandstone, siltstone and carbonaceous shale. The Fall River aquifer is overlain by approximately 250 feet of the Mowry and Skull Creek shales unit, which act as confining beds. Twenty-six domestic and stock-watering wells are known to be developed in the Fall River formation within a four-mile radius of the mine site. Many of these are flowing at the surface.

The Fall River formation is underlain by Fuson shale member of the Lakota formation. Thickness of the Fuson is on the order of 60 feet in the site vicinity. The Fuson acts as a leaky aquitard between the Fall River and Lakota aquifers. A physical examination of undisturbed core samples of Fuson indicates that the shale itself has a very low permeability. However, aquifer tests suggest a direct connection through the Fuson which may be the result of some as-yet-unidentified structural features or old unplugged exploration holes.

The Chilson member of the Lakota formation is the second most widely used aquifer in western Fall River County, as the source for some 23 wells within a four-mile radius of the mine site. It is also the uranium-bearing unit to be mined. The Chilson consists of about 120 feet of consolidated to semi-consolidated, fine-grained sandstone and siltstone. It is underlain by the Morrison formation consisting of interbedded shale and fine-grained sandstone. Regionally, the Morrison is not considered an aquifer. Under conditions of groundwater withdrawal from the Chilson, the Morrison is expected to act as an aquitard.

Recharge to the Fall River and Lakota aquifers is believed to occur at their outcrop areas. Bowles (1968) has theorized that recharge to these aquifers may also be derived from the upward movement of ground water along solution collapses and breccia pipes from the deeper Minnelusa and Pahasapa aquifers. The solution collapse and breccia pipe features lie within the Dewey and Long Mountain structural belts.

## AQUIFER TEST DESIGN

The objective of the aquifer testing program was to obtain sufficient quantitative information about local hydrogeologic conditions to enable prediction of mine dewatering requirements and impacts to both the Fall River and Lakota aquifers. Since the two aquifers involved are separated by the Fuson aquitard, two distinct pumping tests were required to obtain the necessary information about each formation: one test in which the Lakota aquifer was pumped, and another in which pumping was limited to the Fall River aquifer. During both tests ground-water levels were monitored in observation wells developed in each of the three formations. Data obtained from these tests were then analyzed to obtain estimates of the hydraulic properties of the aquifers and aquitard.

The Burdock test well was constructed approximately 600 feet north of the proposed mine shaft. Total depth of the well is 559 feet. The well is screened in both the Fall River and Lakota aquifers as shown in Figure 2.

Fifteen observation wells were constructed within an approximate one-mile radius of the pumping well as indicated in Figure 3. Seven of these wells are developed in the Fall River formation, five in the Lakota, and three in the Fuson. In addition, there is a single well developed in the Sundance formation located approximately one mile from the test well. This well was not constructed specifically for the aquifer tests, but was monitored periodically during the Lakota aquifer test. Construction details for these wells are given in Table 2.

TABLE 2. Observation Well Construction Details

| Well No. | Total Depth (feet) | Casing Diameter (inches) | Depth Interval of Open Borehole or Well Screen (feet) | Distance From Pumped Well (feet) |
|---|---|---|---|---|
| B-10LAK | 550 | 4 | 510-550 | 195 |
| B-10FU | 395 | 4 | 377-395 | 255 |
| B-10FR | 350 | 4 | 300-350 | 177 |
| B-1LAK | 570 | 4 | 525-570 | 405 |
| B-1FU | 440 | 4 | 420-440 | 350 |
| B-1FR | 376 | 4 | 334-376 | 373 |
| B-11LAK | 550 | 4 | 504-550 | 618 |
| B-11FR | 360 | 4 | 315-360 | 620 |
| B-9LAK | 545 | 1 | 503-545 | 1540 |
| B-9FR | 293 | 1 | 251-293 | 1540 |
| B-7LAK | 441 | 1 | 399-441 | 2507 |
| B-7FR | 252 | 1 | 210-252 | 2540 |
| Sundance Well | 880 | 7 7/8 | 666-780 | 4763 |

Inasmuch as water levels in each hydrogeologic unit will respond differently during pumping tests, it is important that each observation well reflect the potentiometric head in the intended uncased borehole interval. Several observation wells used in previous tests were suspected of leaking along the grout seal placed in the annular space between well casing and borehole wall. As a result, special precautions were taken to ensure proper construction of the observation wells used in the present tests. A geophysical device known as a cemeton logging probe was used to check the continuity of the cement grout seal in each well after construction. All were found to be properly sealed.

The so-called ratio-method of multiple-aquifer test analysis (Neuman and Witherspoon, 1973) requires that the response of water levels in both the pumped and unpumped aquifers and in the intervening aquitard be monitored during the test. Water level responses in these units must be measured in wells located at approximately the same radial distance from the pumped well. To obtain the necessary data, two groups of observation wells were constructed, each group having one well developed in the Fall River, one in the Fuson, and one in the Lakota (Chilson member). The B-10 group was located approximately 200 feet northeast of the pumping well, while the B-1 group was located approximately 375 feet to the southwest. These well groups were located close to the pumped well to ensure response in the aquitard and in the unpumped aquifer, if such responses were to occur at all. The remaining well groups (B-7, B-9 and B-11 series) contain only Fall River and Lakota wells.

Under natural conditions, the test well and all monitor wells except for those of the B-7 group flow at ground surface if not capped. The two previous tests conducted at the site indicated that observation wells in the pumped aquifer located close to the pumping well would become non-flowing at some point during the test. Thus, pressure sensing devices would be required during the early part of the test and depth measuring techniques during later periods. To ensure adequate data records, each flowing well was equipped with two pressure measuring devices. Malfunctions of several pressure gauges on previous tests pointed out the need for a back-up pressure measuring device.

Three types of pressure sensors were used: mercury manometers, electronic pressure transducers, and mechanical pressure gauges. The B-1 and B-10 observation well groups were equipped with mercury manometers and pressure transducers. As the closest wells to the pumping center, the data from these wells are most important in the multiple aquifer analysis and warrant the best instrumentation. Pressure transducers from all wells were wired to a central terminal and could be monitored frequently during the tests. Each well in groups B-9 and B-11 was equipped with a mercury manometer and a mechanical pressure gauge. Electric probes were used to measure water levels in the non-flowing wells of the B-7 group. These devices were also used to measure water levels in other wells which became non-flowing during pumping tests. Potentiometric head in the pumped well was measured with a mercury manometer, an air line and an electric probe.

## LAKOTA AQUIFER TEST

Several months prior to the Lakota test, a pneumatic packer was set within the Fuson section of the test well to prevent communication between the Fall River and Lakota aquifers through the well. A submersible pump was set below packer to restrict pumping to the Lakota aquifer. Well-head valves on the test well and other artesian observation wells were closed to prevent flow in order to bring the ground-water system into equilibrium before testing.

Hydrographs for the test well and observation wells prior to test are shown in Figures 4 and 5. These hydrographs typify the basic relationship between the potentiometric heads in the Fall River, Fuson and Lakota, i.e., heads are highest in the Lakota, lowest in the Fall River, and at an intermediate position within the Fuson. The irregular readings recorded during January and February 1979 were due to depressurization of the aquifers during the installation of instrumentation and new wells. The pre-test ground-water level configuration in the Lakota aquifer on April 18 is shown in Figure 6.

### Test Procedures and Results

A constant-discharge aquifer test was initiated at 1300 hours on April 18, 1979. Discharge from the well was pumped via pipeline to a stock-watering pond located approximately 0.75 miles from the test well. Pumpage was measured with an in-line flow meter and with an orifice plate and manometer device at the end of the discharge line. The pumping rate varied little during the test ranging from 201 to 205 gpm and averaging 203 gpm. The pumping phase of the test lasted for

73 hours (3.04 days) and was followed by a 30 day period of recovery measurements.

Figure 7 shows a semilogarithmic graph of drawdown (s) versus time (t) for the pumping well (Lakota aquifer). Erratic readings during the first 200 minutes of the test are the result of problems with the airline equipment, and are not due to discharge variations. These difficulties were subsequently corrected, but in general airline measurements are believed to be accurate only to within about ±2 feet.

Semilog graphs for the observation well groups are shown in Figures 8 through 12. Note that a slight initial increase in hydrostatic pressure is indicated in the Fall River and Fuson wells of the B-10 and B-1 well groups. This anomalous trend is more pronounced in the Fuson wells than in the Fall River wells and persists for approximately 90 minutes in B-10FU. The response is believed to be due to an increase in pore pressure resulting from deformation of the matrix of these formations.[1] In any case, the anomalous trend was recorded by both the pressure transducers and mercury manometers, and is not the result of measurement error.

The Jacob straight-line method (see Walton, 1970, pp. 130-133) was applied to the semilog graphs for the Lakota wells to obtain the values of transmissivity (T) and storativity (S) presented in Table 3. In the case of the closer observation wells, two straight-line

[1]During the early stages of pumping, water removed from the Lakota in the immediate vicinity of the well causes compaction of the aquifer. This, in turn, may cause the overlying strata to flex slightly in the area where the underlying support of the Lakota has been reduced. The resulting deformation in the overlying formations causes compressive forces which temporarily increase pore pressures in these materials. Subsequently, the effect of pumping-induced depressurization is transmitted through the overlying materials, gradually lowering the hydrostatic pressure.

TABLE 3. Lakota Aquifer Properties

| Well No. | r (ft) | Jacob Method $T_e$ (gpd/ft) | Jacob Method $S_e$ -- | Jacob Method $T_\ell$ (gpd/ft) | Jacob Method $S_\ell$ -- | Theis Method $T_e$ (gpd/ft) | Theis Method $S_e$ -- | Theis Method $T_\ell$ (gpd/ft) | Theis Method $S_\ell$ -- | Recovery Method $T_e$ (gpd/ft) | Recovery Method $T_\ell$ (gpd/ft) |
|---|---|---|---|---|---|---|---|---|---|---|---|
| PW-LAK | 0.67 | 1980 | -- | 1260 | -- | -- | -- | -- | -- | -- | -- |
| B-10LAK | 195 | 2680 | $7.6\times10^{-5}$ | 1370 | $3.5\times10^{-4}$ | 2530 | $8.4\times10^{-5}$ | 1660 | $1.6\times10^{-4}$ | 2060 | 1300 |
| B-1LAK | 405 | 2140 | $4.4\times10^{-5}$ | 1340 | $1.2\times10^{-4}$ | 2120 | $4.8\times10^{-5}$ | 1550 | $8.4\times10^{-5}$ | 1970 | 1240 |
| B-11LAK | 620 | -- | -- | -- | -- | 2530 | $1.1\times10^{-4}$ | 1530 | $1.5\times10^{-4}$ | -- | 1250 |
| B-9LAK | 1540 | -- | -- | -- | -- | -- | -- | 1370 | $1.3\times10^{-4}$ | -- | 1290 |
| B-7LAK | 2507 | -- | -- | -- | -- | -- | -- | 1760 | $6.5\times10^{-5}$ | -- | 1500 |
| Average: | | 2270 | $6.0\times10^{-5}$ | 1320 | $2.4\times10^{-4}$ | 2390 | $8.1\times10^{-5}$ | 1570 | $1.2\times10^{-4}$ | 2015 | 1270 |

NOTE: Subscript "e" denotes an aquifer parameter determined using early drawdown (or recovery) data. Similarly, subscript "ℓ" denotes a parameter computed from late data.



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solutions were possible: one using the early data and another using the late data. Note that data for wells B-7L, B-9L and B-11L cannot be analyzed by the Jacob method because data do not satisfy the criterion that $r^2S/4Tt \leq 0.01$ (consistent units), where r is the distance between the pumped well and the observation well.

Logarithmic graphs of drawdown data for all observation wells are given in Figures 13 through 17. Theis curve-matching techniques (Walton, 1970, pp. 209-211) were applied to the Lakota curves to obtain T and S estimates for the Lakota aquifer. As with the Jacob analyses, two curve-match solutions were possible: one using the early, steeply-rising portions of the s-t curves, and another using the later data. Both solutions are given in Table 3.

A semilogarithmic graph of distance versus drawdown (Figure 18) was constructed by plotting the final drawdown in each Lakota well versus its radial distance from the pumped well. The Jacob straight-line techniques were applied to these data to obtain T and S values for the Lakota of 1780 gpd/ft and $7.7 \times 10^{-5}$, respectively. However, this type of analysis is applicable only to nonleaky aquifer systems. Since leakage obviously occurred during the test, the results are considered unreliable.

Contour maps of the final drawdown in the Lakota and Fall River aquifers at the end of the test are shown in Figures 19 and 20, respectively. The drawdown cone in both aquifers is slightly elongated in a northwesterly direction. This is probably an indication of anisotropic transmissivity, with the transmissivity in the direction parallel to the axis of elongation being somewhat greater than that in the direction normal to the axis of elongation. The principal direction of trans-

missivity parallels the strike of a regional fracture-joint set, suggesting a possible explanation for the observed drawdown configuration.

Following the pumping phase of the test, water level recovery measurements were made at all observation wells for a period of 30 days. Attempts were also made to monitor recovery in the pumped well using an airline. However, data collected were highly erratic suggesting a malfunction of the airline equipment. Semilogarithmic graphs of residual drawdown versus t/t' (ratio of time since pumping started to time since pumping stopped) for the observation wells are shown in Figures 21 through 25. Lakota graphs were analyzed using Jacob straight-line techniques to obtain the estimates of transmissivity presented in Table 3. Again, two straight-line fits are possible for the closer Lakota wells. Both are given in Table 3.

## Interpretation of Test Results

The drawdown trends recorded in the observation wells indicate some important qualitative information about hydrogeologic conditions at the proposed mine site, in addition to providing a basis for determining hydraulic properties of materials. The relative response of the Fall River, Fuson and Lakota formations as reflected in the B-10 and B-1 groups (Figures 13 and 14), is not typical of the response that would be expected in an ideal leaky multiple aquifer system. Ideally, the s-t curve for the intervening aquitard lies between the curves for the pumped and unpumped aquifers. That is, in a logarithmic plot of s-t data the aquitard (Fuson) curve would lie below the curve for the pumped aquifer (Lakota), and above the curve for the unpumped aquifer (Fall River). However, "ideal" trends are not evident in the

observed data until after 300 minutes of pumping in the case of the B-10 group, and not until after 2000 minutes in the case of the B-1 group. The fact that a greater pumping response is observed in Fall River formation than in the Fuson during the early part of the test indicates that direct (though restricted) avenues through the Fuson must exist. This condition was suspected before the test, and is believed to be the result of numerous old, unplugged uranium exploration boreholes in the test site vicinity. The shift to a more ideal relationship among the s-t curves exhibited during the latter part of test possibly indicates that general leakage through the Fuson itself has caught up with leakage through the open boreholes.

The leakage condition which is apparent in the response of the Fuson and Fall River wells is not evident in the Lakota well data. Under ideal conditions, the rate of drawdown in the Lakota observation wells would be expected to gradually decrease and perhaps even level off completely for some period of time. However, the opposite effect is noted in Lakota s-t plots, particularly the semilog graphs for B-10 LAK and B-1 LAK (Figures 8 and 9). The rate of drawdown increases in the latter stages of pumping which might indicate decreasing transmissivity of the Lakota aquifer in the site vicinity. The decrease in transmissivity may be due to aquifer thinning or possibly a facies change to less permeable materials. In any case, it is suspected that the leakage effects in the Lakota drawdown data are masked by the conflicting effect of a decreasing transmissivity in the site vicinity.

In general, the agreement between the Theis and Jacob analyses of s-t data is good. T values computed using early drawdown data average 2390 gpd/ft using the Theis method, and about 2270

gpd/ft using the Jacob method. Early data storativities are also in good agreement averaging $6.0 \times 10^{-5}$ for the Jacob method and $8.1 \times 10^{-5}$ for the Theis method. The T values computed from the late data ($T_\ell$) are significantly lower than those determined from the early data, whereas late storativities are larger. The Jacob method yields $T_\ell$ values which average 1320 gpd/ft and storatitivies averaging $2.4 \times 10^{-4}$. The Theis method produced an average $T_\ell$ of 1570 gpd/ft and an average $S_\ell$ of $1.2 \times 10^{-4}$. The late Theis T values are somewhat higher than the Jacob T's because the Theis method gives some consideration to the earlier data which the Jacob method does not. Transmissivities estimated by the recovery data average 1270 gpd/ft, and are in close agreement with the late Jacob results, although slightly lower.

Ordinarily, in selecting representative T and S for the pumped aquifer in a leaky multiple aquifer system, more emphasis would be placed on the early data collected in the pumped aquifer at the pumped well and closest observation wells. These data are considered least affected by leakage. However, because of the apparent decrease in transmissivity of the Lakota aquifer during the latter stages of the test, it is believed that Lakota parameters computed from the late data are more representative of aquifer properties under a long-term pumping situation such as mine dewatering. On this basis the average transmissivity of the Lakota is estimated to be 1400 gpd/ft and the average storativity $1.8 \times 10^{-4}$.

## FALL RIVER AQUIFER TEST

Following completion of recovery measurements associated with the Lakota aquifer test, pumping equipment in the Burdock well was rearranged for the Fall River test. A submersible pump was set within the Fall River section of the well and the pneumatic packer reset below the pump in the Fuson section of the well in order to restrict pumping to the Fall River. A preliminary test of the pump and other equipment lasting less than one hour was conducted on May 29. Unexpectedly, the Fall River aquifer was capable of yielding only about 10 gpm on a sustained basis. Since other Fall River wells in the region yield up to 40 gpm, it was assumed that either the well screen was encrusted or the well was not fully developed, or both. An unsuccessful effort was made to develop the well by pumping. A television camera was subsequently lowered into the well to examine the well screen. Little or no encrustation was observed on the screen. Ultrasonics were used in the well to remove any existing encrustation but the yield of the well was not improved. The low productivity of the well is, therefore, attributed to locally poor water-bearing characteristics of the Fall River formation.

### Test Procedures and Results

A constant discharge test commenced at 1100 hours on July 24. Water levels in all geologic units were stable prior to the test, as there was no pumping activity in the site vicinity since the completion of well development on July 3. Discharge was measured with an in-line flowmeter, and checked with a 55-gallon container and stopwatch.

During the test the pumping rate varied from 7.6 to 10.4 gpm, and averaged 8.5 gpm. Ground-water levels were monitored in all observation wells shown in Figure 3. The constant discharge test was terminated at 1200 hours on July 26 after 49 hours of pumping. Subsequently, ground-water level recovery measurements were made for a period of six days.

Semilog graphs of drawdown data recorded at the pumped well and observation well groups B-1, B-10 and B-11 are shown in Figures 26 through 29, respectively. No graphs are presented for B-11LAK or the B-7 and B-9 groups as there was no measureable drawdown in these wells. Except for B-11FR, these graphs exhibit a typical straight-line drawdown trend during the first part of the test, followed by a gradual decrease in slope towards the end of the test. This slope change is the result of leakage from adjacent formations, and/or an increase in aquifer transmissivity at some distance from the pumped well. The Jacob method was applied to the semilog graphs to obtain the transmissivity and storativity values shown in Table 4. The $T_e$ and $S_e$ values were obtained using early drawdown data recorded during approximately the first 500 minutes of the test. $T_l$ and $S_l$ values were computed from data recorded after about 1000 minutes. The only reliable estimates are considered to be those computed for B-1FR and B-10FR. Drawdown data for the pumped well is affected by wellbore storage which is significant in this test because of the relatively low pumping rate. The pumped well drawdown data may also be affected by low well efficiency. The semilog plot for B-11FR cannot be analyzed by the Jacob method because the criterion that $r^2S/4Tt \leq 0.01$ is not satisfied for any of the data.

TABLE 4. Fall River Aquifer Properties

| Well No. | r (ft) | Jacob Method $T_e$ (gpd/ft) | Jacob Method $S_e$ -- | Jacob Method $T_\ell$ (gpd/ft) | Jacob Method $S_\ell$ -- | Theis Method $T_e$ (gpd/ft) | Theis Method $S_e$ -- | Recovery Method $T_e$ (gpd/ft) | Recovery Method $T_\ell$ (gpd/ft) |
|---|---|---|---|---|---|---|---|---|---|
| PW-FR | 0.67 | 16.(?) | -- | -- | -- | -- | -- | 11(?) | -- |
| B-10FR | 177 | 140. | $1.8 \times 10^{-5}$ | 410. | -- | 150. | $1.7 \times 10^{-5}$ | 80. | 340. |
| B-1FR | 373 | 150. | $0.8 \times 10^{-5}$ | 420. | -- | 150. | $1.1 \times 10^{-5}$ | 90. | 350. |
| B-11FR | 618 | -- | -- | -- | -- | -- | -- | -- | -- |
| Average: | | 145 | $1.3 \times 10^{-5}$ | 415. | -- | 150. | $1.4 \times 10^{-5}$ | 85. | 345. |



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Logarithmic graphs of drawdown data for the pumped well and observations well groups B-10, B-1 and B-11 are presented in Figures 30 through 33, respectively. Theis curve-matching techniques were applied to the Fall River curves to obtain the aquifer properties given in Table 4.

Semilog recovery curves for the pumped well and well groups B-10, B-1 and B-11 are shown in Figures 34 through 37, respectively. Again, properties computed from the pumped well recovery data are invalidated by well-bore storage effects. Separate estimates of transmissivity obtained from early and late phases of the recovery data are given in Table 4.

## Interpretation of Fall River Aquifer Test Results

There is good agreement between the early Jacob and Theis results for B-1FR and B-10FR. These analyses indicate an average $T_e$ of about 150 gpd/ft and an average $S_e$ of approximately $1.4 \times 10^{-5}$. Application of the Jacob method to the late drawdown data yields an average $T_l$ of 415 gpd/ft. No meaningful storativity values could be computed from the late data. The $T_e$ values computed by the recovery method are considerably lower than those computed by the other two methods and are believed to be unrealistic. The $T_l$ values derived from the recovery analyses compare reasonably well with the Jacob late drawdown results.

The computed transmissivity and storativity values are representative of the aquifer only within the relatively small area influenced by the pumping test. The yield of the test well is substantially less than that of several other wells in the region. The difference in well

yields suggests that the Fall River aquifer is less permeable in the mine site vicinity than in certain surrounding areas. The aquifer parameters computed from the early drawdown and recovery data are believed to be representative of the aquifer in the immediate vicinity of the test wells. Parameters obtained from analysis of the late data are probably more representative of regional aquifer characteristics.

## FUSON AQUITARD PROPERTIES

The hydraulic properties of the Fuson aquitard were estimated using an analytical technique known as the "ratio method" developed by Neuman and Witherspoon (1973). The method requires (1) a knowledge of the transmissivity and storativity of the pumped aquifer; (2) drawdown data for the pumped and unpumped aquifers and the aquitard measured in wells located at approximately the same radial distance from the pumped well; and (3) the vertical distance between the aquifer-aquitard boundary and the perforated section of each aquitard well (Z). The method yields a value of aquitard hydraulic diffusivity, $\alpha'$, equal to $K'_v/S'_s$, where $K'_v$ is the vertical hydraulic conductivity of the aquitard and $S'_s$ is the specific storativity of the aquitard. To determine $K'_v$ or $S'_s$ from $\alpha'$; either $K'_v$ or $S'_s$ must first be known. In the following analyses a value of $S'_s = 10^{-6}$ $ft^{-1}$ is assumed for the Fuson aquitard. Experience indicates that specific storativities of geologic materials do not vary over as wide a range as do hydraulic conductivities. For this reason, and considering the difficulty and expense of obtaining an accurate measure of $S'_s$ over the site vicinity, it appears justifiable to assume a value of $S'_s$ typical of similar geologic materials.

The first step in the analysis is to compute a value of $s'/s$ at a given radial distance from the pumped well, r, and at a given time, t. Next a value of $t_D$ (dimensionless time for the aquifer equal to $tT/r^2S$) is determined. The values of $s'/s$ and $t_D$ are used to compute a value for $t'_D$ (dimensionless time for the aquitard equal to $K't/S'_sZ^2$) using a family of type curves given in Figure 3 of Neuman and Witherspoon (1973). The vertical hydraulic conductivity of the aquitard $K'_v$ is then obtained from the following equation:

$$K'_v = t'_D Z^2 S'_s/t \qquad (1)$$

Since separate pumping tests were conducted in the Lakota and Fall River aquifers, it is possible to calculate two independent values of $K'_v$ for each well group. Fuson aquitard properties computed by the ratio method along with certain pertinent parameters used in the calculations are presented in Table 5.

Note that since the Fall River, Fuson and Lakota observation wells in each well group do not lie at exactly the same radial distance from the pumped well, an average radial distance $r_{avg}$ is used in the calculations. The $r_{avg}$ values shown in Table 5 were obtained by averaging the radial distance for the pumped aquifer observation well and the radial distance for the aquitard observation well. Also note that the column labeled "Time Interval" represents the time interval during which $K'_v$ values were computed. Generally, three or four values of $K'_v$ were computed at specific times within this interval. These values were then averaged to obtain the $K'_v$ values shown in Table 5.

The vertical hydraulic conductivity of the Fuson ranges from about $10^{-4}$ ft/d at the B-1 well group to about $10^{-3}$ ft/d at the B-10 well group. The agreement between the conductivities computed at each well group site for both tests is good. The reason for the order of magnitude difference between the conductivities at the different well sites is unknown, but may be related to errors caused by differences in the radial distances of observation wells--these differences being somewhat greater for the wells of the B-10 group.

TABLE 5. Fuson Aquitard Properties

| Test | Well Group | $r_{avg.}$ (ft) | Z (ft) | Time Interval (min.) | $K'_v$ (gpd/ft$^2$) | $K'_v$ (ft/d) |
|---|---|---|---|---|---|---|
| Lakota | B-10 | 225 | 28 | 100-393 | $2.0 \times 10^{-2}$ | $2.7 \times 10^{-3}$ |
| | B-1 | 378 | 11 | 100-393 | $1.0 \times 10^{-3}$ | $1.3 \times 10^{-4}$ |
| Fall R. | B-10 | 216 | 25 | 100-300 | $4.8 \times 10^{-3}$ | $6.6 \times 10^{-4}$ |
| | B-1 | 362 | 40 | 1200-2350 | $1.3 \times 10^{-3}$ | $1.8 \times 10^{-4}$ |

The magnitudes of computed conductivities are slightly higher than expected on the basis of the physical characteristics of the Fuson, although they are still within reason. The presence of open boreholes may have caused a more rapid drawdown response in the Fuson monitor wells than would have occurred otherwise. As a result, the calculated $K'_v$ values are probably larger than the actual conductivity of the Fuson shale. The calculated $K'_v$ values are, however, probably smaller than the effective $K'_v$ of the aquitard in the areas where it is breached by open boreholes.

## COMPUTER MODEL SIMULATIONS

The hydraulic properties estimated for the Fall River, Fuson and Lakota formations were incorporated into a computer model of the site geohydrologic system. Simulations of the Lakota aquifer test were performed to see if the model could reproduce the drawdown responses observed during the test. An acceptable match between the measured and computed responses would indicate the validity of the estimated formation properties, and thus enhance the credibility of the model for predicting mine dewatering requirements and impacts.

A finite element numerical model developed by Narasimhan et al. (1978) was used for the aquifer test simulations. The aquifer/well-field system was modeled in three dimensions using axial symmetry. The hydraulic properties of the Fall River, Fuson and Lakota formations obtained from the aquifer test analyses were used as initial input data (see Table 6). Uniform properties were assumed for each hydrogeologic unit. The shale units which lie above the Fall River formation and those which lie below the Lakota were assumed to be impermeable in the model. All simulation comparisons were made for the Lakota aquifer test. The Lakota test stressed a larger portion of the multiple aquifer system than did the Fall River test, and more closely approximates the flow regime expected during mine dewatering.

A comparison of the measured and computed results for the initial simulation run are shown in Figure 38. In general, the agreement between the computed and observed drawdown graphs for the Lakota aquifer are good. However, there are large discrepancies in the Fall River and Fuson responses.

TABLE 6. Parameters Used In Computer Simulations

| | Initial Parameters | | | | | Final Parameters | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Formation | T (gpd/ft) | S (--) | $K_v$ (ft/d) | $K_v/K_h$ (--) | Ss ($ft^{-1}$) | T (gpd/ft) | S -- | $K_v$ (ft/d) | $K_v/K_h$ -- | Ss ($ft^{-1}$) |
| Fall River | 150. | $1.4 \times 10^{-5}$ | $5.6 \times 10^{-2}$ | 1/3 | $1.2 \times 10^{-7}$ | 400 | $1.4 \times 10^{-5}$ | $4.6 \times 10^{-2}$ | 1/10 | $1.2 \times 10^{-7}$ |
| Fuson | 0.13 | $6.0 \times 10^{-5}$ | $1.7 \times 10^{-4}$ | 1/3 | $1.0 \times 10^{-6}$ | 0.45 | $6.0 \times 10^{-5}$ | $1.0 \times 10^{-3}$ | 1/1 | $1.0 \times 10^{-6}$ |
| Lakota (Chilson) | 1400. | $1.8 \times 10^{-4}$ | $5.0 \times 10^{-1}$ | 1/3 | $1.5 \times 10^{-6}$ | 1400. | $1.0 \times 10^{-4}$ | $1.5 \times 10^{-1}$ | 1/10 | $8.3 \times 10^{-7}$ |



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Several attempts were made to improve the match between the computed and observed drawdown responses by trial-and-error adjustment or calibration of model parameters. The most reliable parameters, such as the computed Lakota and Fall aquifer coefficients, were only slightly altered in the calibration process, whereas the least reliable parameters, including the ratio of vertical to horizontal permeability and the Fuson properties, were allowed to vary over a wider (though reasonable) range. The hydraulic properties within each hydrogeologic unit were assumed to be uniform throughout the calibration process.

The set of hydraulic parameters yielding the best agreement between measured and observed drawdown data is given in Table 6. The final parameter set differs only slightly from the original. The largest changes were made in the $K_v/K_h$ terms which were unknown to begin with; and in the Fuson hydraulic conductivity which was increased by a factor of five. Both the early and late Fall River T values computed from the aquifer test analyses (150 and 415 gpd/ft, respectively) were tested during model calibration. The drawdown response of the model was found to be relatively insensitive to the value of T used. A transmissivity of 400 gpd/ft is included in the final parameter set as it is believed to be more characteristic of the aquifer regionally.

The match between the measured and computed drawdown responses, shown in Figure 39, is considered acceptable in light of the fact that uniform aquifer-aquitard properties were used in the model. The apparent discrepancies are believed to be due to the heterogeneity and anisotropy of the actual system. The departures which occur during the early phase of the simulation appear large, but are not significant.

The ability of the model to predict the long-term response of system is more important. Thus, more significance is attached to the agreement between the simulated and observed results for the latter part of the test which, in most cases, is quite good. The final set of aquifer-aquitard properties are considered to represent a valid basis for future predictive modeling.

## SUMMARY AND CONCLUSIONS

The aquifer test results indicate that the Fuson member of the Lakota formation is a leaky aquitard separating the Fall River and Lakota aquifers. The hydraulic communication between the two aquifers observed during the tests-is believed to be the result of (1) general leakage through the primary pore space and naturally occurring joints and fractures of the Fuson shale, and (2) direct connection of aquifers via numerous old unplugged exploratory boreholes. Whereas, the former leakage mechanism is a regional characteristic of the Fuson, leakage caused by borehole short-circuiting is probably limited to the relatively small area of intensive uranium exploration in the Burdock vicinity.

The Lakota (Chilson) aquifer has an estimated transmissivity of approximately 1400 gpd/ft and a storativity of about $1.0 \times 10^{-4}$. These properties are representative of the Lakota in the area affected by the pumping test, and are consistent with what is known or suspected about the aquifer regionally. The transmissivity and storativity of the Fall River aquifer are estimated at approximately 400 gpd/ft and $1.4 \times 10^{-5}$, respectively. Test results indicate that the transmissivity of the Fall River may be considerably less than 400 gpd/ft in the immediate vicinity of the test site. However, the selected transmissivity value is more consistent with regional aquifer characteristics.

The hydraulic conductivity of the Fuson aquitard is estimated at approximately $10^{-3}$ ft/d. The specific storativity of the Fuson was not measured but is assumed to be about $10^{-6}$ $ft^{-1}$. If open boreholes

are present at the test site as suspected, the computed hydraulic conductivity is probably higher than the true conductivity of the shale, yet lower than the effective conductivity of the aquitard where short-circuited by open boreholes. For this reason, the selected aquitard conductivity of $10^{-3}$ ft/d should provide a conservative estimate of mine dewatering impacts. Outside of the relatively small area where the aquitard is breached by boreholes, leakage between the two aquifers will be governed by the true conductivity of the shale which is probably on the order of $10^{-4}$ ft/d or less.

The hydraulic properties of the Fall River, Fuson and Lakota (Chilson) formations computed from aquifer test data were incorporated into a computer model of the site geohydrologic system. These parameters were refined through repeated simulations of the Lakota aquifer test until the model could reproduce the drawdown responses observed during the test. The agreement between the observed and computed responses indicates the validity of the aquifer-aquitard properties, and should enhance the credibility of future predictive models using these parameters.

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1. Gott, G. B., D. E. Walcott, and C. G. Bowles, "Stratigraphy of the Inyan Kara Group and Localization of Uranium Deposits, Southern Black Hills, South Dakota and Wyoming." USGS Prof. Paper 763, 1974.

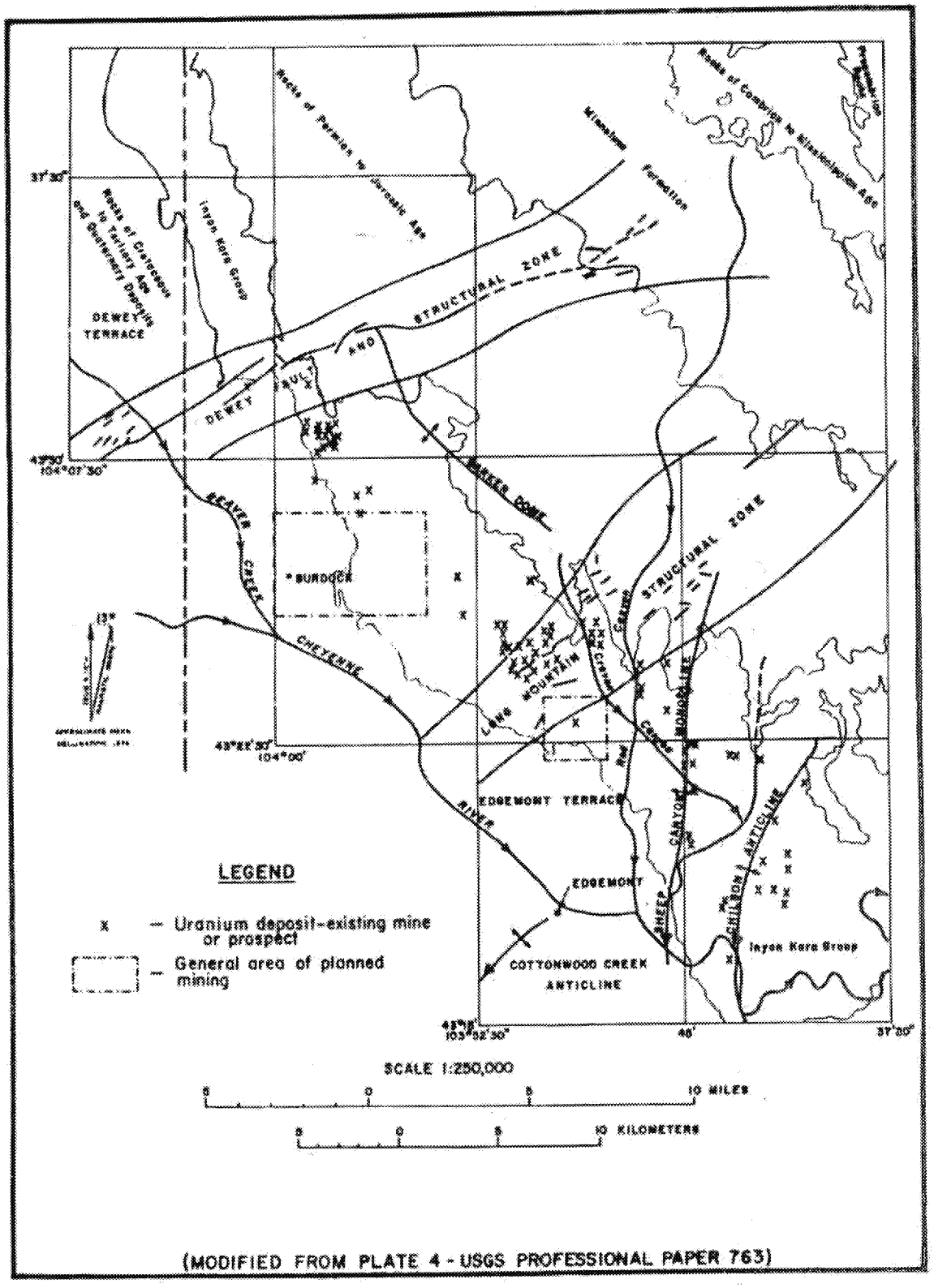
2. Keene, J. R., "Ground-water Resources of the Western Half of Fall River County, South Dakota." Rept. of Inv. No. 109, S. D. Geol. Survey, 1973.

3. Narasimhan, T. N., S. P. Neuman, and P. A. Witherspoon, "Finite Element Method for Subsurface Hydrology Using a Mixed Explicit-Implicit Scheme," Water Resources Research, Vol. 14, No. 5, 1978.

4. Neuman, S. P. and P. A. Witherspoon, "Field Determination of the Hydraulic Properties of Leaky Multiple Aquifer Systems," Water Resources Research, Vol. 8, No. 5, 1973.

5. Walton, W. C., Groundwater Resource Evaluation, McGraw-Hill, New York, 1970.

# APPENDIX




(MODIFIED FROM PLATE 4 - USGS PROFESSIONAL PAPER 763)

Figure 1 : Generalized Geologic Map of Site Region

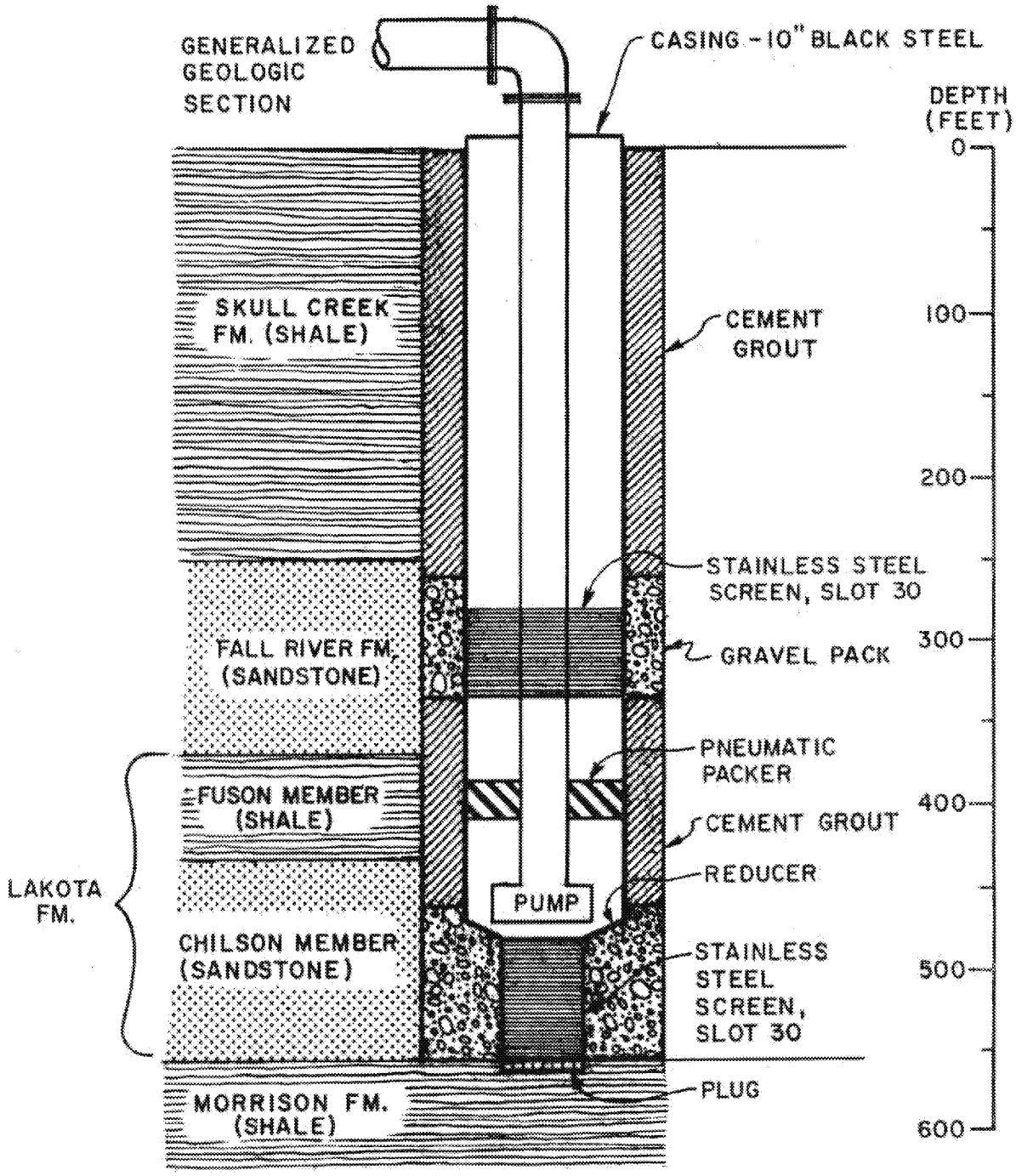



Figure 2 : Burdock Well Profile

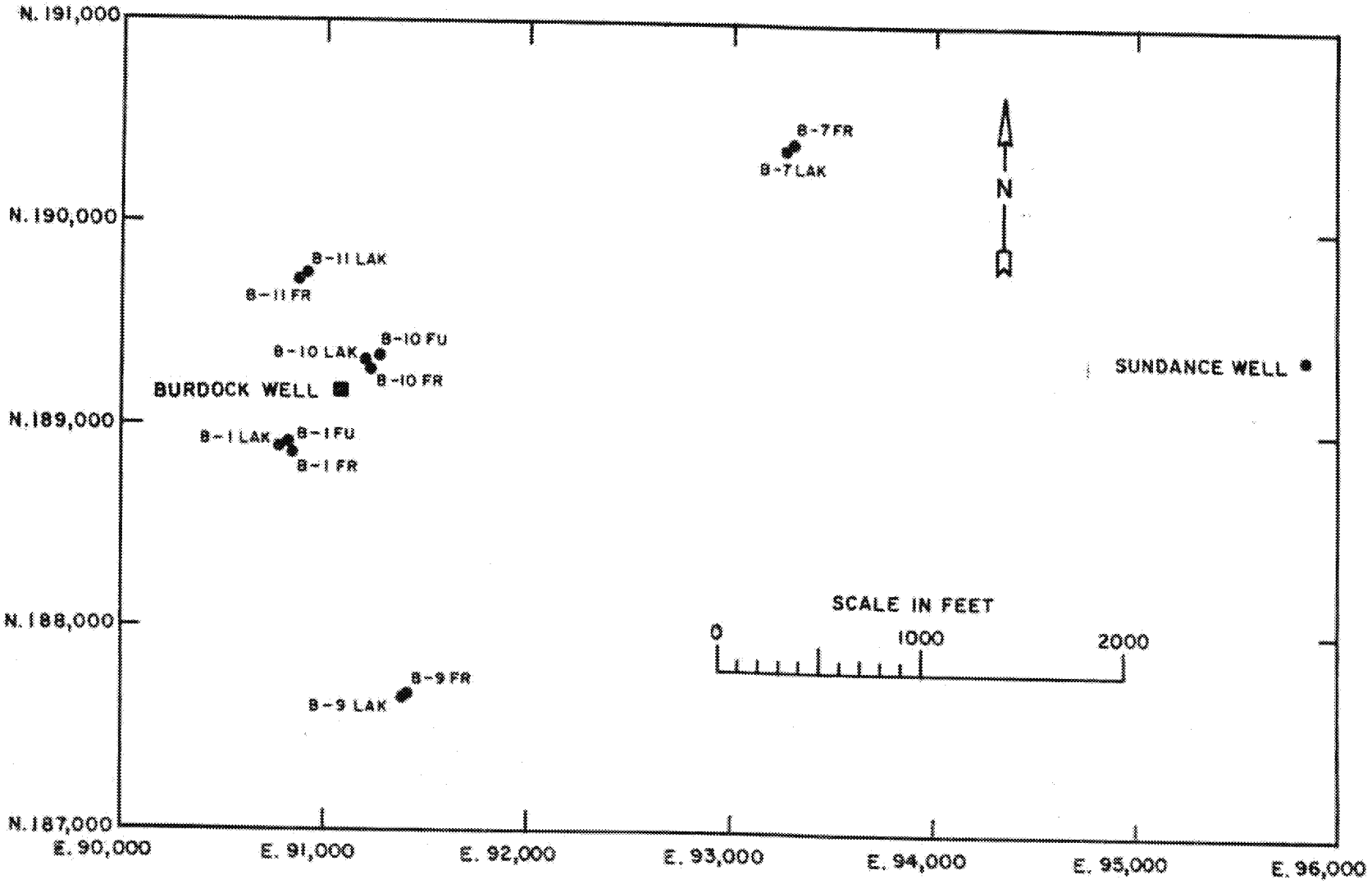



Figure 3: Well Location Map



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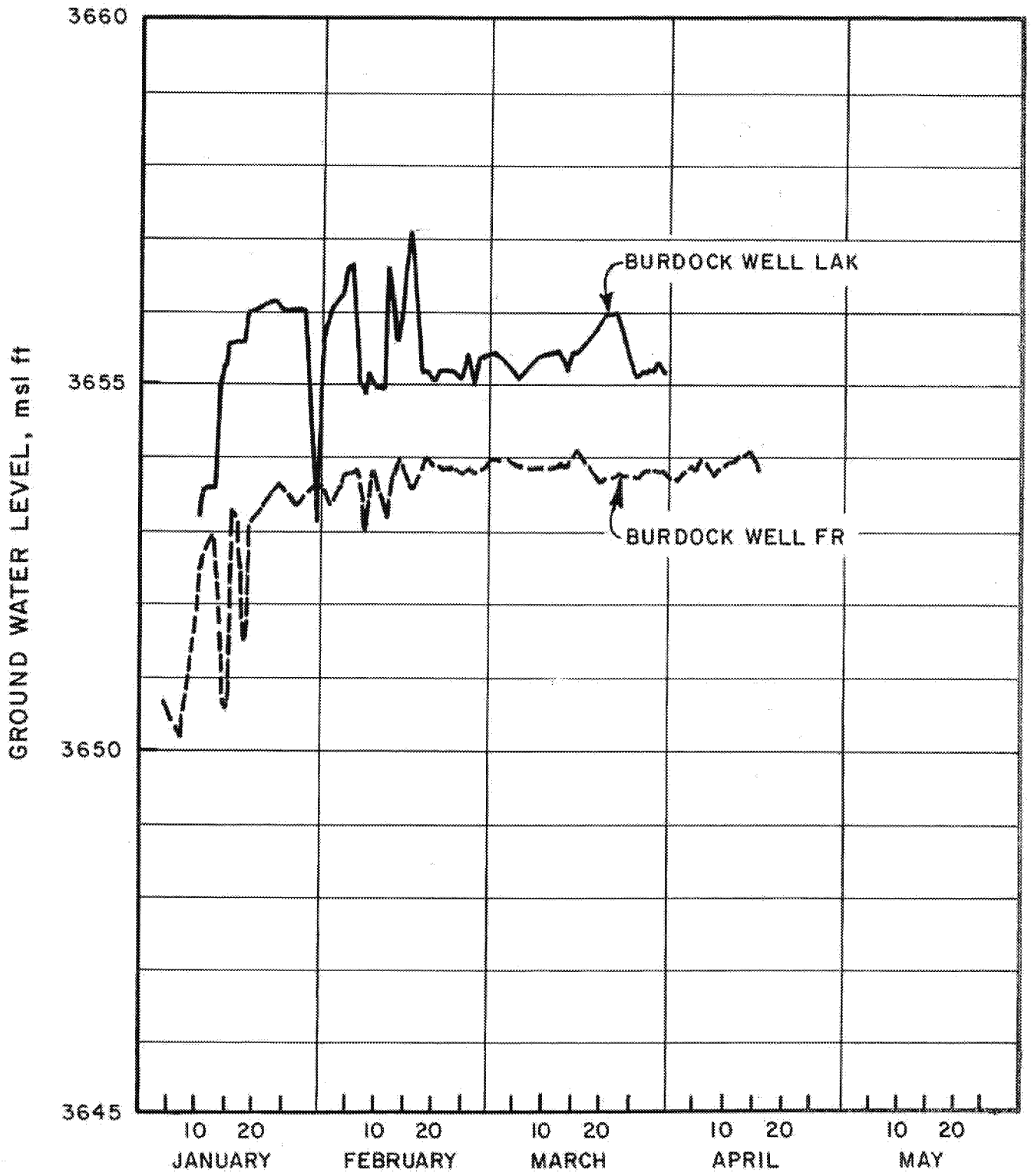


Figure 4 : Hydrographs for Burdock Test Well, January 1 through April 17, 1979

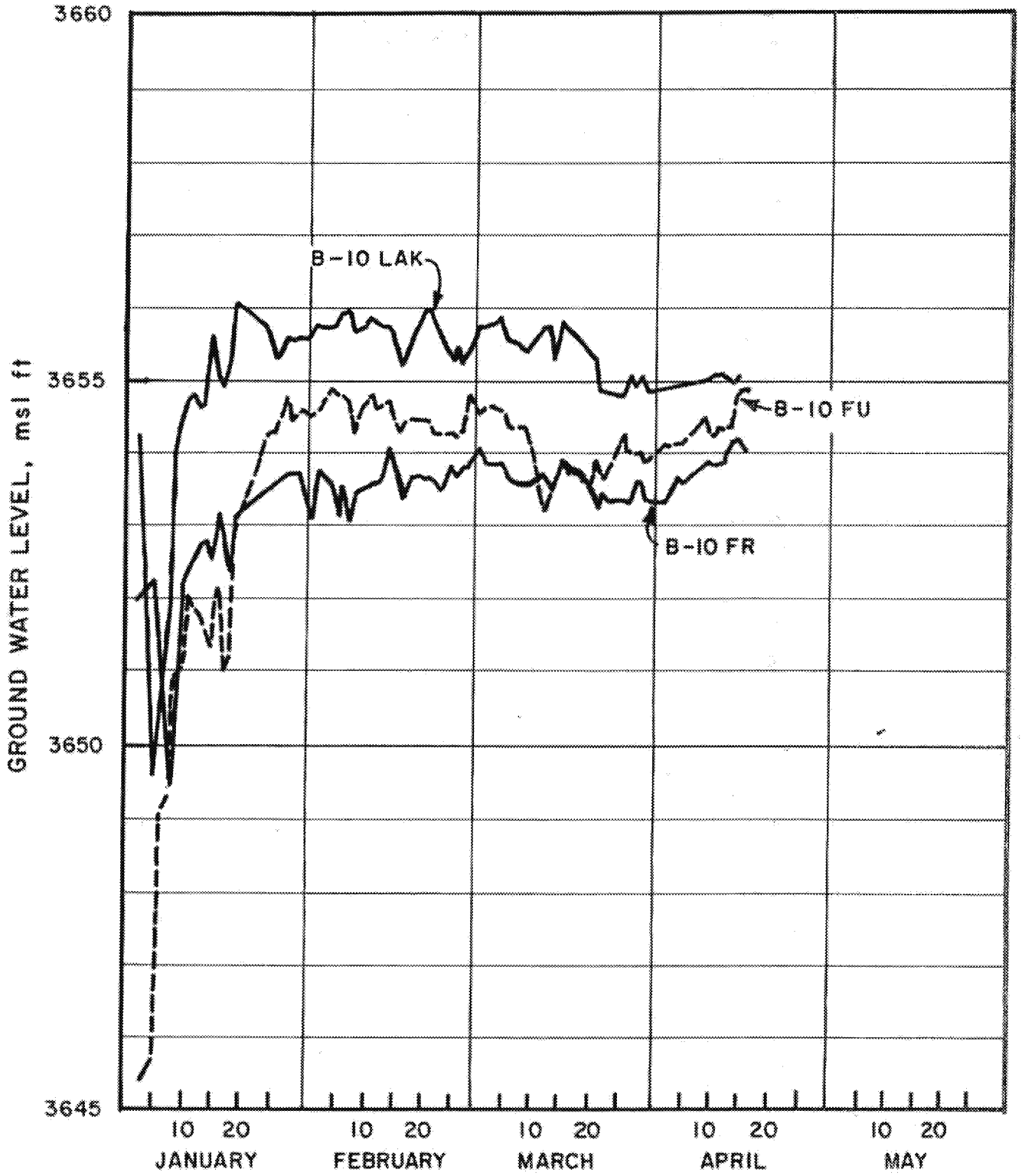


Figure 5 : Hydrographs for B-10 Observation Well Group, January 1 through April 17, 1979

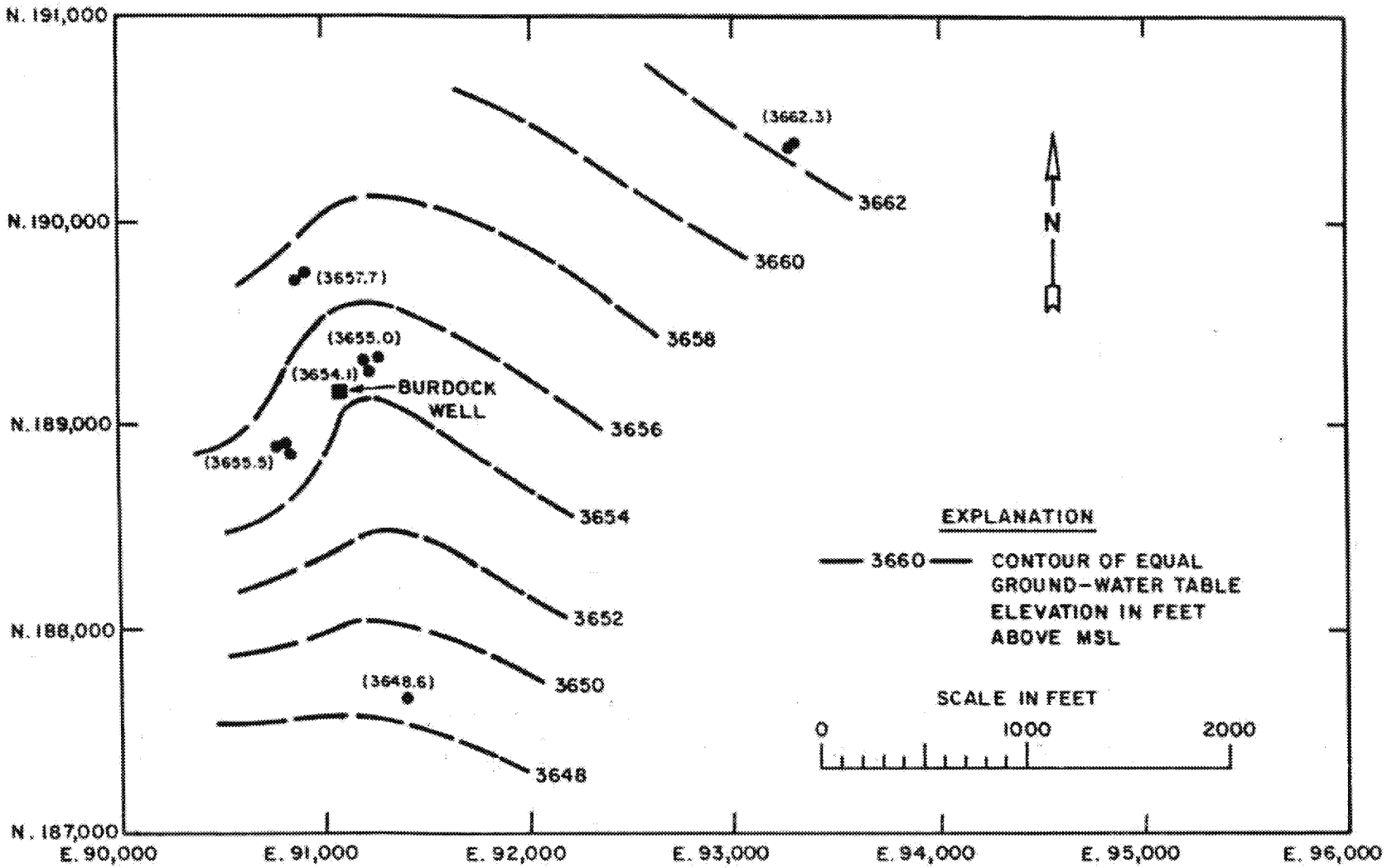


Figure 6 : Pre-Test Ground-Water Level Contour Map for Lakota Aquifer



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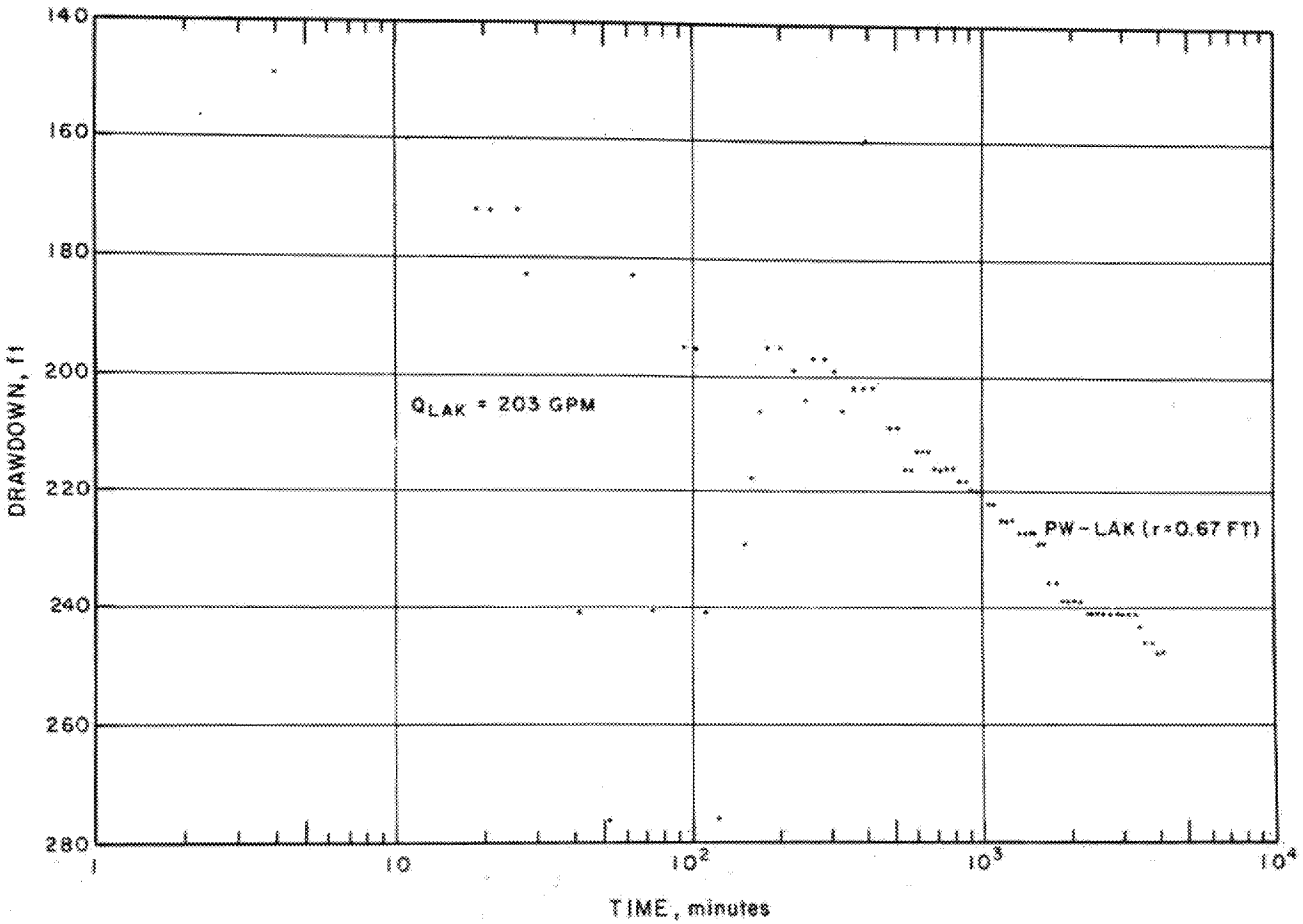


Figure 7: Semilogarithmic Graph of Drawdown for Pumped Well, Lakota Aquifer Test



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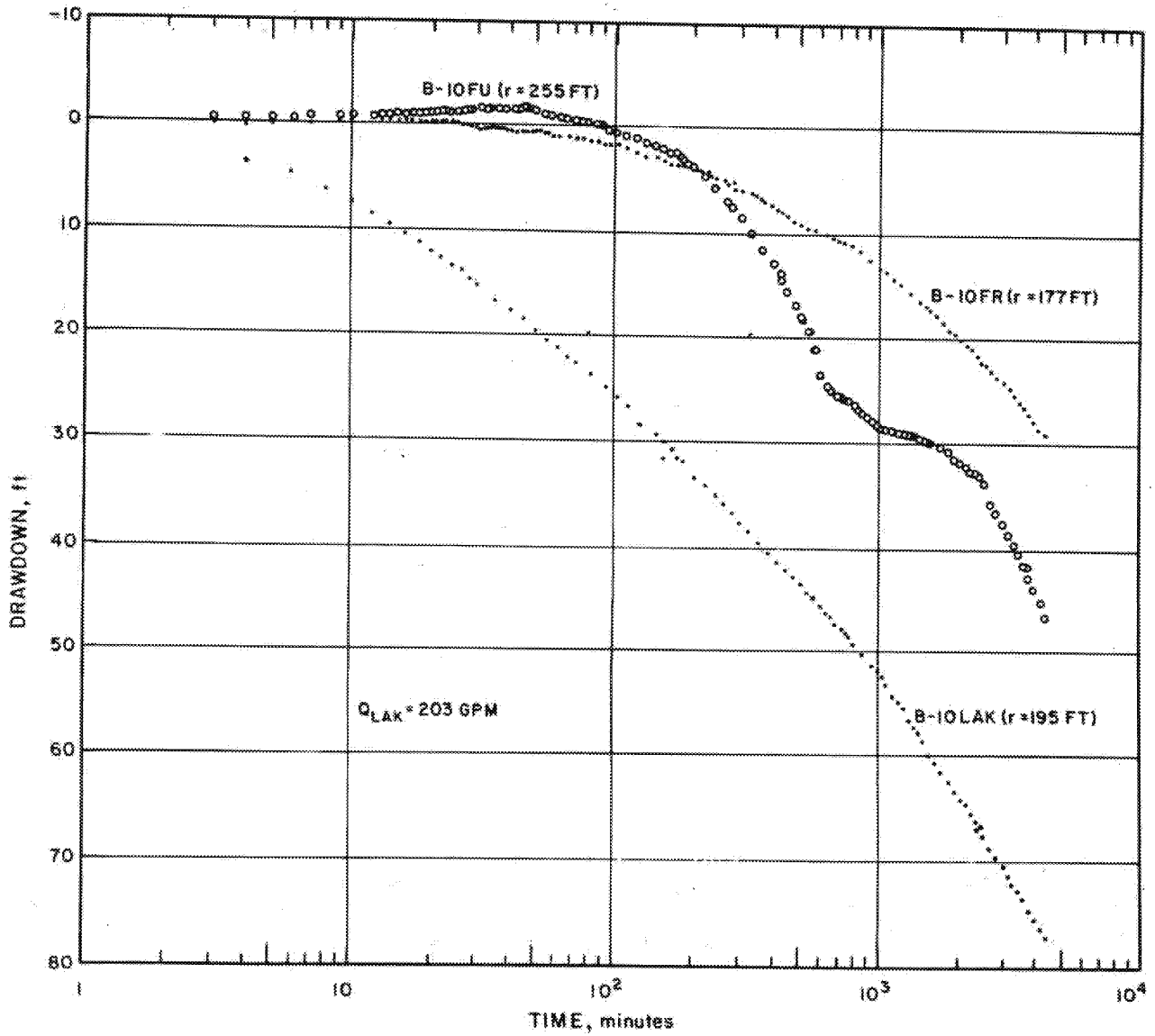


Figure 8 : Semilogarithmic Graphs of Drawdown for B-10 Observation Well Group, Lakota Aquifer Test



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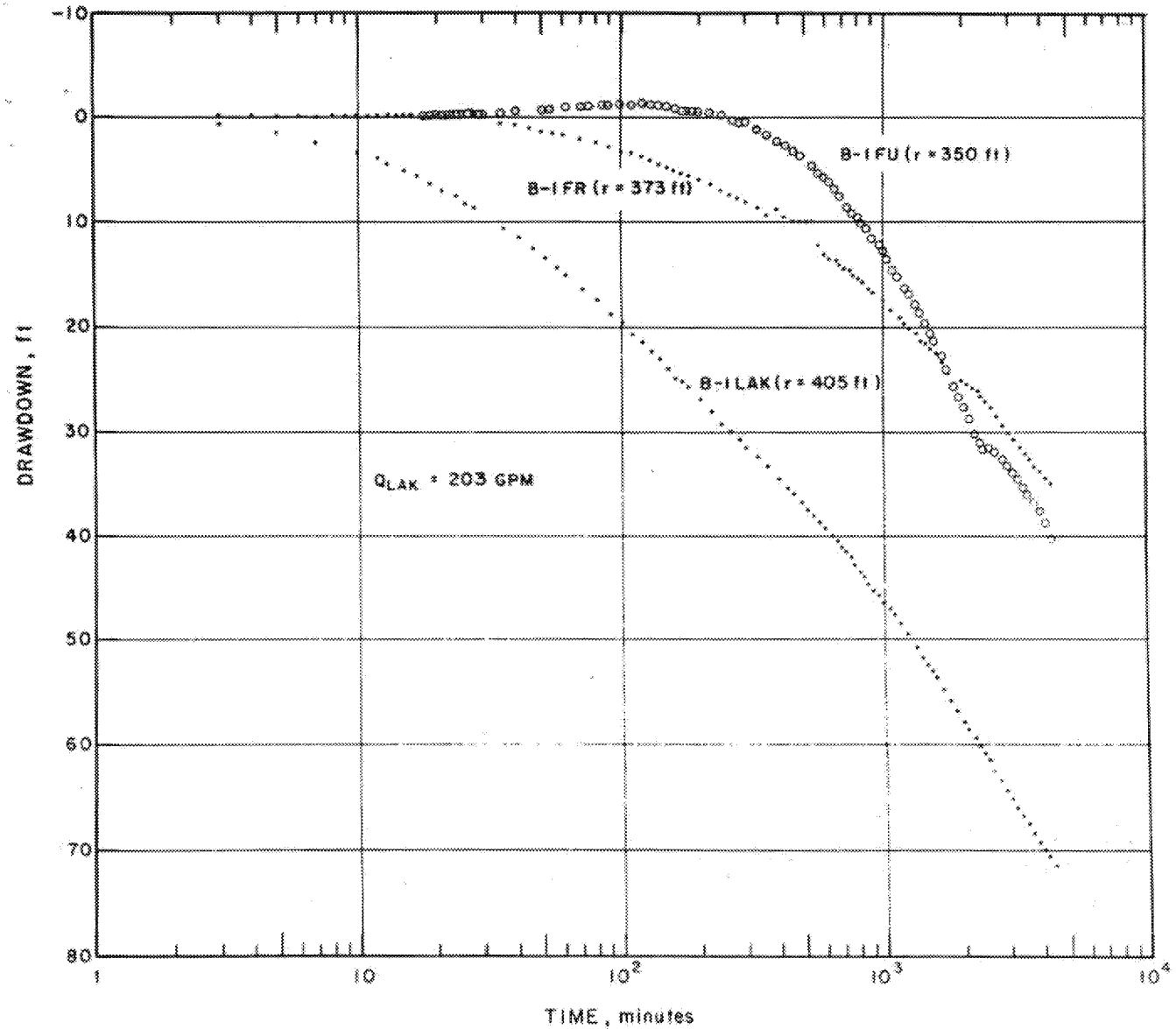


Figure 9: Semilogarithmic Graphs of Drawdown for B-1 Observation Well Group, Lakota Aquifer Test

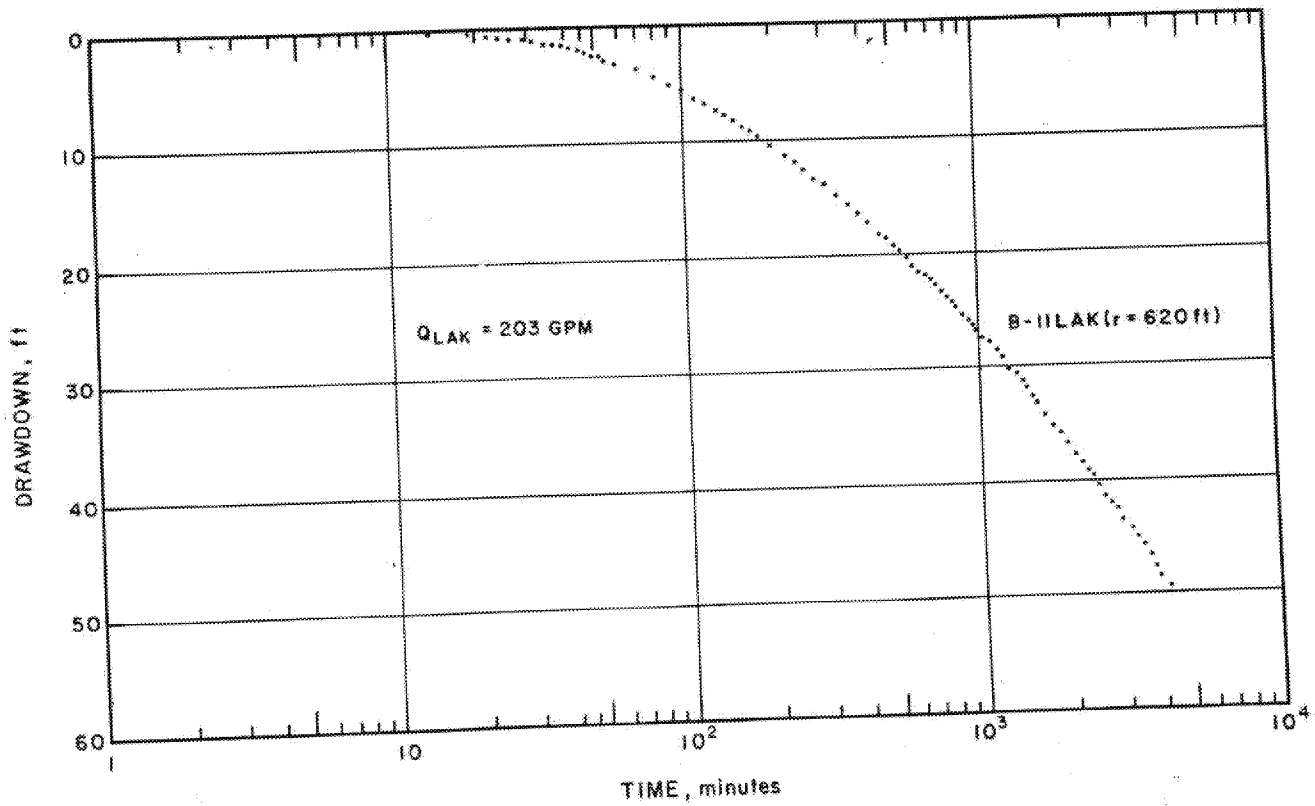


Figure 10: Semilogarithmic Graph of Drawdown for B-11 Observation Well Group, Lakota Aquifer Test



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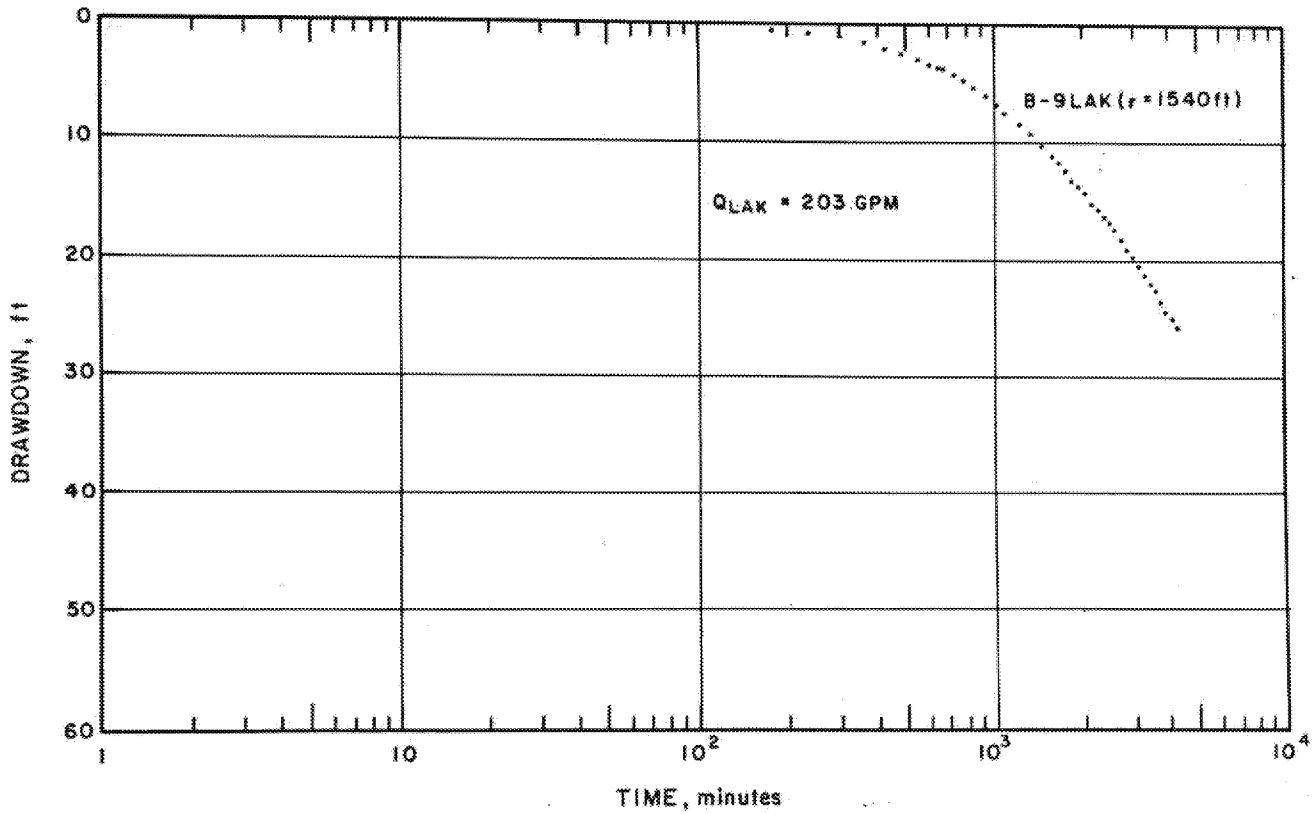


Figure 11: Semilogarithmic Graph of Drawdown for B-9 Observation Well Group, Lakota Aquifer Test



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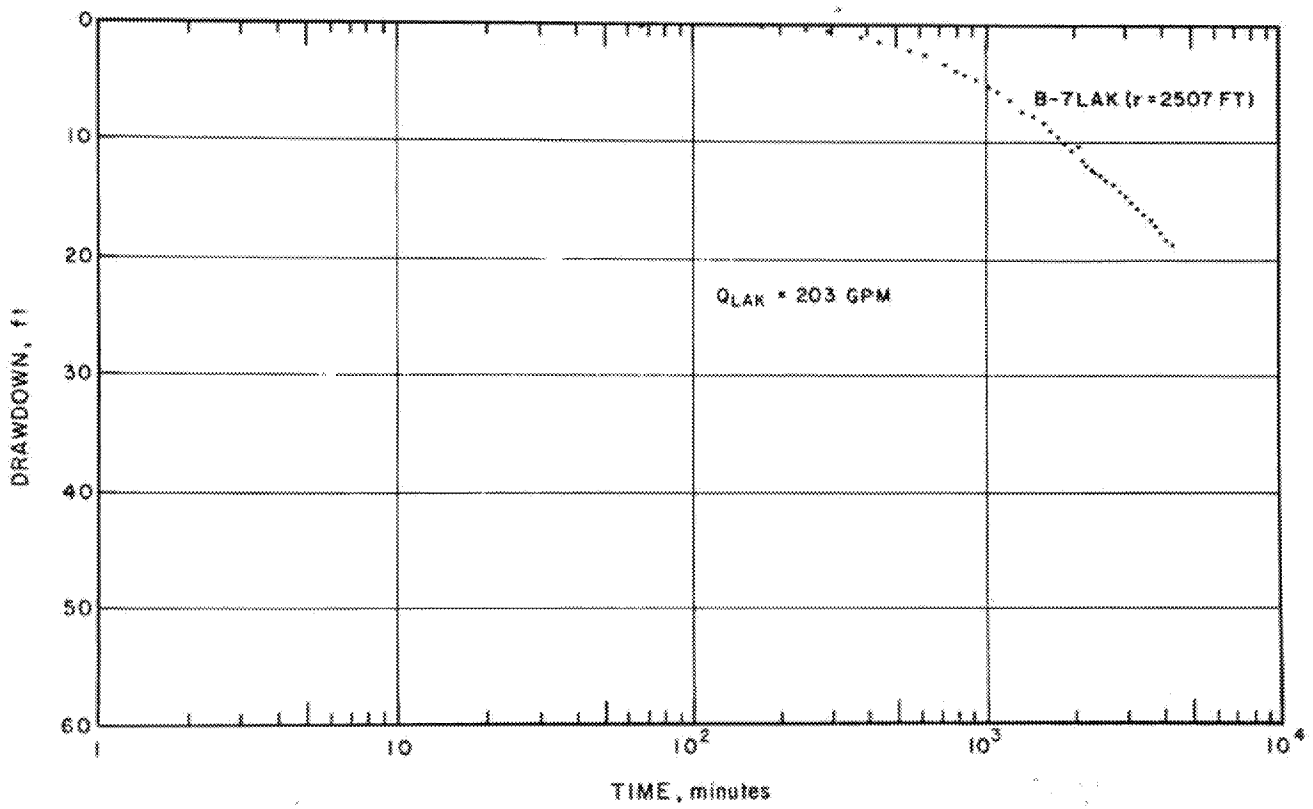


Figure 12: Semilogarithmic Graph of Drawdown for B-7 Observation Well Group, Lakota Aquifer Test



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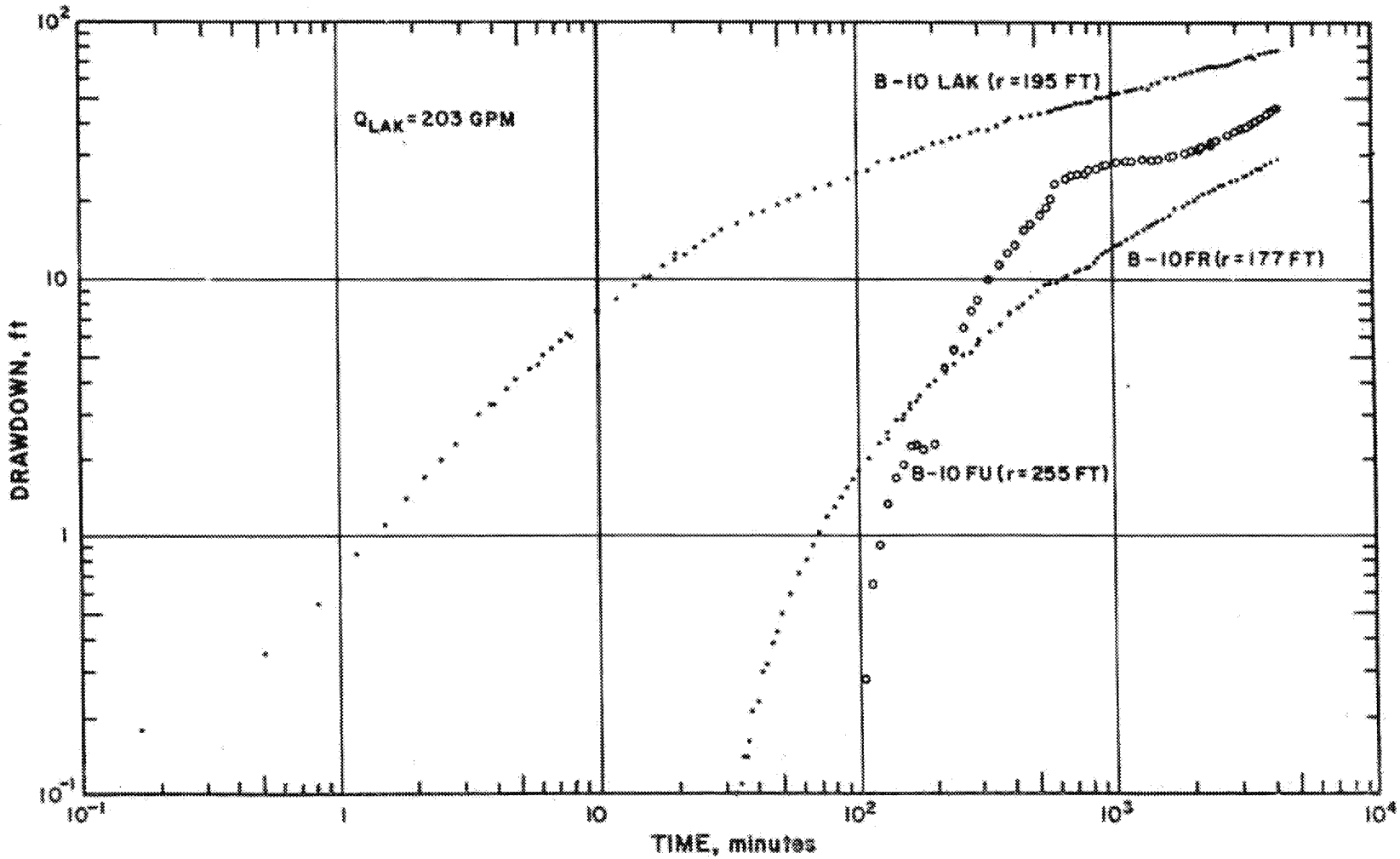


Figure 13 : Logarithmic Graphs of Drawdown for B-10 Observation Well Group, Lakota Aquifer Test

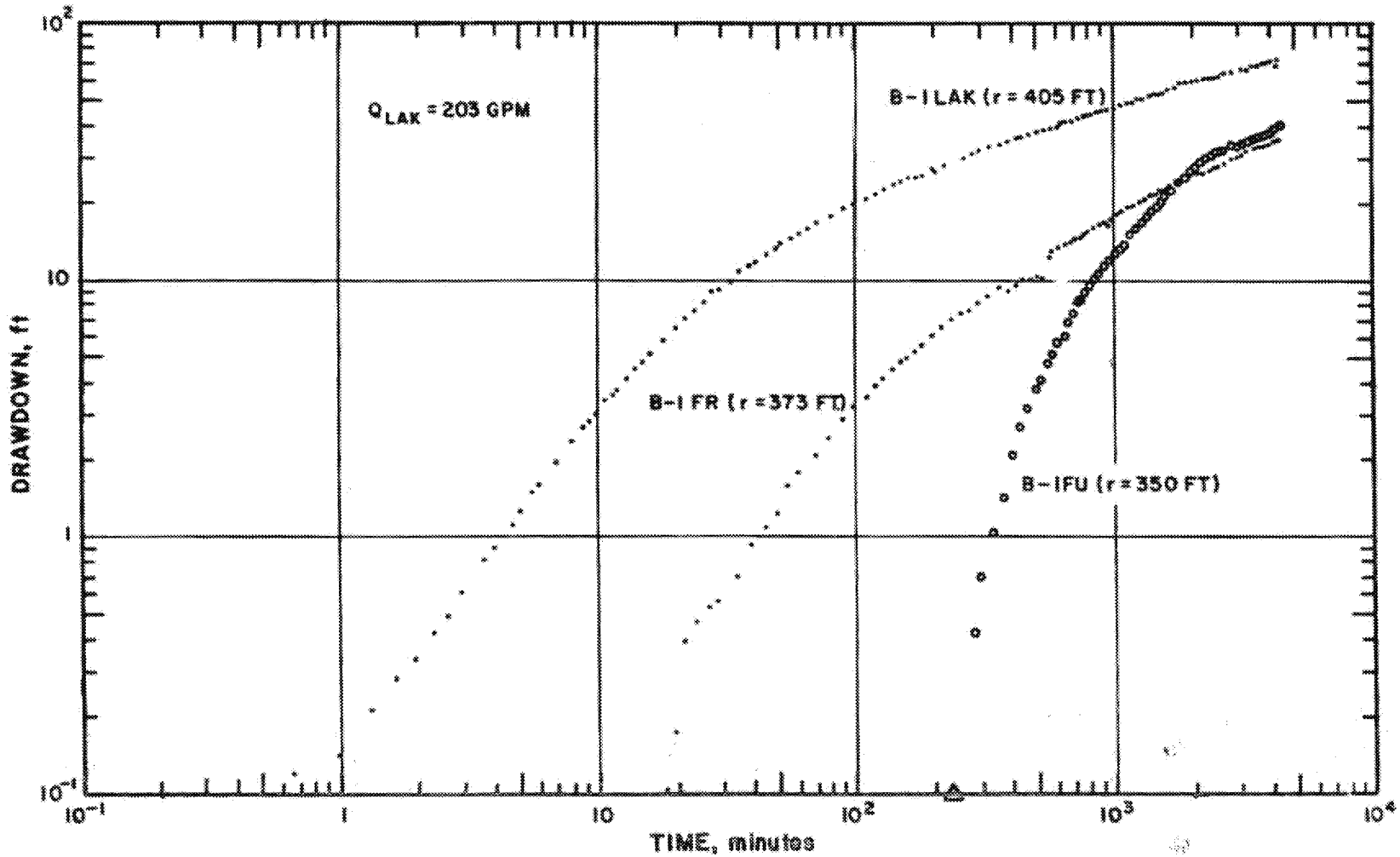


Figure 14 : Logarithmic Graphs of Drawdown for B-I Observation Well Group, Lakota Aquifer Test



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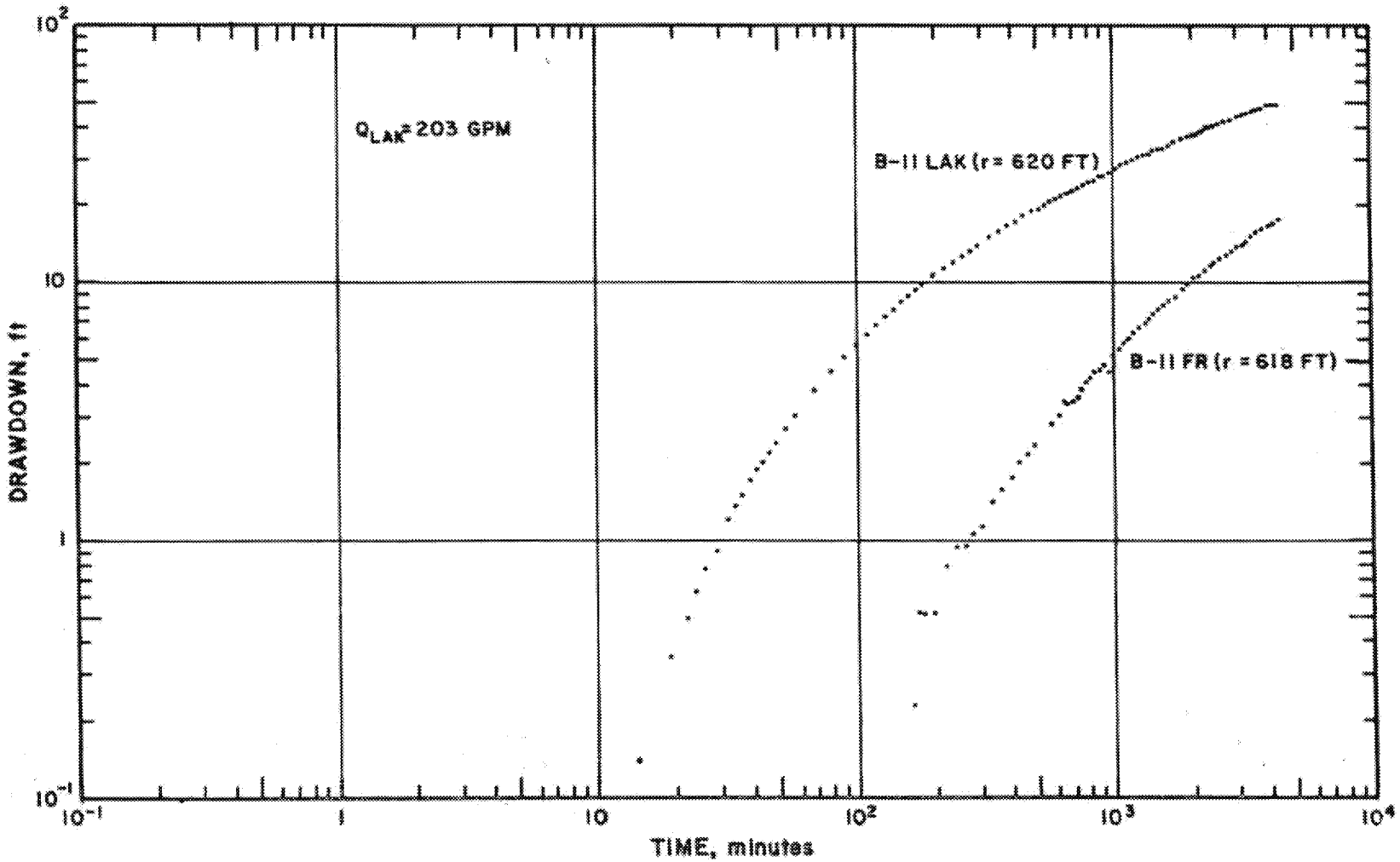


Figure 15: Logarithmic Graphs of Drawdown for B-11 Observation Well Group, Lakota Aquifer Test

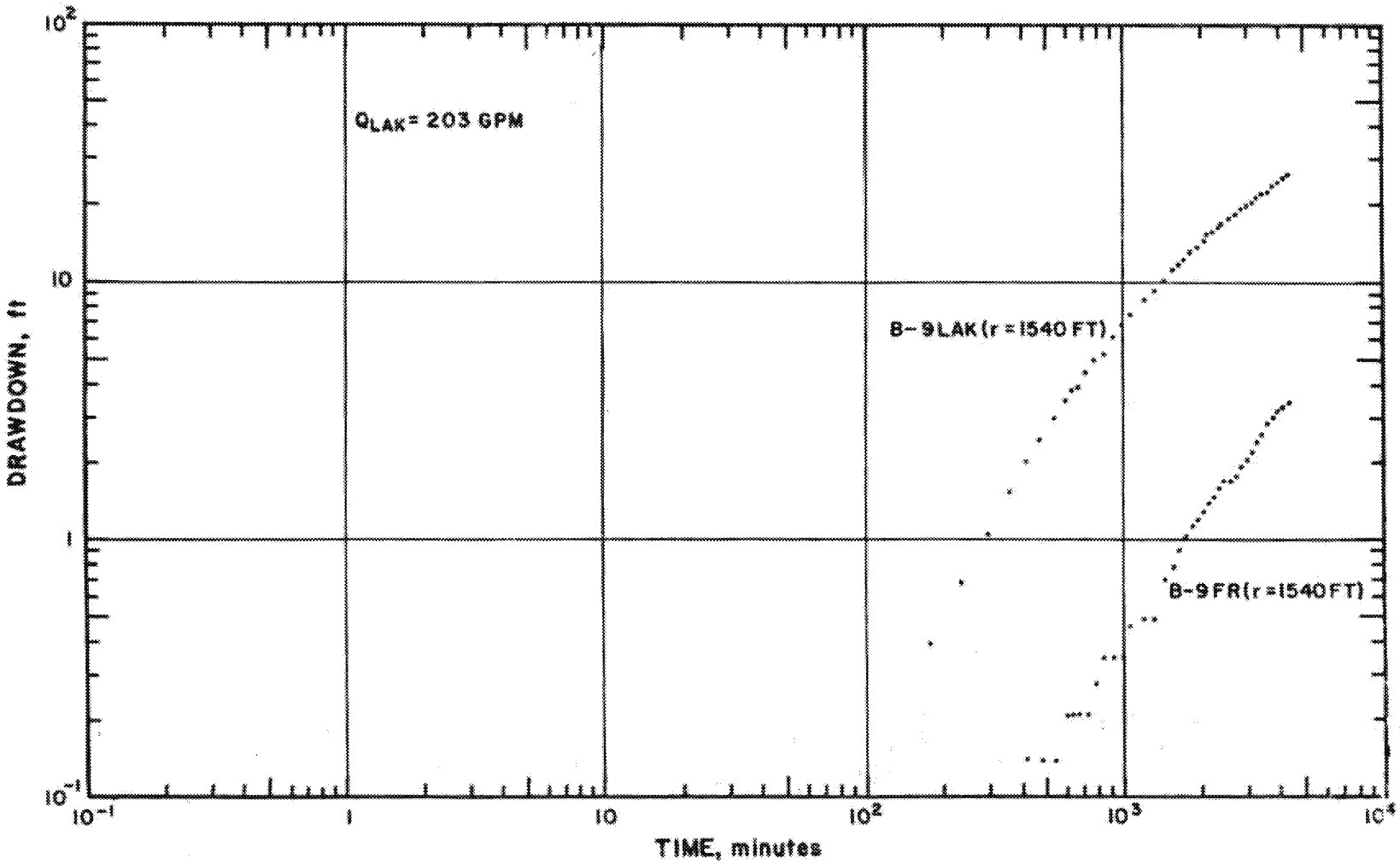


Figure 16 : Logarithmic Graphs of Drawdown for B-9 Observation Well Group, Lakota Aquifer Test



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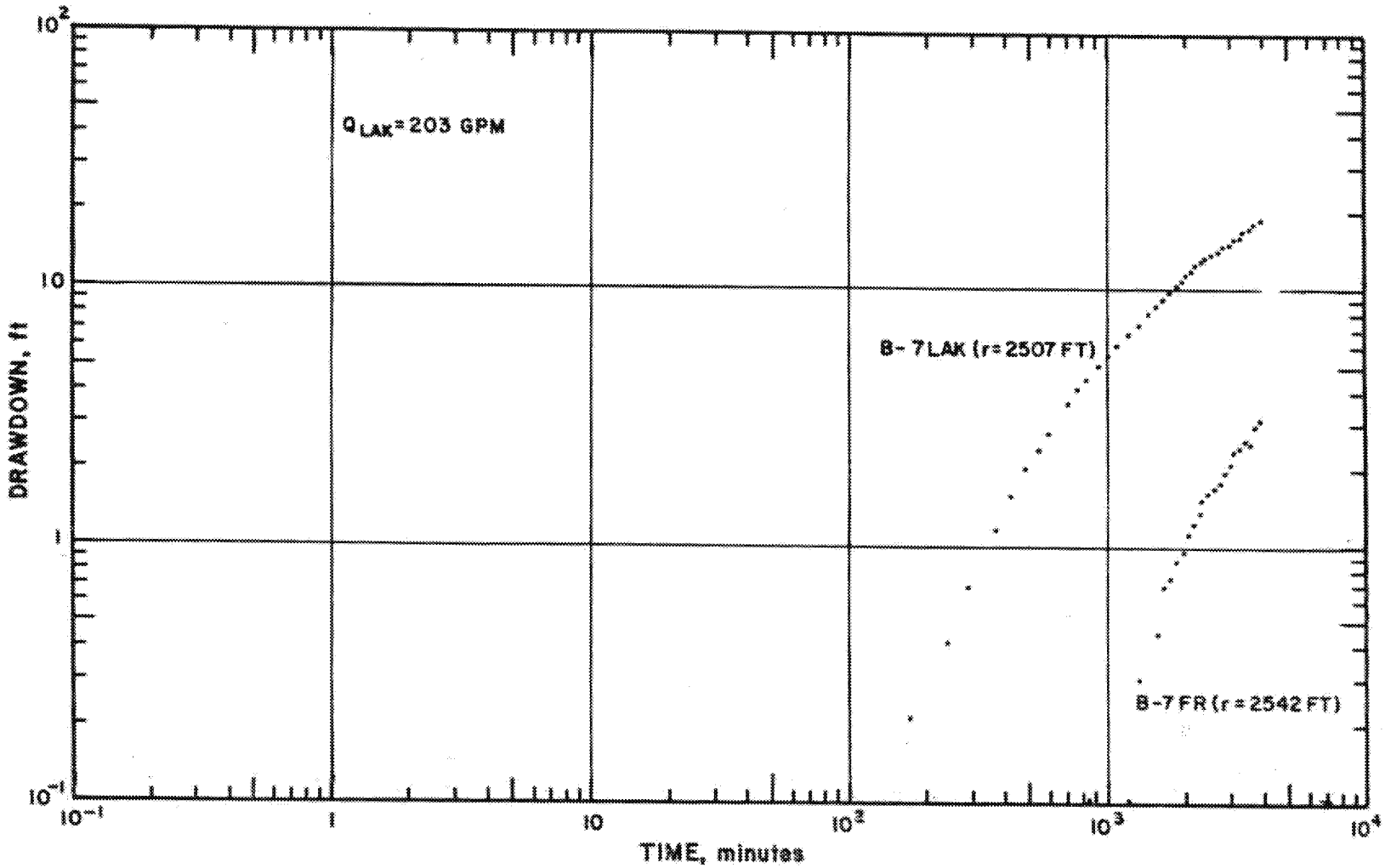


Figure 17 : Logarithmic Graphs of Drawdown for B-7 Observation Well Group, Lakota Aquifer Test



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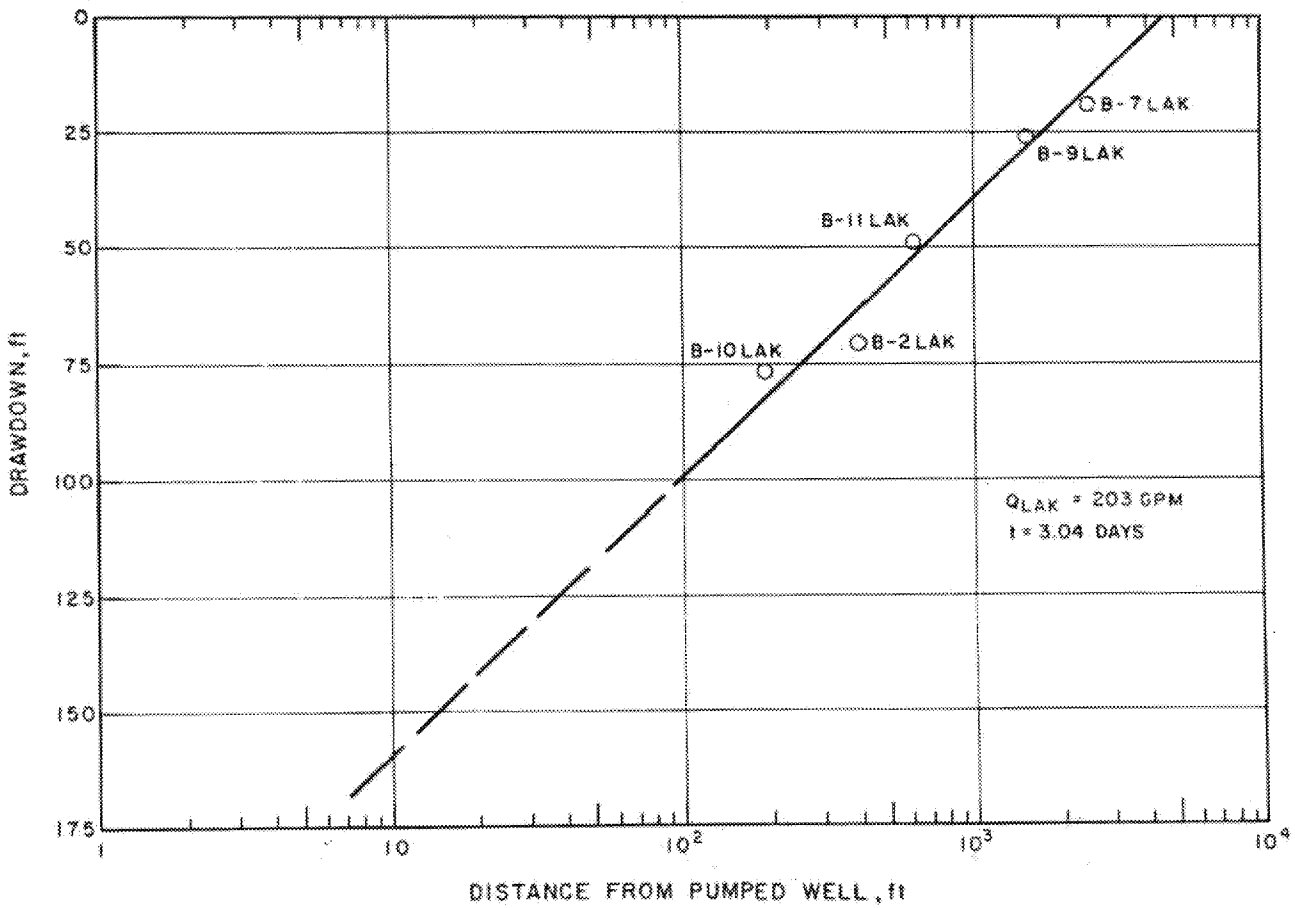


Figure 18 : Semilogarithmic Graph of Distance vs. Drawdown at End of Pumping Test, Lakota Aquifer Test

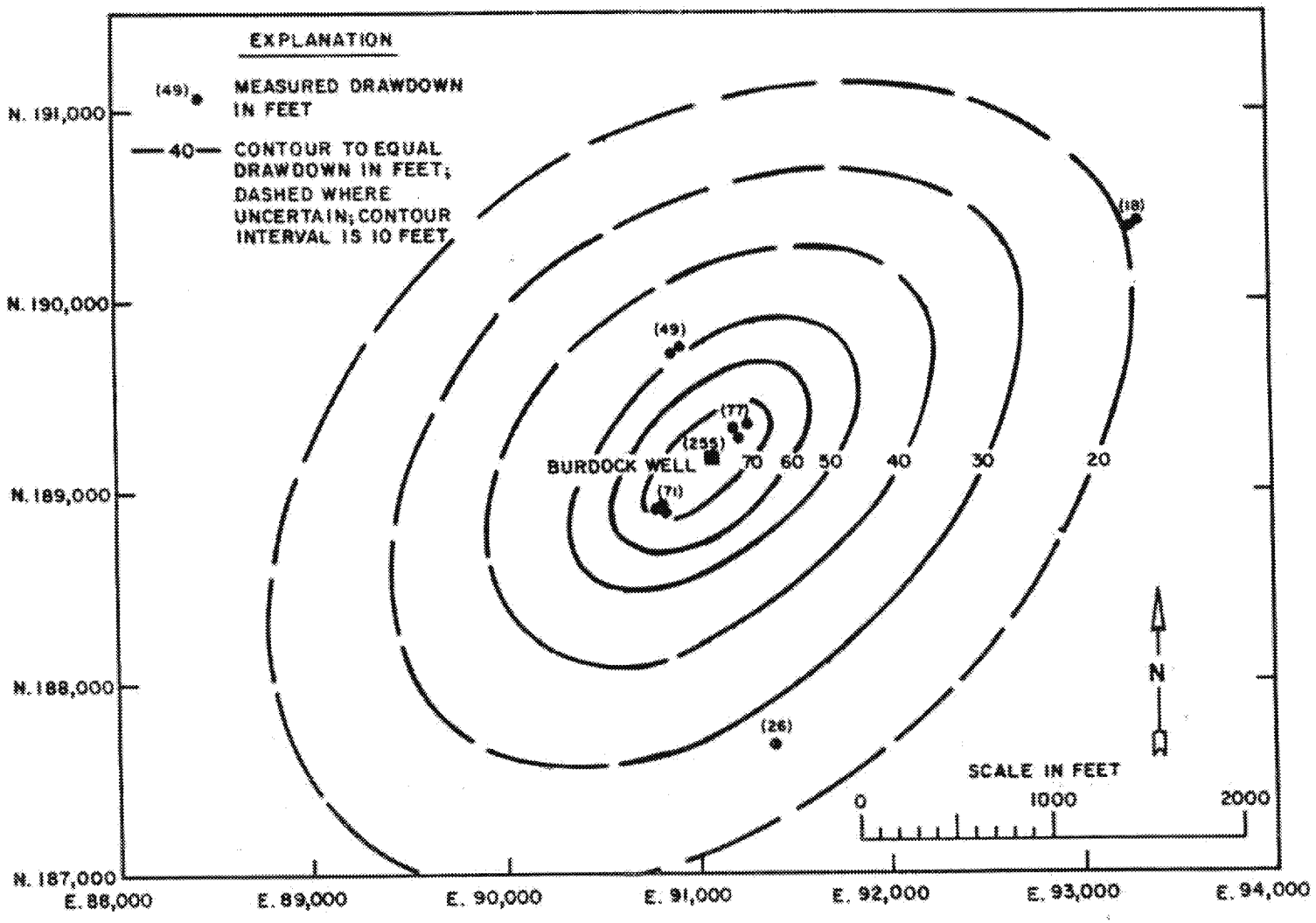


Figure 19 : Drawdown in Lakota Aquifer at End of Lakota Test

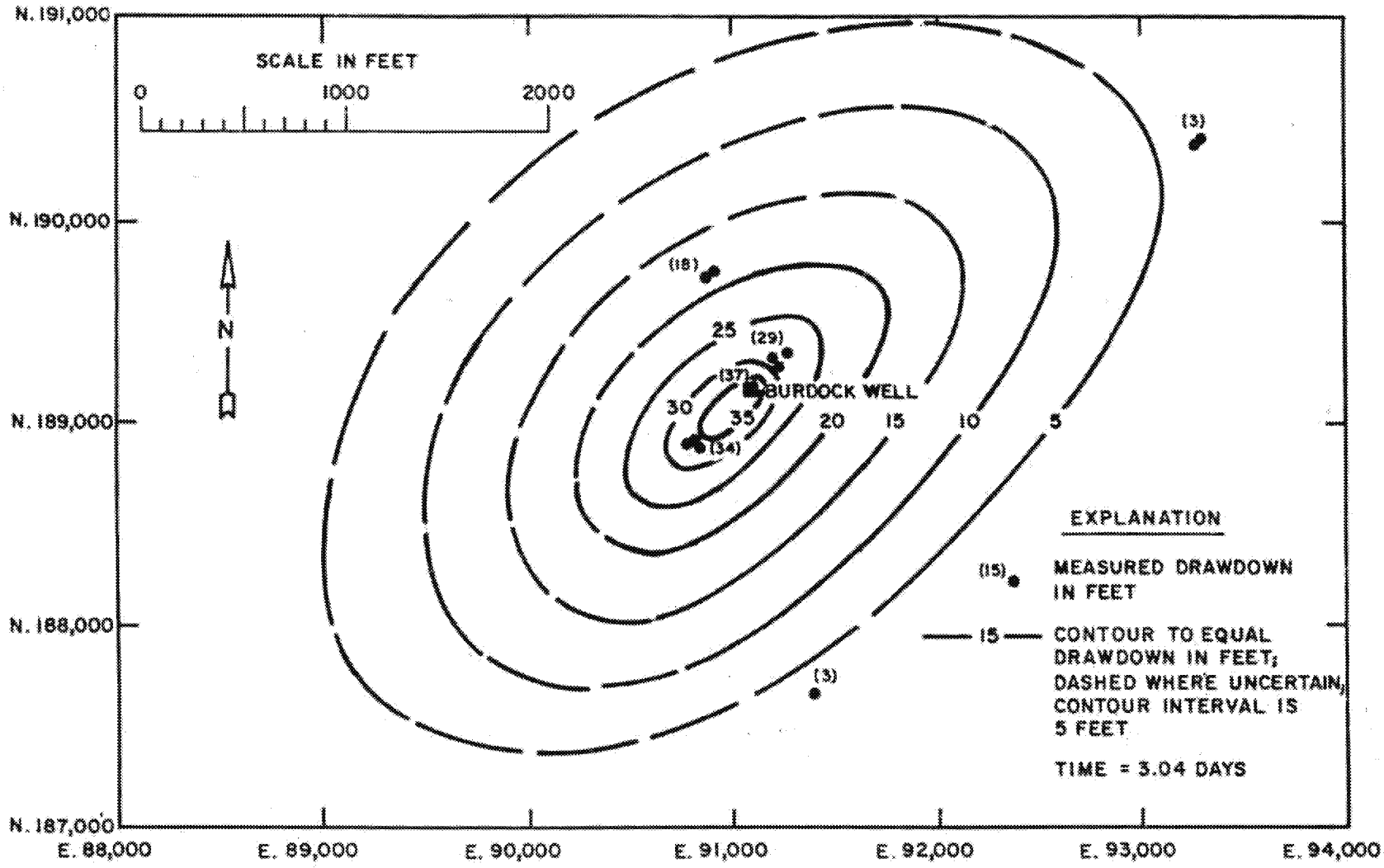


Figure 20 : Drawdown in Fall River Aquifer at End of Lakota Test



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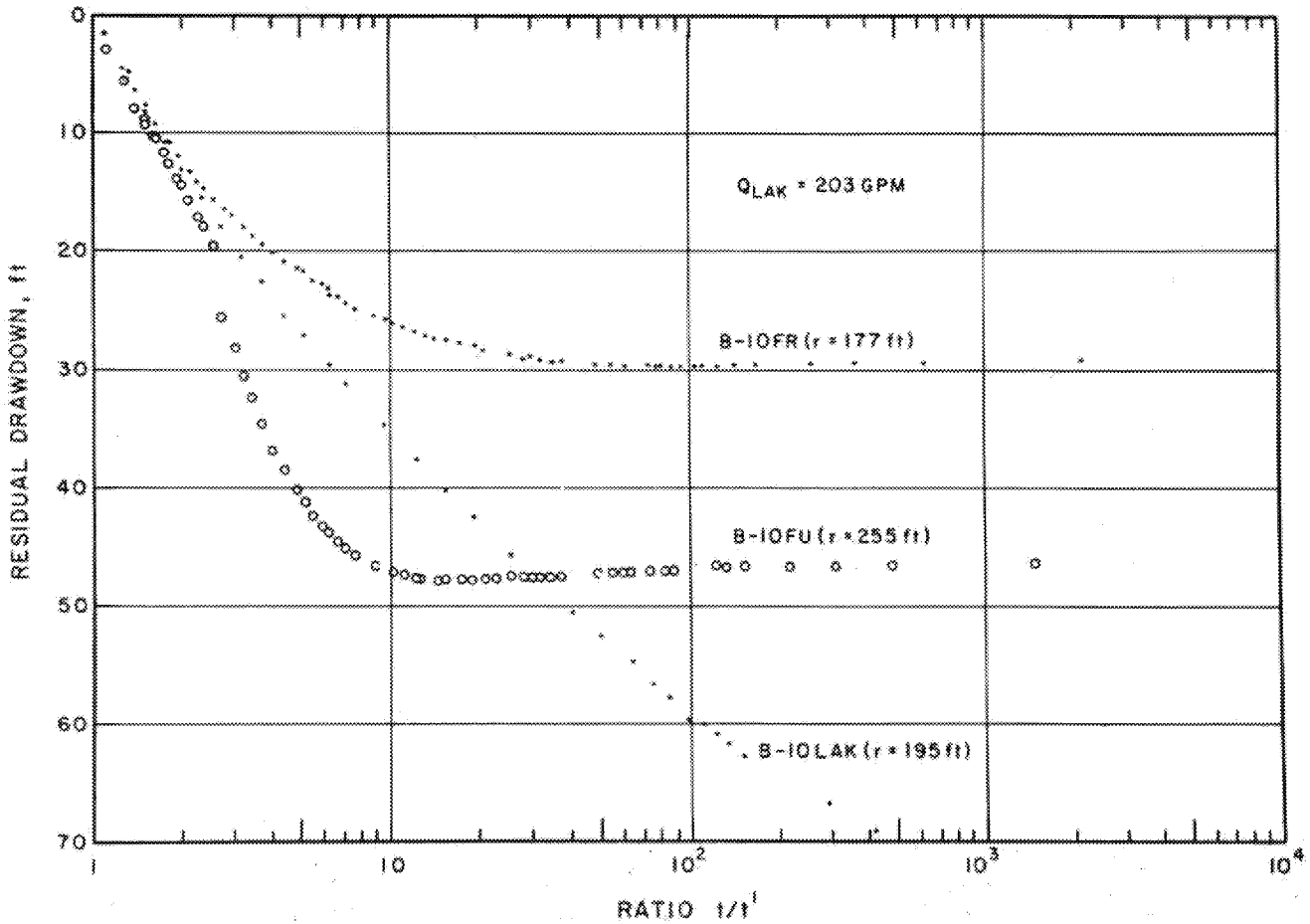


Figure 21: Recovery Graphs for B-10 Observation Well Group, Lakota Aquifer Test

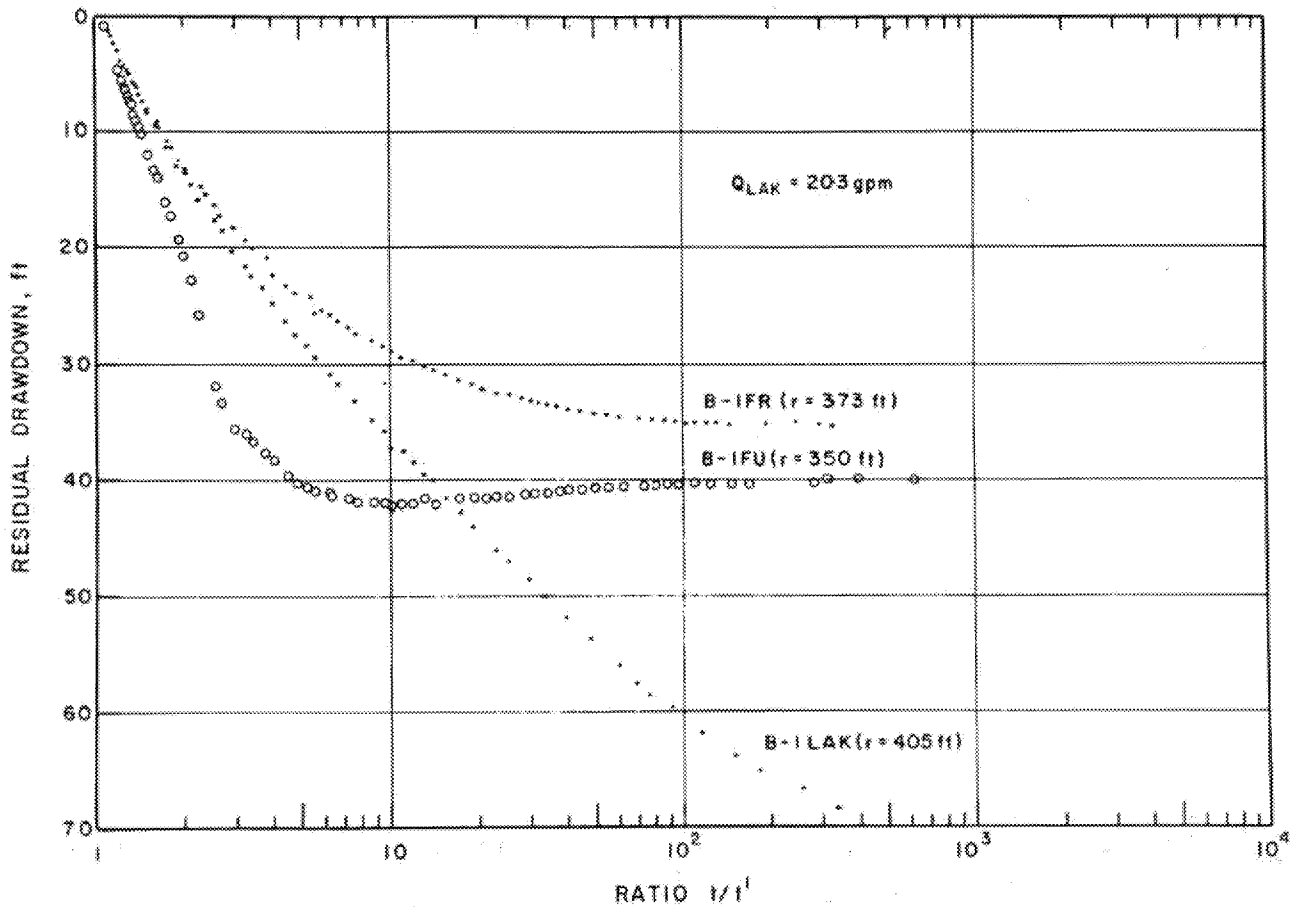


Figure 22: Recovery Graphs for B-1 Observation Well Group, Lakota Aquifer Test

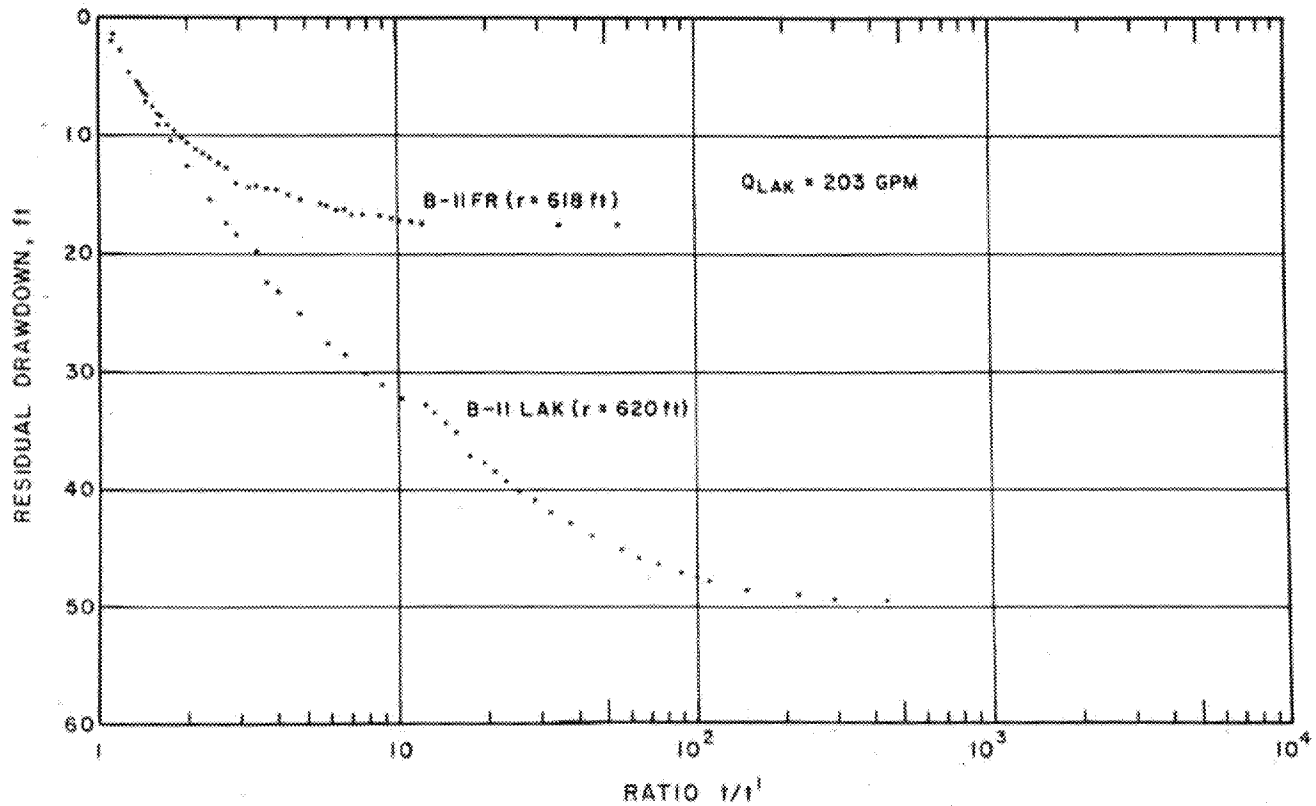


Figure 23: Recovery Graphs for B-11 Observation Well Group, Lakota Aquifer Test



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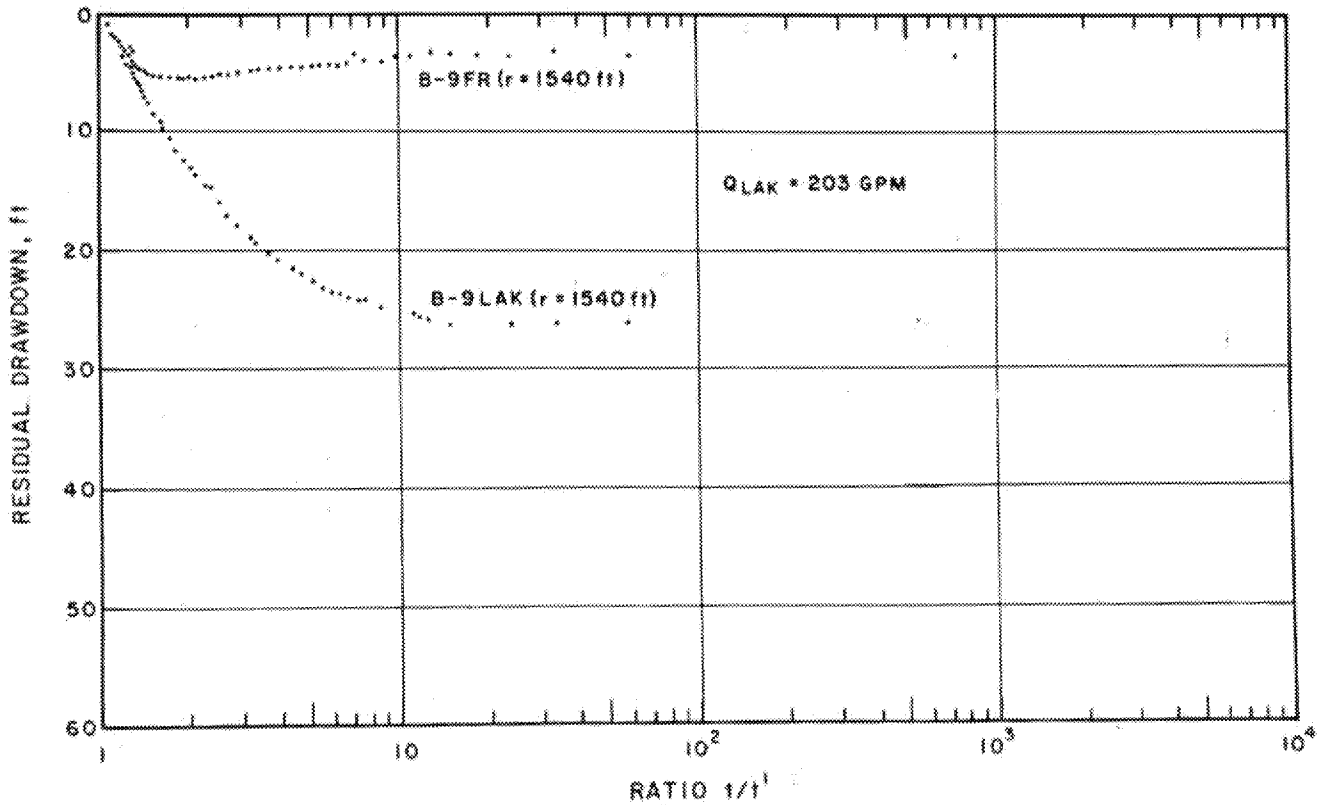


Figure 24: Recovery Graphs for B-9 Observation Well Group, Lakota Aquifer Test



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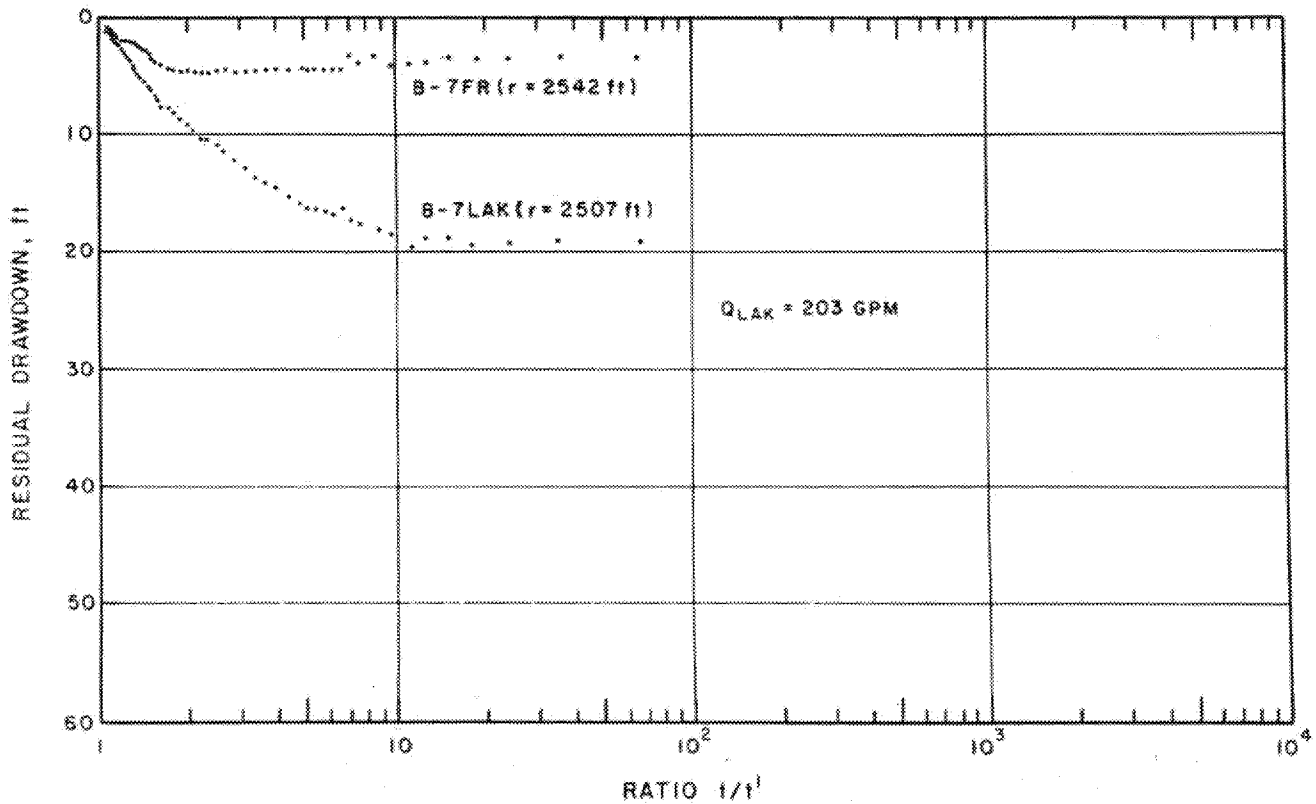


Figure 25: Recovery Graphs for B-7 Observation Well Group, Lakota Aquifer Test



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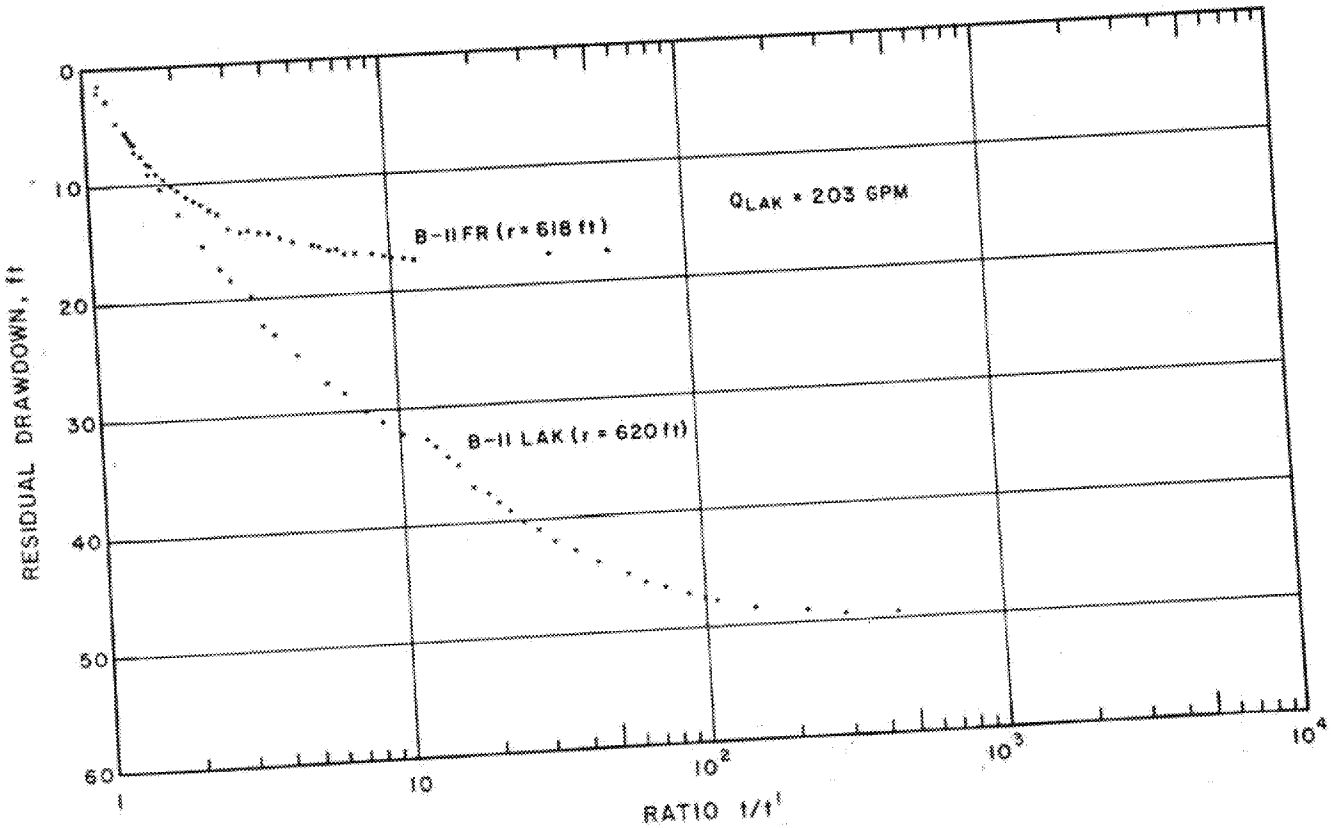


Figure 23: Recovery Graphs for B-11 Observation Well Group, Lakota Aquifer Test



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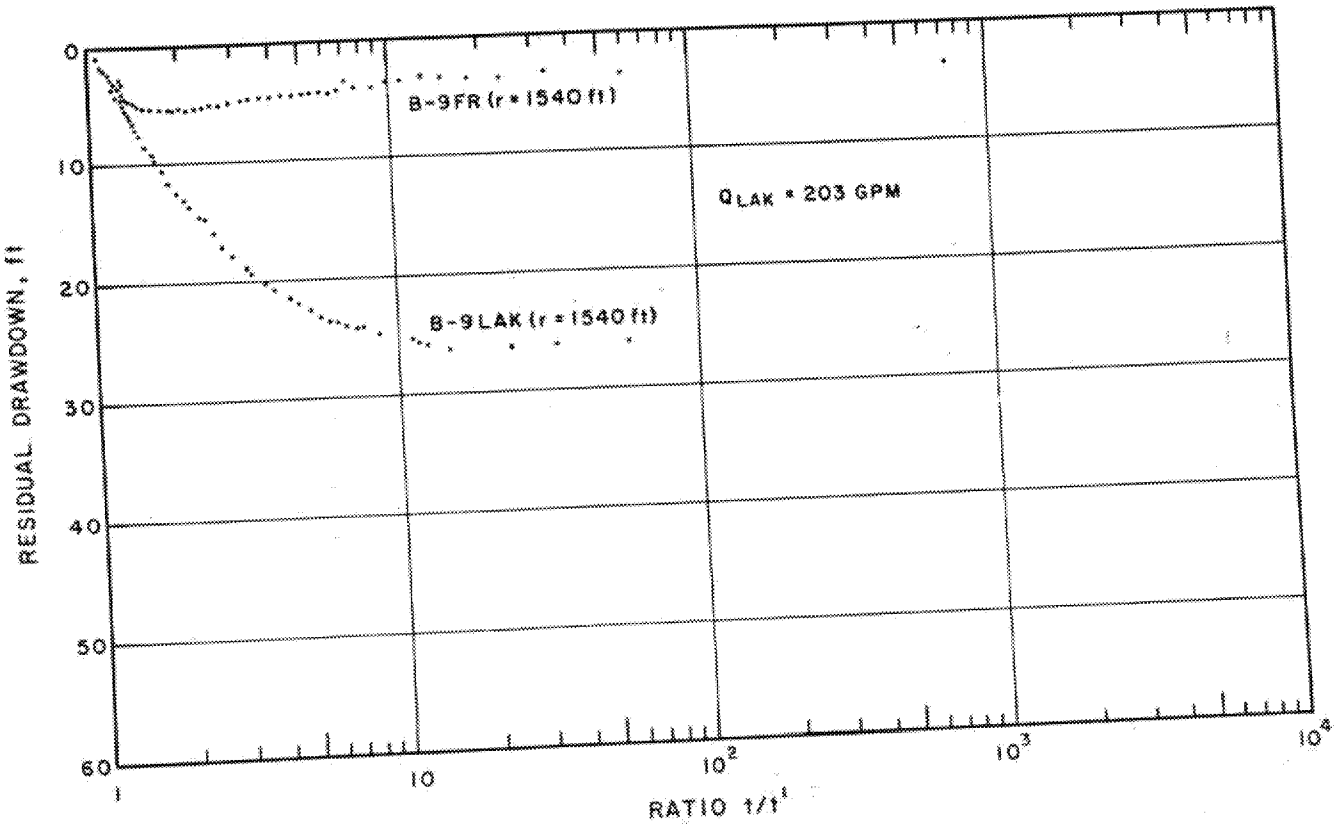


Figure 24: Recovery Graphs for B-9 Observation Well Group, Lakota Aquifer Test



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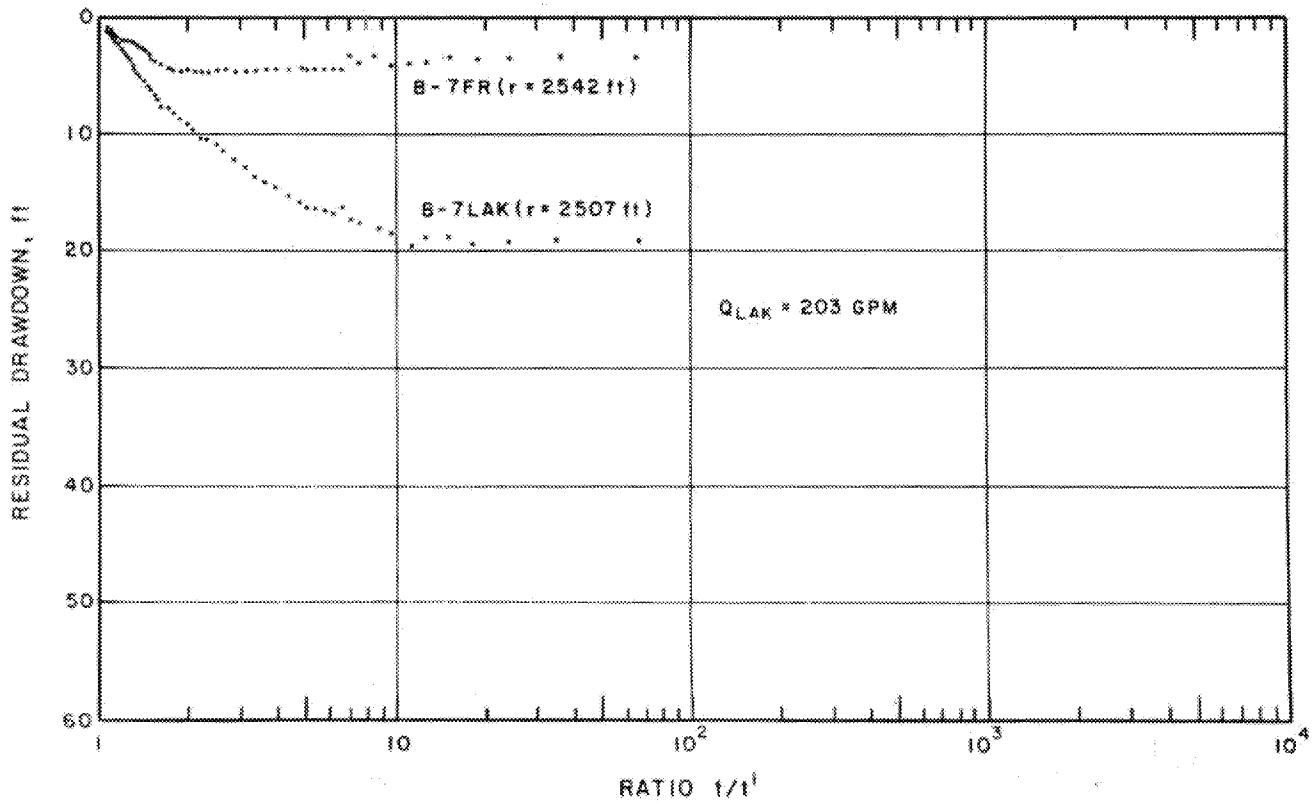


Figure 25: Recovery Graphs for B-7 Observation Well Group, Lakota Aquifer Test



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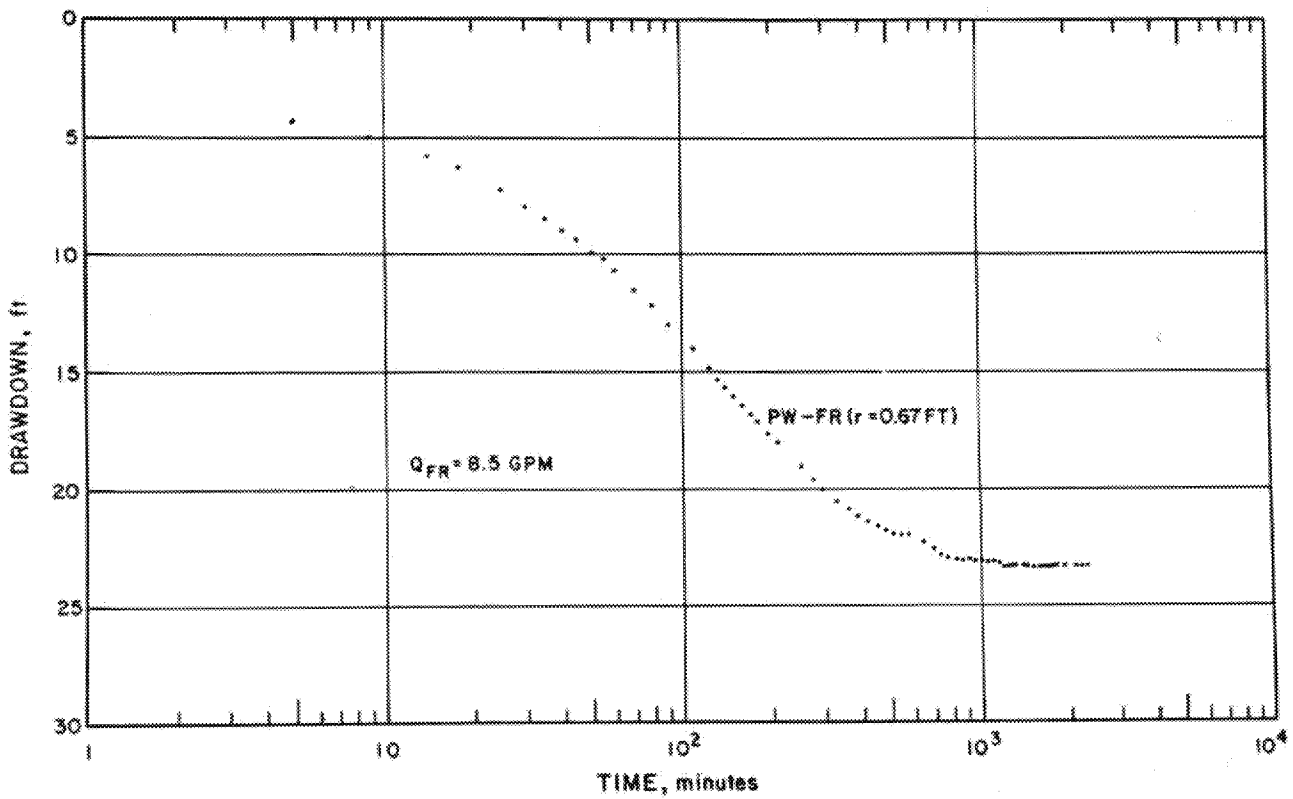


Figure 26: Semilogarithmic Graph of Drawdown for the Pumped Well, Fall River Aquifer Test

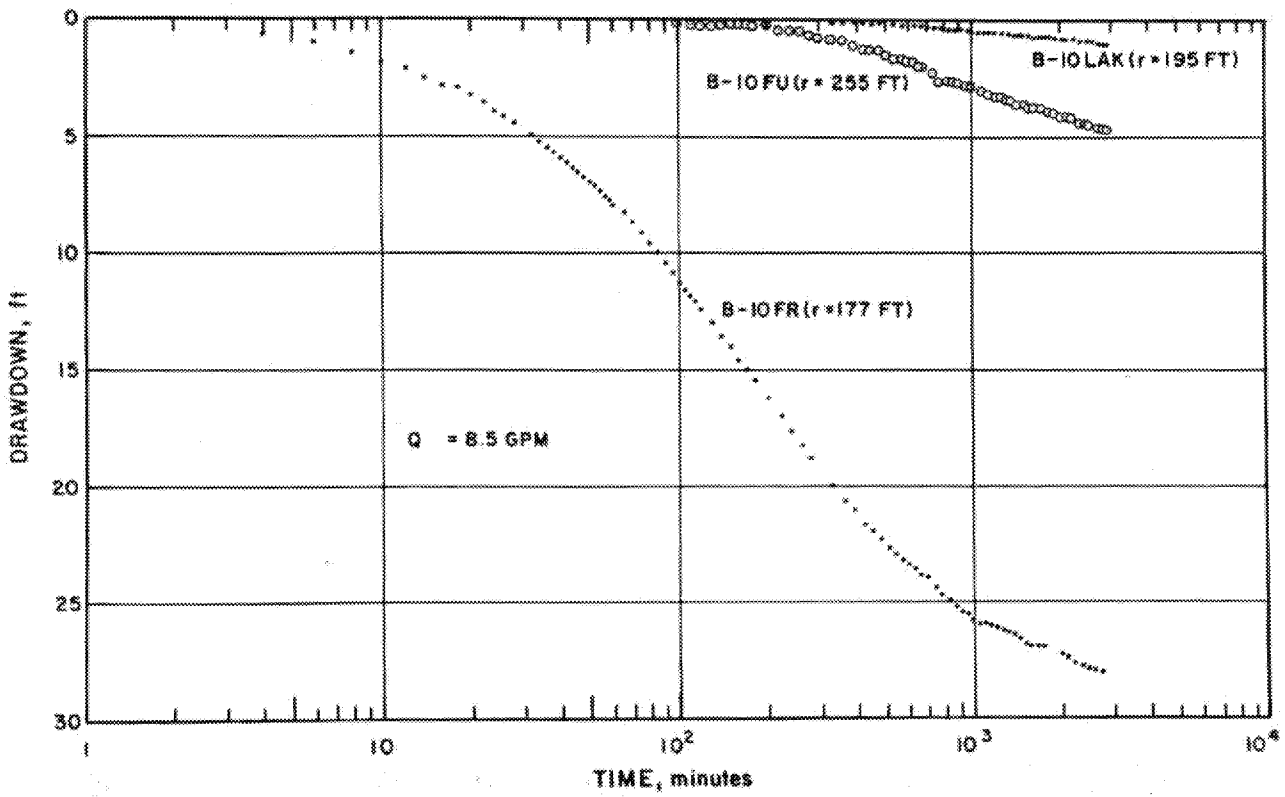


Figure 27: Semilogarithmic Graphs of Drawdown for B-10 Observation Well Group, Fall River Aquifer Test



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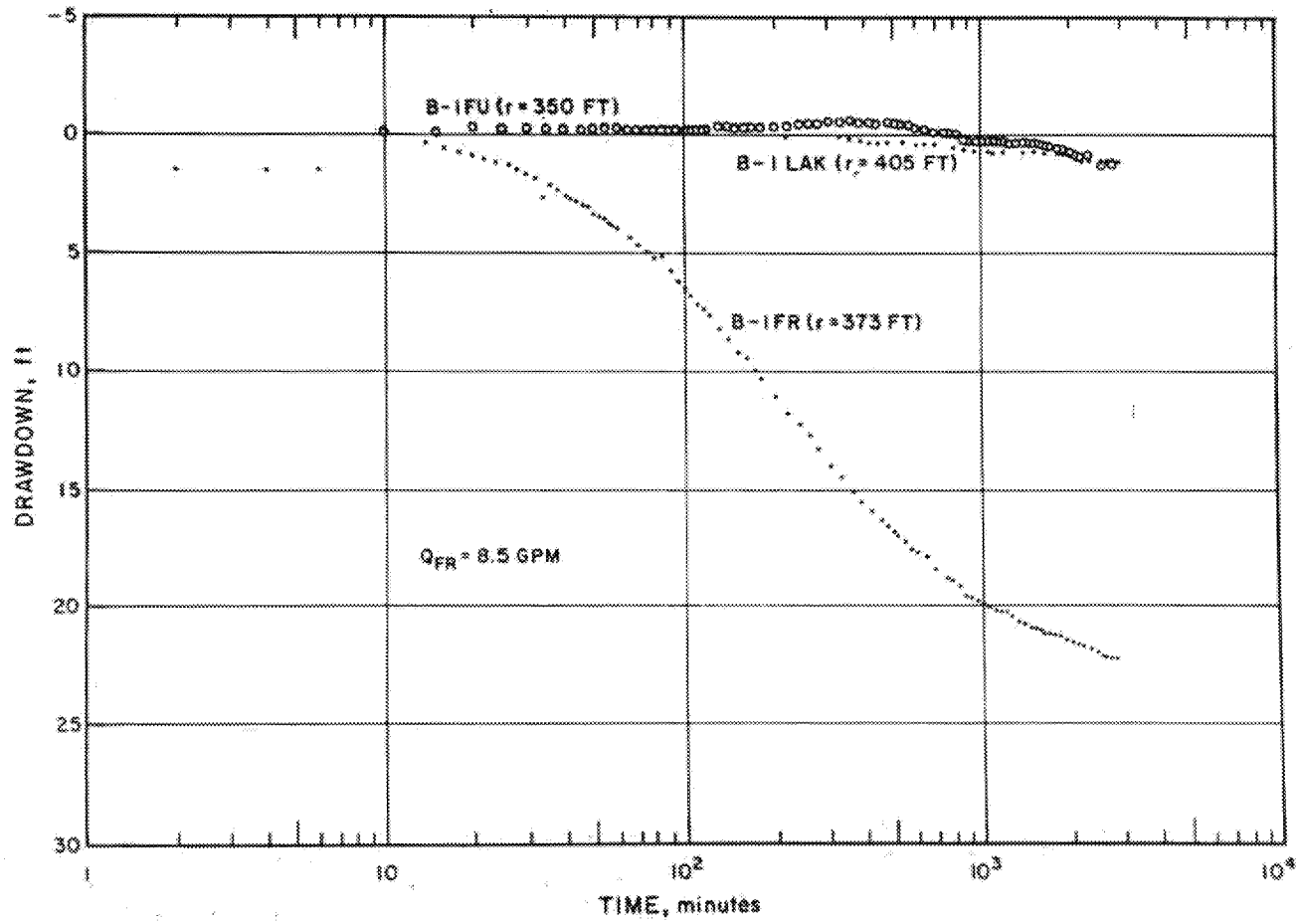


Figure 28 : Semilogarithmic Graphs of Drawdown for B-1 Observation Well Group, Fall River Aquifer Test

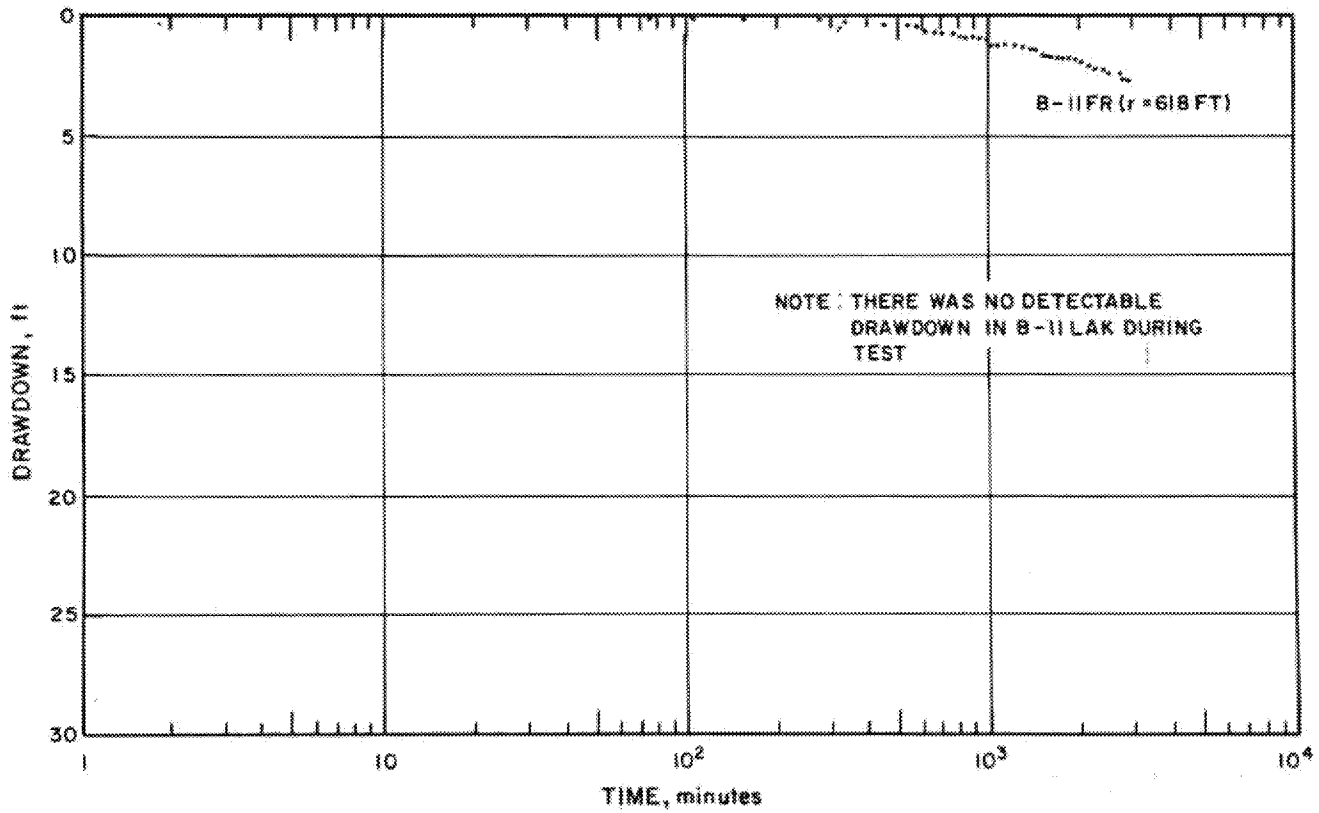


Figure 29: Semilogarithmic Graph of Drawdown for B-11 Observation Well Group, Fall River Aquifer Test

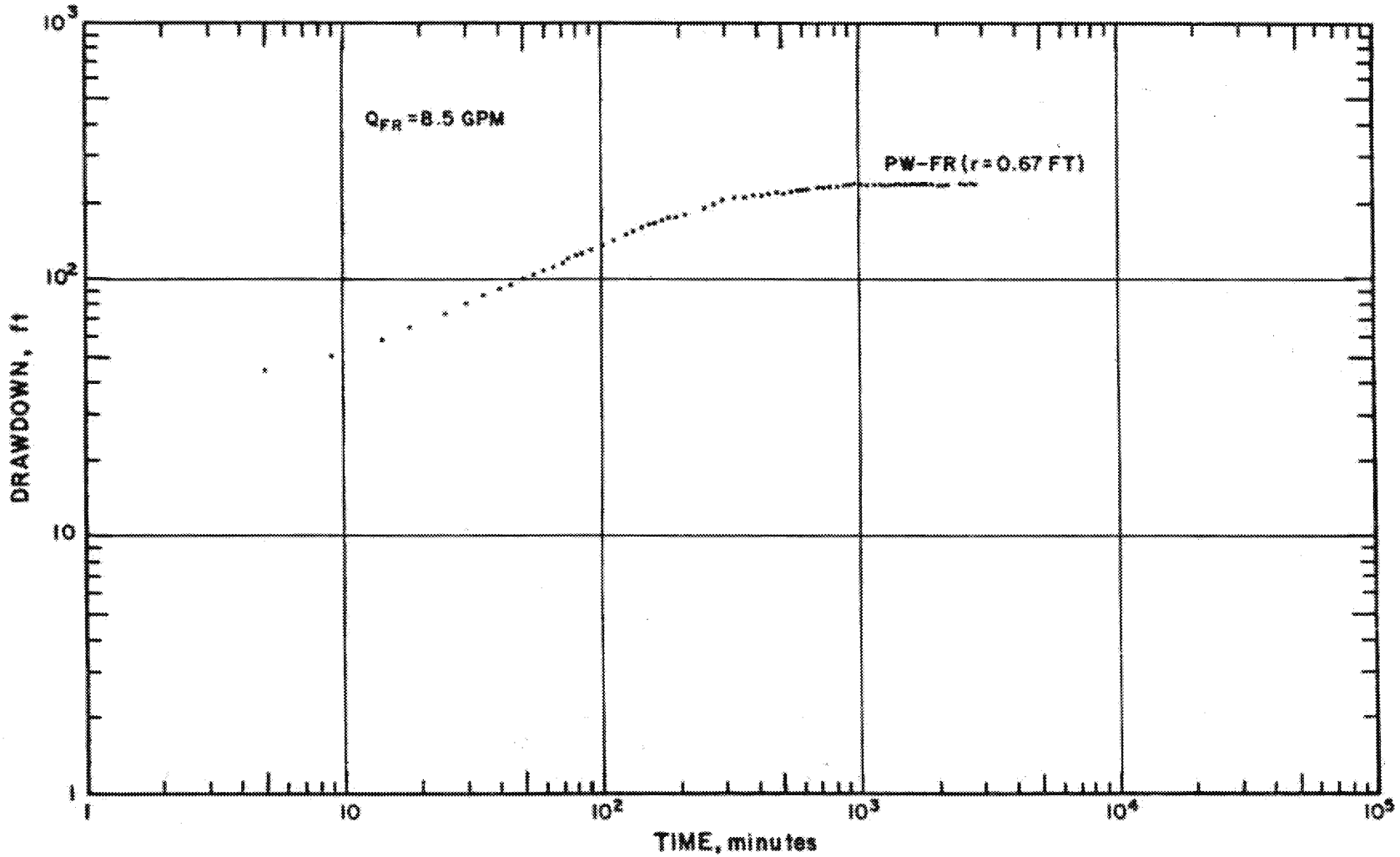


Figure 30: Logarithmic Graph of Drawdown for Pumped Well, Fall River Aquifer Test

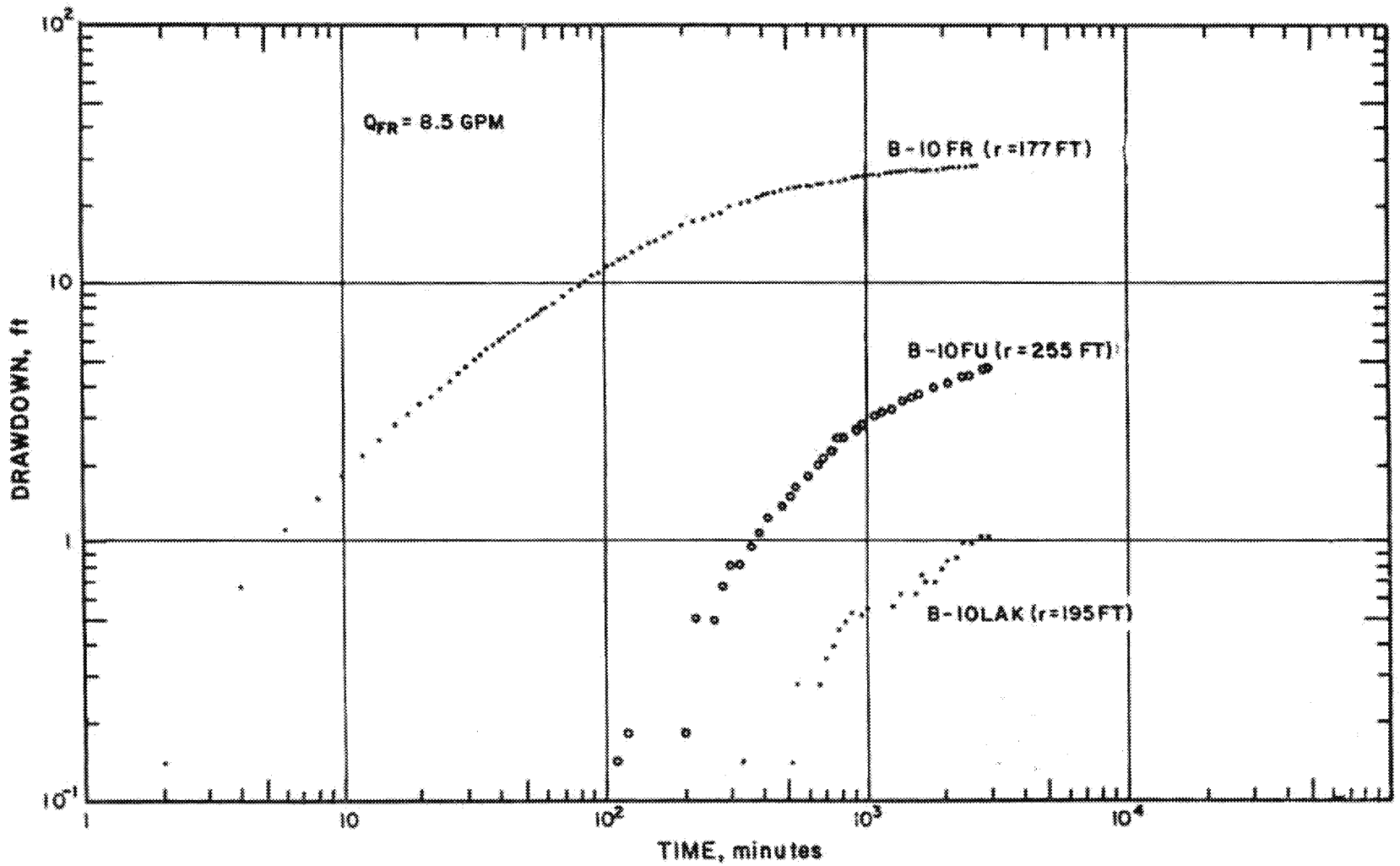


Figure 31: Logarithmic Graphs of Drawdown for B-10 Observation Well Group, Fall River Aquifer Test



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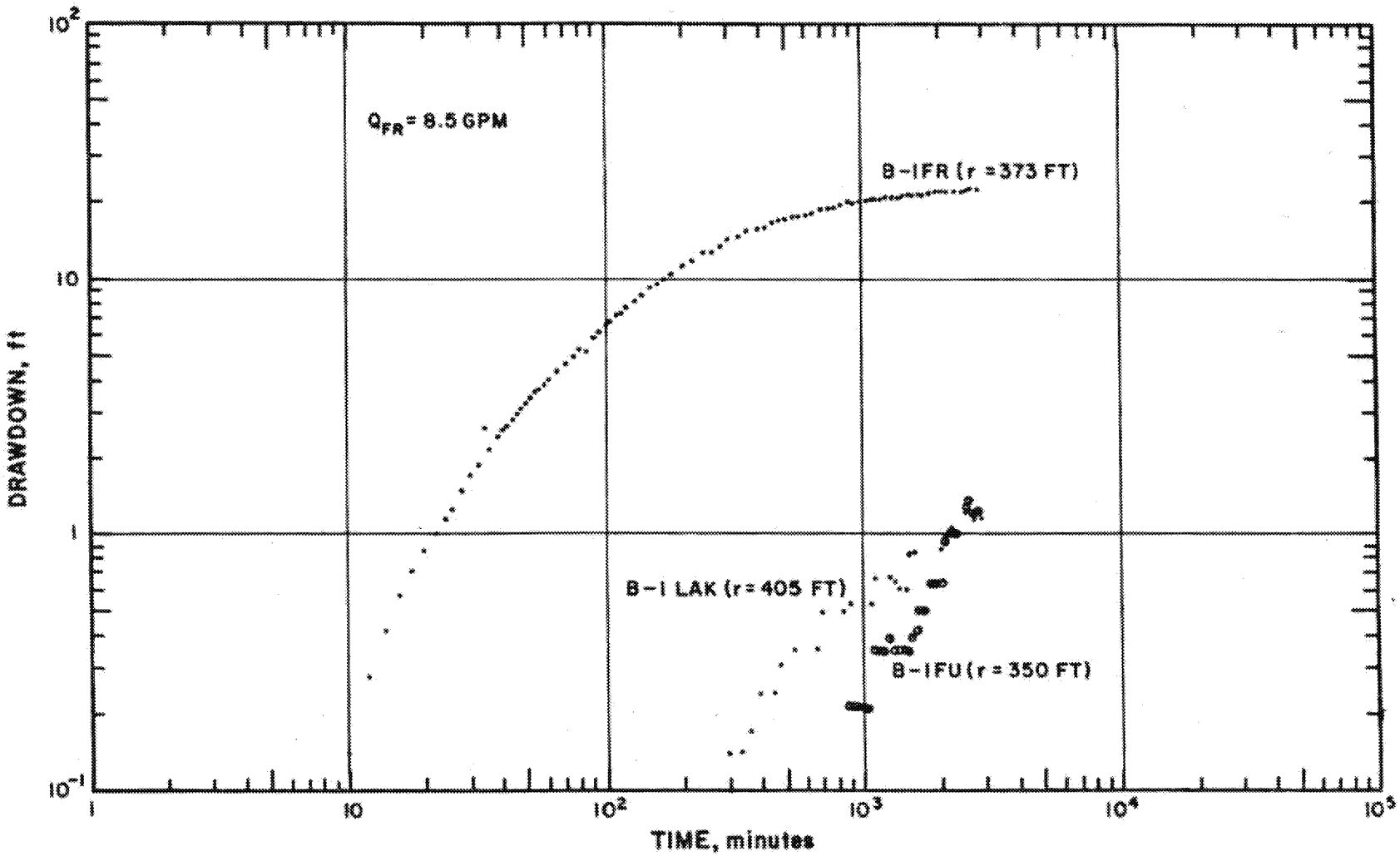


Figure 32: Logarithmic Graphs of Drawdown for B-I Observation Well Group, Fall River Aquifer Test

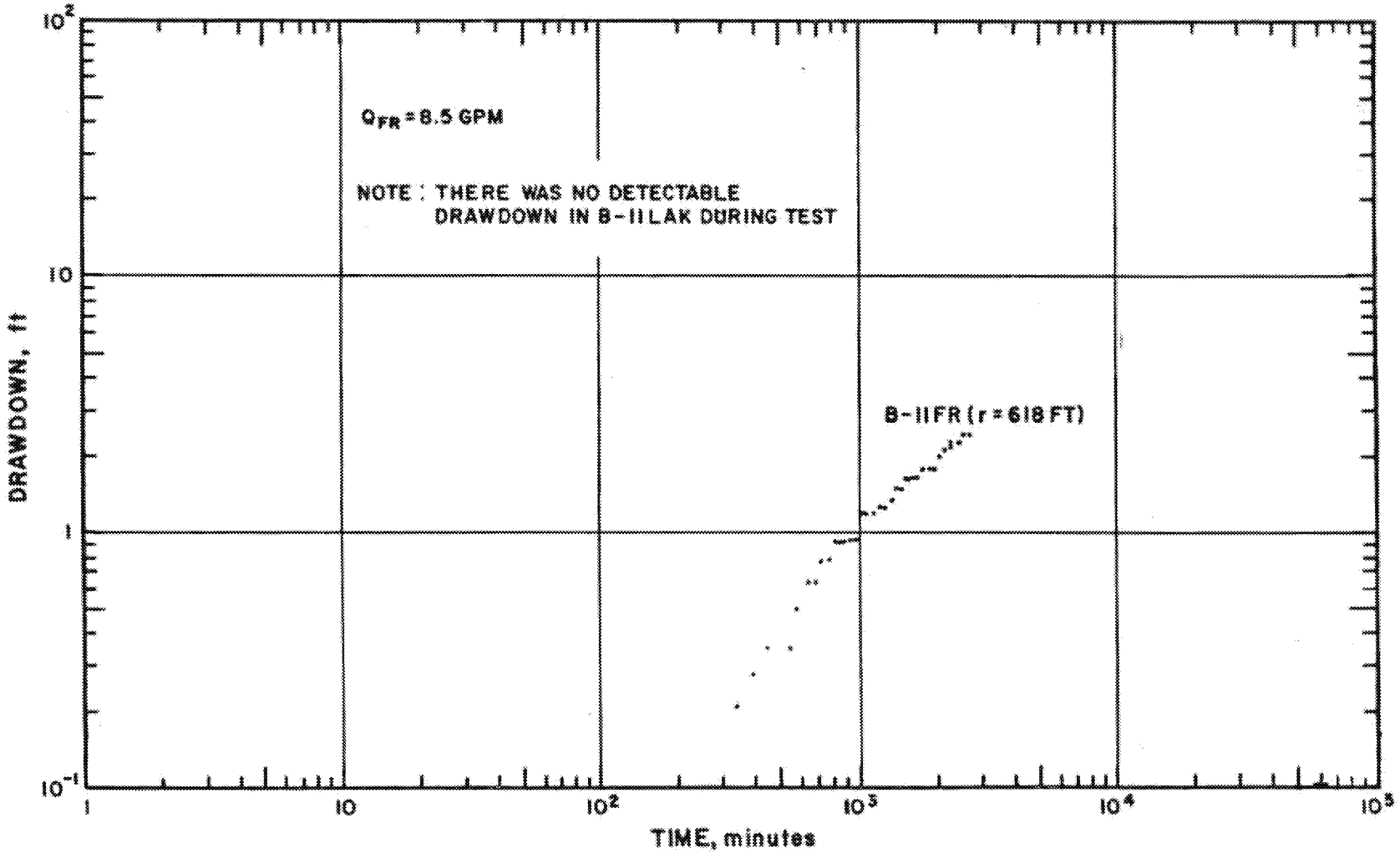


Figure 33: Logarithmic Graphs of Drawdown for B-11 Observation Well Group, Fall River Aquifer Test

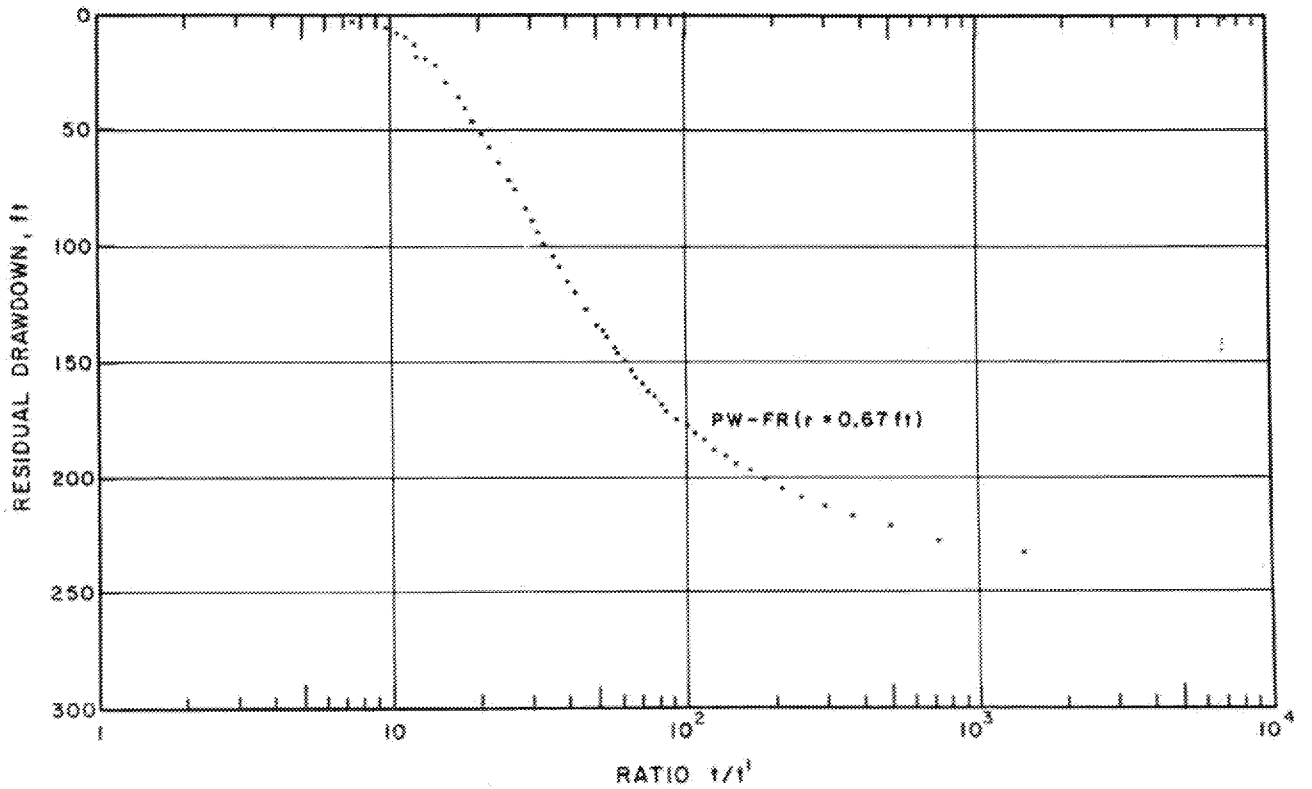


Figure 34: Recovery Graph for Pumped Well, Fall River Aquifer Test



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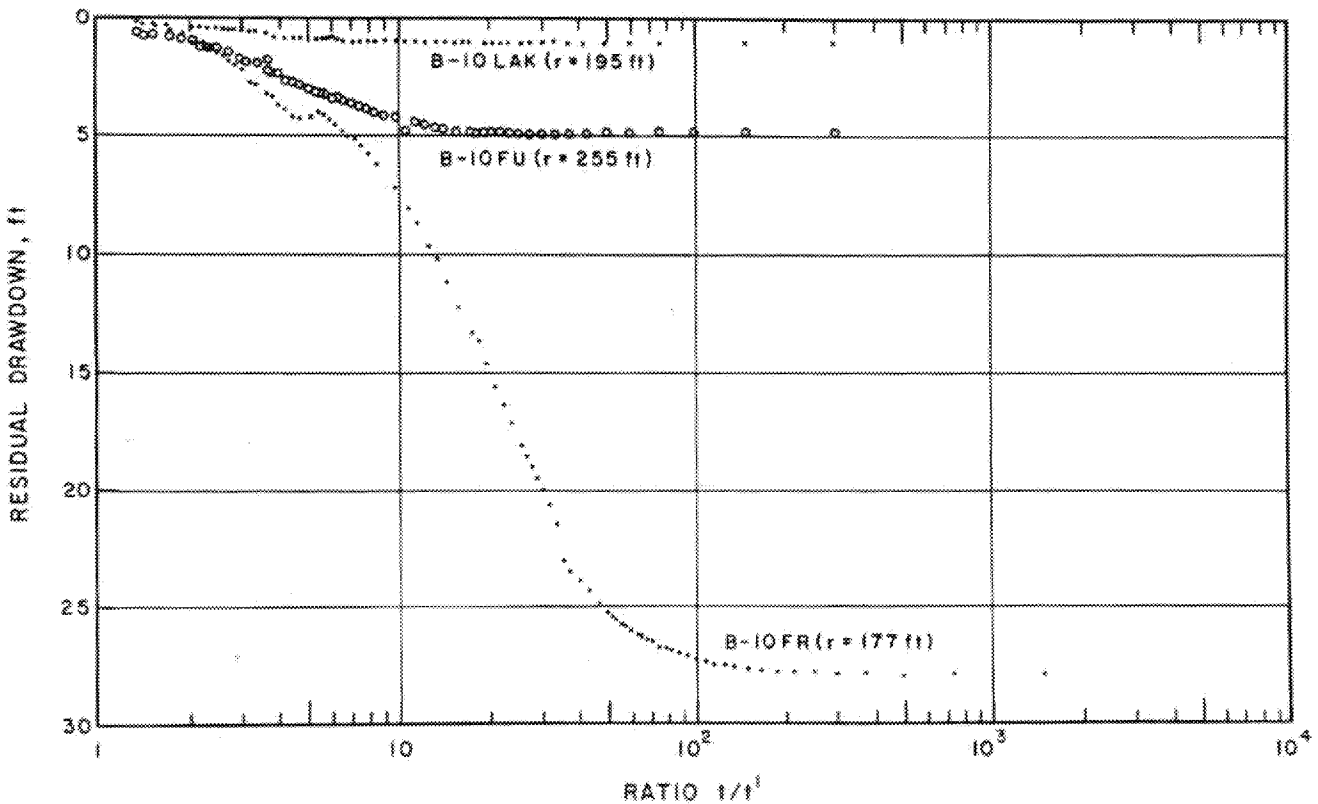


Figure 35: Recovery Graphs for B-10 Observation Well Group, Fall River Aquifer Test

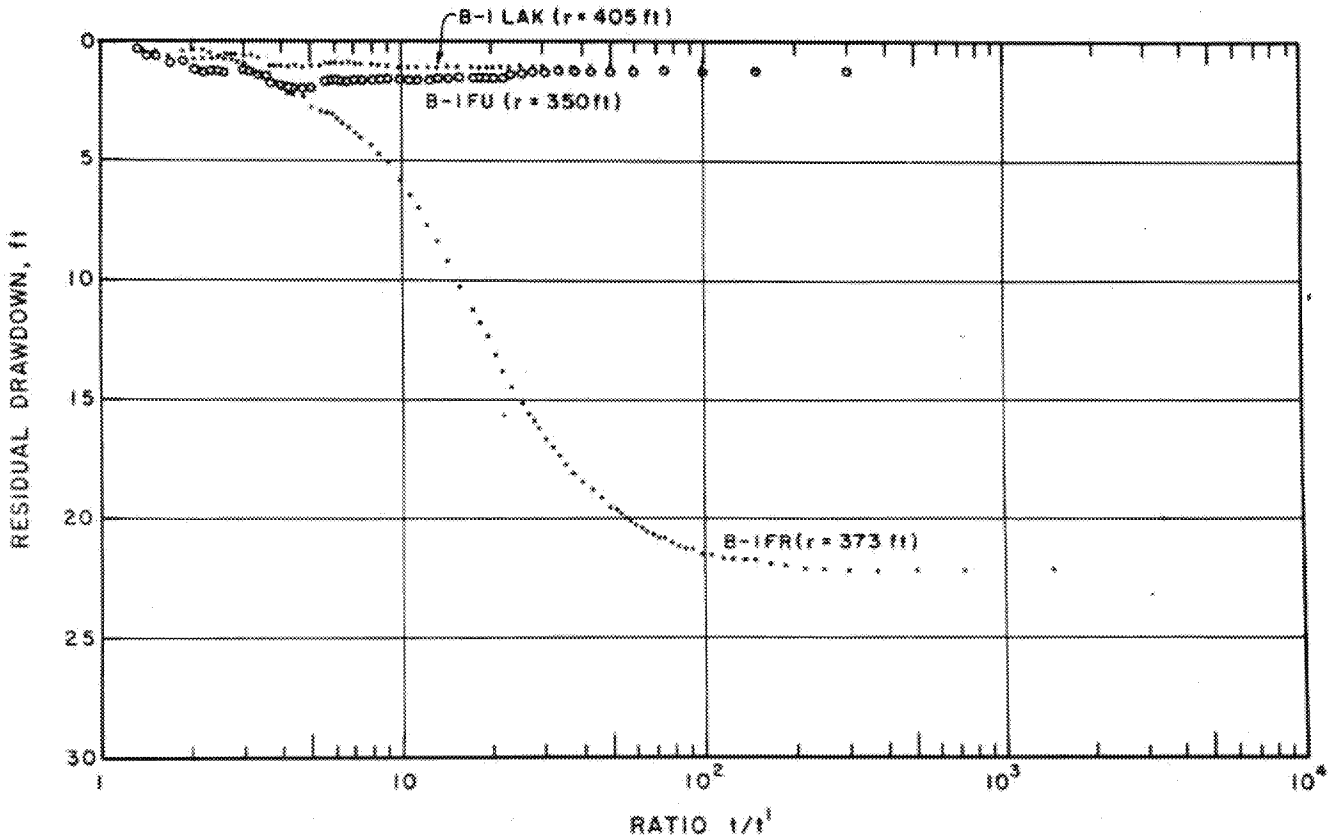


Figure 36: Recovery Graphs for B-1 Observation Well Group, Fall River Aquifer Test

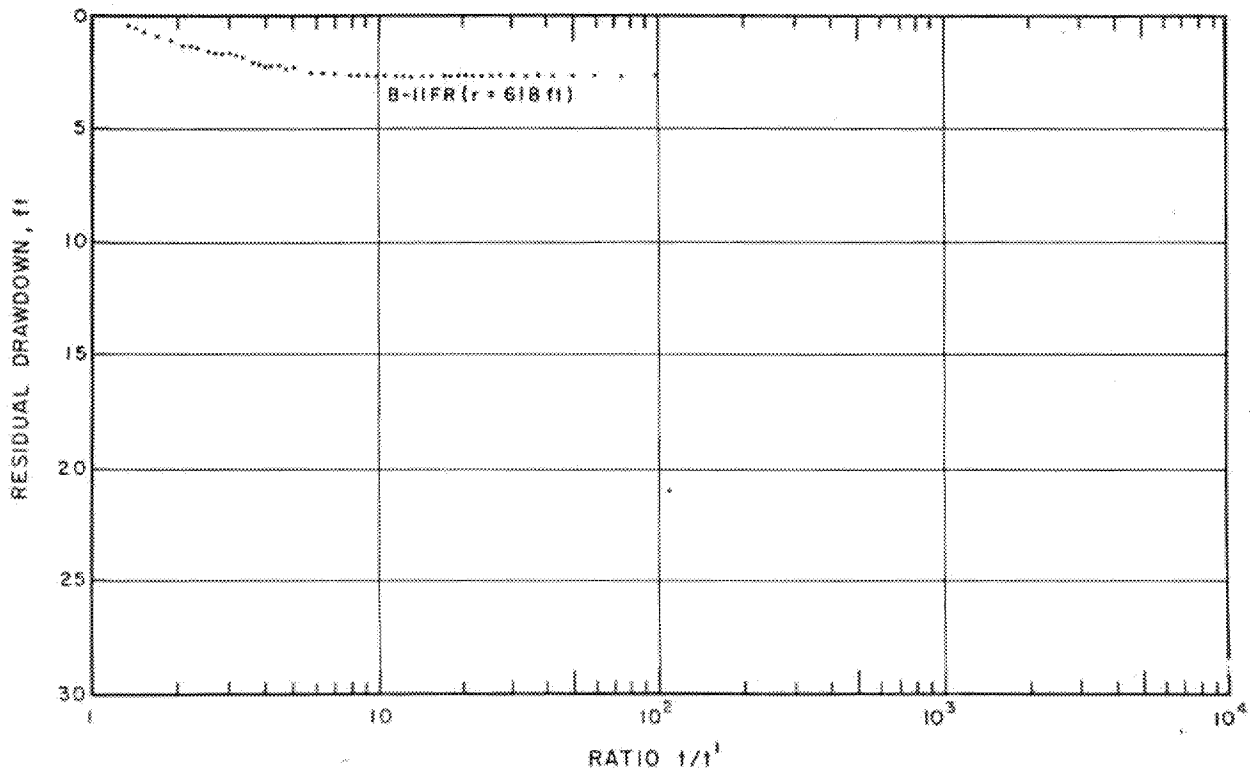


Figure 37: Recovery Graph for B-11 Observation Well Group, Fall River Aquifer Test

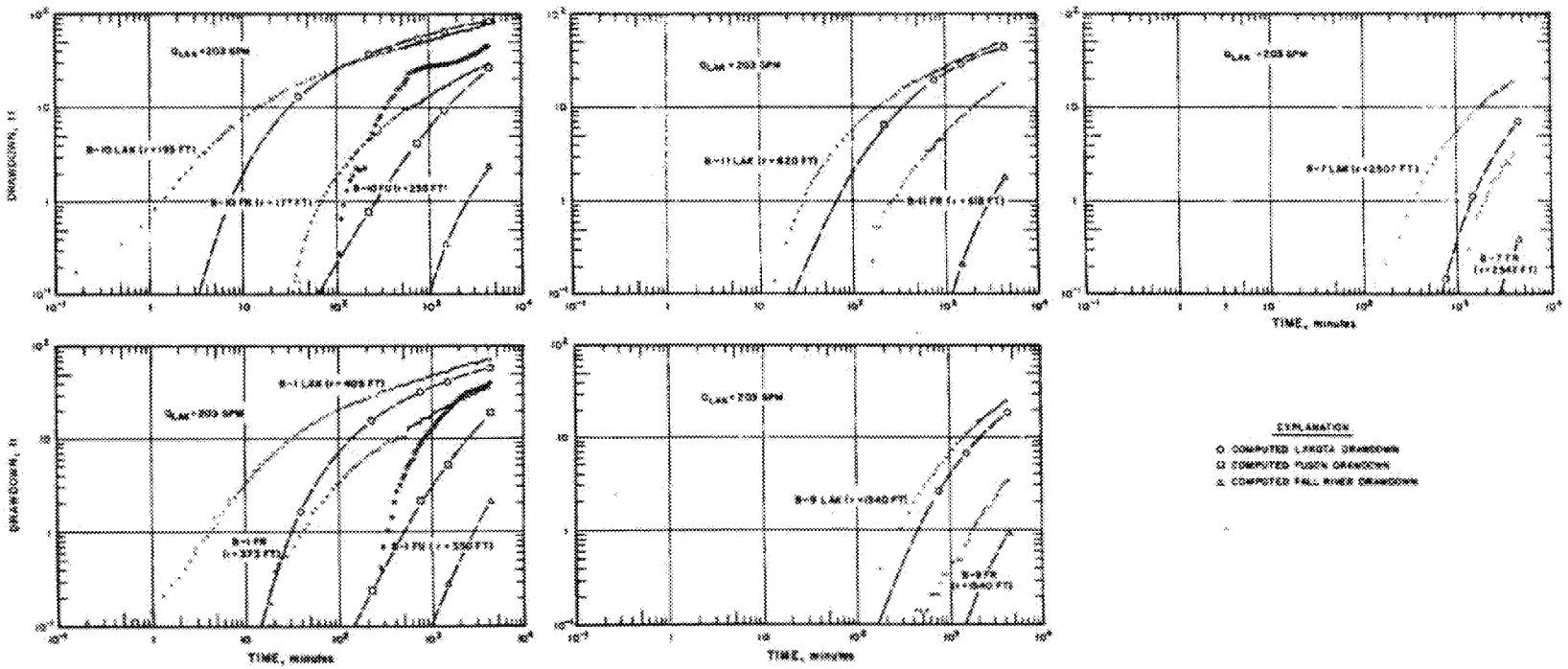


Figure 38 : Results of Initial Lakota Aquifer Test Simulation

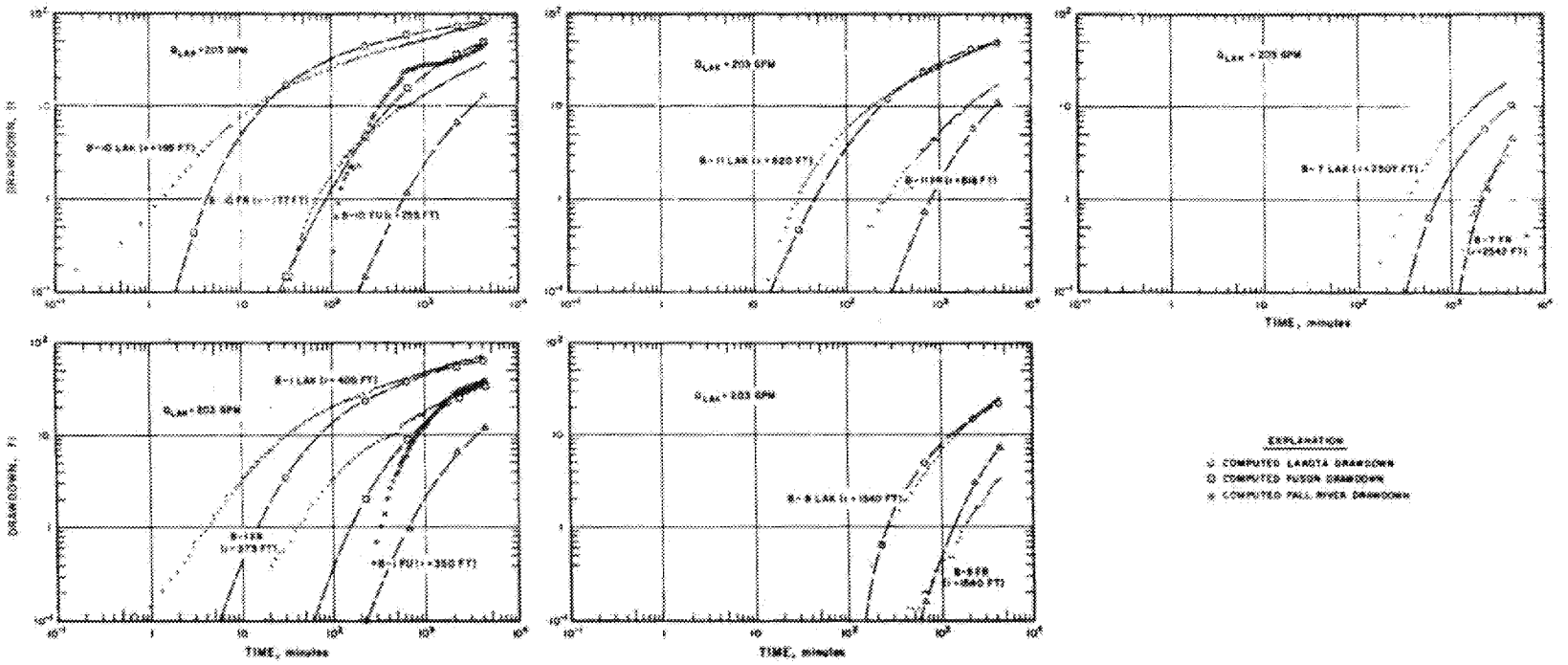


Figure 39 : Results of Final Lakota Aquifer Test Simulation



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BULLETIN OF THE AMERICAN ASSOCIATION OF PETROLEUM GEOLOGISTS
VOL. 40, NO. 5 (MAY, 1956), PP. 871-878, 2 FIGS.

# CLAY MINERALOGY OF MORRISON FORMATION, BLACK HILLS AREA, WYOMING AND SOUTH DAKOTA[1]

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## ABSTRACT

A study of the stratigraphy, lithology, and clay mineralogy of the Morrison formation is described. The geologic work was done in the Black Hills area, where four stratigraphic sections of the Morrison formation were examined, measured, and sampled, in detail.

The clay minerals were identified by the X-ray diffraction powder method. It was found that illite is the predominant clay mineral present in the formation. Kaolinite is abundant, and montmorillonite is rare.

It is concluded that there are various clay-mineral assemblages within the formation. They are of local significance only, and can not be used as a basis for subdividing the formation in this area.

The clay minerals are used as indicators to interpret a tentative environment of deposition.

## INTRODUCTION

Research on clay minerals during the past 30 years has done much to add to the relatively meager knowledge of these common substances, and the profession is now aware of the many possible implications afforded by studies of clay minerals. Efficient and positive identification of the clay minerals in sedimentary rock samples is no longer a problem. However, some difficulties exist. There are insufficient data on the clay mineralogy of recent sediments and ancient sediments of known origin. It is at present impossible to differentiate detrital and authigenic clay minerals in sediments; and it is also impossible to evaluate the relative importance of the different environments—weathering, sedimentation, and diagenesis—in the evolution of clay minerals.

An investigation of the stratigraphy, lithology, and clay mineralogy of the Morrison formation in the Black Hills area is described in this paper. X-ray and geologic data are evaluated and integrated with the object of contributing information on the clay mineralogy of a formation of known origin.

## LOCATION

The site of the geological work is shown on the index map (Fig. 1). Four exposures, located in Custer and Fall River counties, South Dakota, and Crook County, Wyoming, were sampled and studied in detail.

## GENERAL GEOLOGY

The Morrison formation can be recognized throughout the Black Hills area, with the exception of the southeastern part. It crops out in a narrow zone below

[1] Based on a thesis written in partial fulfillment for the degree of Master of Science, University of Wisconsin, 1955. Manuscript received, September 10, 1955.

[2] L. M. Cline, of the University of Wisconsin, suggested the study and acted as thesis supervisor. S. W. Bailey, of the University of Wisconsin, gave much invaluable information and advice on the X-ray technique and procedures. T. C. Larson, student at the University of Wisconsin, accompanied the writer in the field.



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escarpments of Lakota sandstone, except in a few localities where it occurs as outliers. The outcrop area conforms with the regional anticlinal structure, and is not complicated by local structure, except for some slumping. The geology of the area has been described in detail by N. H. Darton (1909).

## FIELD PROCEDURE

All of the accessible locations of the Morrison formation in the Black Hills area were visited and examined by the writer. Sections were measured with a steel tape to an accuracy of one inch, and samples were collected representing every vertical lithologic change. Lateral lithologic changes were noted and considered in sampling and descriptions. Every effort was made to collect only fresh, unweathered samples. Thirteen stratigraphic sections were referred to more detailed laboratory examination.

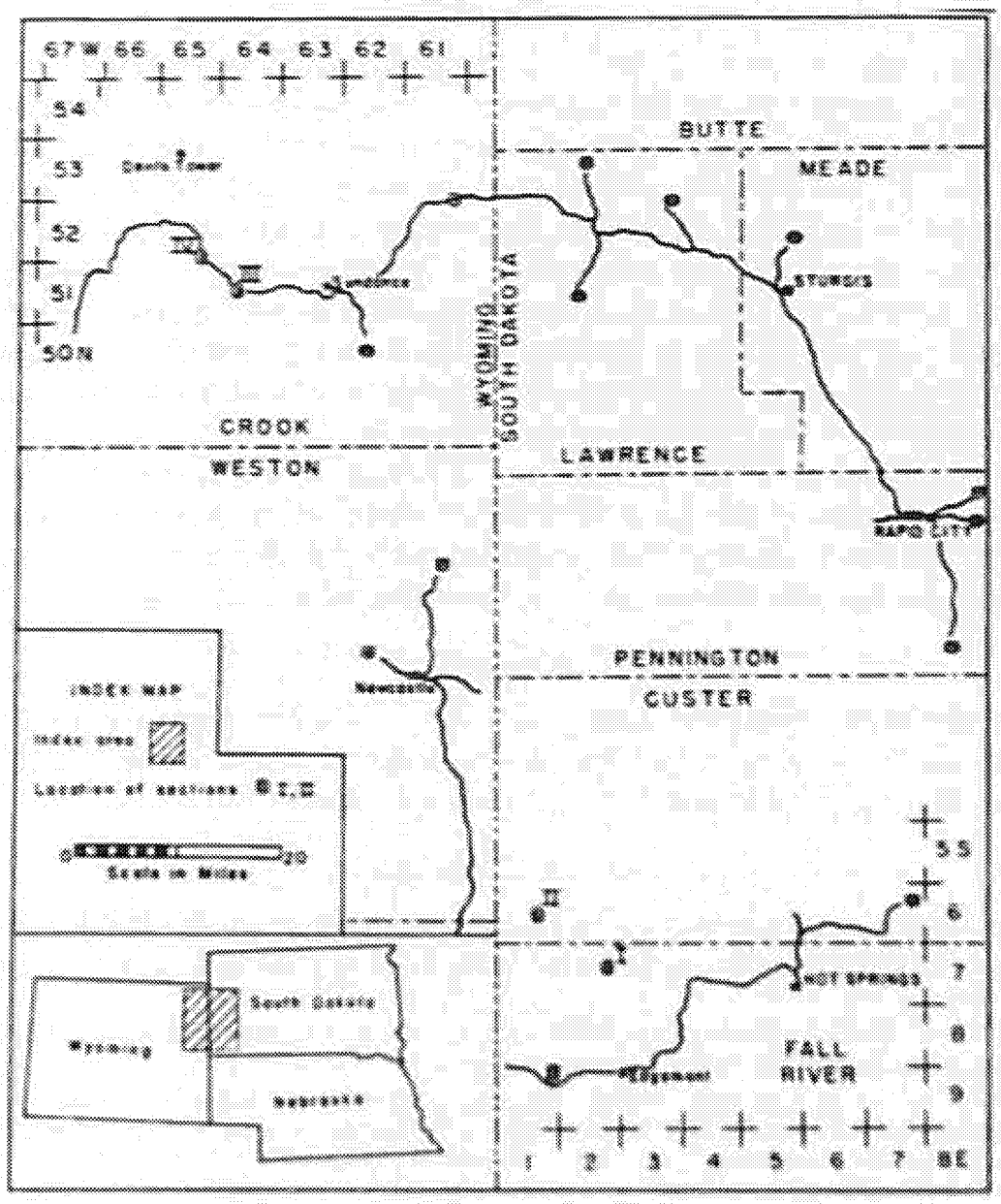


FIG. 1.—Map showing location of sections studied.

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## LABORATORY PROCEDURE

All lithologic samples collected in the field were examined in the sedimentation laboratory. The samples from four of the thirteen stratigraphic sections were prepared for X-ray work according to the procedure outlined by M. L. Jackson *et al.* (1949). This procedure consists essentially of the destruction of carbonates, saturation with hydrogen, oxidation of organic matter, dispersion with sodium carbonate, and separation of silt from clay at two microns.

Each clay sample was then ground to a fine powder, mixed with an equal volume of powdered gum tragacanth, moistened with water and rolled between two glass microscope slides until a rod 0.1–0.5 mm. in diameter was obtained. The powder rod was then mounted in a 114.6 mm. camera and photographed, by using filtered CuK$\alpha$ radiation.

The clay minerals were identified by comparing the unknown powder patterns with standard quartz, kaolinite, illite, and montmorillonite patterns. Solvation and heating methods were used to establish the presence of montmorillonite and kaolinite.

## MORRISON STRATIGRAPHY

In the Black Hills area, the Morrison formation rests unconformably on the Jurassic Sundance formation or Unkpapa sandstone, and is overlain disconformably by the Lakota sandstone. The upper contact is sharp and represented by an abrupt lithologic change, whereas the lower contact is commonly gradational. The formation shows a great range in thickness, ranging from a featheredge to 223 feet, and averaging approximately 150 feet.

In this area the Morrison consists of lenticular strata of variegated mudstones and claystones, light gray, finely crystalline, argillaceous limestones, and minor amounts of sandstone, chert, and gypsum. Horizontally bedded and structureless units are common. The formation can not be divided into members. Lithologic units or discrete facies are not sufficiently continuous or distinct to warrant recognition of members.

The consensus is that the Morrison is largely fluviatile and fluviolacustrine in origin (Hatcher, 1903; Lee, 1915; and Mook, 1916). More recently, Craig *et al.* (1951) studied the Morrison in the Colorado Plateau province, the Southern Rocky Mountain province, and the western edge of the Great Plains province. Lithologic and mineralogic data from their study furnishes evidence for a fluviatile and fluviolacustrine origin.

The age of the formation has been the subject of considerable discussion. Most recently R. W. Imlay (1952) assigned the formation to the Upper Jurassic.

## CLAY MINERALOGY

Because of the abundance of argillaceous rocks in the Morrison formation, a special study of their clay minerals was undertaken. The main objective was to contribute information on the clay mineralogy of a formation of known origin. It was also proposed to investigate the possibility of correlating and subdividing the formation on the basis of the clay minerals.

A. J. Gude (1950), by use of X-ray diffraction, subdivided the Laramie formation at Golden, Colorado, into three stratigraphic intervals, based on clay-mineral assemblages. W. D. Keller (1953) subdivided the Morrison formation at the type locality (as proposed by Waldschmidt and Le Roy, 1944) on the basis of the most abundant clay mineral. Keller recognized five zones in the Morrison.

Time and facilities allowed only the identification of the main groups of clay minerals. Powder diffraction patterns were made from samples of the various argillaceous rocks selected from four stratigraphic sections. These sections were considered to represent fully the Morrison lithologic characteristics of the Black Hills. Sections I and II are most typical of the Morrison in this area and were found to correlate best on the basis of lithology and similar position. The relative abundance of clay minerals was estimated from the X-ray patterns, which were generally good. This suite, although not ideally complete, is probably numerous enough to give a representative sample of the clay mineralogy of the formation.

Quartz was found in all of the samples. No feldspar, as such, was identified in the X-ray patterns. No carbonates were found in stratigraphic sections III and IV, and all carbonates were removed from sections I and II before X-rays were made. Three types of clay minerals—illite, kaolinite, and montmorillonite—were found distributed throughout the stratigraphic sections. The distribution of the clay minerals and their relation to lithologic character are presented in Figure 2.

Illite is present in all of the stratigraphic sections examined, and is the most abundant clay mineral. It is the dominant clay mineral in sections I, II, and IV, and is associated with kaolinite in section III.

Kaolinite is also present in all of the examined stratigraphic sections. It is the dominant clay mineral in section III and is associated with illite in sections I, II, and IV. It is nowhere associated with the calcareous argillaceous rocks, and generally occurs near the top of the formation.

Montmorillonite is the least abundant clay mineral. It occurs in only two samples. Its presence would seem to confirm the observations of those who consider the Morrison to have been derived in a large part from fragmental volcanic material. However, in the area examined by the writer, its occurrence is local, and the absence of chards and a suite of minerals characteristic of volcanic material suggest that the origin of the montmorillonite could be better explained by local environmental conditions.

At Edgemont (stratigraphic section I) the zones of dominant clay minerals in the argillaceous members of the Morrison formation have the following approximate thicknesses from top to base.

| | *Feet* |
|---|---|
| 1. Covered interval | 19.00 |
| 2. Montmorillonite | 1.00 |
| 3. Illite | 3.50 |
| 4. Kaolinite-illite | 11.75 |
| 5. Illite | 45.74 |
| 6. Kaolinite-illite | 5.00 |
| 7. Illite | 56.25 |

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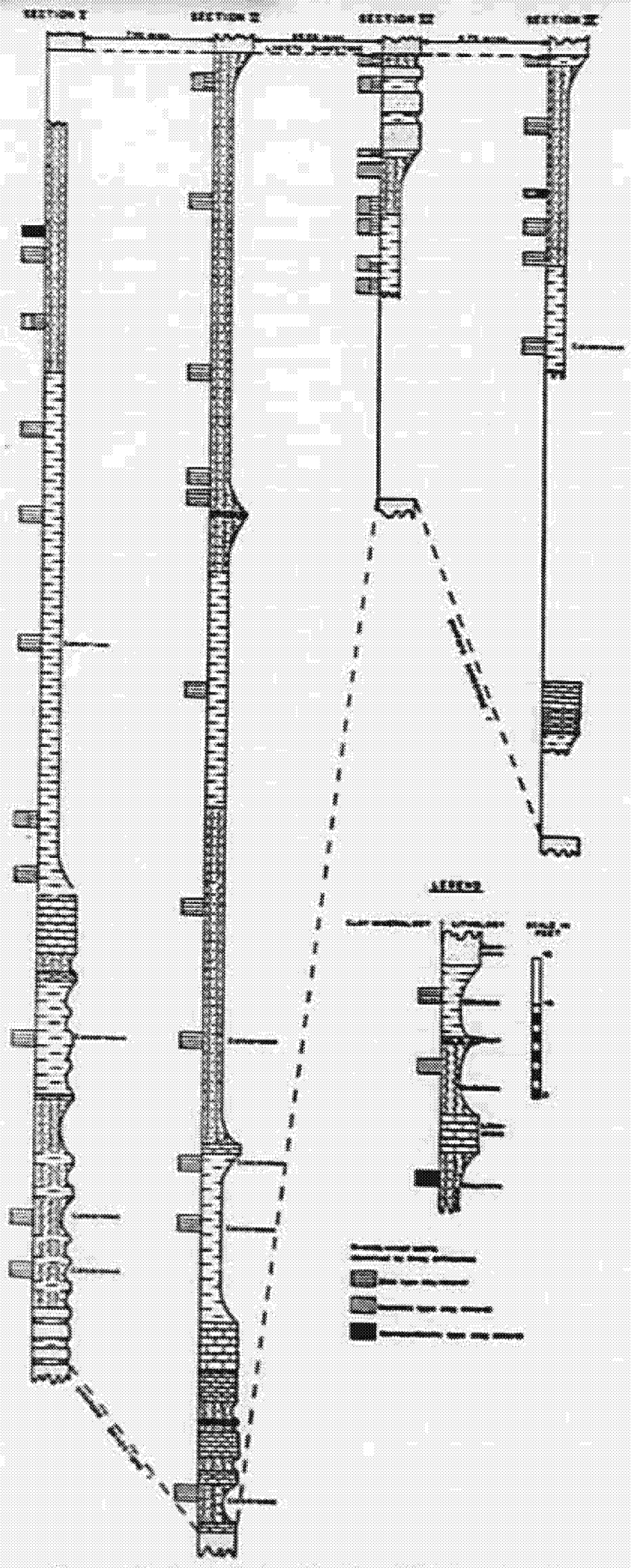

FIG. 2.—Lithology and clay mineralogy of Morrison formation.

Mineralogical studies of sections II, III, and IV show that the clay mineral zones of the Edgemont section (stratigraphic section I) do not apply to the area north of Edgemont. For instance, a zonation of section II, based on dominant clay minerals in the argillaceous members, would consist of an upper kaolinite-illite zone (5 feet) and a lower illite zone (153 feet). There is this marked difference despite the fact that the formations are only 7 miles apart, and are closely correlative on the basis of gross lithologic character and similar position. Sections III and IV can not be zoned because the base of the formation is not exposed. They are included, however, because they do illustrate the marked differences in the clay-mineral assemblages of the formation in this area.

## ENVIRONMENT OF DEPOSITION

With the development of methods for studying the clay minerals themselves, it began to be recognized that these might yield valuable evidence of the origin of the sediment. It is known that the clay minerals are notably sensitive in a quantitative way to their physical and chemical environment (Ross and Hendricks, 1945; Grim, Dietz, and Bradley, 1949; Grim, 1951; Millot, 1952; Keller, 1953). However, some difficulties exist, and one must be cautious in using the clay minerals as indicators of environment. There are insufficient data on the clay mineralogy of recent sediments and ancient sediments of known origin. It is at present impossible to differentiate detrital and authigenic clay minerals in sediments. It is also impossible to evaluate the relative importance of different environments—weathering, sedimentation, and diagenesis—in the evolution of clay minerals.

Because of these difficulties the following environmental interpretations should be regarded as only tentative.

It has been noted that montmorillonite is rare in the area studied, and that its occurrence and associations do not suggest a volcanic origin. Millot (1952) found that montmorillonite was an uncommon component of ancient sediments and that no general conclusions regarding its origin could be reached. Grim *et al.* (1949) found widespread montmorillonite in modern sediments. The consensus is that montmorillonite is formed under conditions of arrested drainage and restricted oxidation. Probably these conditions did exist locally and local conditions (such as low potassium or magnesium availability) favored the preservation of montmorillonite.

Kaolinite is abundant in the Morrison formation of this area, being the dominant clay mineral in section III. The calcareous argillaceous rocks are notably lacking, a condition which is consistent with the usual occurrence of kaolinite (Millot, 1952). In environments of deposition, kaolinite genesis is favored by an abundance of circulating, "aggressive," acid waters, which characterize the continental lacustrine and fluviolacustrine facies of Millot (1952). This environment is consistent with the non-marine origin which is generally accepted for the Morrison.

The predominance of illite in sections I, II, and III, suggests a depositional

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environment consisting of fairly stagnant waters, alkaline pH, and abundant cations (metal). These conditions characterize the normal marine environment, but are not foreign to "fresh-water" (low NaCl content). Millot's (1952) basic continental lake facies is characterized by the common presence of carbonate, salts ($CaSO_4$), flint, a fauna consisting of *Limnea*, *Planorbis*, *Unio*, *Helix*, *et cetera*, in some places by the three-layer minerals (illite, chlorite, montmorillonite), and in others by the fibrous minerals of the polygorskite group. These characteristics, lithologic, paleontologic, and mineralogic, are also characteristic of the examined stratigraphic sections.

The occurrence of kaolinite in these sections can be explained by changes in the character of the waters, that is, from stagnant and alkaline to increased circulation, less $K^+$, and more $H^+$. Millot (1952) has also suggested that the presence of carbonates depresses the development of kaolinite.

The foregoing tentative environmental interpretations were based on an authigenic origin of the clay minerals. It is possible, however, that the conditions of sedimentation and diagenesis may be more important than the nature of the environment being studied. One can not deny the importance of the nature of the parent material, the location and relief of source areas, climatic changes, character and abundance of vegetation, rates of deposition, and the function of time in the evolution of the minerals being studied. Certainly they do afford convenient and possibly valid alternative explanations for some of the mineral associations.

The occurrence and association of specific clay minerals suggest a series of lakes, some of them basic, calcareous, saline, and fairly stagnant, and others, acid, and characterized by "aggressive" waters and heavy leaching. This environment is consistent with the non-marine environment generally concluded from the Morrison fauna and flora. The lack of continuous lithologic units or discrete facies and the variability of clay mineral assemblages suggest that the lakes were of limited extent, and that deposition and erosion alternated.

## SUMMARY OF MINERALOGICAL DATA

1. Illite is the predominant clay mineral in the formation. Kaolinite is abundant, and montmorillonite is rare.

2. There are various clay-mineral assemblages. They are of local significance only, and can not be used as a basis of subdividing the Morrison formation in this area.

3. It is too early to assess fully the value of clay minerals as indicators of environment. More information—clay mineralogy integrated with lithologic, stratigraphic, and petrographic characteristics—is necessary. At present it is best to regard any environmental interpretations as tentative.

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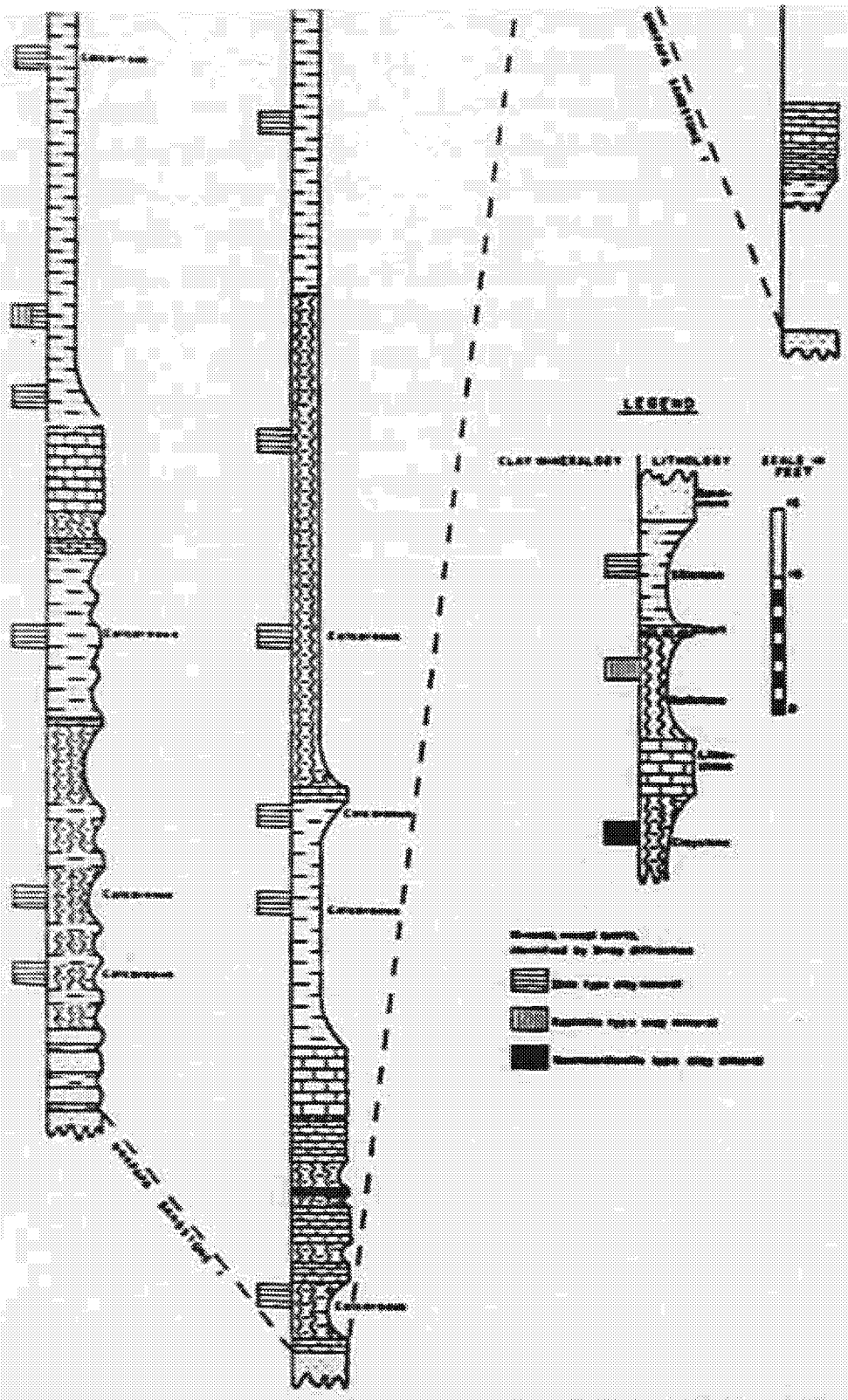
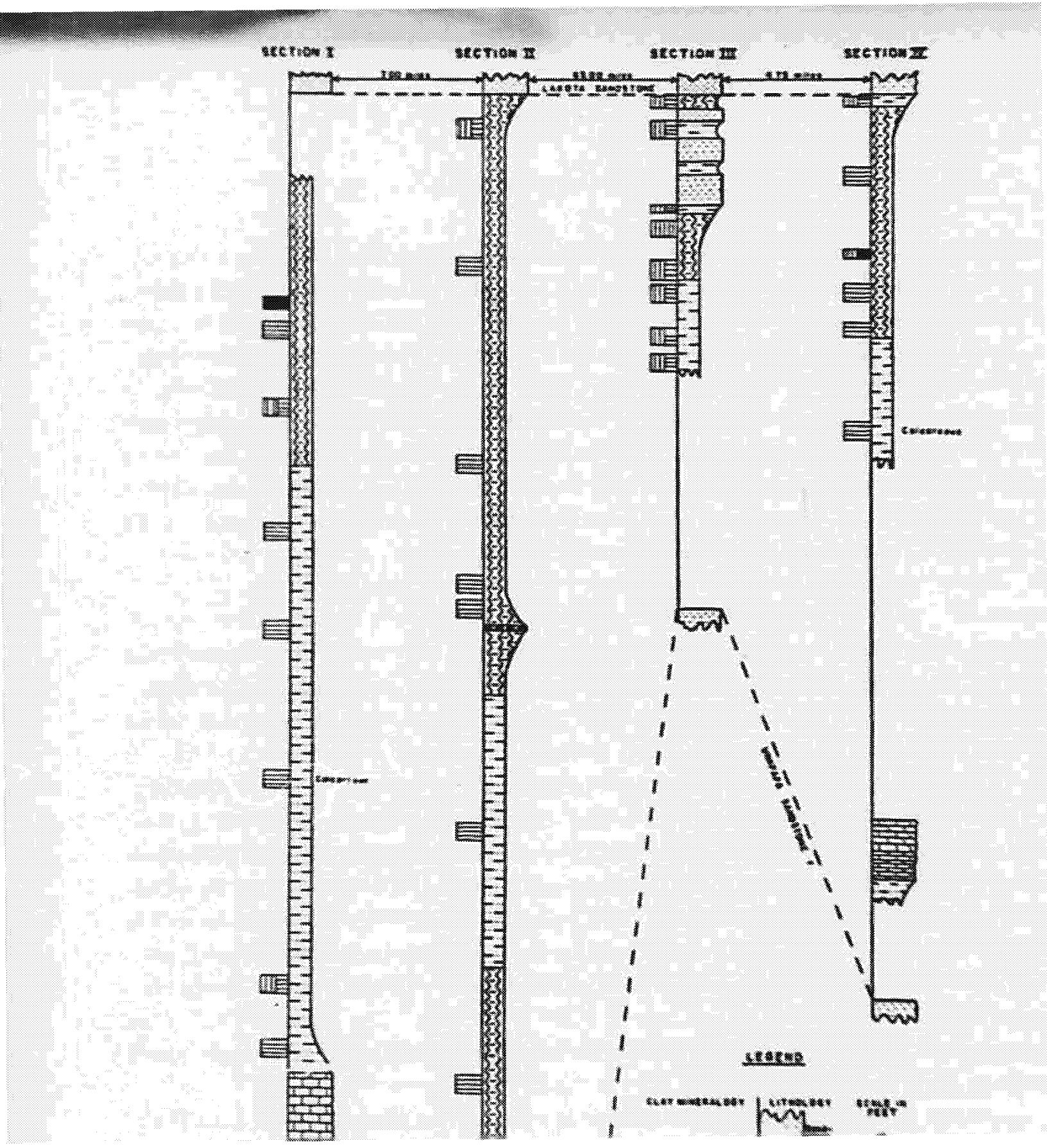



FIG. 2.—Lithology and clay mineralogy of Morrison formation.


SECTION I
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LEGEND

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# PERMEABILITY OF THE INYAN KARA GROUP IN THE BLACK HILLS AREA AND ITS RELEVANCE TO A PROPOSED IN-SITU LEACH URANIUM MINE

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## ABSTRACT

Fluvial sandstone channels in the Cretaceous Inyan Kara Group in western South Dakota have variable thickness and texture, causing variability of the hydraulic conductivity. Pumping tests in two 120-ft thick sandstones at a proposed in-situ leach uranium mine in the Dewey/Burdock area provide hydraulic conductivity data. The hydraulic conductivity in the upper sandstone (Fall River Formation) is approximately 0.45 ft/day and the lower sandstone (Chilson Member of the Lakota Formation) is approximately 1.56 ft/day. These data, along with the prevailing gradient of the potentiometric surface, yield an average groundwater velocity for these two sandstones in the Inyan Kara Group of approximately 66 ft/year.

A groundwater velocity determination of 5,480 ft/year in the Inyan Kara Group near the Dewey/Burdock site was based on 1963 tritium data (Gott et al. 1974). This value seems very high, and contradicts the velocity based on hydraulic conductivity, but if valid, indicates fast groundwater movement through very permeable units or through fractures.

An important environmental consideration following the abandonment of this proposed uranium mine is that the groundwater will migrate down gradient and may contain a high concentration of dissolved uranium (with daughter products radium and radon) and selenium. The rate of movement of these elements would be less than the groundwater velocity because of retardation associated with geochemical reactions related to changes of pH and oxidation/reduction potential.

Keywords

Permeability, groundwater, Inyan Kara Group, uranium mine

## INTRODUCTION

This paper contains information about the hydrogeology and permeability of a Cretaceous sandstone aquifer in South Dakota called the Inyan Kara Group. Particular attention is focused on the southwestern Black Hills area where an in-

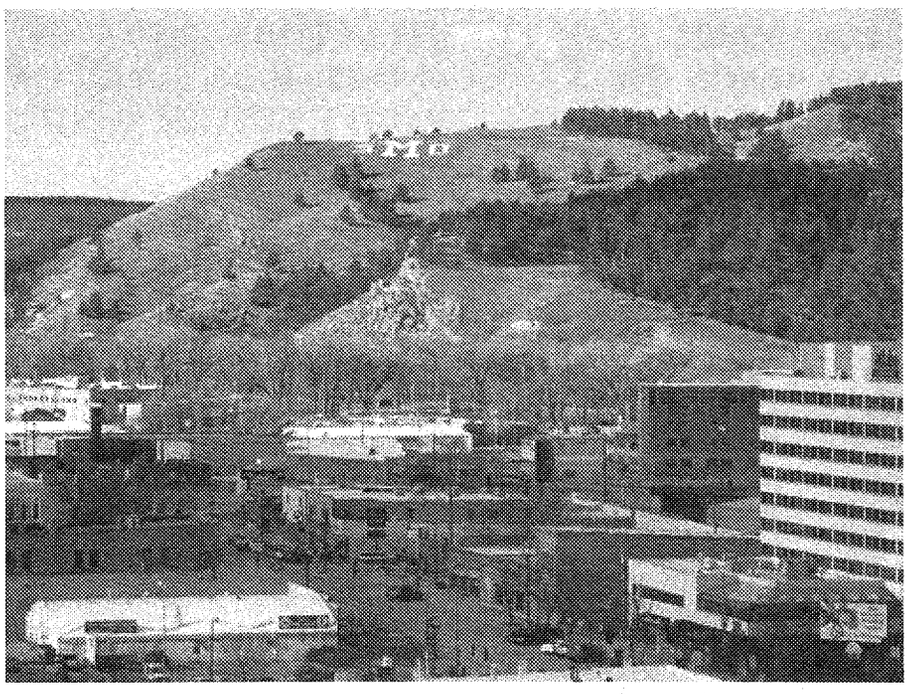

*Figure 1. Photograph of the Rapid Creek water gap in Rapid City, as seen from the top of the Alex Johnson hotel. The "M" is on the Chilson Member of the Lakota Formation. The closer sandstone is the Fall River Formation. The two Cretaceous sandstones dip easterly at approximately 20 degrees.*

situ leach (ISL) uranium mine is planned. The purpose of this paper is to evaluate the permeability of the Inyan Kara Group and to ascertain the groundwater velocity and potential for contaminant transport from this mine.

The Inyan Kara aquifer, originally called the Dakota aquifer, underlies much of South Dakota and is one of the most famous aquifers in the United States. In the Black Hills area the Inyan Kara Group contains two prominent sandstone strata, the Chilson Member of the Lakota Formation and the overlying Fall River Formation (Figure 1).

Darton (1909) conducted some of the earliest hydrogeologic studies of this aquifer. Gries (1958) developed a stratigraphic model showing that the Dakota Sandstone in eastern South Dakota is roughly equivalent to the Newcastle Formation and the Inyan Kara Group in western South Dakota. Schoon (1971) studied facies within the Inyan Kara Group and showed that the sandstone units, such as the Chilson Member, are fluvial channel units in the Lakota Formation. Keene (1973) studied the Inyan Kara aquifer in Fall River County and found the potentiometric surface in western Fall River County slopes southerly. Strobel et al. (2000) showed the potentiometric surface elevation for the Inyan Kara Group in the southern Black Hills. Bredehoeft et al. (1983) examined alternate theories for regional recharge to this aquifer and concluded that much recharge occurs

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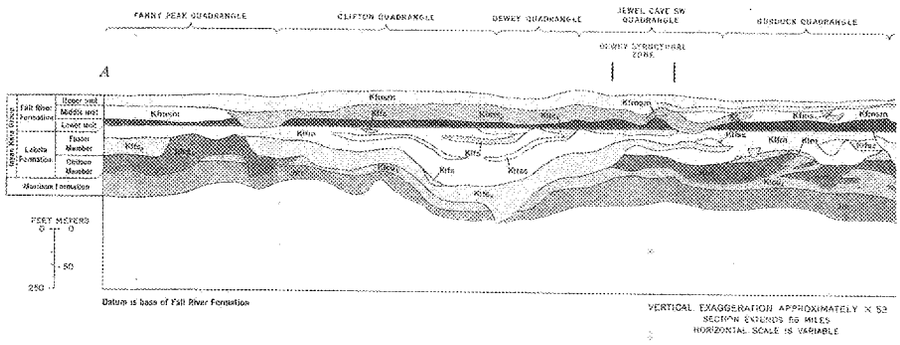


***Figure 2. Diagrammatic geologic cross section showing stratigraphy of the Inyan Kara Group in the southern Black Hills (from Gott et al. 1974). The Fall River Sandstone is shown as $Kfms_s$, and the Chilson sandstone member of the Lakota Formation is shown as $Klcs_l$. The two main sandstone units show great variability in thickness from the Wyoming border through the Dewey, Burdock and Edgemont areas.***

from leakage from overlying shale. Case (1984) and Carter et al. (2003) showed typical permeability values for the Inyan Kara aquifer.

Detailed geologic mapping in the southern Black Hills was conducted by the U.S. Geological Survey (USGS) in the 1950s and 60s for the purpose of evaluating uranium resources. Figure 2 is a cross section of the Inyan Kara Group in the southwestern flank of the uplift showing stratigraphic facies and the variable thickness of this unit.

## HYDRAULIC CONDUCTIVITY DETERMINATION

Several published reports quantitatively document the hydraulic conductivity (K) of the Inyan Kara Group (Table 1). Information concerning the data shown in Table 1 and other studies is given below.

***Table 1. Permeability data for the Inyan Kara Group (Driscoll et al. 2002)***

| | Hydraulic Conductivity (ft/day) | Transmissivity ($ft^2$/day) |
|---|---|---|
| Niven (1967) | 0 – 100 | — |
| Miller and Rahn (1974) | 0.712 | 178 |
| Gries et al. (1976) | 1.26 | — |
| Bredehoeft et al. (1983) | 8.3 | — |
| Kyllonen and Peter (1987) | — | 0.86 – 6,000 |

Niven (1967) measured the permeability of cored samples from outcrops in the Black Hills and found the mean hydraulic conductivity of the Lakota Formation is 22.5 ft/day and the Fall River Formation is 4.8 ft/day. Bredehoeft et al.

(1983) pointed out that "one would expect the outcrop to yield higher hydraulic conductivities than exist in the subsurface". Using a best-fit model of western South Dakota, Bredehoeft et al. (1983) determined a horizontal hydraulic conductivity of 8.29 ft/day in the Inyan Kara Group sandstone units.

Based on a recovery test for a 2,300-ft well into the Fall River and Lakota Formations at Box Elder, Miller and Rahn (1974) found the transmissivity (T) to be 1,333 gpd/ft (equivalent to 178 $ft^2$/day). Because the thickness (b) of the two sandstone units at Box Elder is 250 ft, the hydraulic conductivity (K) is 0.712 ft/day.

Three observation wells were used at Wall, South Dakota, where a pumping test showed anisotropic transmissivity (Rahn 1992). The 3,300-ft deep wells are open to the Lakota Formation, and the sandstone thickness is approximately 200 ft. The transmissivity averages 2,400 gpd/ft (321 $ft^2$/day) and storativity is 0.000,027. The average hydraulic conductivity is: K = T/b = 321 $ft^2$/day/200 ft = 1.60 ft/day. The principal transmissivity direction was found to be N 35° W, interpreted as the paleodirection of Cretaceous rivers.

An 11-day constant discharge pumping test involving 13 observation wells was conducted in the Lakota aquifer at TVA's proposed underground uranium mine near Dewey, South Dakota (Boggs 1983). In this area the Cretaceous Inyan Kara Group dips approximately 5 degrees towards the west-southwest off the Black Hills uplift and consists of two sandstone aquifers, the Fall River Formation, typically 120 ft of fine-grained sandstone, underlain by the Chilson Member of the Lakota Formation, 120 ft of fine-to-coarse grained sandstone (Boggs and Jenkins 1980; Boggs 1983). Figure 3 shows these two units. The pumping tests indicate the Lakota at this location is exceptionally permeable, having a transmissivity of 4,400 gpd/ft (587 $ft^2$/day). Boggs (1983) noted that this test site is in an area where the Lakota is composed of a thick, exceptionally coarse-grained sandstone.

A pumping test in the Chilson Member of the Lakota Formation for the proposed Tennessee Valley Authority (TVA) underground mine at Burdock, South Dakota, by Boggs and Jenkins (1980) indicated the transmissivity is approximately 1,400 gpd/ft (187 $ft^2$/day). A contour map of the drawdown (Boggs and Jenkins, 1980, Figure 19) shows a slight elongation in the northeasterly direction [Note: Boggs and Jenkins (1980) showed this map but mistakenly reported this

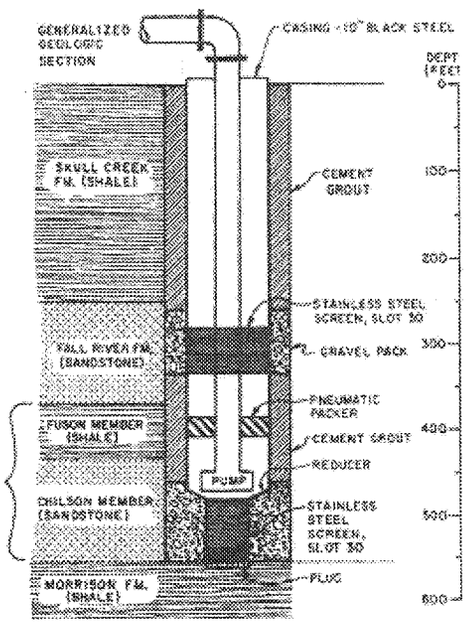


*Figure 3. Geologic log of Burdock well (Boggs and Jenkins 1980).*

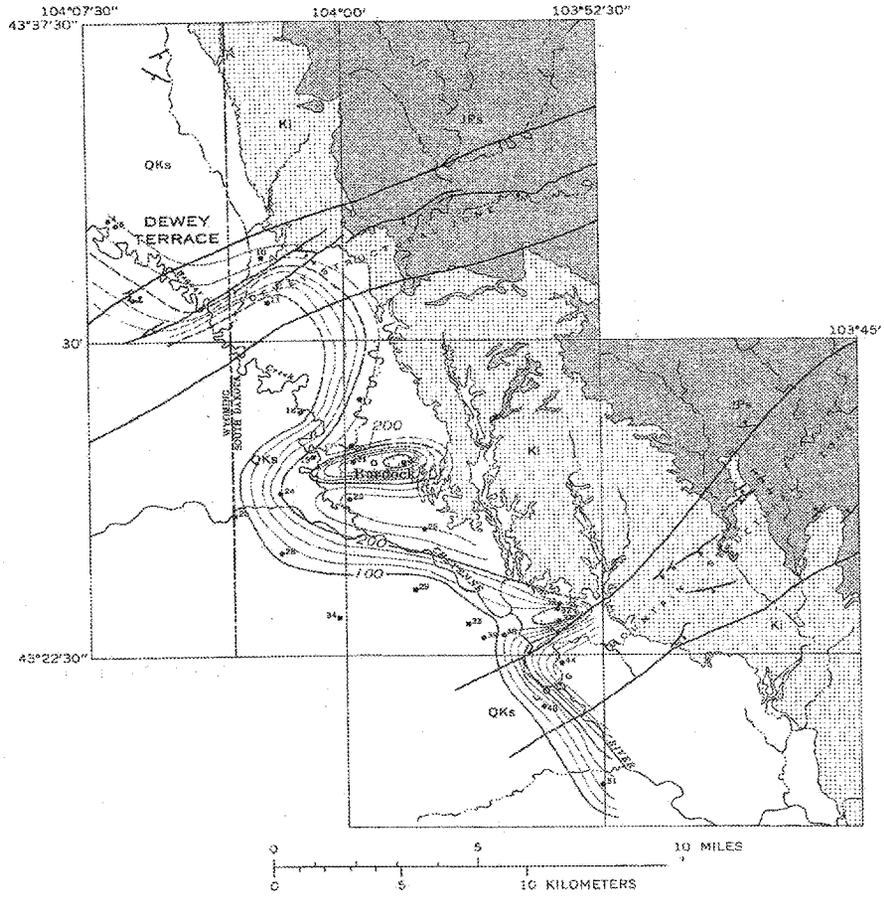


***Figure 4. Map showing tritium distribution in groundwater in the Inyan Kara Group (from Gott et al. 1974).***

elongation is "...in a northwesterly direction".] The greater permeability in the northeast-southwest direction most likely reflects the orientation of the Cretaceous stream channels. The Chilson Member consists of 120 ft of fine-grained sandstone and siltstone; hence the hydraulic conductivity is 11.7 gpd/ft (1.56 ft/day). A second test on the Fall River Formation found the transmissivity to be 400 gpd/ft (53.5 $ft^2$/day). The Fall River Formation consists of approximately 120 ft of interbedded fine-grained sandstone, siltstone, and carbonaceous shale; hence the hydraulic conductivity is 3.33 gpd/ft (0.45 ft/day). Subsequent pumping tests for the proposed Powertech ISL mine in the Dewey/Burdock area (Knight-Piesold 2008; Powertech 2009a, 2009b) indicate similar transmissivity values to those determined by the TVA investigations.

## TRITIUM

An unusual insight into the permeability and groundwater velocity was provided by Gott et al. (1974) who reported the presence of tritium in groundwater in the Inyan Kara Group near Burdock, South Dakota (Figure 4). The tritium originated from the 1963 Pacific hydrogen bomb fallout. From the location of the tritiated groundwater, Gott et al. (1974) determined that "...near the confluence of Beaver Creek and the Cheyenne River, a flow of 15 feet per day is required to transmit tritium rain-out of the year 1963 from the recharge area at the Inyan Kara outcrop to the positions of the large tritium concentration..." No supporting groundwater velocity calculations were provided by Gott et al. (1974), and this velocity seems quite high. It is possible that there was a tritium sampling error. If, in fact, the true velocity ($V_t$) is 15 ft/day (equivalent to 5,480 ft/year), two unlikely scenarios would be manifest:

1. **Hydraulic conductivity.** The Darcy velocity ($V_d$), also called the "specific discharge", through an aquifer is equal to the true velocity ($V_t$) times the porosity (here assumed to be 10%). Therefore: $V_d = V_t$ (porosity) = 15 ft/day (0.1) = 1.5 ft/day. Near Burdock the potentiometric surface in the Inyan Kara Group slopes south-southwesterly (Boggs and Jenkins 1980). TVA (1979) reported a hydraulic gradient of 9.8 m/km in the Lakota Formation at the Burdock site. The spacing of the equipotential contour lines varies locally, and in the Dewey/Burdock area a head loss from 3700 ft to 3600 ft elevation occurs over a distance of approximately 2.4 miles. Therefore, H/L = 100 ft/12,672 ft = 0.0079. From "Darcy's Law" (Rahn, 1996): $V_d = K$ (H/L); therefore the hydraulic conductivity (K) = $V_d$ /H/L = 1.50 ft/day/0.0079 = 190 ft/day. This value seems unrealistically high. For example, Boggs and Jenkins (1980) show the hydraulic conductivity of the Fall River Formation at Burdock is only 0.45 ft/day.

2. **Recharge rate.** Consider the discharge (Q) of groundwater through 1 $ft^2$ cross section of the Inyan Kara aquifer having $V_t$ = 15 ft/day. With 10% porosity, the effective cross-sectional area is 0.1 $ft^2$, and the discharge through this cross section would be: Q = $V_t$ A = 15 ft/day (0.1 $ft^2$) = 1.5 $ft^3$/day. Adequate recharge from precipitation on Inyan Kara outcrops is necessary to sustain this discharge. Brobst (1961) shows the Inyan Kara Group in this area dips approximately 500 ft/mile (equivalent to 5.4 degrees); thus the discharge through a horizontally-oriented recharge area required to service a 1 $ft^2$ cross section of sandstone = 1.5 $ft^3$/day (sin 5.4 degrees) = 1.5 (0.09427) = 0.1414 $ft^3$/day. Sustaining this discharge would require 365 (0.1414) = 51.6 ft of precipitation recharging annually on the outcrops. Obviously this is not possible.

Gott et al. (1974) could have over-estimated the groundwater velocity because they underestimated the distance of transport from the suspected recharge area to the sampling site. Figure 4 shows the locations of wells and springs sampled

in 1967 for tritium. The distance to the Inyan Kara outcrops ranges from approximately one to five miles away. Gott et al. (1974) do not show calculations supporting their velocity determination of 15 ft/day, but most likely they assumed a slug flow of tritiated water moved from the recharge area to the sampled well or spring site from rainout that fell in 1963. [Note: tritiated precipitation peaked in 1963 (Freeze and Cherry 1979); Back et al. (1983) show tritiated rain fell in the Black Hills area as early as 1953.] From Figure 4, fifteen feet per day appears to be the maximum velocity.

Another possible explanation for the presence of tritium in the sampled wells is that it entered the aquifer quite close to the sampling locality. It may have leaked downward through overlying shale (from Figure 3 the Fall River Formation is only 250 ft depth). This explanation would support the model by Bredehoeft et al. (1983) suggesting recharge to the Inyan Kara Group occurs through the overlying shale. Another possible explanation is that tritiated water may have leaked down along the casing of the sampled well. However this seems unlikely since many of the sampled sites are artesian wells or springs.

A study by Johnson (2012) shows recent tritium concentration data in this area of up to 15.3 tritium units. Considering that the half-life of tritium is 12.3 years, these data may essentially represent the same water as 1967 except that the tritium has undergone radioactive decay. This indicates the water is not moving through the aquifer at 15 ft/day.

Another possible explanation for the presence of tritium as shown in Figure 4 is that in 1963 it recharged the outcrops as visualized by Gott et al. (1974) but traveled along extremely permeable pathways. These could be fractures in the sandstone (Figure 5) or very permeable conglomerate channels. Gott et al. (1974) point out that cross-bedded sandstone beds contain many intertonging lenses that vary from fine-grained sandstone to conglomerate with pebbles greater than three inches in diameter. The direction of dip of the crossbeds within the sandstones indicates the paleostreams flowed northwesterly. Figure 4 shows the "Dewey Fracture Zone". This zone is shown on geologic maps as the Dewey Fault by Brobst (1961) and the Dewey Fault and Structural Zone by DeWitt et al. (1989). Schnabel (1963) describes well-defined vertical joint systems in the Burdock quadrangle that typically strike N 75-85 degrees E and N 35-45 degrees E. The isograms of tritium content on Figure 4 seem to bend in a manner suggestive that high tritium is associated with the fractures. While the 15 ft/day groundwater velocity posited by Gott et al. (1974) seems enigmatic, a possible explanation is that the tritiated water followed fractures, and did not travel through the sandstone interstices.

Hydrogeologists recognize that at a specific local site groundwater may move faster than the general regional flow. For example, in another Black Hills aquifer, the karstic Madison Limestone, there are diffuse flow components as well as solution-enlarged conduits that transport groundwater very rapidly (Long and Putnam 2004; Long et al. 2007). Back et al. (1983) used $^{14}C$ to determine the age of groundwater over a large area of western South Dakota. At Midland, for example, they found that the water was recharged 20,100 years ago, and using 10% porosity and the 260-km (162 mile) distance to the recharge area, they determined that the velocity was 12.9 m/yr (42.3 ft/year). The hydraulic gradient

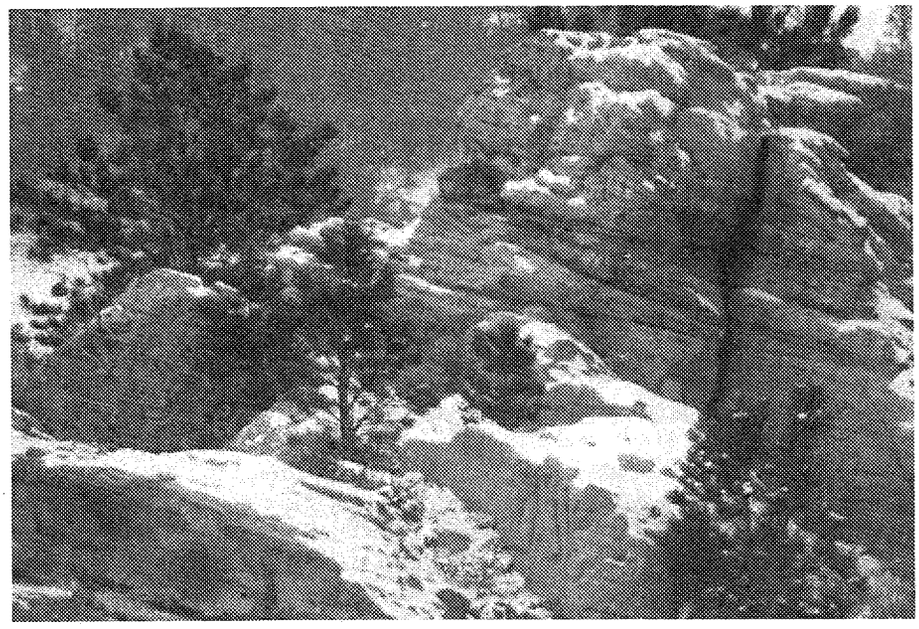

*Figure 5. Photograph of "Hangman's Hill" in Rapid City showing the cross-bedded sandstone (Chilson Member of the Lakota Formation) and a pronounced fracture.*

in the Midland area is 1.7 $X10^{-3}$, and the hydraulic conductivity was determined to be 24 X $10^{-6}$ m/sec (0.63 ft/day). This hydraulic conductivity is close to that determined from pumping tests in Rapid City (Greene and Rahn 1995). Despite these determinations of hydraulic conductivity and velocity, locally there are conduits in the Madison Limestone that permit exceptionally fast movement. For example, dye introduced into sinkholes along Boxelder Creek was traced to Gravel Spring in 68 minutes (Rahn and Gries 1973). The distance is 2,200 ft, so the groundwater traveled at 47,000 ft/day. The dye was traced to City Spring in Rapid City in 34 days (Rahn and Gries 1973; Greene and Rahn 1995). This distance is 7.5 miles, so the groundwater traveled at 1170 ft/day. Unlike the Madison Limestone, the Inyan Kara Group is not a karst aquifer; nevertheless local high groundwater velocity may occur.

In spite of the seemingly enigmatic tritium data, this paper shows a groundwater velocity determination through the two sandstones at the Dewey/Burdock area in the conventional manner using hydraulic conductivity data from pumping tests. These calculations assume that no fractures or extremely permeable conglomerate units are present, and that groundwater flows through the sandstone in a manner predicted by Darcy's Law.

## APPLICATION OF PERMEABILITY DATA TO THE PROPOSED DEWEY/BURDOCK MINE

The impact of the withdrawal of groundwater is an important part of any environmental assessment. The South Dakota Department of Environment and

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Natural Resources (SD DENR) approved the withdrawals for this ISL mine but is currently involved in litigation over Powertech's proposed withdrawal of 8,500 gallons per minute (gpm) from the Inyan Kara aquifer and 551 gpm from the Madison aquifer. Most of this water is pumped back into the aquifer and is used to introduce oxidizing chemicals necessary for the solution of the uranium minerals. Actual water consumed ("make-up water") is estimated by Powertech to be only 170 gpm. The predicted drawdown from groundwater withdrawals has been discussed in the Water Rights Section of the SD DENR website and is not included in this paper. Rather, the emphasis of this paper is to assess the natural groundwater velocity in this aquifer since this is a critical factor for evaluating the long-term impacts of introducing chemicals ("lixiviants") into this aquifer.

A major concern of ISL uranium mining is the chemistry of the residual groundwater after mining ceases, the rate of groundwater movement downgradient through this aquifer, and the possibility of mixing with water in other aquifers. Studies of existing ISL mines have shown that dissolved uranium and selenium are of particular concern (Borch et al. 2012). In order to assess the environmental impact of residual groundwater following mining at the proposed Dewey/Burdock project area, one can use permeability data to predict the groundwater velocity in the channel sandstones of the Inyan Kara Group.

For the purpose of this paper, pumping test data and the conventional use of hydraulic conductivity with Darcy's Law were applied to determine the groundwater velocity. Table 2 summarizes aquifer parameters that are most relevant to the proposed Dewey/Burdock in-situ leach uranium project. Figure 3 is a geologic section of the Burdock well used in a pumping test by Boggs and Jenkins (1980). The top of the Fall River Formation lies at 250 ft depth and the top of the Chilson Member of the Lakota Formation lies at 430 ft depth. From Table 2, transmissivity averages 365 $ft^2/d$ at the three Lakota Formation (Chilson Sandstone Member) sites. The range of values, from 187 to 587 $ft^2/d$, is caused, by some degree, to the variable thickness of the sandstone. The coarseness of the sandstone is certainly another reason for transmissivity variability; for example, the largest value, 587 $ft^2/d$, occurs where coarse-grained sandstone is reportedly present.

***Table 2. Relevant aquifer data (modified from Boggs and Jenkins 1980)***

| Site | Unit studied | Hydr. Cond. (ft/d) | Thickness (ft) | Transmissivity ($ft^2/d$) |
|---|---|---|---|---|
| Dewey | Lakota Fm. (Chilson) | 4.92 | 120 | 587 |
| Burdock | Lakota Fm. (Chilson) | 1.56 | 120 | 187 |
| Burdock | Fall River Fm. | 0.45 | 120 | 53.5 |

Groundwater velocity at the Dewey and Burdock area can be estimated by using the data from Table 2. The natural potentiometric surface slopes approximately WSW at a gradient (H/L) of approximately 0.0079. The effective porosity has been reported at 17% for the sandstones in the Inyan Kara Group (Rahn

1981), but this may be high since hydrogeologists using Darcy Law calculations for other aquifers in the Black Hills area have used 10% effective porosities (Back et al. 1983). For simplicity, in this paper, if one assumes that the effective porosity is 10%, then the groundwater velocity can be determined as follows:

- Dewey area (Lakota Fm): $V_t = V_d/10\% = K\ (H/L)/0.1 = 4.92\ (0.0079)/0.1 = 0.389$ ft/day (equivalent to 142 ft/year).
- Burdock area (Lakota Fm): $V_t = 1.56\ (0.0079)/0.1 = 0.123$ ft/day (equivalent to 44.9 ft/year).
- Burdock area (Fall River Fm): $V_t = 0.45\ (0.0079)/0.1 = 0.0316$ ft/day (equivalent to 11.5 ft/year).

An average groundwater velocity within the Inyan Kara Group at the Dewey/Burdock area is assumed to be the average of these three velocities, i.e. 0.18 ft/day (equivalent to 66 ft/year). [Note: this velocity is greater than the "maximum natural groundwater velocity" of approximately 12 ft/year estimated by Powertech (2009a).]

As shown in Figure 2, the Inyan Kara Group in the southern Black Hills has complex stratigraphy and hence has considerable permeability variability. The Inyan Kara Group includes permeable sandstone channels that could carry groundwater faster than an average value of 66 ft/year. At some places the sandstone channels are not present. A crude estimate of the permeability variability can be made by comparing the hydraulic conductivity values from western South Dakota pumping tests described in the above references. These values include: 0.94 (Miller and Rahn 1974); 1.52, 1.47, and 1.85 (Rahn 1992); 1.85, 1.73, 1.70, 1.53, 1.98, 0.17, and 0.17 ft/d (Boggs and Jenkins 1980). Also using 8.3 ft/d (from Bredehoeft et al., 1983) yields twelve values. These values have an approximate log-normal distribution, and hence the largest 10% hydraulic conductivity value would be approximately 9 ft/d. For the velocity determinations of the three sites described above, average hydraulic conductivity is 2.31 ft/d. Therefore, there is a 10% probability that the hydraulic conductivity would be approximately 9/2.31 = 4 times that value. Another factor that plays an important part of any sensitivity analysis is the effective porosity, which in this paper is assumed to be 10%.

## RELEVANT HYDROGEOLOGIC CONDITIONS IN FALL RIVER COUNTY

Figure 6 is a geologic cross section near Edgemont, South Dakota, illustrating the typical geology of much of southern Fall River County. At Igloo, for example, the Inyan Kara Group was encountered at 1,085 ft depth and the Madison Limestone was encountered at 3,590 ft. The potentiometric surface of the Madison at the Igloo site is 3,700 ft elevation (Strobel et al. 2000). This is above the land surface, and creates a flowing artesian well. The potentiometric surface of the Inyan Kara, on the other hand, is only 3,250 ft; this elevation is below the land surface. Under these conditions, it is very unlikely that groundwater could

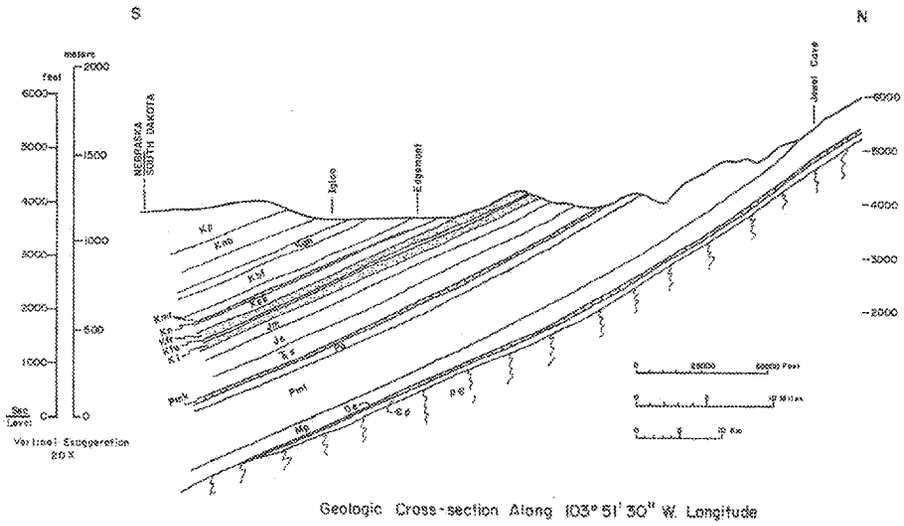


***Figure 6. Geologic cross section near Edgemont, South Dakota (from Roggenthen et al. 1985). The sedimentary rocks include the Fall River Formation ($K_{fr}$) ,the Lakota Formation ($K_l$) and the Pahasapa Limestone ($M_p$).***

move from the Inyan Kara aquifer down to the Madison Limestone in most of southern Fall River County.

A relevant groundwater quality issue involves Powertech's plan to drill a waste disposal well into the Minnelusa or Deadwood Formation (Nuclear Regulatory Commission 2012). Rahn and Gries (1973) and Greene (1999) showed that there is a hydraulic connection between the Minnelusa Formation and the Madison Limestone at places. There is the possibility that the Madison aquifer could become contaminated with this waste.

## DISSOLVED VS SOLID URANIUM IN A SANDSTONE AQUIFER

The ISL mining process will dissolve solid uranium minerals that occur in the sandstone. A consideration relevant for a pre-mining environmental assessment of an uranium ISL site is a comparison between the amount of uranium that is naturally dissolved in groundwater and the amount of uranium found as solid minerals in the aquifer matrix.

For the purpose of these calculations, a hypothetical uraniferous sandstone aquifer simulating the Dewey/Burdock area in the southwestern Black Hills is used, i.e., the 120 ft (36.6 m) thick Chilson Member of the Lakota Formation. An area underlying 10 acres (4.047 ha) is used for these calculations. The sandstone at this site is nearly horizontal; hence the volume can be approximated as: 36.6 m ($4.047 \times 10^4$ m$^2$) = $1.48 \times 10^6$ m$^3$.

**Solid uranium**

According to the U.S. Senate (1972), as of October 1, 1963, uranium mining in the Black Hills totaled 367,497 tons ($3.3339 \times 10^8$ kg) of ore; this ore contained 1,352,000 lbs ($6.1327 \times 10^5$ kg) of $U_3O_8$. The actual amount of uranium within $U_3O_8$ ("yellowcake") can be determined from the atomic weights of uranium (238) and oxygen (16) as follows: 3 (238)/3 (238) + 8 (16) = 0.848 = 84.8%. Therefore, from the historic mining data, the amount of uranium mined in the southern Black Hills is 84.8% ($6.1327 \times 10^5$ kg) = $5.2039 \times 10^5$ kg.

TVA (1979) reported that at the Dewey/Burdock area "...the ore minerals coat sand grains and fill interstices of complexly cross-stratified sandstone along solution fronts similar to 'roll' type deposits..." For this paper, the proportion of uranium in the sandstone at the Dewey/Burdock site is assumed to be the same as the uranium in the ore historically mined in the southern Black Hills. This proportion equals $5.2039 \times 10^5$ kg/ $3.3339 \times 10^8$ kg = 0.0015609 = 0.1561%. Assuming the sandstone weighs 2.20 gm/cm$^3$, the mass of the sandstone at the Dewey/Burdock site would be $2.2 \times 10^4$ kg/m$^3$ ($1.480 \times 10^6$ m$^3$) = $3.257 \times 10^{10}$ kg. Assuming the ore is distributed throughout the sandstone, the mass of uranium in solid form within this sandstone is 0.00156 ($3.257 \times 10^{10}$ kg) = $5.080 \times 10^7$ kg. [Interestingly, this is equivalent to approximately 15% of all the uranium historically mined in the southern Black Hills. Also of interest is that at the Dewey and Burdock site Powertech Uranium Corporation (2010) estimates the total amount of $U_3O_8$ to be 10,813,000 lb ($4.905 \times 10^6$ kg.]

**Dissolved uranium**

Williamson and Carter (2001) showed data on dissolved uranium in groundwater in the Black Hills. In the Edgemont area, the highest concentration is approximately 30 micrograms per liter (μg/L), the same as U.S. Environmental Protection Agency's maximum permissible concentration for drinking water. In the southern Black Hills, Oak Ridge Gaseous Diffusion Plant (1980) showed uranium concentrations in groundwater; 340 samples averaged approximately 10 μg/L, although values up to 200 μg/L were found. Groundwater in Cretaceous rocks typically had high values. TVA (1979) reported that in 1977 the Burdock Well #1 had dissolved uranium ranging from 0.10 to 9.50 μg/L and dissolved $^{224}$Ra ranging from 111.4 to 230.1 ρCi/L. For this paper it is assumed that dissolved uranium in the groundwater at this site has a concentration of 30 μg/L (equivalent to $3 \times 10^{-5}$ kg/m$^3$). Assuming 10% porosity, the ten-acre sandstone unit used for these calculations contains 0.10 ($1.48 \times 10^6$ m$^3$) = $1.480 \times 10^5$ m$^3$ of groundwater. Therefore the amount of dissolved uranium at this site is $1.48 \times 10^6$ m$^3$ ($3 \times 10^{-5}$ kg/m$^3$) = 44.4 kg.

**Comparison**

From above, the mass of the solid uranium under the ten acre site is $50.8 \times 10^6$ kg, and the mass of the liquid uranium under this site is 44.4 kg. The ratio is $1.14 \times 10^6 : 1$. Solid uranium (in the form of minerals such as carnotite, coffinite, uraninite, etc.) vastly exceeds the uranium dissolved in groundwater. This indicates that ISL uranium mining has the potential to dissolve vast amounts of uranium from its natural solid form.

The originally proposed method of mining by TVA at the Dewey/Burdock site was to be a conventional underground mining method (TVA, 1979). The proposed method of mining by Powertech (2009a, 2009b) is "solution mining", known as "in-situ leach", also called "in-situ recovery". This method will utilize chemicals pumped into the sandstone that dissolve the solid uranium minerals. Given the vast quantities of solid uranium that could be dissolved at this site, after mining ceases there will most likely still be a high concentration of dissolved uranium (as well as other elements) in the groundwater. The Nuclear Regulatory Commission (2012) notes "at the end of the uranium recovery process, constituents that were mobilized by the lixivients remain in the production aquifer. The NRC requires that groundwater quality be restored to a concentration limit established by the NRC." This water will migrate down gradient. Dissolved uranium generally precipitates in fully reduced zones, but uranium sorption also depends on the presence of iron hydroxides (Johnson and Tutu 2013, who concluded "...the resulting uncertainty of uranium sorption is quite high."). Although chemicals could be introduced to mitigate high concentrations of dissolved uranium, its ultimate concentration is unknown.

## ENVIRONMENTAL IMPACTS FROM ISL URANIUM MINES

A major concern of conventional or ISL uranium mines is the fate of radioactive elements that remain in the area after mining ceases. Environmental impacts from conventional uranium mines in the Edgemont area are described by Rahn and Hall (1982).

A draft Environmental Impact Statement (DEIS) for the proposed Dewey/Burdock ISL uranium mine was prepared by the Nuclear Regulatory Commission (2012). [The NRC refers to the in-situ-leach (ISL) method of solution mining as in-situ recovery (ISR) method.] The DEIS, available "on line", contains a wealth of background environmental data but has no post-mining groundwater velocity determination such as given in this paper. Rather, the impacts envisioned by this project are discussed in terms of tables showing "ratings". For instance, NRC states the overall groundwater impact will be "small to moderate" and the "proposed mitigation measures will eliminate or substantially lessen potential adverse environmental impacts."

Following mining, the residual fluids in the project area will begin migrating through the aquifer. A major concern about ISL uranium mines is that no dissolved minerals or chemicals introduced into the mined zone should escape the project area. Mining companies assure the public that this will not happen

because, during operation, recovery wells surround the injection wells. Presently there are six active in-situ leach (ISL) uranium recovery mines in the U.S. (Borch et al. 2012). Hall (2009) studied two ISL uranium mines in Texas and found that dissolved uranium and selenium are the two elements most likely to be above restoration objectives following termination of ISL operations.

In nearby Crawford, Nebraska, the Crow Butte ISL uranium mine has been in operation by Cameco Resources for 21 years. Coatings of coffinite, carnotite, and uraninite occur in basal Chadron conglomerate beds 65 -135 m (213 – 443 ft) below the ground surface (Spalding et al. 1984). The Crow Butte mine includes a system of 4,500 wells that use a solution of water, oxygen, and bicarbonate to dissolve uranium minerals and bring the liquid to a processing plant on the surface. A system of monitoring wells on the perimeter of the mined area is used to detect any excursions from the mine area. Dave Carlson, retired from the Nebraska Department of Environmental Quality, commented that the project has not negatively affected the surrounding aquifers (Woster 2012). A website for the SD DENR states that the most commonly reported problems at the Crow Butte mine are spills from production fluids and leaks in pond liners. They also report that "other problems include excursions for process fluids beyond the limits of the production zone".

Commenting on efforts to restore groundwater at an ISL mine at the Christensen Ranch area near Pumpkin Buttes, Wyoming, Lustgarten (2012) stated that a Nuclear Regulatory Commission report "... concluded that restoring water to baseline levels was 'not attainable' for many of the contaminants, including uranium".

## SUMMARY

The chemistry of groundwater at an abandoned ISL uranium mine will be changed from its pre-mine condition. The amount of chemical change and the groundwater velocity downgradient from the mined site are important for any environmental assessment. The chemistry of this water will be greatly altered. Elements such as uranium, radium, and selenium will be dissolved by chemicals during the mining operation. These elements originally were bound up within the Inyan Kara aquifer as solid minerals. Solution mining will set them free as dissolved constituents in the groundwater. Their concentration and mobility within the aquifer is uncertain.

The ultimate fate of groundwater contaminants from an ISL uranium mine depends on the groundwater velocity and the natural attenuation that could immobilize contaminants such as uranium and selenium. In this paper, the natural groundwater velocity through the Inyan Kara aquifer in the Dewey/Burdock area is determined to be approximately 66 ft/year. If this relatively slow rate is representative, the average migration of contaminants from the proposed Dewey/Burdock ISL uranium mine would not appear to be a great concern to landowners who live miles away. The 1963 tritium data showing much faster velocity is an unresolved issue. It is not known if the data are accurate; but if they are, there could be fractures or permeable conglomerate channels that transmit

groundwater much faster than the velocity calculated by traditional Darcy Law as presented in this paper.

Future research should include detailed hydrogeologic study of the permeability of fractures and the coarse-grained facies of the Inyan Kara Group as well as quantification of the chemical changes that could retard contaminant transport in groundwater from an ISL uranium mine.

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# Uranium Activities' Impacts On Lakota Territory.

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Uranium exploration, mining, and milling are the "front end" of the nuclear chain – the often-forgotten activities without which neither nuclear power nor nuclear weapons could exist. The history of these activities is virtually unknown to the general public outside mining areas, but most uranium mining in the United States has occurred on or near reservations. Both mining and milling were common on the northern Great Plains from the 1940s until the early 1980s.

This paper focuses on the history and impacts of those activities on Lakota Territory – the area now known as western South Dakota and North Dakota, eastern Montana and Wyoming, the panhandle of Nebraska, and northeastern Colorado. The general problems with past uranium activities, and current projects are covered.

In the last several years, a boom in uranium exploration and proposed new mining projects has brought new attention to the ongoing impacts of old mining and milling sites. This new uranium boom is a result of the belief that nuclear power will have a "renaissance" as a "clean" alternative to fossil fuels in an era of climate change -- and to a resulting spike in uranium prices. However, nuclear power is not clean, as this paper illustrates and as the crisis at the Fukushima nuclear plants makes clear.

Before going into the specific impacts on Lakota Territory, an overview is provided of the uranium mining and milling processes. This will be followed by a summary of the known impacts on each past mining area and by brief information on current uranium activities.

## Uranium Mining Overview

Uranium is unique because it emits radiation. When uranium is underground, it is not generally dangerous. But when it is brought to the surface and concentrated by mining activities, it emits dangerous levels of radiation.

Uranium breaks down into a series of other substances in a decay process, and each step of that process emits radiation. Each substance has a "half-life," the amount of time it takes for its radiation emissions to decrease by half. The half-life of uranium-238 – a major waste product of uranium milling – is 4.5



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billion years. Some uranium byproducts, such as radon and radium, are more dangerous than the uranium itself. Eventually, uranium decays into a stable form of lead.[1]

There are three major types of uranium mining, all of which have been used in Lakota Territory. The first is open pit mining. The second is underground shaft mining. The third is a newer process, *in situ* ("in place") leach mining. In situ leach mining involves pumping a chemical/water solution into the ground, where it leaches uranium out of a water-bearing rock layer. The uranium solution is then pumped to the surface for further refining.

The ore recovered during open pit and underground mining must be milled to remove uranium-235, which is concentrated and used for nuclear power or weapons. Uranium can be milled by a grinding-and-chemical process, by heap leaching – putting the ore in a pile and leaching the uranium out with acids [2]-- or by burning the ore, which is done when uranium is naturally mixed with lignite coal.[3]

The remaining ore is left in tailings piles, which are 85% as radioactive as the uranium that is taken for further processing. Tailings piles are large – covering hundreds of acres and involving millions of tons. Tailings also contain substances commonly found with uranium, such as molybdenum, arsenic, lead, and selenium. [4]They are the consistency of sand and move easily in the wind or water. In some locations, before their danger was understood, people used them for construction materials. Tailings may also be disposed of by mixing them with water in large ponds. Tailings pond dams have occasionally broken. A 1979 dam break at Churchrock, NM, was the largest expulsion of radioactive materials in U.S. history. In Lakota Territory, there have been three tailings releases in Wyoming and one in South Dakota.[5]

All types of mining and milling, like all nuclear activities, emit radiation into the environment. Uranium exploration, mining, and milling contaminate surface and groundwater, soil, and air with radioactive materials and heavy metals. Plants and the animals that eat them, in turn, take up these

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[1] Environmental Science Division, Argonne National Laboratory.2002.Natural Decay Series: Uranium, Radium, and Thorium.www.ead.anl.gov/pub/doc/NaturalDecaySeries.pdf.Accessed December 23, 2009.

[2] R.G. Woolery, S. Ramachandran, and M.R. Woolery, Union Carbide Corporation.1983.Heap Leach in the Edgemont Area.In Maurice C. Fuerstenau and Bruce R. Palmer, eds.*Gold, Silver Uranium, and Coal: Geology, Mining, Extraction and the Environment*.New York: The American Institute of Mining.

[3] U.S. Energy Information Administration.Belfield Ashing Facility Site.www.eia.doe.gov/cneaf/nuclear/page/umtra/belfield_title1.html.Accessed December 29, 2009.

[4] US Energy Information Administration.Uranium Mill Sites under the UMTRA Project.www.eia.doe.gov/cneaf/nuclear/page/umtra/background.html.Accessed December 23, 2009; WISE Uranium Project.Uranium Radiation Properties.www.wise-uranium.org/rup.html.Accessed December 23, 2009; WISE Uranium Project.Uranium Maps.www.wise-uranium.org/umaps.htm?set=tail.Accessed November 3, 2009; Eric Mogren.2002.*Warm Sands: Uranium Mill Tailings Policy in the Atomic West*.Albuquerque: University of New Mexico Press.

[5] *Ibid.*; WISE Uranium Project.Chronology of Uranium Tailings Dam Failures.www.wise-uranium.org/mdafu.html.Accessed December 23, 2009; US Nuclear Regulatory Commission.1980.Regulatory Guide 3.11.1: Operational Inspection and Surveillance of Embankment Retention Systems for Uranium Mill Tailings; Marley Shebala.July 23, 2009.Poison in the Earth: 1979 Church Rock spill a symbol for uranium dangers.*Navajo Times* Online.http://navajotimes.com/news/2009/0709/072309uranium.php.Accessed December 28, 2009.; Bruce E. Johansen.1997.The High Cost of Uranium in Navajoland.www.ratical.org/radiation/UraniumInNavLand.html.Accessed October 4, 2007.



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contaminants. The animals that eat animals, including humans, can then ingest these contaminants at the top of the food chain.[6]

These are some of the reasons why there are concerns about both current and old uranium operations in Lakota Territory. In addition to health and environmental concerns, there are negative impacts on cultural and historical resources, community and cultural cohesion, local economies, and the long-term survival of indigenous communities. Keeping these impacts in mind, the specifics of past operations will be considered.

## Overview of Past Operations

As mentioned above, there are old uranium operations across Lakota Territory. The US Environmental Protection Agency combined over a dozen lists of old and current mine and prospect sites to create the *Uranium Location Database Compilation: Technologically Enhanced Naturally Occurring Radioactive Materials (TENORM)* [7]in 2006.As part of this research, the TENORM database was consulted, and the different lists were checked to prevent double counting. The results are shown in Table One.

*Table One: Old and Operating Uranium Mines and Prospects: Lakota Territory: Northern Missouri River Basin*

| STATE | WATERSHED | NUMBER |
|---|---|---|
| **COLORADO** | | |
| | SOUTH PLATTE | 351 |
| | NORTH PLATTE | 36 |
| STATE TOTAL | | 387 |
| | | |
| **MONTANA** | | |
| | YELLOWSTONE | 102 |
| | MISSOURI | 295 |
| STATE TOTAL | | 397 |
| | | |
| **NORTH DAKOTA** | | |
| | SOURIS | 13 |
| | MISSOURI | 100 |
| STATE TOTAL | | 113 |

[6] Portage Environmental.2004.*Human Health and Ecological Risk Assessment for the Riley Pass Uranium Mines in Harding County, South Dakota*. Butte, MT.; for US Forest Service, Department of Agriculture, Missoula, MT.

[7] It is unclear how radioactive materials can be both "technologically enhanced" and "naturally occurring."



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| | | |
|---|---|---|
| | | |
| **SOUTH DAKOTA** | | |
| | CHEYENNE | 169 |
| | MOREAU/GRAND | 103 |
| STATE TOTAL | | 272 |
| | | |
| **WYOMING** | | |
| | YELLOWSTONE | 1039 |
| | NORTH PLATTE | 397 |
| | CHEYENNE/BELLE FOURCHE | 667 |
| STATE TOTAL | | 2103 |
| | | |
| **OVERALL TOTAL** | | **3272** |

The database lists approximately 3,272 sites in Lakota Territory, all of them in the northern Missouri River basin, which flows into the Mississippi River. Nearly two-thirds of these sites are in Wyoming. These old mines and prospects are generally located on private, tribal, Bureau of Land Management, or National Forest Service land.

This overview of uranium activities' impacts on Lakota Territory is organized according to current state boundaries, beginning with southwestern North Dakota.

### Impacts in Southwestern North Dakota

In southwestern North Dakota, there were several uranium mines and two uranium-removal facilities in the 1960s.Both of these facilities burned uranium-bearing lignite coal, which concentrated the uranium. Kerr-McGee Oil Industries ran the first facility, which was near Bowman, from 1964 to1967.The second facility, which was one mile south of Belfield, was operated by Union Carbide Corporation from 1965 to 1967.[8]

At the Bowman site, wastes eventually covered 12 acres. There were an estimated 28,000 cubic yards of contaminated materials on the site and 100,000 more outside the site boundary. Pollution leached into the ground, and water under the site was contaminated with sulfate, chromium, selenium, and uranium. Because of the contamination, one local rancher lost 2500 sheep. Before they died, the sheep

[8] Energy Information Administration, US Department of Energy.Bowman Ashing Facility Site.www.eia.doe.gov/cneaf/nuclear/page/umtra/bowman_title1.html.Accessed April 27, 2008; Energy Information Administration, US Department of Energy.Belfield Ashing Facility Site. www.eia.doe.gov/cneaf/nuclear/page/umtra/belfield_title1.html.Accessed April 27, 2008.



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glowed and lost their hair. The State of North Dakota has been responsible for remediation of the site, and it has not been cleaned up.[9]

Forty years after the Bowman site closed, its impacts on stream sediments were studied. Researchers from the South Dakota School of Mines and Technology looked at sediments in the Bowman-Haley Reservoir on the South Dakota-North Dakota border. They found the highest levels of uranium where Spring Creek entered the reservoir, a site about 15 miles downstream from the Bowman site. And they concluded that the Bowman facility was the source of these elevated readings.[10]

The second site, at Belfield, left 58,000 square yards of contaminated material along the Heart River. Contamination, including airborne materials, covered 32 acres. Residents reported that a red dust blew over town when materials were loaded onto rail cars, and mine wastes were used to backfill buildings' foundations. In addition, an estimated 4.7 million gallons of groundwater were contaminated because pollution leaked into the ground. The contaminants included selenium, radium[226] and [-228], molybdenum, and uranium. The State did clean up this site in 2004.[11]

There are also an estimated 113 old uranium mines and prospects in North Dakota. One of the larger mines was the Fritz Mine. There, uranium was removed by burning the actual coal seam. Observers reported that there was no vegetation around the mine, and that the water that filled it was a dead green color.[12]

Seven of the abandoned mines -- a total of 440 acres -- were reclaimed, and a water monitoring program was put in place. The water monitoring process was suspended in the mid-1990s.[13]

### Impacts in Montana

There are old exploration sites and two abandoned uranium mines in Custer National Forest in the Pryor Mountains in south-central Montana. In this area, a state study found that waste piles at one mine had uranium readings that were up to 369 times the background level – the level of radiation that is present naturally. At the second mine, readings were as high as 145 times background. In this former mining area, as elsewhere, members of the public have explored the old mine sites. A study noted that radioactivity may be a hazard at both mines.[14]

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[9] Energy Information Administration, Bowman, *ibid.*; US Department of Energy.Section 3.2.14: Bowman, North Dakota.*Technical Approach to Groundwater Restoration*.www.lm.doe.gov/documents/3_pro_doc/guidance/gw/peis/umtra_3.htm.Accessed April 27, 2008; Lauren Donovan.November 15, 2003.Belfield family looks for connection between uranium mine and illness.*Bismarck, ND, Tribune*.

[10] Lance Larson, James Stone, and Larry Stetler.2010.Arsenic and Uranium Impacted Sediment Behavior Within the Bowman-Haley Reservoir, Bowman County, North Dakota.Paper Abstract: Western South Dakota Hydrology Conference.

[11] Energy Information Administration, Belfield, *op cit.*; US Department of Energy.Section 3.2.13: Belfield, North Dakota.*Technical Approach to Groundwater Restoration*; Donovan, *ibid.* www.lm.doe.gov/documents/3_pro_doc/guidance/gw/peis/umtra_3.htm.Accessed April 27, 2008; State to reclaim abandoned Belfield uranium mine.December 16, 2003.*Bismarck, ND, Tribune*; Donovan, *ibid.*

[12] Donovan, *ibid.*

[13] Donovan, *ibid.*

[14] *Op. cit.,* Kerschen, et al.



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### Impacts in Northwestern South Dakota

Of all the areas covered in this report, the best records on the environmental impacts of uranium activity in Lakota Territory were created in what is now northwestern South Dakota. Due to a series of studies, most of them done by Oglala Lakota College and the South Dakota School of Mines and Technology, reports have been created on contamination of water, soil, stream sediment, and air around a number of old open pit mines. These studies show widespread contamination of the Grand River and Moreau River watersheds, which then flow east through the Standing Rock and Cheyenne River Reservations.

Uranium mining took place in northwestern South Dakota from 1954 until 1964.Most mining was on US Forest Service land in four areas: the North Cave Hills, South Cave Hills, Slim Buttes, and Flint Buttes. There are 103 identified former mining sites, and exploration sites, mines, and spoils covered almost 1,000 acres. No restoration was required when the mining was done, and Stone and Stetler described spoils piles as "mostly devoid of vegetation" with high erosion rates. Because mining was done on the tops of buttes, wastes often slid or were pushed downhill. [15]

In this area, as in some other locations, uranium is found in deposits that also include arsenic. So both were often measured to determine risks to human health.[16]

An initial study of contamination in areas that might need clean-up was done in 1990 and 1991 – nearly 30 years after mining had ceased. This study looked at 12 bluffs at the Riley Pass uranium mines in the North Cave Hills. It found gamma radiation readings as much as 100 times the background level. The report found that radioactive materials in the soil were three times higher than the background level at nine sites. Arsenic, molybdenum, and thorium were more than three times background.[17]

Surface water samples at and downstream from the mining area showed widespread contamination by arsenic, lead, molybdenum, selenium, thorium, vanadium, and radium[226].Stream sediment samples were at least three times background for at least some of the contaminants at seven of the bluffs. Sediment ponds constructed in 1989 along the waterway were trapping some contaminated particles as the water moved downstream.[18]

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[15] James Stone and Larry D. Statler.Study of Abandoned Uranium Mine Impacts On Private Land Surrounding US Forest Service Land In Western South Dakota.http://uranium.sdsmt.edu/default.htm.Accessed September 29, 2009; Michael D. Kerschen, Phyllis A. Hargrave, John J. Metesh, Catherine McDonald, and Robert Wintergerst.2003.Abandoned-Inactive Mines on Custer National Forest-Administered Land.Montana Bureau of Mines and Geology, for US Forest Service.

[16] John Kenneth Dane.1978.Alteration of Sedimentary Rocks Related to Uranium Mineralization in the North Cave Hills of Harding County, South Dakota.Master's Thesis: Geology: South Dakota School of Mines and Technology;James Stone and Larry Stetler.2008.Environmental Impacts from the North Cave Hills Abandoned Uranium Mines, South Dakota.In *Uranium, Mining and Hydrogeology*.Berlin: Springer.

[17] Denver, Knight, Piesold Investigation Results.1991.In US Forest Service.*Riley Pass Uranium Mines, Harding County, South Dakota: Draft Final Engineering Evaluation/Cost Analysis (EE/CA).Missoula, MT: US Forest Service.*

[18] *Ibid.*; Portage Environmental, Inc.2004.*Human Health and Ecological Risk Assessment for the Riley Pass Uranium Mines in Harding County, South Dakota*.Butte, MT.Prepared for US Forest Service, Missoula, MT.



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A second study was done in 2004 by Portage Environmental and again focused on the North Cave Hills. Soil and surface water samples were collected. The results for soil samples are shown in Table Two. The results for surface water samples are shown in Table Three.[19]

Clearly, uranium activities had major negative impacts on the environment in the North Cave Hills. The report then went on to calculate the risks to humans from the old mine sites. The conclusions were that, in this area:

- Construction workers would be considered "radiation workers" under federal Nuclear Regulatory Commission (NRC) guidelines; and
- Recreational visitors and ranchers who held grazing permits faced unacceptable risks for cancer as a result of exposure to arsenic and radiation. [20]

*Table Two: Soil Sample Results for 2004 North Cave Hills Study*

| | **MAXIMUM READING** | **NUMBER OF TIMES HIGHER THAN AVERAGE BACKGROUND** |
|---|---|---|
| Arsenic | 3390 mg/kg | 121 |
| Molybdenum | 6550 mg/kg | 1638 |
| Selenium | 98 mg/kg | 20 |
| Radium$^{226}$ | 116 pCi/g | 64 |
| Uranium$^{238}$ | 151 pCi/g | 151 |
| Uranium$^{234}$ | 156 pCi/g | 156 |
| Thorium$^{230}$ | 161 pCi/g | 107 |
| Uranium$^{235}$ | 7.1 pCi/g | 71 |

*Table Three: Surface Water Sample Results for 2004 North Cave Hills Study*

| | **MAXIMUM READING** | **NUMBER OF TIMES HIGHER THAN MAXIMUM BACKGROUND** |
|---|---|---|
| Arsenic | 1420µg/L | 53 |
| Copper | 442 µg/L | 50 |
| Lead | 442 µg/L | 69 |
| Molybdenum | 335 µg/L | 38 |
| Selenium | 34 µg/L | 10 |
| Vanadium | 944 µg/L | 41 |
| Radium$^{226}$ | 16 pCi/L | 13 |

[19] *Ibid.*, Portage.
[20] *Ibid.*



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A third study was done in 2000 – 2001.This study found that soil at Slim Buttes was as much as 1,704 times more radioactive than background levels. Fifteen other samples exceeded the background level for uranium by more than 20 times.[21]

A mix of South Dakota School of Mines (SDSMT) students and faculty and Oglala Lakota College faculty then completed follow-up studies. They looked at groundwater, airborne contaminants, stream sediments, and surface water. A groundwater study looked at the potential for contamination in a well located 1.9 miles from the abandoned Riley Pass mines. The authors concluded that groundwater in that area was moving only .047 feet per day. At this rate, it would take contamination about 370 years to reach the well. It wasn't clear why this well was selected, and the overall effect of abandoned uranium mines on groundwater in that area has yet to be determined.[22]

Wind erosion of surface dust was studied at 30 locations in the North Cave Hills. The authors noted that soils could be moved beginning at a wind speed of 10 – 11 mph. They then say that the conservative threshold wind speed for the study area is 13 mph, and that winds blow harder than that about 23% of the time. Not surprisingly, the tests found high readings for uranium, arsenic, selenium, molybdenum, and vanadium in the air – although not all of these were present at all sites. The authors concluded that "Uranium concentration distribution show the highest correlation to the abandoned mine sites and the prevailing wind direction," although other factors were likely to be at work.[23]

Stream sediment and surface water testing, the third and fourth areas of study, were done at all four mining areas. In the Slim Buttes region, nearly half of the stream sediment samples exceeded background levels for uranium and for arsenic. Just over a third of the surface water samples exceeded background for uranium, and a quarter exceeded it for arsenic. The author concluded that old uranium mines posed "a great concern and potential for contamination of offsite drainages." However, this study actually minimized the potential risks, because of the way the researcher calculated background levels -- she used samples that were collected only 5 km downstream from abandoned mine sites. Since other studies showed that there was contamination at least eight times further downstream, her methodology inflated the background numbers and minimized the amount of contamination that was identified.[24]

A study by Albertus-Benham measured stream sediments at the North Cave Hills, South Cave Hills, and Flint Hills sites in order to determine if arsenic and uranium had migrated onto private lands. The results indicated that they had at all three locations. Arsenic levels were as much as 33 times background, and were elevated as much as 42 km (26 miles) downstream from mining areas. Uranium was as much as 23 times background and was elevated as far as 37 km (23 miles) downstream. [25]An additional finding for the North Cave Hills was that the sedimentation ponds built in 1989 and noted

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[21] *Op. cit.*, Kerschen, et al.
[22] *Ibid.*
[23] *Ibid.*
[24] Hannah Albertus-Benham.2009.*Surface water and sediment investigation concerning abandoned uranium mines within the Slim Buttes region, Harding County, South Dakota.*Master's Thesis: Civil and Environmental Engineering: South Dakota School of Mines and Technology.
[25] *Op. cit.*, Albertus-Benham.



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above, which were designed to stop contamination from moving downstream, were no longer working.[26]

While all these studies were being done, ranchers in the area asked for better clean up of the old mining areas. Tronox, Inc. – a spin-off of Kerr-McGee Corporation, the company that had mined in Harding County -- was initially going to do some clean up.Unfortunately for local ranchers, when Tronox was made a separate company in 2006, Kerr-McGee made the new company responsible for environmental remediation and litigation costs. Not surprisingly, Tronox declared bankruptcy in 2009.[27] This corporate maneuver let Kerr-McGee off the hook for cleaning up after its mining operations.

Today, local residents report that the trail to a local cave cannot be reached without going through radioactive spoils piles. Past mining destroyed archeological sites, and some that remain are too dangerous to visit. Mine dust still blows in the wind.[28] And contamination flows toward both the Cheyenne River and Standing Rock Reservations.

### Impacts in Southwestern South Dakota

Uranium deposits are located in an oval around the outside rim of the Black Hills in the Inyan Kara geological formation. There are at least 169 abandoned uranium mines and prospects in southwestern South Dakota in the Black Hills. The Hills are the sacred center of Lakota Territory, and digging up the ground is considered sacrilege. There are thousands of specific cultural and historical sites, including petroglyphs, camp sites, and burials, as well as locations of particular importance, such as Wind Cave and Mato Paha (Bear Butte).

The majority of Black Hills uranium mines are in Fall River County in the far southwestern corner of what is now known as South Dakota. These include both open pit and underground mines. There are also thousands of old exploration holes and a former mill site at Edgemont.

Starting at the front end of the nuclear chain, exploration holes were drilled in the 1960s and 1970s along the rim of the Hills. Exploration holes create pathways between groundwater aquifers, making it possible for contaminated water to pollute clean water. In the southern Black Hills, a 1980 study showed that these types of connections between aquifers exist near the town of Burdock. Other problems related to exploration have also been reported, including "uranium test holes that were uncased, unplugged, and flowing at the surface." This wasted huge amounts of water.[29]

Turning to mine sites, two studies of the southern Black Hills paint a dismal picture. Hall, a graduate student at the South Dakota School of Mines and Technology, prepared the first study in 1982.He identified 38 of the old mines, 491 acres of disturbed areas, and 390,620 square yards of spoils piles.

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[26] Emmanuel Tuombe.2009.*Surface water and sediment investigation concerning abandoned uranium mines in the South Cave Hills, North Cave Hills, and Flint Buttes region, Harding County, South Dakota*.Master's Thesis: Civil and Environmental Engineering: South Dakota School of Mines and Technology.

[27] Brandon Bennett.January 13, 2009.Tronox Bankruptcy raises questions about uranium cleanup.*Black Hills* Spearfish, SD *Pioneer.*

[28] Jerry Wilson.July/August 2009.Radioactive Hills: Can uranium be safely mined the second time around?*South Dakota Magazine*: 53-58.

[29] *Op. cit.,* Boggs and Jenkins; Jack R. Keene.1970.*Ground Water Resources of the Western Half of Fall River County, South Dakota*.Master's Thesis: Geological Engineering: South Dakota School of Mines and Technology.



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He observed that, "Essentially no reclamation was done in the old mined areas," and that spoils piles were exposed and potentially dangerous.[30]

He also measured above-ground gamma rays, the most dangerous type of radiation associated with uranium mining.All the readings were at least four times higher than background levels, and one was 60 times higher than the background level. Measurements in small mine shafts were as much as 27 times higher than what the author set as a "safe" level for members of the public who visited the area.[31]

Besides looking at radiological hazards, the author looked at impacts on the land, noting, "Uranium mining usually involves considerable disturbances of surface lands and associated biota." Among the hazards identified were:

- Unplugged and hidden drill holes up to 8" in diameter and 200 feet deep at 30 out of 32 sites;
- Eroded roads and spoils piles;
- Mining trash at all the mines and open pit mines being used as garbage dumps;
- 31 out of 32 mines were unfenced;
- Cave-ins at underground mines;
- Two mines that "could easily be driven into at night as a result of their obscure nature;"
- Underground mines that were used as recreational sites and cattle shelters;
- Two unmarked and obscured mine ventilation shafts that were two feet wide and 60 feet deep. Hall provided a photo of his legs dangling into one of these holes, which was plenty large enough for a person to fall into. [32]

Having said all this, the author was pro-mining. He feared that the impacts of unreclaimed sites hurt uranium mining's image. The negative impacts, he said, gave "radical groups" such as the Black Hills Alliance – an area organization -- fuel in their opposition to future uranium mining.[33]

The second study, done by Webb, Davis, and Hodge in 1995, looked water samples from two old open pit mines, a downstream stock dam, a nearby well, and the site of the former uranium mill in Edgemont. The mill and its associated tailings had, by this time, been buried at a cost of $33 million. One of the open pit mines was described as "a large, open pond of highly acidic and radioactive seepage water."[34]

The study, done 13 years after the first research, recorded similar conditions. At the Diane-A mine, the levels of uranium in water were up to 500 times higher than background. Contamination had reached the stock dam and ranch well below the mine, and it had reached Cottonwood Creek by the old uranium mill. The authors noted that the latter was a threat to groundwater, because the water in the creek's sediments and riverside wells could be linked to underground aquifers. [35]To date, according to

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[30] Rowland L. Hall.1982.*Radiological and Environmental Assessment of Abandoned Uranium Mines in the Edgemont Mining District, South Dakota*.Master's Thesis: Geology: South Dakota School of Mines and Technology.

[31] *Ibid.*

[32] *Ibid.*

[33] *Ibid.*

[34] C.J. Webb, A.D. Davis, and V.F. Hodge.March 1995.Rare Earth Elements at Abandoned Uranium Mines in the Southern Black Hills of South Dakota.Presented at the Annual Meeting of the Society for Mining, Metallurgy, and Exploration.

[35] *Ibid.*



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the State of South Dakota, four mines on US Forest Service land have been reclaimed, and a fifth has been partially reclaimed.[36]

These problems are not unusual. As should be clear by now, mining poses a variety of risks. There are also major risks from uranium mills, and the former mill at the town of Edgemont has had dramatic impacts on the area. As noted by the 1995 study, there were clear impacts on water even after the mill and its associated wastes had been removed and buried.

Uranium ore was milled at Edgemont from 1956 to 1972. The mill site covered 213 acres and included 2.5 million tons of tailings. The tailings blew across the area and were used in construction of houses and commercial buildings -- a basement room in one house had radiation levels 39 times the background level, and the family abandoned its home. A cluster of dwellings known as the Cottonwood Community was surrounded on three sides by mill operations, and windblown tailings "significantly contaminated" the area.[37]

The tailings also contaminated soil and plants. Soil at the tailings site had high concentrations of uranium, radium$^{226}$, lead$^{210}$, polonium$^{210}$, and gross alpha radiation. The highest uranium reading was 38 times higher than the highest offsite reading, and the highest rate for radium$^{226}$ was 121 times higher. Uranium concentrations were significantly higher in plants, as well.[38]

But the greatest damage was to surface water. In addition to the usual erosion, 200 tons of tailings washed into Cottonwood Creek in 1962 and were carried down the Cheyenne River. The river flows from the southern end of the Black Hills and across the corner of the Pine Ridge Reservation, and is the southern boundary of the Cheyenne River Reservation. Several studies of water quality have been done since the tailings spill. This research will be discussed in some detail, because of its implications for modern Lakota and their land base.

The first study was done by the Tennessee Valley Authority, the mill's owner, as part of its plan for decommissioning the site. The highest uranium readings taken downstream of the mill were nearly 3 times higher than the highest readings taken upstream of the site. Bottom sediments were also contaminated. More alarming, the highest uranium readings for groundwater at the mill were 71 times higher than the highest readings for wells that were away from the area.[39]

A second study compared 1988 data with 1994 data. Concentrations of uranium, selenium, and molybdenum were high in both datasets.[40] In another study in 1997, the Bureau of Reclamation looked at sediment contamination in the Cheyenne River between Edgemont and Red Shirt, at the corner of the Pine Ridge Reservation. At the site nearest the reservoir's dam and at a downstream pond, the levels

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[36] Mike Cepak, Department of Environment and Natural Resources.October 30, 2009.E-mail correspondence.

[37] Harvey Wasserman and Norman Solomon.1982.*Killing Our Own: The Disaster of America's Experience with Atomic Radiation*.New York: Dell Publishing Co., Inc.;US Energy Information Administration, Department of Energy.Edgemont Mill Site.www.eia.doe.gov/cneaf/nuclear/page/umtra/edgemont_title1.html.Accessed January 20, 2010;Tennessee Valley Authority.1980.*Edgemont Uranium Mill Decommissioning Plan: Environmental Report.*

[38] *Ibid.*, Tennessee Valley Authority;Mark A. Rumble and Ardell J. Bjugstad.1986.Uranium and Radium Concentrations in Plants Growing on Uranium Mill Tailings in South Dakota.*Reclamation and Revegetation Research*: 4:271-277.

[39] *Ibid.*, Tennessee Valley Authority.

[40] Steven K. Sando and Joyce E. Williamson.2001.*Irrigation Drainage Studies of the Angostura Reclamation Unit and the Belle Fourche Reclamation Project, Western South Dakota: Results of 1994 Sampling and Comparisons with 1988 Data.*Water Resources Investigations Report 01-4103.US Geological Survey, Department of the Interior.



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of uranium were elevated. There were also higher levels of uranium contamination at Red Shirt. The authors noted that the levels were higher than in the 1988 or 1994 data.[41] This indicated that the contamination was not getting better with time.

A fourth study is cited in the US Geological Survey's *Atlas of Water Resources in the Black Hills Area.* This 2001 study showed that the highest levels of uranium along the Cheyenne River were located in Edgemont and near the Pine Ridge Reservation. Elevated levels were present all along the Cheyenne River.[42]

Taken together, the studies track uranium contamination from the Edgemont mill site to the Reservation – a total of about 60 miles as the crow flies. On the Reservation, there have been chronic problems with radioactive contamination of water supplies. A 1980 community survey done by Women of All Red Nations showed higher levels of miscarriages and cancer than in a control population. In the same year, samples of groundwater showed high gross alpha levels at Red Shirt and ten other locations. Samples taken at Red Shirt in 1999-2002 also showed that gross alpha radiation was as much as four times the federal Maximum Contaminant Level (MCL), and a 2007 water sample taken just upstream of Red Shirt also found gross alpha radiation above the MCL. Signs were posted warning people not to use the water.[43]

In addition to the environmental impacts of uranium activities in southwestern South Dakota, Edgemont suffered the typical economic impacts as a result of the mining "boom and bust" cycle. The "boom" brought new people and employment. But the town's population dropped substantially, as workers sought employment elsewhere during the "bust" part of the mining cycle. Today, most buildings on the main street are empty. A few bars, a municipal building, and the offices of a new uranium company are among the only operating buildings.

Rivers across western South Dakota have been impacted by past uranium mining and milling. The air, soil, groundwater, and economy have also suffered. But South Dakota has not experienced nearly as much uranium activity as Wyoming, to which we now turn.

### Impacts in Eastern Wyoming

The state of Wyoming has more old uranium operations than any other state in Lakota Territory – over 2100 in the northeastern two-thirds of the state. There have been two boom-and-bust cycles for Wyoming's uranium industry. When the price of uranium dropped the last time, in the 1980's, all of the

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[41] *Op. cit.,* US Bureau of Reclamation.Sediment at Angostura Reservoir.

[42] J.M. Carter, D.G. Driscoll, and J.E. Williamson.*Atlas of Water Resources in the Black Hills Area, South Dakota.*US Geological Survey, Hydrologic Investigations Atlas HA-747.

[43] Owe Aku/Bring Back the Way.A Summary of the OST Rural Water Reports and Indian Health Service.www.bringbacktheway.com/50.html. Accessed September 25, 2009;Bob Yellowbird. July 30, 1980.Memo the the Oglala Sioux Tribe Health Board; Women of All Red Nations.1980.*Report to Mr. Stanley Looking Elk, Tribal President, the Oglala Sioux Tribal Council, the Tribal Health Board, and the People of the Pine Ridge Reservation.* Pine Ridge Health Investigation; Defenders of the Black Hills. July 16, 2007.Radiation Warning Signs Placed on Cheyenne River; http://www.defendblackhills.org/index.php?option=com_content&task=view&id=104&Itemid=3. Accessed August 2, 2007;Charmaine White Face.June 18, 2007.Memo to Everit Poor Thunder, Red Shirt Village.



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state's mills and nearly all of its mines shut down. Mining towns, like Jeffrey City in the central part of the state, quickly went bust; the town lost 95% of its population in just three years.[44]

For the purposes of this paper, the mining areas within Wyoming that are in Lakota Territory will be broken down into the Powder River Basin, the Northern Black Hills, and the Gas Hills in the center of the state. Pumpkin Buttes in the Powder River Basin became the first uranium district in the state in 1951 and extended from Campbell County west into Johnson County. Ore was taken to the mill at Edgemont, SD.[45]

To the south, the Monument Hill area produced 90% of the uranium mined in the Powder River Basin between 1953 and 1965.Most of this ore was shipped to Edgemont, but there was also a uranium heap leaching facility -- aptly named the Spook Site -- in Converse County, which operated between 1962 and 1965.Heap leaching involves making a heap of ore, then leaching the uranium out using acid. At the Spook Site, this left 55 acres of tailings, which were buried in an old open pit mine. Groundwater was contaminated both under the site and up to half a mile away with uranium, selenium, chromium, molybdenum, radium, and other contaminants. The site is currently considered "stabilized," but there is still groundwater contamination.[46]

In Johnson County, Cogema Mining (more recently Uranium One) has operated two in situ leach mines, the Irigary site and the Christensen Ranch site. From 1980 to 2000, 4.7 million pounds of uranium were recovered. In 2001, Cogema put its licensure on "possession-only" status, but it is now working to restart mining at these sites.[47]

The Christensen Ranch site and the nearby Irigary site have been plagued with operational difficulties. According to the company's records, there have been over 1 million gallons of production and injection fluid spills at the two sites, both during past operations and after mining ended. These include above-ground and below-ground spills. At Christensen Ranch, there were 34 underground "excursions" of mining fluids between 1992 and 2009, meaning that underground mining fluids left the mine area. As of the end of 2009, seven of those excursions were still not controlled.[48]

Given these sloppy operations, it is not surprising that Cogema's own study indicated that post-restoration water quality at a Christensen Ranch mine field exceeded both "target restoration values" and federal or state groundwater standards. Groundwater standards were exceeded for uranium and for radium[226], which was at 47 times the standard.[49]

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[44] *Op. cit.,* Amundson.

[45] MINOBRAS.1976.*Uranium Guidebook for Wyoming.*Dana Point, CA.: MINOBRAS.

[46] US Energy Information Administration, Department of Energy.Spook Leaching Facility Site.www.eia.doe.gov/cneaf/nuclear/page/umtra/spook_title1.html.Accessed February 18, 2010;US Department of Energy.Environmental Management: Spook, Wyoming (UMTRA Site).www.em.doe.gov/bemr/BEMRSites/spok.aspx.Accesses February, 18, 2010;Legacy Management, US Department of Energy.Undated.Spook, Wyoming, Disposal Site: Fact Sheet.

[47] US Nuclear Regulatory Commission.Cogema Mining, Inc.www.nrc.gov/info-finder/decommissioning/uranium/cogema-mining-inc.html.Accessed February 18, 2010;Cogema Mining, Inc./Petrotek, Engineering Corporation.2008.Restoration Data Package: Mine Unit 5: Christensen Ranch Project.Mills, WY.

[48] Tom Hardgrove, Areva Resources.December 17, 2009.E-mail to Ron Linton, Nuclear Regulatory Commission.

[49] WISE Uranium.Christensen Ranch/Irigary (Wyoming).www.wise-uranium.org/umopwy.html.Accessed February 18, 2010; *Ibid.*, Cogema Mining.



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Further south in the Powder River Basin is the Highland area, which is still an active mining district. Historically, the area included a number of open pit mines, underground mines, and the Highland Mill, now owned by ExxonMobil, which operated from 1972 to 1984.At the Highland mill, the old tailings were buried, but a pit lake was left behind. It contained elevated levels of radon, gross alpha radiation, uranium, and selenium. In addition, a plume of contamination reached the water under the tailings site. The company has denied that this pollution has migrated offsite. However, the Nuclear Regulatory Commission stated that there is offsite pollution, which includes contamination of a local well.[50]

The second area under consideration is the northwestern part of the Black Hills, which stretches from South Dakota into Wyoming. This area, like the rest of the Black Hills, contains numerous cultural and historical sites, including Mato Tipila (Devil's Tower).In this area, uranium production began in 1953 and continued until 1968, and the ore was milled at Edgemont. In the early 1970s, there was renewed exploration just west of Oshoto. Over 5500 exploration holes were drilled, and a small in situ leach test was done. In 1979, restoration at this project, known as the Nubeth site, was described as "imminent." Uranium, molybdenum, and vanadium were still above "upper restoration limits" (URL) approved by the NRC and the State of Wyoming. Uranium was 4.5 times higher than the URL, and vanadium was 88 times higher. The URLs, in turn, allowed contamination that was several times higher than pre-mining standards for radium, gross alpha radiation, and gross beta radiation. By 1982, restoration was being described as "nearing completion."[51]

The third uranium mining district within Lakota Territory and Wyoming is the Gas Hills district. It is in the central part of the state and – while spread out – focuses on the towns of Jeffrey City and Riverton. The Gas Hills district produced large amounts of uranium beginning in 1953.

Early in the nuclear era, there was a mill at Riverton, operated by Susquehanna Western. The Riverton mill contaminated 115 acres and left 900,000 tons of tailings. These materials were buried between 1988 and 1990, but polluted the Little Wind River. Over time, three more major mills were built along the Natrona County–Fremont County line. These were operated by Federal-American Partners, Utah International (later Pathfinder and then Cogema), and Union Carbide Corporation (now UMETCO).The Union Carbide operation included both a conventional mill and a heap leaching operation. Two additional heap leaching mills were located at Western Nuclear's Split Rock and Day Loma sites.[52]

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[50] Keith I. McConnell, Nuclear Regulatory Commission.August 12, 2008.Letter to Maheshi Vidyasagar, ExxonMobil; U.S. Nuclear Regulatory Commission.Exxonmobil Highlands.www.nrc.gov/info-finder/decommissioning/uranium/exxonmobil-highlands.html.Accessed on February 18, 2010.

[51] *Op. cit.,* MINOBRAS;Michael Douglas Buswell.1982.*Subsurface Geology of the Oshoto Uranium Deposit, Crook County, Wyoming*.M.S. Thesis, Geology, South Dakota School of Mines and Technology;Francis X. Canaday.1979.Restoration Summary Report On In Situ Solution Mining Test Site, Sundance Project, Crook County, Wyoming: Source Material License No. SUA-1331: Docket No. 40-8663.

[52] *Op. cit.,* MINOBRAS;US Energy Information Administration, Department of Energy.Riverton Mill Site.www.eia.doe.gov/cneaf/nuclear/page/umtra/riverton_mill_title1.html.Accessed February 18, 2010; WISE Uranium.Day Loma heap leach site, Wyoming. www.wise-uranium.org/udusawy.html.Accessed February 18, 2010; WISE Uranium.Western Nuclear Split Rock uranium mill site, Wyoming. www.wise-uranium.org/udusawy.html.Accessed February 18, 2010;Legacy Management, US Department of Energy. Undated.Riverton, Wyoming, Processing Site: Fact Sheet.



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Information is available on the three major mills, all of which left serious contamination. The Utah International mill, also known as the Lucky McMill, operated from 1958 to 1988.The milling left behind 241 acres of tailings that contaminated both ground and surface water. After reclamation attempts didn't clean up the site, the company gave up. [53]Instead of forcing the company to reclaim the site, the Nuclear Regulatory Commission (NRC) changed the reclamation standards to make them fit the situation. This is a common move in uranium reclamation that is known as "relaxing" water quality standards. In this situation, a company asks a government body to declare its current water reclamation efforts – however poor – to be "within the law." The current water quality standard is "relaxed" (raised), and more contamination is allowed. Then the company only has to meet the higher standard for its reclamation to be considered "successful."

This may leave water many times more contaminated than current regulations allow. Table Four shows what happened at the Pathfinder mill. As a result of these relaxed standards, reclamation at the Pathfinder mill was declared "complete" in 2004.[54]

*Table Four: Relaxed Groundwater Standards at Pathfinder Mill*

| CONTAMINANT | CURRENT STANDARD | RELAXED NRC STANDARD AT PATHFINDER MILL | NRC STANDARD = x TIMES CURRENT STANDARD |
|---|---|---|---|
| Uranium (milligrams/liter) | .11 | 1.70 | 15.5 |
| Selenium (mg/l) | .01 | 1.10 | 110 |
| Nickel (mg/l) | .09 | .85 | 9.4 |
| Radium226 + 228 (picoCuries/l) | 5.0 | 7.50 | 1.5 |

The NRC also relaxed federal water quality standards at Western Nuclear's Split Rock mill, which operated from 1958 until 1984.The federal Department of Energy knew that it would eventually become the custodian of the mill wastes and objected to the idea. But the NRC made the changes anyway. There was also groundwater contamination, but the NRC let the company stop reclamation that was designed to contain the pollution – allowing clean groundwater to become contaminated.[55]

At the Union Carbide/UMETCO site, the story was similar. The mill, which operated from 1960 to 1979, was dismantled, and tailings were moved to an old mine. Some of the topsoil used to cover the tailings was dangerously radioactive, so the NRC relaxed the air quality standard for radium[226] and allowed levels that were three times higher than the standard. Groundwater was also contaminated, and

[53] US Nuclear Regulatory Commission.Pathfinder – Lucky Mc. http://www.nrc.gov/info-finder/decommissioning/.uranium/pathfinder-lucky-mc.html Accessed February 18, 2010;WISE Uranium.Gas Hills North disposal site (ex Pathfinder Mines Lucky Mc uranium mill site), Fremont County, Wyoming.www.wise-uranium.org/udusawy.html.Accessed February 18, 2010.

[54] *Ibid.*

[55] WISE Uranium.Western Nuclear Split Rock uranium mill site, Wyoming.www.wise-uranium.org/udusawy.html.Accessed February 18, 2010; US Nuclear Regulatory Commission.Western Nuclear, Inc. – Split Rock.www.nrc.gov/info-finder/decommissioning/uranium/western-nuclear-inc-split-rock.html.Accessed February 18, 2010.



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the company asked the NRC to relax water quality standards. The NRC obliged, as shown in Table Five.

*Table Five: Relaxed Groundwater Standards AT UMETCO Mill*

| CONTAMINANT | CURRENT STANDARD | RELAXED NRC STANDARD AT UMETCO MILL | NRC STANDARD = x TIMES CURRENT STANDARD |
|---|---|---|---|
| Uranium (milligrams/liter) | .29 | 34.1 | 117.6 |
| Selenium (mg/l) | .01 | .53 | 53 |
| Nickel (mg/l) | .04 | 9.34 | 233.5 |
| Radium226 + 228 (picoCuries/l) | 24.9 | 353 | 14.2 |
| Arsenic (mg/l) | .05 | 1.8 | 36 |
| Gross alpha radiation (pCi/l) | 17.8 | 6223 | 349.6 |
| Lead210 (pCi/l) | 4.6 | 46.7 | 10.2 |
| Thorium230 | 6.6 | 57.4 | 8.7 |

These were the impacts of conventional mining and milling operations. In addition to the Nubeth site, mentioned above, information was collected on three additional in situ leach mines. Company employees wrote a 1984 article about these three pilot projects – the Bison Basin, Leuenberger, and Reno Creek projects. These projects were very small and short-term, as each operated for only a few months.[56] These small, brief projects might be expected to have little environmental impact.

Nonetheless, where post-restoration numbers were provided, they were stunning. At the Leuenberger project, radium remained nearly twice pre-mining levels at the end of the project. At the Reno Creek project, post-mining uranium was as much as 122 times higher than the baseline. At the Bison Basin project, the average concentration of uranium was 85 times higher than baseline.[57] What was perhaps most interesting about this article was that the authors bragged about the "success" of their efforts.

In the portion of Wyoming that is within Lakota Territory, the environmental impacts of past uranium activities continue. Mill sites continue to pollute water because of the NRC's willingness to relax water quality standards to whatever level a company thinks is financially beneficial. According to the State's Abandoned Mine Land Project Manager, there have been only 49 reclamation projects for old uranium mines, mostly large open pit mines.[58]

While the impacts of uranium activities have not been thoroughly measured in Wyoming, the information that is available is not encouraging. There is clearly a lot of contamination that is not being cleaned up, and monitoring of old sites appears superficial.

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[56] Glenn Catchpole, Roger Garling, and Mike Neumann.June 1984.Groundwater Restoration at Wyoming Uranium Solution Mining Sites.*The Mining Claim*: 6-9;Glenn Catchpole, Roger Garling, and Mike Neumann. Date unknown (after June 1984).Groundwater Restoration at Wyoming Uranium Solution Mining Sites (Part II).*The Mining Claim*: 14-19.

[57] *Ibid.*

[58] Marcia Murdock, Abandoned Mine Land Project Director, State of Wyoming.December 21, 2009.E-mail to Lilias Jarding.



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### Impacts in Northeastern Colorado

The Great Plains of Colorado formed the southwestern portion of Lakota Territory. In the 1950s through the 1970s, there were about 387 uranium mines and prospects in northeastern Colorado, as well as a test facility for in situ leach uranium mining. Most of these sites were small and were located in the South Platte River watershed. The larger uranium mines and the mills in Colorado have been located on the western slope of the Rocky Mountains along the Utah border.

In the Platte River watershed, exploration and mining took place in South Park, North Park, and along the Front Range of the Rocky Mountains. The Front Range is by far the most populous area within Lakota Territory.

There is no available research specific to contamination from past exploration, open pit mines, or underground mines. However, there are at least 2,600 abandoned exploration holes in the Wyoming/Nebraska/Colorado border region. [59]These holes pose a threat to groundwater, especially if in situ leach (ISL) mining is started in the area, as proposed.

There was experimental ISL mining in the late 1970s near the town of Grover. The experiment, which was done by Wyoming Mineral Corporation, left elevated levels of gross alpha radiation, gross beta radiation, molybdenum, and selenium in the water. More troubling in the long run was the fact that, after the State signed off and said that the mine had been restored, the amount of contaminants in the water actually rose.[60]

This indicated that the contaminated water that was sucked out of the mining area during the restoration process was only part of the problem. After the company and the State considered restoration complete, contaminated water was still moving around underground. This was significant, because closed ISL mines only have to be monitored for a short period of time. Radioactive contamination, however, lasts for thousands of years. Contaminated groundwater may not reach people's wells for decades – or longer -- by which time mining companies are usually long gone.

Clearly, past uranium operations have had significant impacts in Lakota Territory. Air, soil, stream sediment, and both surface and groundwater have been polluted. The end of the last uranium rush in the 1980s did little to correct this situation, as few mines were cleaned up and plumes of contamination reached out from old mining and milling sites.

But, across Lakota Territory, the uranium was still in the ground, and mining companies still knew where it was located. All it took was talk of an expansion of nuclear power -- a "nuclear renaissance" -- for companies to return to former mining areas. So beginning in the mid-2000s, new exploration activities were undertaken. Companies staked claims, leased private land, and began to publicize their proposals for new uranium projects. Most of these proposals were for in situ leach mines. This history

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[59] Jeffrey C. Parsons.September 29, 2009.Letter to Colorado Division of Reclamation, Mining and Safety RE: Powertech (USA) Inc. Request for Modification to Notice of Intent (NOI) File No. P-2008-043.Western Mining Action Project.

[60] Susan Hall.2009. *Groundwater Restoration at Uranium In-Situ Recovery Mines, South Texas Coastal Plain*. Reston, VA: US Geological Survey; Kenneth S. Wade.1981.Uranium In Situ Solution Mining and Groundwater Quality at the Grover Test Site, Weld County, Colorado. Master's Thesis: Earth Resources: Colorado State University.



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of uranium activities concludes with a summary of the current proposed and operating projects in Lakota Territory.

## Current and Proposed Operations

### Western Nebraska

The Crow Butte in situ mine near Crawford, in the far northwestern part of Nebraska, is the only uranium mine that has been opened since the 1980s uranium "bust." It began operating in 1991 and is owned by Cameco. The mine is about 60 miles and upstream from the Pine Ridge Reservation – both in terms of surface and groundwater. A proposal to enlarge the mine is currently under consideration by the Nuclear Regulatory Commission. Citizens in the area, including an organization on the Reservation, are formally opposing this proposal.[61]

The Crow Butte mine, like other ISL mines, has had its share of problems. Those related to water quality have included:

- Failing to report the release of well development water onto the ground for nearly three years;
- Failure to restore water to baseline conditions after mining was completed, including contamination from alkalinity, arsenic, radium[226], and vanadium;
- During the restoration process, levels of contaminants actually increased, leading the NRC to deny approval of the mine's clean-up process; and
- At least 35 violations of the mine's license to operate, including leaks in evaporation ponds, excursions of mining fluids out of the mining area, and a 10,260-gallon spill of mining fluid.[62]

In 2006, there were wildfires east of the Crow Butte central processing plant, and evacuation was discussed. This threat to in situ plants is commonly overlooked.[63]

### Western North Dakota

At least two companies are exploring for uranium in Billings and Slope Counties in southwestern North Dakota. Prospect Uranium, Inc., has leased more than 1,000 acres for its Connors Project, which might include in situ leach mining and/or open pit mining. Formation Resources, Inc., a subsidiary of Australian company PacMag Metals, has received exploration permits from the state. The permits cover exploration at the company's Sentinel Project, which would extract uranium, germanium, and molybdenum. The company has said it wants to use an acid heap leaching process.[64]

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[61] Stephen F. Collings and Ralph H. Knode.1983?.Geology and Discovery of the Crow Butte Uranium Deposit, Dawes County, Nebraska.www.wma-minelife.com/uranium/papers/crwbtt01.htm. Accessed January 20, 2010; Cameco.Crow Butte: History/Innovations.www.cameco.com/mining/crow_butte/history/.Accessed January 20, 2010.

[62] Hannan LaGarry. January 14, 2008.E-mail Correspondence; WISE-Uranium.Crow Butte in-situ leach uranium mine, Dawes County, Nebraska.www.wise-uranium.org/umopusa.html.Accessed January 20, 2010.

[63] *Ibid.,* WISE-Uranium; J.A. Davis and G.P. Curtis.2007.*Consideration of Geochemical Issues in Groundwater Restoration at Uranium In-Situ Leach Mining Facilities.*Menlo Park, CA: US Geological Survey.

[64] Associated Press.September 22, 2009.Company considers chemical ND uranium extraction.www.kxnet.com/getArticle.asp?setCity=min&ArticleId=441159.Accessed January 20, 2010; PacMag Metals Limited.Sentinel Project (North Dakota, USA) – PagMag 100%.



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### Eastern Wyoming

Wyoming is the most active uranium mining area within Lakota Territory. There are both exploration and, as noted above, operating in situ leach mines.

Together, the Smith Ranch and Highlands mines constitute the nation's largest ISL uranium mine. Problems in past years were talked about earlier, and they continue. The company has been cited for failing to report uranium solution excursions into the surrounding aquifer and for a 198,500-gallon spill of injection fluid. [65]The Smith Ranch portion of the operation has been cited for violations that include failure to cap drill holes and monitoring wells, radiation levels that exceed the public dose limit, and hiring an unqualified radiation safety officer.[66]

The mines' most severe public relations setback came in 2008, when the State's Department of Environmental Quality apparently lost patience. The State issued a Notice of Violation citing, among other things, an "inordinate number of spills, leaks and other releases," inadequate reclamation, and surface and groundwater contamination. The State also said that bonds designed to cover reclamation, in case the company left or went bankrupt, were woefully inadequate.[67] The company and the state reached a settlement in which the company paid a fine of $900,000, with $400,000 suspended for good behavior. Bonding was increased to about half of what the state said could be necessary.[68]

In addition to the Smith Ranch-Highlands project, a Russian/Canadian company, Uranium One, is in the process of restarting the Irigary and Christensen Ranch projects, as noted above. The company has all the permits needed to resume mining. Uranium One completed its purchase of the mines in 2010 and announced that it planned to incorporate three other facilities – Moore Range, Ludeman, and Allemand-Ross – under the same license.[69]

As of the end of 2009, fifteen facilities are expected to apply for Nuclear Regulatory Commission permits, seven of them in the Powder River Basin.[70] At least three uranium companies are exploring along the northwestern Black Hills: Peninsula Energy (Australian), Bayswater Uranium (Canadian), and Powertech Uranium (Canadian). Bayswater is the closest to beginning a mining operation at its 17,500 acre Reno Creek property. Strathmore Minerals is exploring in the Gas Hills district. Rare

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www.pacmag.com.au/sentinel_project.36.html. Accessed January 20, 2010;Prospect Uranium, Inc.Connors Uranium Project.www.prospecturanium.com/s/Midwest.asp. Accessed January 20, 2010; James MacPherson.March 31, 2008.North Dakota has first uranium land lease in three decades.*Grand Forks, ND, Herald*; Ed Murphy.Uranium Exploration Permits Issued.www.dmr.nd.gov/ndgs/newsletter/n/0908/pdfs/uranium.pdf.Accessed January 20, 2010.

[65] WISE Uranium. Cameco Resources Highland Uranium Project (Wyoming).www.wise-uranium.org/umopwy.html.Accessed February 18, 2010.

[66] Jeff E. Whitten, Nuclear Regulatory Commission.November 16, 2009.Letter and Attachments to John McCarthy;State of Wyoming, Department of Environmental Quality.August 28, 2008.Notice of Violation, Docket No. 4314-08.WISE Uranium.Smith Ranch, Converse County (Wyoming).www.wise-uranium.org/umopwy.html.Accessed February 18, 2010.

[67] John V. Corra, Wyoming Department of Environmental Quality.March 10, 2008.Letter, Notice of Violation, and Attachments to John McCarthy.

[68] WISE Uranium.Wyoming DEQ denounces poor environmental compliance at Smith Ranch/Highland in situ leach mine, issues Notice of Violation to PRI for failure to conduct concurrent reclamation.www.wise-uranium.org/umopwy.html.Accessed February 18, 2010.

[69] WISE Uranium.Christensen Ranch/Irigary (Wyoming).www.wise-uranium.org/umopwy.html.Accessed February 18, 2010.

[70] Steve McManamen.November 14, 2009.Uranium Renaissance.*Gillette News Record*.www.gillettenewsrecord.com/articles/2009/11/15/news/today/news01.txt.Accessed November 16, 2009.



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Element Resources, a Canadian company, is also exploring for "rare earths." Rare earths mining leaves radioactive thorium and uranium as waste products.[71]

Because these operations are often "below the radar" until claims or leases are made public, and because companies change their names and buy each other out at a rapid pace, it is difficult to tell exactly what is going on. The existing in situ leach operations, the permitting of the Christensen Ranch-Irigary project, and the many exploration activities insure that eastern Wyoming will remain the most active uranium mining area within Lakota Territory.

### Western South Dakota

Four companies are known to be exploring in western South Dakota. The most active project is a proposed in situ leach mine along the Wyoming border, at the southwest corner of the Black Hills in the heart of Lakota Territory. This is known as the Dewey-Burdock project. Powertech Uranium, the company that proposes the mine, has been doing exploration drilling. The company is working on getting the necessary permits from the US Nuclear Regulatory Commission, US Environmental Protection Agency, and US Bureau of Land Management. It also applied to the state Department of Environment and Natural Resources.[72]

The company's original permit applications to the NRC and the State were deemed inadequate, and the company had to rewrite and resubmit them. After the State turned down the company's application twice, the company went to the legislature, which passed a law suspending most state regulation of ISL uranium mining. The NRC recently stopped consideration of the safety portion of the company's application, because the company has repeatedly failed to provide adequate information. Local citizens are also formally opposing the NRC application.

Uranium mining has been successfully opposed in the past in the Black Hills, partly because of staunch Lakota protection of their sacred area. There will undoubtedly continue to be resistance to uranium mining proposals in this area.

### Northeastern Colorado

Six uranium companies – including companies from Canada and Australia – are exploring for uranium in northeastern Colorado. Powertech Uranium is also doing exploration work in Weld County along the Wyoming border at its Centennial project. The company's plan is to do ISL mining on part of its deposit and open pit mining on the other part. The proposed open pit mine is only seven miles from Fort Collins, a college town of 100,000 people. The proposal has been effectively opposed by local organizations, and the state legislature passed three pieces of legislation in 2008 that will make in situ uranium mining very difficult. [73]The company sued the state over the resulting regulations. It has

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[71] Powertech Uranium Corp.Dewey Terrace.www.powertechuranuim.com/s/DeweyTerrace.asp.Accessed January 20, 2010;Bayswater Issues NI 43-101 Technical Report on Elkhorn Project.January 11, 2010.*Earth Times*.www.earthtimes.org.Accessed January 11, 2010;Strathmore Minerals Corp.Gas Hills, Wyoming.www.strathmoreminerals.com/s/GasHills.asp.Accessed September 28, 2009; *Op. cit.,* McManamen.

[72] Powertech Uranium Corp.Dewey Burdock.www.powertechuranium.com/s/DeweyBurdock.asp.Accessed January 20, 2010.

[73] Coloradoans Against Resource Destruction.FAQ 5: What companies are looking for uranium in Weld County?www.nunnglow.com/faqs/faq-6-what-companies-are-looking-for-uranium-in-weld-county.html.Accessed



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recently put this project on hold, so that it can focus its resources on the proposed South Dakota mining.

South Park in Park County has been the other active area in the South Platte River watershed. There, citizen opposition convinced New Horizon Uranium Corporation to abandon any immediate plans after it had made numerous uranium claims.

There are several reasons that opposition to uranium mining has been relatively successful in northeastern Colorado. First, it is more difficult to "sell" uranium mining when 275,000 people live within twenty miles of a proposed mine. Second, the northern Front Range is one of the most highly educated areas in the nation. This means that experts are available who can rebut uranium company claims. Third, Colorado healthcare professionals have taken the lead in opposing mining based on its negative health impacts. This is a powerful and respected segment of the population. As a result, uranium activity has been successfully opposed in northeastern Colorado.

## Summary

Lakota Territory has been the site of extensive uranium activities since the dawn of the nuclear age. From exploration to mining to milling, these activities have left a mark. Past and ongoing contamination has impacted water, soil, plants, livestock, wildlife, air, and people. Cultural and historical resources have been destroyed and continue to be threatened. The boom and bust cycle has created instability for local economies and communities.

Plans to begin, resume, or expand open pit and in situ leach mining could increase these impacts. But Lakota people and their allies are opposing many mining proposals and are meeting with some success. Unlike in the early years of the nuclear age, people who live in uranium mining areas now know the impacts of the front end of the nuclear chain, and there is strong opposition to the idea of a "nuclear renaissance." Whether public opposition, market forces, or other factors will prevent future uranium activities remains to be seen. But the issue is sure to remain contentious in much of Lakota Territory.

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January 20, 2010 ;Powertech Uranium Corp.Centennial.www.powertechuranium.com/s/Centennial.asp. Accessed January 20, 2010.



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Here is the third and last group of articles (for now).

Lilias

# Technical Paper

# Excursions of Mining Solution at the Kingsville Dome In-situ Leach Uranium Mine

by George Rice

Hydrologist, GRGwH

## Abstract

In-situ leach (ISL) uranium mining differs from conventional mining in that it does not require excavation of ore. Instead, uranium is mobilized by injecting leaching fluids into a groundwater-saturated ore body. The uranium enriched groundwater (mining solution) is then brought to the surface through extraction wells. Approximately 1 to 3 percent more water is extracted from a uranium production well field than is injected. The purpose of this "bleed" is to prevent the escape of mining solution (excursions) by maintaining a hydraulic gradient toward the extraction wells.

The Kingsville Dome Mine is 13 km southeast of Kingsville, Texas. ISL mining began in 1988 and continued intermittently until 2009. The mine covers 864 ha and is divided into three production areas. This paper focuses on production area three (PA-3).

The bleed at PA-3 did not contain the increased pressures caused by injection of leaching fluids. A hydraulic gradient was rapidly established between the injection wells and the mine boundary, as shown by a rise in water levels in monitor wells surrounding PA-3. This gradient drove mining solution beyond the mine boundary. These excursions affected a well on the Garcia property, approximately 300 m down gradient of the mine. Since mining began, uranium concentrations in the Garcia well have increased from less than 200 µg/L, to more than 600 µg/L. This is the first time that contaminants in an off-site domestic well have been linked to ISL uranium mining in the United States of America.

## In-situ leach uranium mining

In-situ leach (ISL) uranium mining differs from conventional mining in that it does not require excavation of ore. Instead, uranium is mobilized by injecting leaching fluids into a groundwater-saturated ore body (figure 1). The uranium-enriched groundwater (mining solution) is brought to the surface through extraction wells and routed to a processing plant where the uranium is removed. The uranium-depleted solution is then re-injected into the ore body. This cycle of injection and extraction continues as long as the ore body contains economically recoverable amounts of uranium.



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Leaching fluids typically consist of water, oxidants (e.g., oxygen, hydrogen peroxide), and complexing agents (e.g., carbonates, sulfates) (NRC 2007). The oxidants convert uranium from the relatively insoluble $U^{+4}$ state to the soluble $U^{+6}$ state. The complexing agents combine with the oxidized uranium to form anionic or neutral complexes that remain in solution (e.g., $UO_2(CO_3)_3^{4-}$, $UO_2(SO_4)_3^{4-}$) (Charbeneau 1984). Uranium ore usually contains other toxic constituents such as radium, arsenic, molybdenum, and selenium (NRC 2007). These are also mobilized during ISL mining.

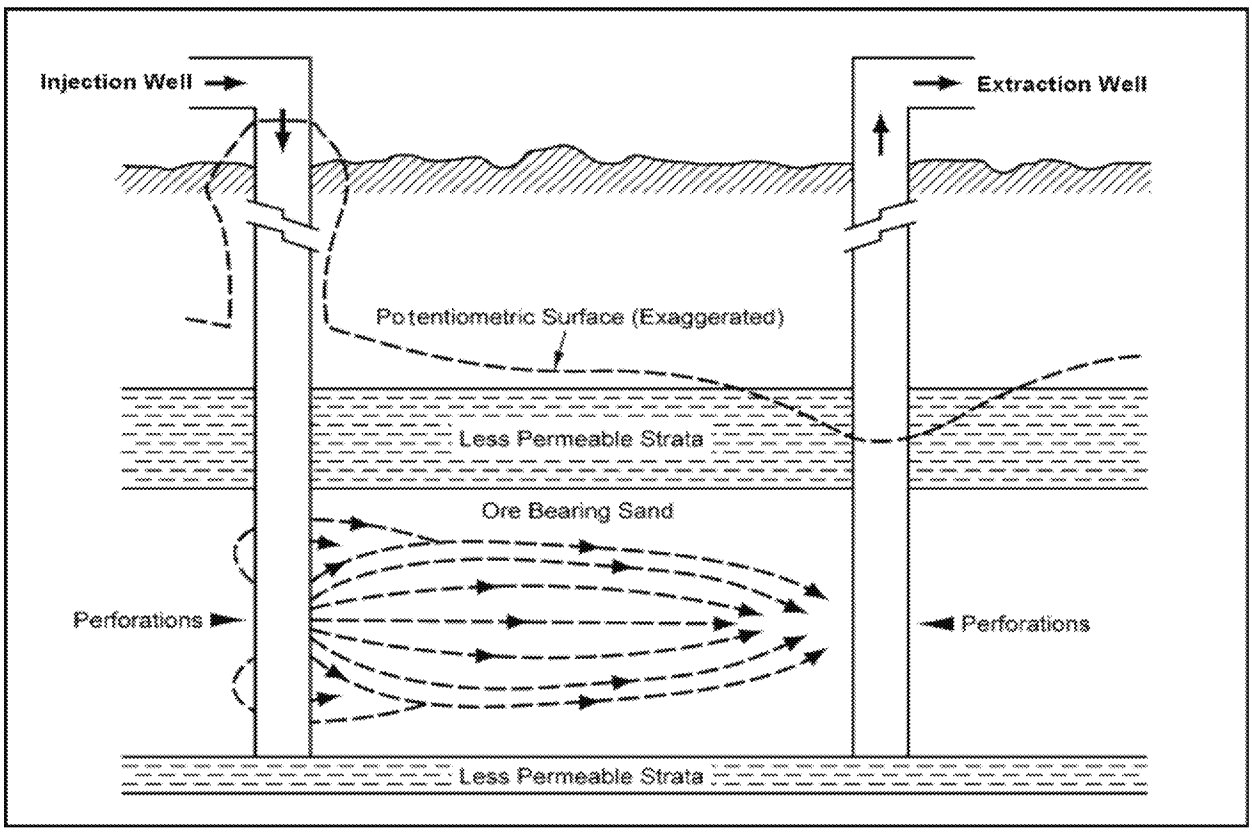


***Figure 1. Schematic Cross Section, Injection and Extraction Wells (adapted from NRC 2009)***

Most ISL mining occurs in fluvial sandstone aquifers (Staub et al. 1986). These fluvial systems are heterogeneous and anisotropic, consisting of interbedded clays, silts, sands, and gravels. They contain paleochannels that act as preferential flow paths, and overbank deposits that impede flow.

Injection and extraction wells are organized in patterns. Figure 2 shows a 5-spot pattern. Other patterns, e.g., 7-spot, are also used. A uranium production well field will usually contain a series of patterns arranged to follow the form of the uranium ore body. Well fields are grouped in production areas, and production areas are surrounded by a ring of monitor wells (NRC 2009).

Approximately 1 to 3 percent more water is extracted from a production area well field than is injected. The purpose of this "bleed" is to prevent the escape (excursion) of mining solution by maintaining a hydraulic gradient toward the extraction wells. An excursion is the flow of mining solution beyond the monitor well ring.

Figure 2 is an idealized depiction of groundwater flow. In practice, excursions are initiated when mining solution flows beyond the capture zones of extraction wells. This may be caused by failure to balance injection and extraction rates, failure to maintain sufficient bleed rates, or when mining solution is diverted by paleochannels.



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After mining at a production area is completed, groundwater is supposed to be restored to its pre-mining quality (Texas Administrative Code, Title 30, §331.107). However, groundwater restoration after ISL mining is difficult. The United States Geological Survey reviewed 22 uranium production areas in Texas (USGS 2009). Toxic constituents (e.g., uranium, arsenic, selenium) had been restored to their pre-mining levels at only two of them. In no case had all constituents, including non-toxic constituents such as calcium and sulfate, been restored to their pre-mining levels (USGS 2009). Nonetheless, the Texas Commission on Environmental Quality (TCEQ) considers groundwater restoration to be complete at all 22 production areas (USGS 2009).

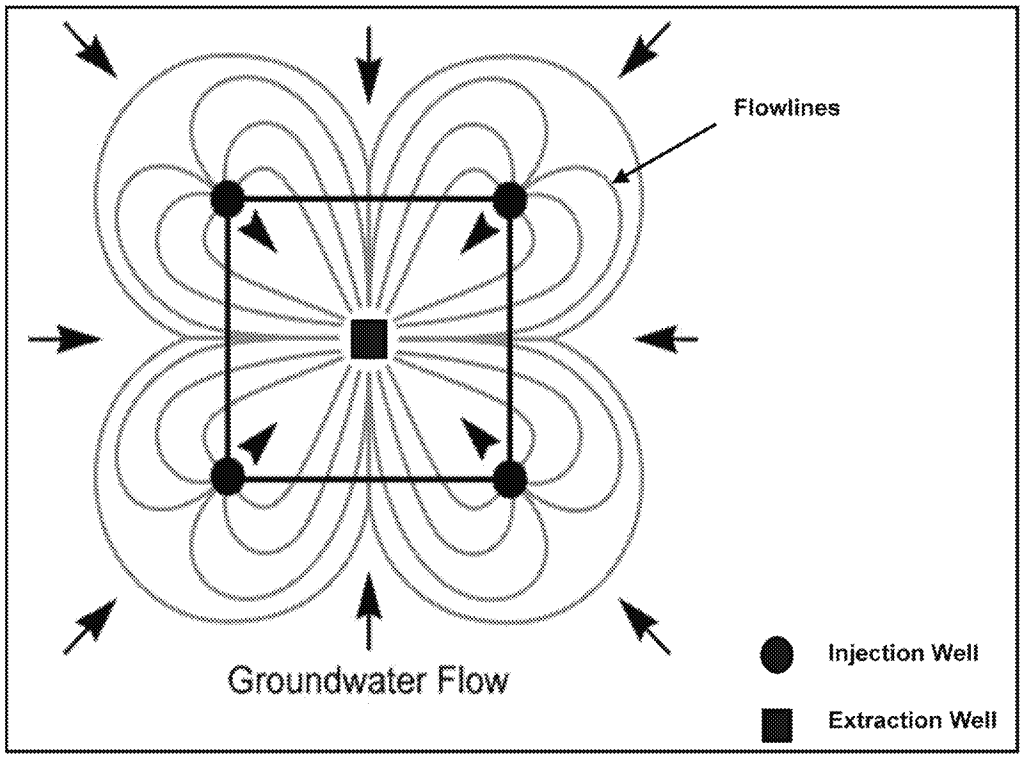


***Figure 2. Schematic, 5-spot Injection-Extraction Well Pattern*** *(Adapted from NRC 2009)*

# ISL mining at Kingsville Dome

The Kingsville Dome (KVD) mine is owned and operated by Uranium Resources Inc. (URI). The mine is in Kleberg County, Texas, approximately 13 km southeast of Kingsville (figure 3). ISL mining began in 1988 and continued intermittently until 2009. The area licensed for mining covers 864 ha (TBRC 1985) and is divided into three production areas (PAs) (figure 4). This paper focuses on PA-3. Unless otherwise noted, all of the site-specific data regarding the KVD mine was obtained from documents submitted by URI to the TCEQ or its predecessor agencies.

There are domestic wells near the mine. All of them are monitored for uranium and other constituents associated with ISL mining. Two of them, the Garcia wells, are directly down gradient of PA-3 (figure 4).



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The ore occurs in the Goliad Aquifer, a fluvial deposit consisting of interbedded clay, silt, and sand (Rice 2006). The ore is found between about 150 m and 225 m below land surface. The principal uranium minerals are believed to be uraninite ($UO_2$) and coffinite ($U(SiO_4)(OH)_4$) (McKnight 2006).

The groundwater is confined (Rice 2006) and generally flows toward the northwest (TBRC 1985). The current flow direction is not the natural direction. Under natural conditions, groundwater flowed southeast, toward the coast. However, pumpage in the vicinity of Kingsville reversed the hydraulic gradient and groundwater now flows toward Kingsville (Rettman 1983). Local groundwater flow directions vary. Calculated flow rates range from about 0.3 m/yr to 100 m/yr (Rice 2006). This range reflects the heterogeneity of the fluvial deposits. It should be noted that these flow rates are for non-mining conditions. During mining, local flow rates may be much higher due to the steep gradients caused by the operation of injection and extraction wells.

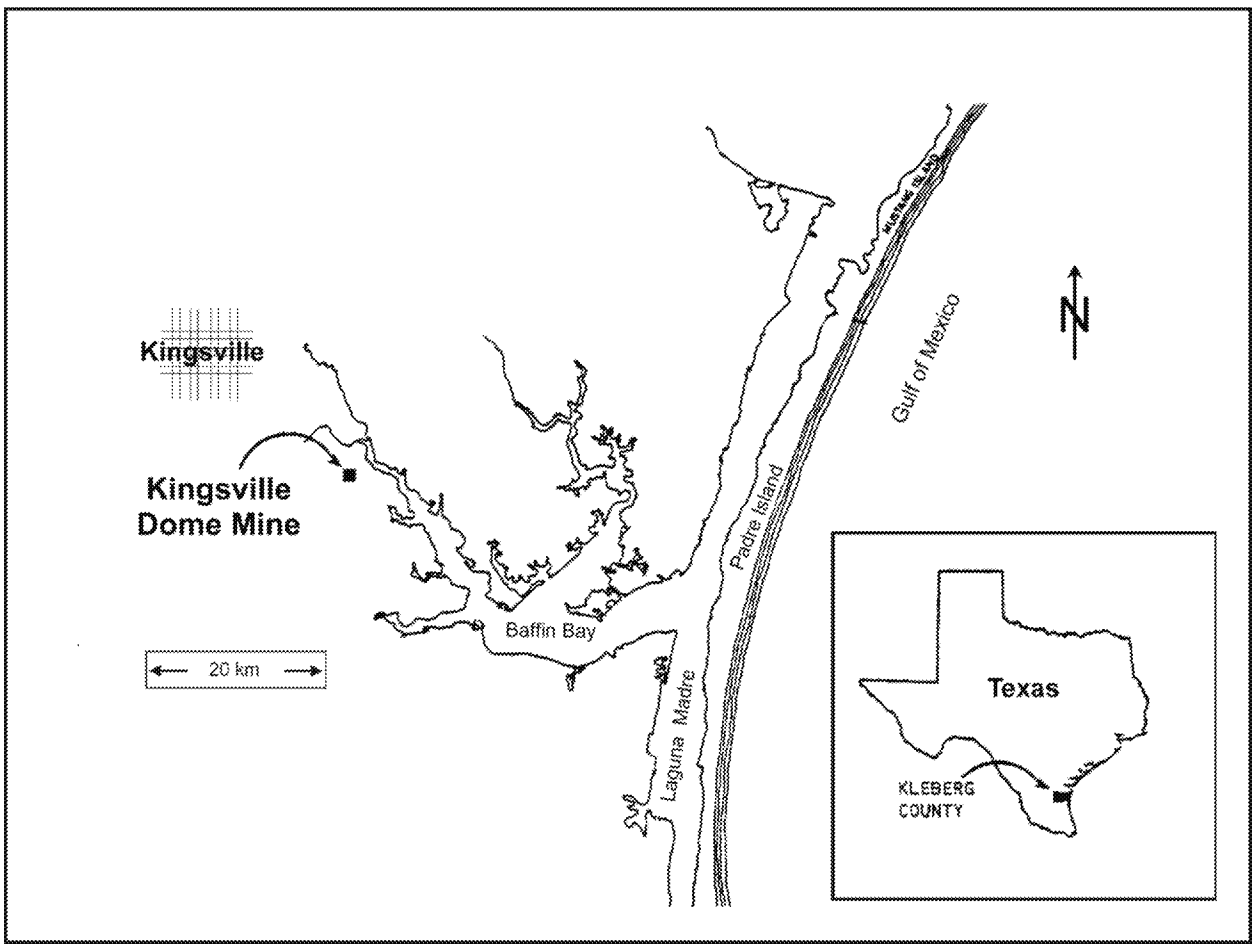


*Figure 3. Mine Location Map*

The leaching fluid used at the KVD mine is oxygenated water. Table 1 shows typical concentrations of constituents in the mining solution. URI uses a computerized model to adjust injection and extraction rates, but the model does not account for aquifer heterogeneities (Grant 2006). URI maintains a bleed of approximately one percent. The bleed is supposed to continue until groundwater restoration is completed, but URI has not always maintained the bleed as required (TCEQ 2003).



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**Table 1 Concentrations of Constituents in a Typical Mining Solution at the KVD Mine***

| pH | Electrical cond. | Uranium | Chloride | Calcium | Bicarb-onate | Sulfate | Molyb-denum |
|---|---|---|---|---|---|---|---|
| (SU) | (µmhos/cm) | (µg/L) | (mg/L) | (mg/L) | (mg/L) | (mg/L) | (mg/L) |
| 6.6 | 4000 | 80,000 | 600 | 400 | 800 | 1200 | 10 |

**URI analysis of mining solution from extraction wells. It may be a mixture of mining solutions from many extraction wells. Data from Mark Pelizza of URI, 2005.*

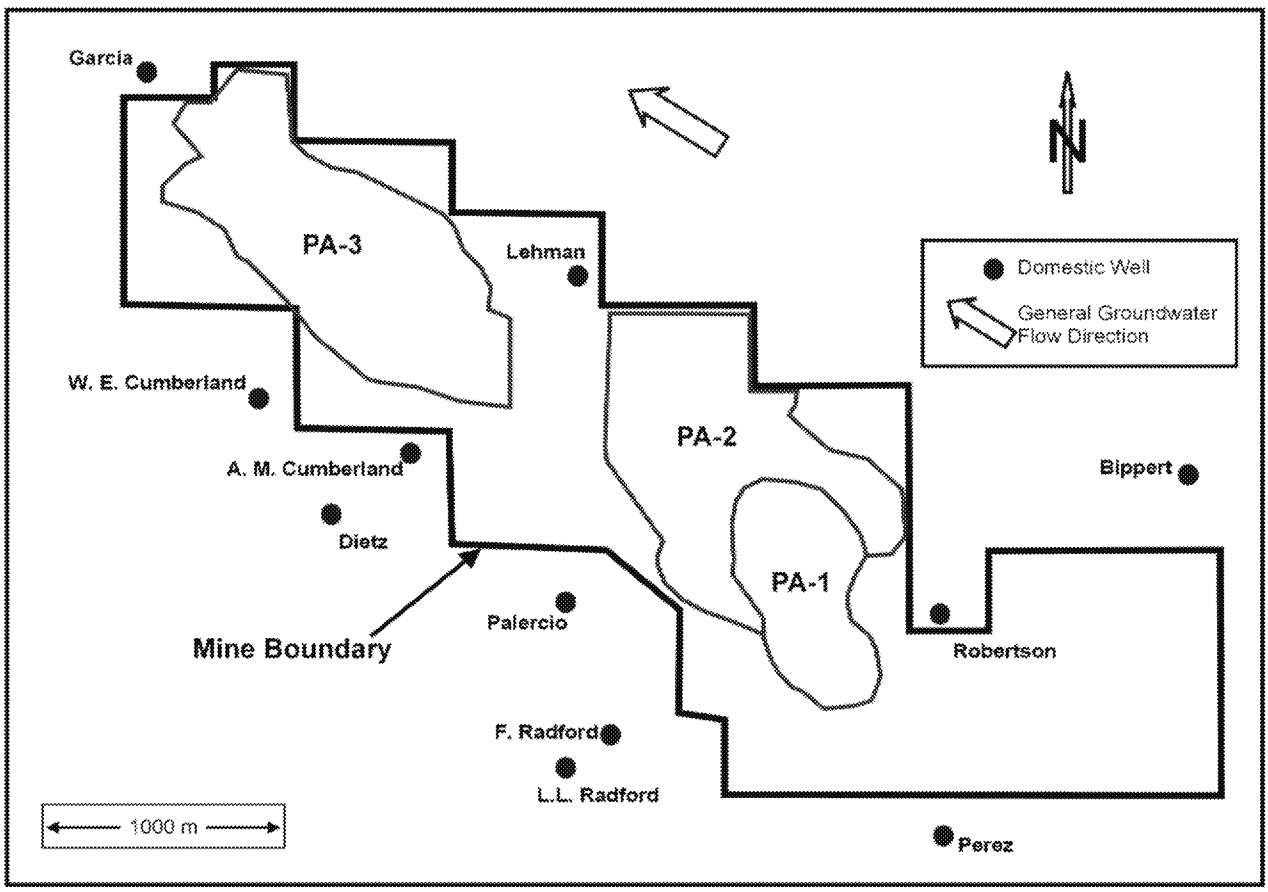


***Figure 4. KVD Mine Map***

## The Effects of Mining on Hydraulic Gradients at PA-3

Excursions are driven by hydraulic gradients. During mining at PA-3, the hydraulic gradients driving excursions were the result of the injection of leaching fluids.

PA-3 covers 151 ha. Mining at PA-3 first began in June 1998 and was suspended in June 1999. During this first period, uranium was produced from well fields 9 and 10 (figure 5). Mining resumed in January 2007 and was



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suspended again in June 2009. During this second period, uranium was produced from well fields 13, 14, 15a, 16a, 16b, 17a and 17b. Well field 15b was installed but was not used to produce uranium (Van Horn 2012). Well field injection rates ranged from about 1400 L/min to 5000 L/min (TCEQ 2008; URI 1999). Complete well field injection data are not available. A request to URI for additional data was refused (URI 2012b).

PA-3 is surrounded by a ring of 49 monitor wells. Water levels have been measured in all the monitor wells, but the lengthiest records are from seven wells monitored under an agreement between URI and Kleberg County. Beginning in 2005, water levels were measured in wells MW-78, MW-83, MW-85, MW-89, MW-97, MW-102, and MW-125. Water levels in these wells were measured quarterly when mining was not taking place, and twice a month during mining. Water levels from these seven wells are used in the discussion below.

The injection of leaching fluids had a rapid effect on water levels in the monitor wells. The effect can be seen by comparing water levels before, during, and after mining. Water levels rose an average of 1.7 m in the year after the resumption of mining (table 2), and fell an average of 2.3 m in the year after the suspension of mining (table 3). Figure 6 shows water levels in two monitor wells for the one year periods immediately before and after mining resumed.

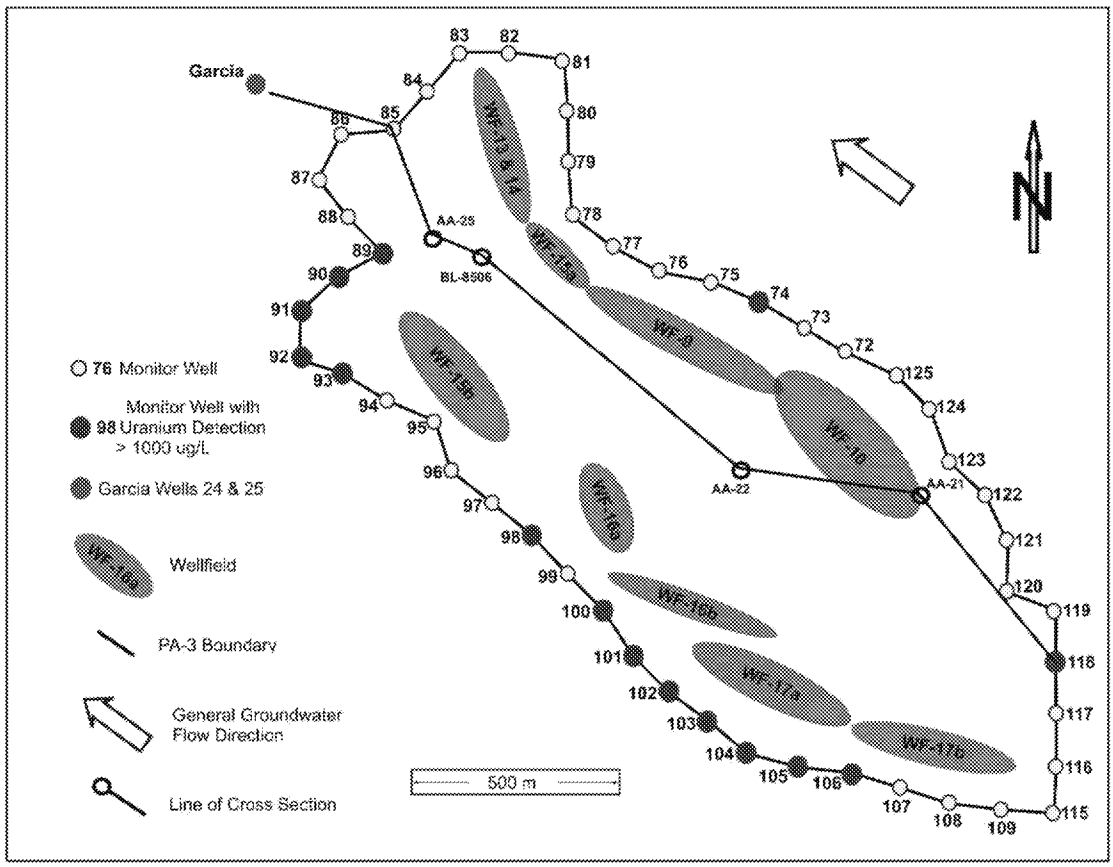


*Figure 5. PA-3, Well Fields and Monitor Wells*

**Table 2 Water Level Rises in Response to Resumption of Mining***



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| Well ID | Average depth to water in the year before mining resumed (Dec 2005 – Dec 2006, m btoc**) | Average depth to water in the year after mining resumed (Jan 2007 – Dec 2007, m btoc) | Average rise in water level in year after mining resumed (m) |
|---|---|---|---|
| MW-78 | 36.21 | 34.53 | 1.68 |
| MW-83 | 39.40 | 37.29 | 2.11 |
| MW-85 | 40.45 | 37.77*** | 2.68 |
| MW-89 | 37.69 | 36.67 | 1.02 |
| MW-97 | 36.80 | 35.61 | 1.19 |
| MW-102 | 37.28 | 35.84 | 1.44 |
| MW-125 | 34.06 | 32.37 | 1.69 |
| | | **Average of all wells:** | 1.67 |

** URI, 2012a. The average bleed rate during the year preceding mining was 62 L/min (URI 2007a, no pumping for restoration appears to have occurred during this period). The average bleed rate during the first three quarters of mining was 67.8 L/min (URI 2007b and 2008). There was no bleed during the remaining period of mining.*

*** btoc: below top of casing.*

**** With outlier removed. The outlier (56.48 m Aug 13, 2007) was approximately 18 m lower than any other measurement (URI 2012a). The average depth without removing the outlier was 38.58 m.*

**Table 3 Water Level Declines in Response to Suspension of Mining***

| Well ID | Average depth to water in the year before mining suspended (June 2008 – May 2009 m btoc) | Average depth to water in the year after mining suspended (June 2009 – May 2010 m btoc) | Average decline in water level in year after mining suspended (m) |
|---|---|---|---|
| **MW-78** | 35.27 | 37.71 | 2.44 |
| **MW-83** | 37.47 | 40.27 | 2.80 |
| **MW-85** | 39.45 | 42.00 | 2.55 |
| **MW-89** | 37.08 | 39.46 | 2.38 |
| **MW-97** | 36.44 | 38.60 | 2.16 |
| **MW-102** | 36.90 | 38.79 | 1.89 |
| **MW-125** | 33.27 | 35.38 | 2.11 |
| | | **Average of all wells:** | 2.33 |

** URI 2012a. The average pumping rate (bleed plus restoration) during the year following mining was 428 L/min (URI 2010).*

This rapid effect on water levels is to be expected. In a confined aquifer, changes in head are quickly propagated in response to the extraction or injection of water (Kruseman and De Ridder 1976). A similar response was seen during a pumped aquifer test at the KVD mine. In that test, water levels more than 1200 m from the pumped well began dropping less than ten hours after pumping began (TBRC 1985).

The rise in water levels shows that the bleed did not contain the increased pressures caused by injecting leaching fluids. The increased pressures were propagated beyond the monitor well ring, creating a gradient between the



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injection wells and monitor wells. Mining solution flowed down this gradient, toward the monitor wells. This resulted in excursions.

## Excursions at PA-3

Excursions are monitored by measuring the concentrations of uranium and chloride, and the value of electrical conductivity (EC) at the monitor well ring. Monitor wells are sampled quarterly when mining is not taking place, and twice a month during mining.

Excursions at PA-3 are most readily identified by increases in uranium concentrations. This is because the concentration of uranium in the mining solution is more than 1000 times greater than the groundwater background concentration, while the concentration of chloride and the value of EC are only about two times greater than background (table 4).

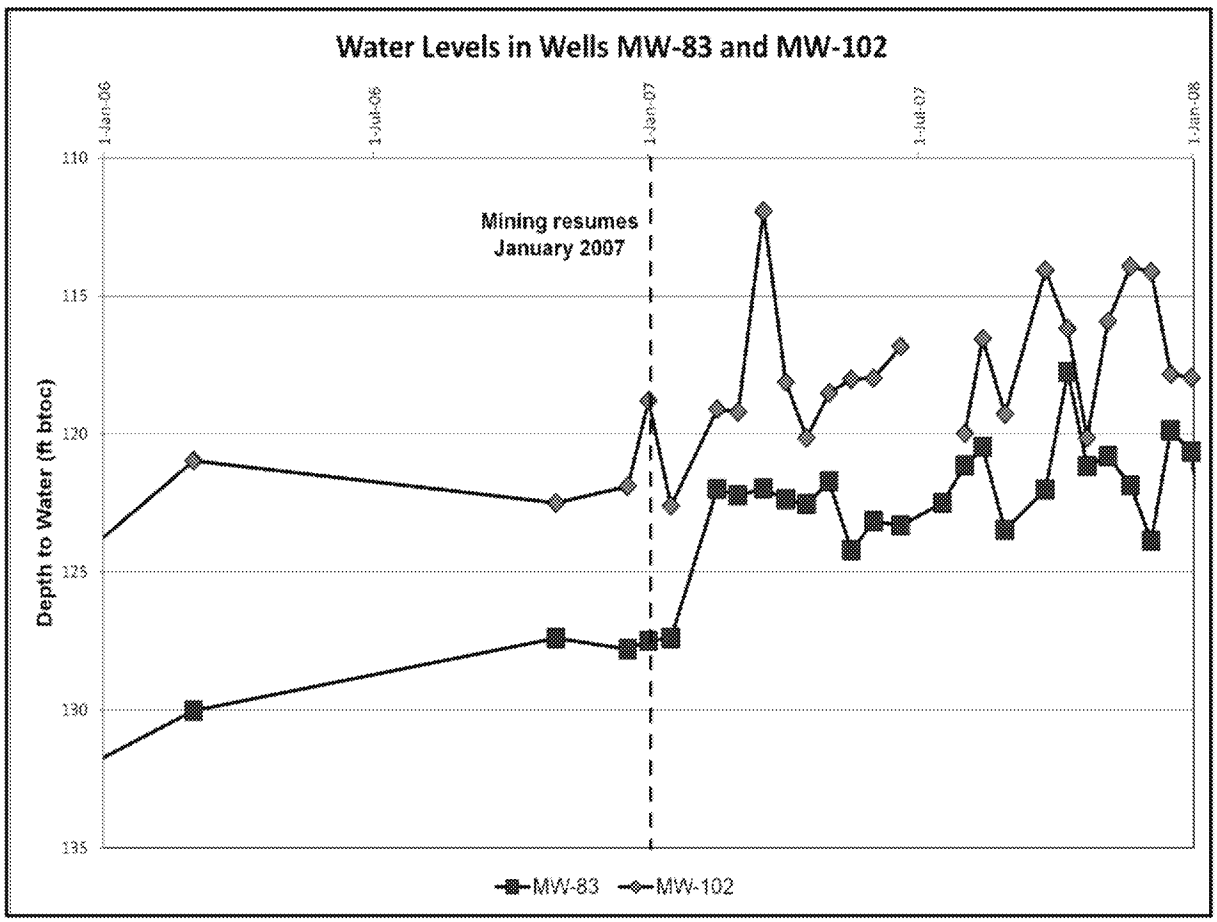


*Figure 6. Response of Water Levels to Injection of Leaching Fluids*



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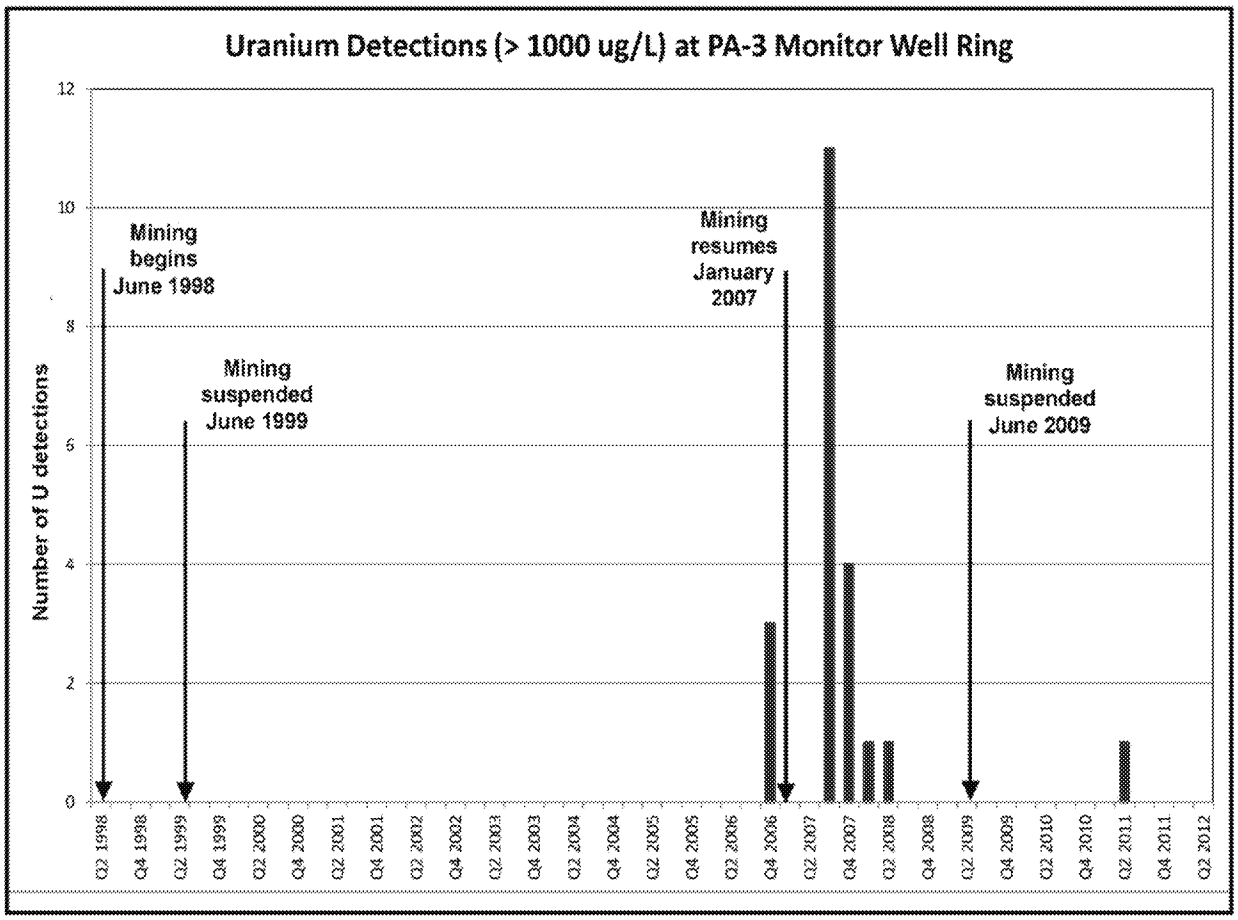


*Figure 7. Timeline of Uranium Detections at PA-3*

**Table 4 . Uranium, Chloride, and EC Values In Mining Solution and Background Groundwater at PA-3**

| Parameter | Typical mining solution value | Range of background values* | Average background values* | Ratio of mining solution value to average background value | EPA drinking water standard** |
|---|---|---|---|---|---|
| **Uranium (µg/L)** | 80,000 | < 0.001 - 187 | 41 | 1950 | 30 µg/L |
| **Chloride (mg/L)** | 600 | 214 - 443 | 282 | 2.1 | 250 mg/L |
| **EC (µmhos/cm)** | 4000 | 1600 - 2590 | 2017 | 2.0 | NA |

** Pre-mining values in monitor well ring surrounding PA-3 (URI 1997).*

*** The uranium standard is a primary maximum contaminant level (MCL). MCLs are health-based and legally enforceable. The chloride standard is a non-enforceable secondary standard based on aesthetic effects (e.g., taste, odor) (EPA, 2009). NA: not applicable.*



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Given the values in table 4, a mixture of 2% mining solution and 98% background groundwater would have the following values of uranium, chloride, and EC.

Uranium: 0.02 (80,000 μg/L) + 0.98 (41 μg/L) = 1640 μg/L
Chloride: 0.02 (600 mg/L) + 0.98 (282 mg/L) = 288 mg/L
EC: 0.02 (4000 μmhos/cm) + 0.98 (2017 μmhos/cm) = 2057 μmhos/cm

Thus, a mixture of several percent mining solution with background groundwater could be readily identified by the increase in uranium concentrations, but the chloride and EC values would be difficult to distinguish from background values.

At least two factors act to reduce concentrations in the sampled mining solution. As the mining solution travels from the well field to the monitor well ring, hydrodynamic dispersion dilutes the concentrations of uranium and other constituents. There is also an apparent reduction in concentrations resulting from the design of the monitor wells. The well screens are 30 m long. Therefore, a plume of mining solution that is less than 30 m thick will be diluted by native groundwater when it is pumped from the well.

It should be noted that it is not necessary for uranium to travel from the well fields to the monitor well ring in order to increase uranium concentrations in the monitor wells. If uranium is present in the formation near the monitor wells, uranium concentrations can be increased by the arrival of oxidizing mining solution.

Apparent excursions of mining solution have been detected 21 times at PA-3 (table 5, and figures 5 and 7). More excursions have probably occurred, but URI does not report the values of uranium concentrations that are less than 1000 μg/L (see below).

## Quality of analytical data and false positives

The uranium concentrations cited in this paper come from analyses performed by commercial laboratories and by URI's in-house laboratory. The background samples and samples from the Garcia wells were analyzed by commercial laboratories. All the monitor well samples, except the background samples, were analyzed by URI's laboratory.

There are two problems with the analyses produced by URI's laboratory. First, although TCEQ accepts the results, problems with their accuracy have been documented (Rice 2006). Second, when reporting uranium concentrations for monitor wells, URI reports only those values greater than 1000 μg/L. If a value does not meet this threshold, it is reported either as less than 1000 μg/L, or as zero. Zero is not an analytical result. It means that the concentration is below the detection limit. In this case, the detection limit appears to be about 20 μg/L (URI 2005). Thus, the uranium analyses reported by URI's laboratory fall into three groups: less than 20 μg/L, between 20 μg/L and 1000 μg/L, and greater than 1000 μg/L. The author has asked URI for the laboratory data showing uranium values below the 1000 μg/L threshold. URI refused (URI 2012b).

The problems with URI's uranium analyses raise the possibility that URI might have reported false negatives or false positives. In the absence of additional data, individual false negatives cannot be identified. But false positives may be identified by examining the circumstances associated with analytical results.



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**Table 5 Monitor Wells with Elevated Uranium Concentrations**

| Well ID | Background U concentration (µg/L) | U concentration during excursion (µg/L) | Date U detected |
|---|---|---|---|
| **MW-74** | 21 | 3200 | 11/16/06 |
| **MW-89** | 22 | 1690 | 8/17/07 |
| **MW-90** | 24 | 1320 | 8/17/07 |
| **MW-90** | 24 | 1060 | 11/27/07 |
| **MW-91** | 31 | 2140 | 8/17/07 |
| **MW-91** | 31 | 1500 | 3/5/08 |
| **MW-92** | 36 | 1670 | 8/17/07 |
| **MW-92** | 36 | 1440 | 10/11/07 |
| **MW-92** | 36 | 1300 | 4/16/08 |
| **MW-93** | 37 | 2500 | 10/11/07 |
| **MW-98** | 59 | 1100 | 4/18/11 |
| **MW-100** | 30 | 3600 | 8/17/07 |
| **MW-101** | 53 | 2520 | 8/17/07 |
| **MW-102** | 20 | 1300 | 11/7/06 |
| **MW-102** | 20 | 5170 | 8/17/07 |
| **MW-103** | 16 | 2790 | 8/17/07 |
| **MW-104** | 36 | 2140 | 8/17/07 |
| **MW-105** | 31 | 2320 | 8/17/07 |
| **MW-106** | 32 | 3900 | 11/7/06 |
| **MW-106** | 32 | 1260 | 8/17/07 |
| **MW-118** | 101 | 1170 | 10/19/07 |

*The uranium concentrations shown in table 5 would not be considered excursions by TCEQ. According to TCEQ, an excursion has not occurred unless uranium concentrations exceed 6540 µg/L (TCEQ 2006).*

Figure 7 is a timeline showing the 21 uranium detections greater than 1000 µg/L. Four of the detections may be false positives because they are inconsistent with the history of mining at PA-3. Three of the four are from samples collected in November 2006, approximately two months before mining resumed. The fourth is from a sample collected in April 2011, almost two years after mining was suspended. There are other possible explanations for these four detections. The 2006 detections could be the result of pre-mining activities (e.g., testing of injection wells), or they could represent slow-moving, remnant solution from mining that occurred in 1998 and 1999. The 2011 detection could also be the result of slow-moving solution from earlier mining. At best, these four detections are suspect.

There are several reasons to believe that the other 17 uranium detections shown in figure 7 are not false positives. First, all of them occurred during mining. Second, all of them occurred after water levels in the monitor wells rose sharply in response to mining. This rise indicates that mining solution was being driven toward the monitor wells. Third, with one exception, the 17 detections are grouped in two clusters of wells: MW-89 – MW-93 and MW-100 – MW-106 (table 5 and figure 5). If the detections were false positives, one would expect them to be distributed



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randomly around the monitor well ring. In four of the wells, values greater than 1000 μg/L were detected more than once (table 5).

A suspicious feature of the detections shown in figure 7 is that 11 of them are from samples that were collected on one day, August 17, 2007. These detections could have been the result of problems in URI's laboratory. However, there are reasons to believe that this is not the case. First, a total of 27 samples were collected on August 17, 2007. Sixteen of the analytical results from that day were below 1000 μg/L. Second, all 11 detections occurred in the two well clusters mentioned above. Third, the 11 detections are not temporally isolated. That is, they are not anomalies that were preceded and followed by non-detections. The 11 wells where the detections occurred were sampled in the two-month periods immediately before and immediately after August 17, 2007. Seventeen samples were collected in the two-month period before August 17$^{th}$. All of the results were between 20 μg/L and 1000 μg/L. Thirty samples were collected in the two-month period after August 17$^{th.}$ Twenty eight of the results were between 20 μg/L and 1000 μg/L, one result was less than 20 μg/L, and one result was more than 1000 μg/L.

Although there are problems with the uranium analyses performed by URI's laboratory, careful consideration of the data leads to the conclusion that most of the uranium detections are not false positives.

## Garcia wells

The Garcia family used to drink water from two wells on their property, W-24 and W-25 (figure 5). These wells are about 60 m apart, and less than 300 m northwest of PA-3. Both of them are completed in the Goliad Aquifer (figure 8). Their depths are approximately 180 m and 240 m (Saenz 2012a). Well W-24 is now used only to water cattle and goats, and W-25 is no longer used (Saenz 2012a).

Water from wells W-24 and W-25 has been sampled since 1996, if not earlier; the records are unclear (figure 9). Before mining began at PA-3, the average concentration of uranium was 180 μg/L. The uranium was probably due to the presence of uranium ore in the Goliad Aquifer where the Garcia wells are completed.



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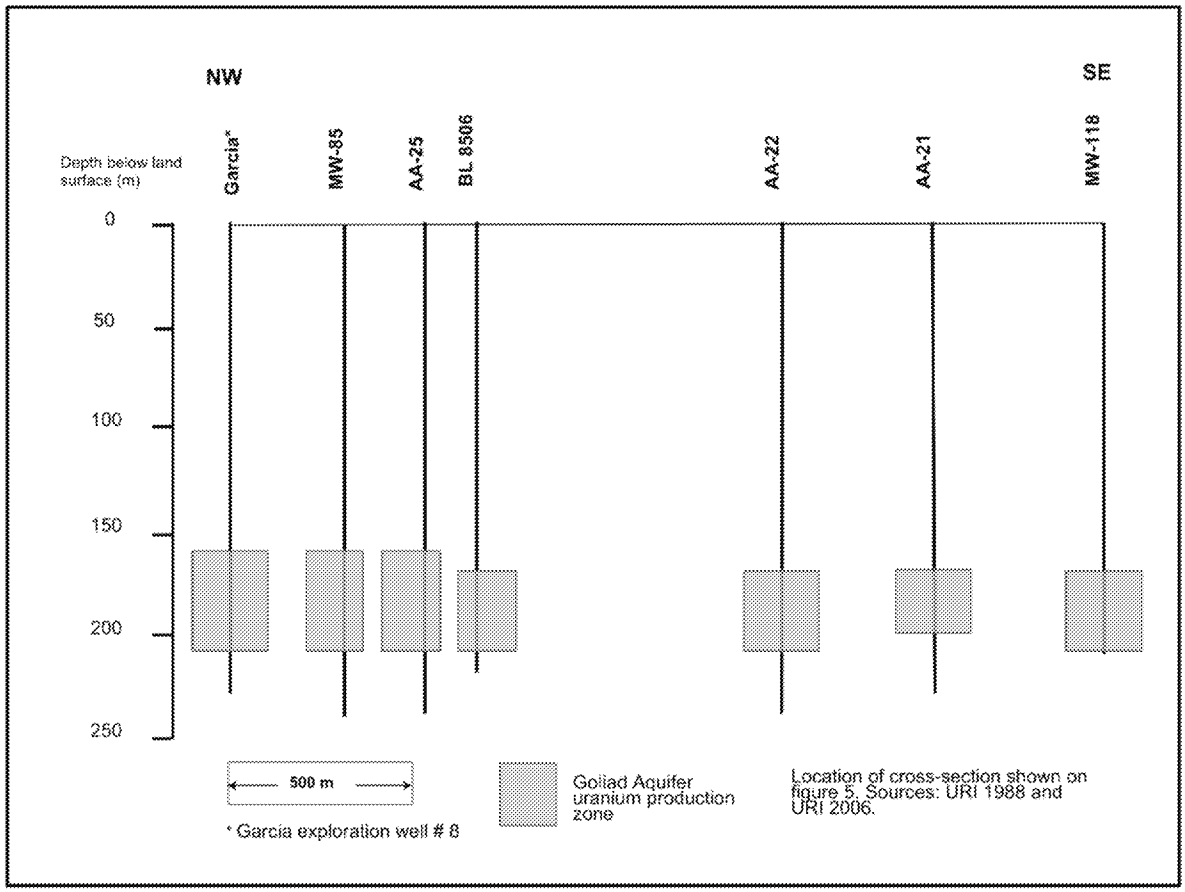


***Figure 8. Cross section through PA-3 and Garcia property***

Until late 2005, water from both Garcia wells was pumped to a single tank, and analyses were performed on samples from the tank. The only exception to this was in June 1998, when separate samples were collected from wells W-24 and W-25. The uranium concentrations were 152 µg/L and 167 µg/L, respectively. Since late 2005, W-24 has been sampled nine times and W-25 one time. The samples from W-24 had an average concentration of 670 µg/L, and the sample from W-25 had a concentration of 10.4 µg/L.

The cause of the low concentration in W-25 is unknown. W-25 no longer contains a pump. At the time it was sampled, W-25 had been unused for about two years and the sample may have been affected by deterioration of the well casing (e.g., occlusion of uranium by precipitating iron). The sample was collected by the author after purging three bore volumes. At the beginning of the purge, the water appeared to be black. When the sample was collected, the water was lightly tinted.

There are two possible causes of the increased uranium concentrations in W-24. First, concentrations in W-24 may have always been high, but were diluted in the tank by low concentrations from W-25. Second, they represent excursions from PA-3.

There are two problems with the first possibility. First, when W-24 and W-25 were individually sampled in 1998, the uranium concentrations were about equal. Second, the volume of water pumped into the tank by each well appears to have been about the same. Three horse-power pumps were installed in both wells, and when the



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storage tank was filled, both wells turned on and off at the same time. (Saenz 2012b). When the author sampled the wells in December, 2008, both wells produced water at a rate of about 35 L/min. An equal mixture of waters containing 10 µg/L and 670 µg/L uranium would contain 340 µg/L uranium. This is almost twice the average value measured in the tank between 1996 and 2005.

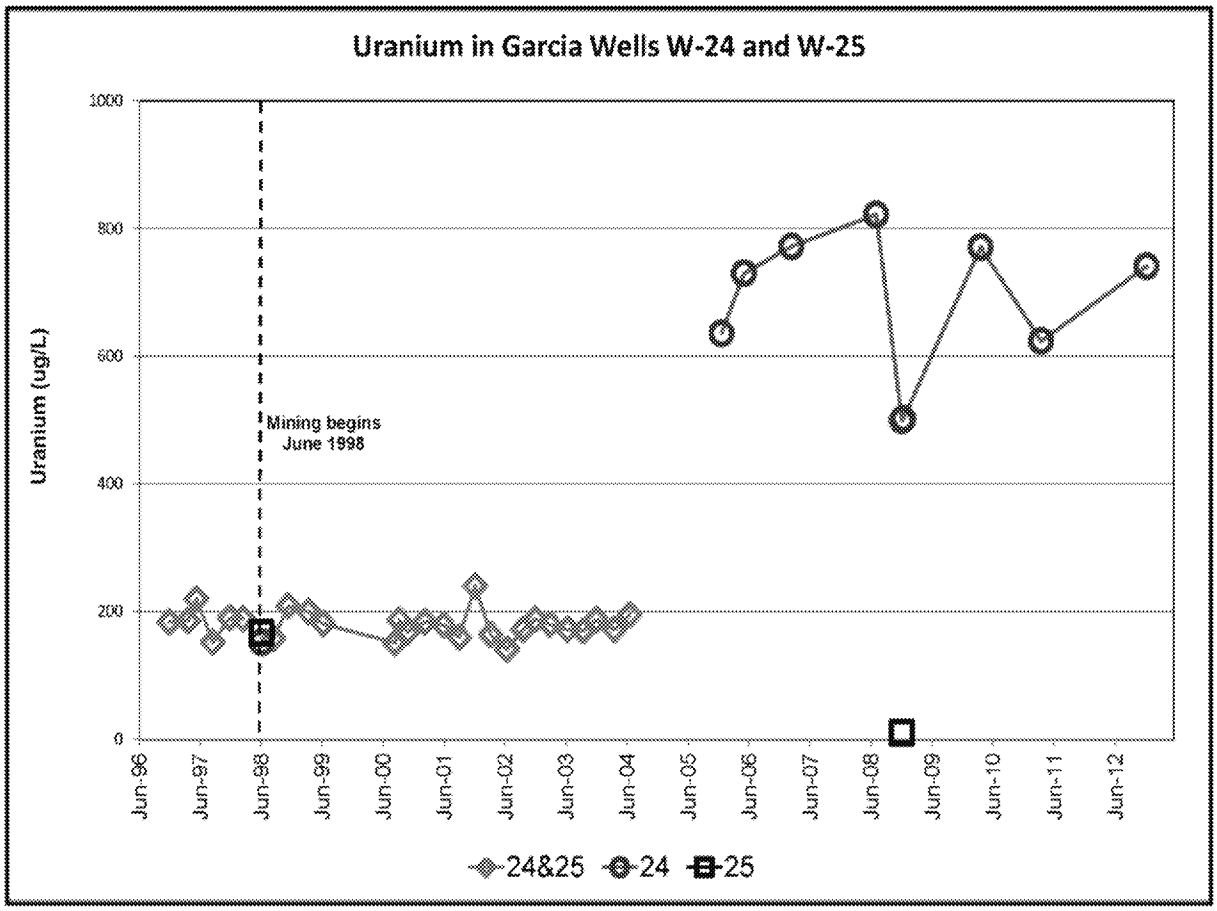


***Figure 9. Uranium Concentrations in Garcia Wells***

There is also a problem with the second possibility. The increased uranium concentrations in W-24 were first detected in late 2005, but excursions at PA-3 were not reported until 2007. However, unreported excursions, that is excursions where the uranium concentration did not reach the 1000 µg/L threshold, probably did occur. This possibility is supported by the following. First, the increased concentrations occurred after mining began at PA-3. Second, the general direction of groundwater flow from PA-3 is toward the Garcia wells, and flow may have been accelerated by pumping of the Garcia wells. Third, excursions have been detected in monitor wells less than 600 m from the Garcia wells (figure 5).

The available data indicate that the likely source of the increased uranium concentrations in the Garcia well is PA-3. To the author's knowledge, this is the first time that contaminants in an off-site domestic well have been linked to ISL uranium mining in the United States of America.



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# Conclusions

Although there are uncertainties associated with some of the available information, a conservative assessment leads to the following conclusions.

1) The injection of leaching fluids at PA-3 created a hydraulic gradient that caused mining solution to flow from injection wells, toward the monitor well ring.
2) The mining solution contained concentrations of uranium that were significantly higher than background concentrations.
3) Excursions occurred. That is, mining solution flowed beyond the monitor well ring surrounding PA-3.
4) The excursions reached the Garcia property. They caused uranium concentrations in well W-24 to increase from an average of less than 200 μg/L, to more than 600 μg/L.

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# HYDROGEOLOGIC INVESTIGATIONS AT PROPOSED URANIUM MINE NEAR DEWEY, SOUTH DAKOTA

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# HYDROGEOLOGIC INVESTIGATIONS AT PROPOSED URANIUM MINE NEAR DEWEY, SOUTH DAKOTA

Report No. WR28-2-520-128

Prepared by
J. Mark Boggs

Norris, Tennessee
October 1983

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## ABSTRACT

The Lakota and Fall River Formations represent aquifers of major importance in the Southern Black Hills Region as well as host rock for uranium ore. An 11-day constant discharge test involving 13 observation wells and numerous private wells was conducted in the Lakota aquifer at TVA's proposed uranium mine near Dewey, South Dakota. The pumping phase of the test was followed by several months of water-level recovery measurements. Results indicate that the test site is located in an area where the Lakota is exceptionally permeable having a transmissivity of 4,400 gpd/ft and a storativity of about $1 \times 10^{-4}$. Outside of this locality the Lakota transmissivity decreases substantially due to aquifer thinning and a change to finer-grained sedimentary facies. The drawdown response in the Fall River aquifer was substantially less than that observed during a similar test conducted at TVA's proposed Burdock mine, indicating that the Fuson shale unit lying between the two aquifers is a more effective aquitard in the Dewey area. It is further concluded that the nearby Dewey fault acts as a barrier to horizontal ground-water movement in the Lakota and Fall River aquifers.

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## INTRODUCTION

The following report describes a hydrogeologic test conducted February 1982 at TVA's proposed uranium mine shaft site near Dewey, South Dakota (Figure 1). The Dewey test is one of a series of tests TVA has conducted in aquifer units of the Inyan Kara Group in the southwestern Black Hills area. The purpose of these tests is to obtain sufficient quantitative information about local hydrogeologic conditions to enable prediction of mine depressurization requirements and impacts to local ground-water users.

## HYDROGEOLOGIC ENVIRONMENT

The principal aquifers in the region are the alluvial deposits associated with the Cheyenne River and its major tributaries, the Fall River formation, the Lakota formation, the Sundance formation, and the Pahasapa (or Madison) formation. Except for the alluvium, these aquifers crop out peripherally to the Black Hills where they receive recharge from precipitation. Ground-water movement is in the direction of dip, radially from the central Black Hills. In most instances, ground water in these aquifers is under artesian conditions away from the outcrop area, and water flows at ground surface from numerous wells in the area.

The Fall River and Lakota formations which form the Inyan Kara Group are the most widely used aquifers in the region. The alluvium is used locally as a source of domestic and stock water. The Sundance formation is used near its outcrop area in central and northwestern Fall River County. The Pahasapa (Madison) formation is locally accessible only by very deep wells and is the source for five wells in the city of Edgemont.

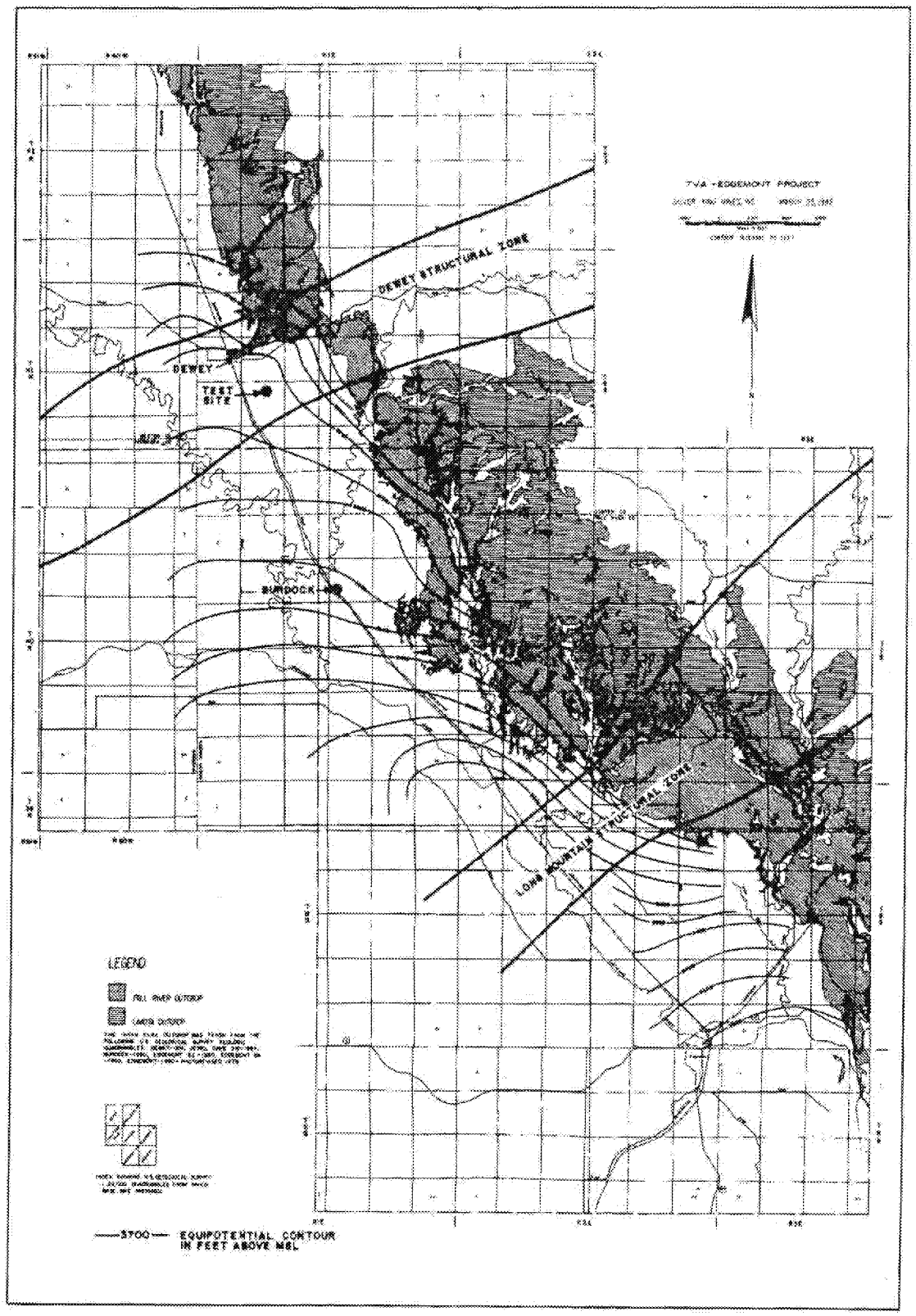


Figure 1: Site Location and Potentiometric Surface Map

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The Fall River and Lakota aquifers are of primary concern because of the potential impact of mine dewatering on the numerous wells developed in these aquifers in the vicinity of the mine. At the proposed mine site, the Fall River consists of approximately 180 feet of interbedded fine-grained sandstone, siltstone and carbonaceous shale. The Fall River aquifer is overlain by approximately 400 feet of the Mowry and Skull Creek shales unit, which act as confining beds. Five domestic and stock-watering wells are known to be developed in the Fall River formation within a four-mile radius of the mine site.

The Fall River formation is underlain by Fuson member of the Lakota formation consisting primarily of siltstone and shale with occasional fine-grained sandstone lenses. Thickness of the Fuson is on the order of 100 feet in the site vicinity. The Fuson acts as a leaky aquitard between the Fall River and Lakota aquifers.

The Chilson member of the Lakota formation is the source for some 30 wells within a four-mile radius of the mine site. It also represents the primary uranium-bearing unit targeted for mining. The Chilson (also referred to as the "Lakota aquifer" in this report) consists of about 120 feet of consolidated to semi-consolidated, fine-to-coarse grained sandstone with interbedded siltstone and shale. It is underlain by the Morrison formation consisting of interbedded shale and fine-grained sandstone. Regionally, the Morrison is not considered an aquifer. Under conditions of ground-water withdrawal from the Chilson, the Morrison is expected to act as an aquitard.

Recharge to the Fall River and Lakota aquifers is believed to occur at their outcrop areas. Gott, et al. (1974), suggest on the basis of geochemical data that recharge to these aquifers may also be derived from the upward movement of ground water along solution collapses and breccia

pipes from the deeper Minnelusa and Pahasapa aquifers. The solution collapse and breccia pipe features lie within the Dewey and Long Mountain structural zones (Figure 1).

Inasmuch as the proposed mine site lies only about one mile south of the Dewey fault trace, one of the primary objectives of the test was to determine the hydrologic significance of the fault and its affect on the propagation of drawdown in the vicinity of the mine during depressurization. Vertical displacement on the major fault generally increases toward the southwest, and is on the order of 200 feet at the point where the fault trace crosses the South Dakota-Wyoming border. Thus, it appears that the Fall River and Lakota aquifers are completely offset by the fault in the site vicinity.

## LAKOTA AQUIFER TEST

### Design

The shaft site for the Dewey mining area had not been selected at the time the aquifer testing designs were made. The test site was, therefore, located in the general vicinity of the proposed mine site within close proximity to the Dewey fault. The test well was completed to a depth of 804 feet and was screened within the Chilson member of the Lakota Formation. A network of eleven observation wells were constructed along two perpendicular lines intersecting at the pumped well for the purpose investigating hydrologic boundary conditions. One line of wells was oriented normal to the Dewey fault trace, and the other was approximately normal to the aquifer outcrop belt to the east (see Figure 2). Seven of these wells were developed in the Chilson member, three in the Fall River formation,

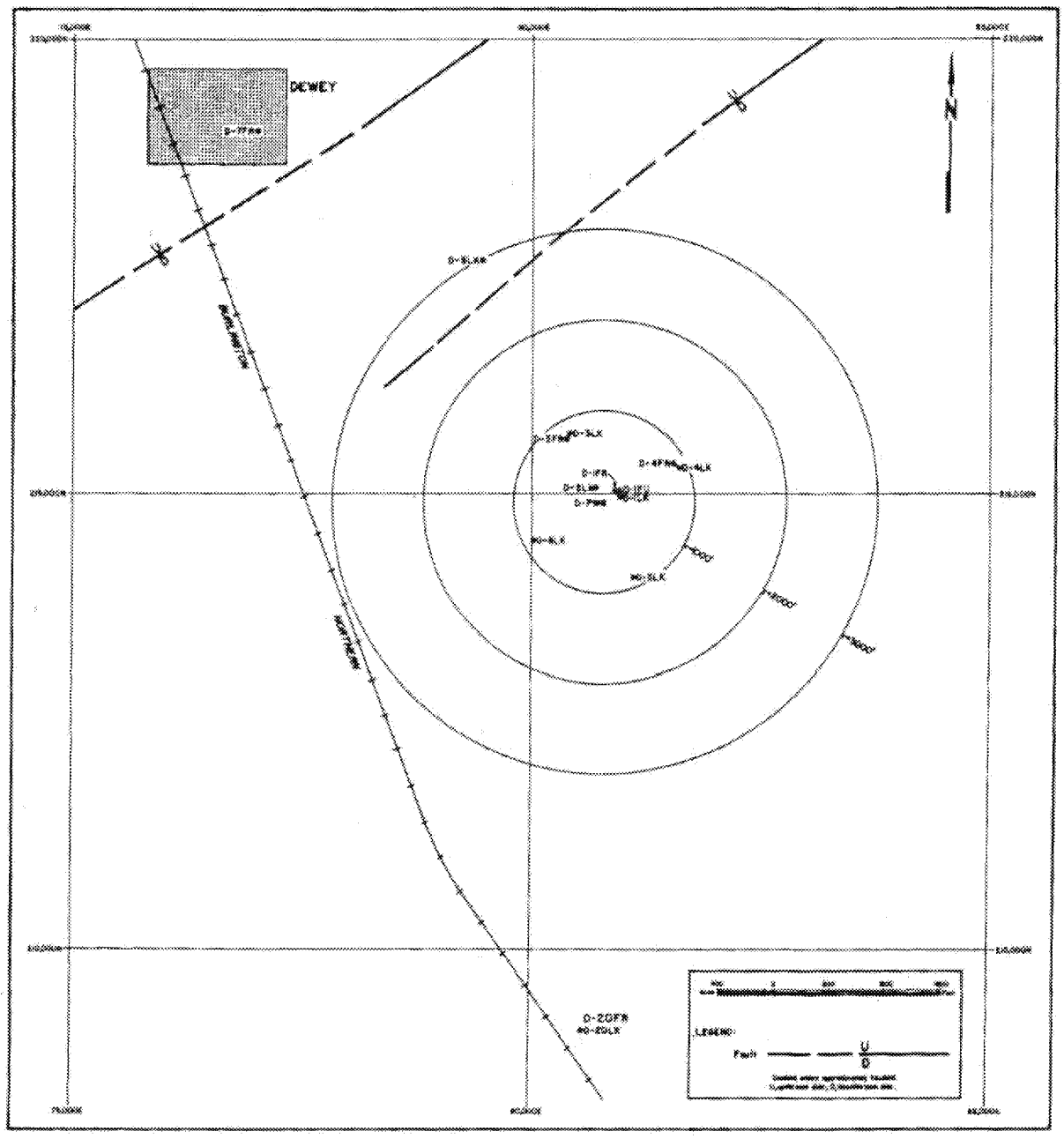


Figure 2: Well Location Map

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and one in the Fuson. Preexisting observation wells BPZ-20LAK and BPZ-20FR (hereafter referred to as D-20LK and D-20FR, respectively) located about one mile south of the test well were also monitored during the test. Construction details for these wells are given in Table 1. In addition, periodic measurements of water level (or well flowrate) were made during the test at all private wells within the test site vicinity.

Based upon preliminary drilling results in the Dewey test site area and experience from the Burdock aquifer tests, it was expected that the Fall River and Lakota aquifers in the Dewey area would respond essentially as a single aquifer system. As a result less emphasis was placed on measurement of the Fuson aquitard properties.

Procedures

A constant-discharge aquifer test was initiated at 1000 hours on February 16, 1982. Discharge from the well was pumped into an arroyo which ultimately drained into a stock pond located about one mile west of the test site. There was no possibility of recirculation of well discharge water during the test due to the 400+ feet thickness of shale between ground surface and the top of the Fall River aquifer. The well pumping rate was monitored with an in-line flow meter and with an orifice plate and manometer device at the end of the discharge line. The pumping rate varied little during the test ranging from 493 to 503 gpm and averaging 495 gpm. The pumping phase of the test lasted 11 days and was followed by approximately 10 months of recovery measurements. Water level measurements in all wells were made with electric probes. Flow rates associated with offsite private wells were checked with a bucket and stop watch.

TABLE 1. Well Construction Data

| Well No. | Depth (feet) | Casing Diameter (inches) | Depth Interval of Open Borehole or Well Screen (feet) | Distance From Pumped Well (feet) |
|---|---|---|---|---|
| D-PW | 804 | 10 | 695-725, 755-800 | -- |
| D-1LK | 800 | 4 | 712-800 | 189 |
| D-1FU | 620 | 4 | 609-620 | 229 |
| D-1FR | 580 | 4 | 504-580 | 186 |
| D-2LK | 800 | 4 | 692-800 | 191 |
| D-3LK | 800 | 4 | 715-800 | 851 |
| D-3FR | 590 | 4 | 505-590 | 810 |
| D-4LK | 780 | 4 | 714-780 | 905 |
| D-4FR | 580 | 4 | 503-580 | 879 |
| D-5LK | 835 | 4 | 735-835 | 872 |
| D-6LK | 810 | 4 | 715-810 | 890 |
| D-7FR | 120 | 4 | 119-120 | 5610 |
| D-8LK | 750 | 4 | 650-750 | 2785 |
| D-20LK | 860 | 4 | 798-860 | 5700 |
| D-20FR | 672 | 1 | 671-672 | 5700 |

Analysis

Semilogarithmic graphs of drawdown (s) versus time (t) for the pumped well and observation wells are given in Appendix A. The drawdown trends in wells D-PW, D-1LK and D-2LK are essentially the same, i.e., there is a period of roughly linear drawdown during the first 1000 minutes of the test, followed by a gradual increase in the rate of drawdown during the remainder of the test. The remaining Lakota wells exhibit s-t curves which have a continuous increase in slope throughout the test without stabilizing to a linear drawdown trend. A slight increase in hydrostatic water level was observed during the early period of the test in the Fall River and Fuson wells. This seemingly paradoxical behavior, known as the Noordbergum effect, is due to a transfer of stress from the pumped aquifer to the adjacent aquitards and aquifers (Gambolati, 1974). Drawdowns observed in the Fall River and Fuson wells were much less than those recorded during a similar test conducted near Burdock (Boggs and Jenkins, 1980). The Jacob straight-line method (Walton, 1970) was applied to the semilog graphs for the Lakota wells to obtain the values of transmissivity (T) and storativity (S) presented in Table 2. In the case of the closer observation wells, two straight-line data fits were possible: one using the early data and another using the late data. Only the late data for the more distant observation wells were analyzed by this method.

Logarithmic s-t graphs for all test wells are given in Appendix B. Theis curve-matching techniques (Walton, 1970) were applied to the Lakota aquifer curves to obtain the T and S estimates presented in Table 2. Due to the somewhat unusual shape of the s-t response curves, the only curve-match solutions possible were those using the early data.

TABLE 2. Computed Lakota Aquifer Properties

| Well | r (ft) | Jacob Method | | | | | Theis Method | |
|---|---|---|---|---|---|---|---|---|
| | | Drawdown | | | Recovery | | | |
| | | $T_e$ | $S_e$ | $T_1$ | $T_e$ | $T_1$ | $T_e$ | $S_e$ |
| D-PW | 0.67 | 4400 | -- | 890 | 4890 | 680 | -- | -- |
| D-1LK | 189 | 5280 | 3.E-05 | 890 | 4890 | 650 | 5210 | 3.E-05 |
| D-2LK | 191 | 4400 | 3.E-04 | 910 | 4710 | 650 | 4090 | 2.E-04 |
| D-3LK | 851 | -- | -- | 920 | -- | 670 | 6900 | 7.E-05 |
| D-4LK | 905 | -- | -- | 900 | -- | 680 | 4090 | 8.E-05 |
| D-5LK | 872 | -- | -- | 900 | -- | 670 | 4410 | 7.E-05 |
| D-6LK | 890 | -- | -- | 900 | -- | 650 | 6030 | 8.E-05 |
| D-8LK | 2785 | -- | -- | 940 | -- | 680 | 3180 | 5.E-05 |
| D-20LK | 5700 | -- | -- | -- | -- | 680 | 1400 | 3.E-05 |

Note: Transmissivity ($T_e$, $T_1$) in units of gpd/ft.



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A semilog plot of the final drawdown in each Lakota well versus its radial distance from the pumped well is shown in Figure 3. The Jacob straight-line method was applied to this plot to obtain T and S values of 4400 gpd/ft and $10^{-6}$, respectively, for the Lakota aquifer. The storativity value computed by this method is considered highly unreliable since it is two orders of magnitude lower than expected.

Water level recovery data for all wells are presented in Appendix C. Data are plotted as semilog graphs of residual drawdown versus t/t' (ratio of time since pumping started to time since pumping stopped). The Lakota graphs were analyzed using the Jacob method. Again, two straight-line fits are possible for the closer Lakota wells. Both are given in Table 2.

Fuson aquitard properties were estimated from the D-1 well group data using the ratio method (Neuman and Witherspoon, 1973). The vertical hydraulic conductivity of the aquitard ($K'_v$) is computed to be approximately $2x10^{-4}$ ft/d based on the average of several computed $K'_v$ during the interval between 1800 and 5000 minutes. For purposes of the analysis, the specific storativity ($S'_s$) of the aquitard was assumed to be approximately equal to that computed for the Lakota aquifer (about $7x10^{-7}$ $ft^{-1}$).

Interpretation

The T estimates obtained from all methods using the early drawdown and recovery data are in reasonably good agreement. Values range from 3180 to 6900 gpd/ft and average approximately 4800 gpd/ft. The T of 4400 gpd/ft derived from the distance drawdown analysis is also consistent with the early T estimates. These values are believed to represent the transmissivity of the Lakota aquifer within the immediate vicinity of the test

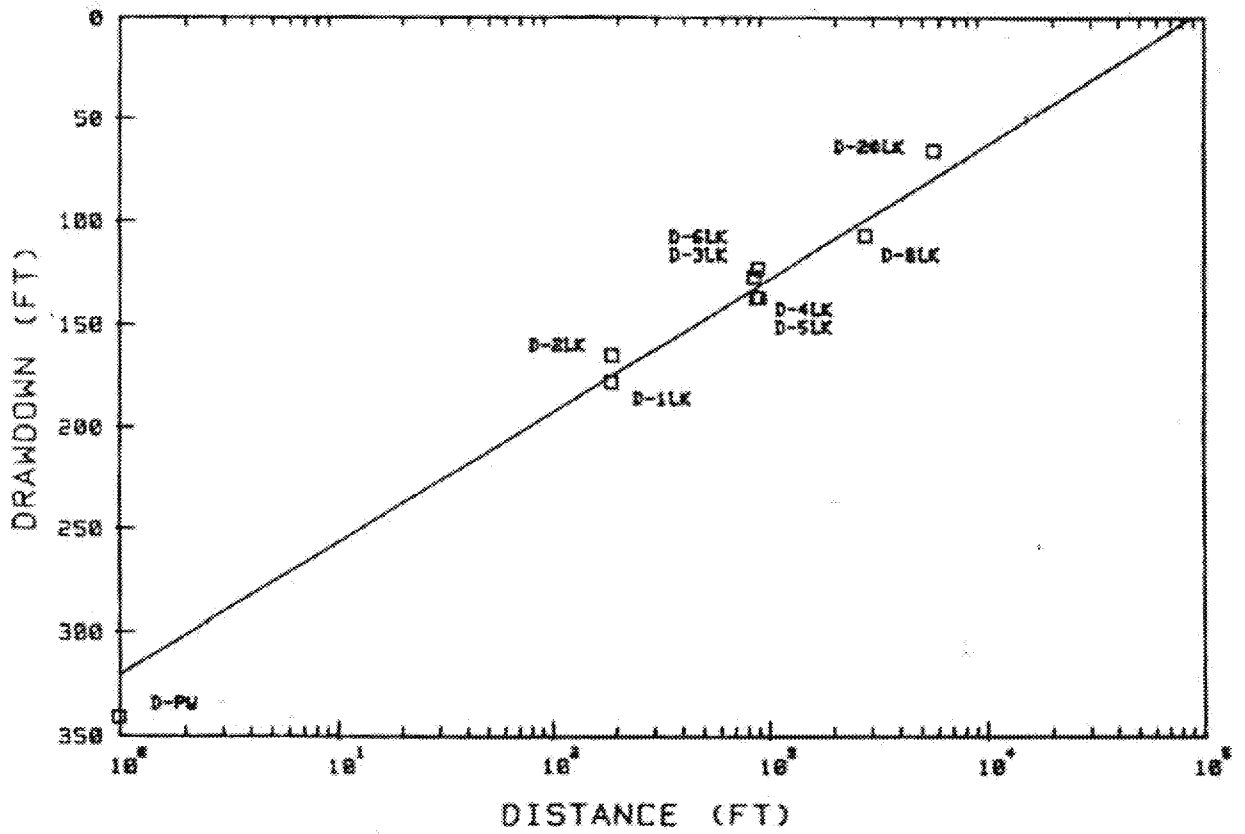


FIGURE 3. DISTANCE-DRAWDOWN GRAPH



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site, and are consistent with the physical characteristics of the aquifer materials within this area. The T values computed from the late drawdown data, although consistent from well to well, are not reliable since the rate of drawdown during the later stage of the test never stabilized to the linear or ideal Theis-curve trend. The late recovery data provide the best estimates of the regional or long-term transmissivity of the Lakota aquifer in the Dewey region because of the long duration of this phase of the test.

In general, drawdown response in the pumped well and closer observation wells is characterized by a period of approximately linear drawdown during the first 1000 minutes of the test, followed by a steadily increasing rate of drawdown until the end of the test. The recovery data reflects the same sort of trend. The late response may be interpreted as either the effect of barrier boundary conditions or a decrease in transmissivity with distance from the test site or both.

Most of the available hydrogeologic information indicates that the Dewey fault acts as a barrier to horizontal ground-water movement in the Inyan Kara aquifers. Vertical displacement along the Dewey fault is on the order of 200 feet in the test site vicinity causing the complete separation of the Lakota aquifer on either side of the fault. Despite the geochemical evidence of Gott, et al. (1974), that the fault may act as conduit for upward circulation of ground water from deeper aquifers to the Inyan Kara Group, a recharge condition is not reflected in the potentiometric surface configuration in the fault zone (Figure 1) or in the test results. A reduction in the rate of drawdown would be expected in the s-t graphs for observation wells closest to the fault if significant recharge occurred in the fault zone. Instead the opposite response is observed in the test data. The s-t curve for well D-8LK (the closest observation well to the fault)

exhibits the steepest slope during the late stage of the test, supporting the idea that the fault is a hydrogeologic barrier. Upward recharge may occur in the fault zone but at relatively low rates. Consequently, the fault does not behave as a recharge boundary.

Computer Simulations

A computer ground-water model of the Dewey region was developed to aid in interpreting the test results and refining aquifer parameters. A three-dimensional ground-water flow code developed by Trescott (1975) was used for the simulations. The Inyan Kara is conceptualized as a three-layer aquifer system consisting of the Lakota (Chilson) aquifer, the Fuson aquitard and the Fall River aquifer, with model layers having uniform thicknesses of 120, 100, and 180 feet, respectively. Impervious boundaries are set above the Fall River layer and below the Lakota layer to represent the relatively impermeable shales which bound the Inyan Kara Group. The model area and finite-difference grid are shown in Figure 4. The outcrop area of the Inyan Kara represents the eastern limit of the modeled region. The remaining three sides of the model are set at sufficient distances from the test pumping well to eliminate the possibility of artificial boundary effects in model simulations. The Dewey fault zone was treated as a barrier boundary.

Simulations were made using two basic conceptual models of the Inyan Kara aquifer system to determine which model best represented observed responses during the Dewey test. For case I, uniform T and S values of 4,400 gpd/ft and $1 \times 10^{-4}$, respectively were assigned to the Lakota aquifer. A uniform T was used for this case despite evidence of a much lower transmissivity outside of the immediate test site in order to determine

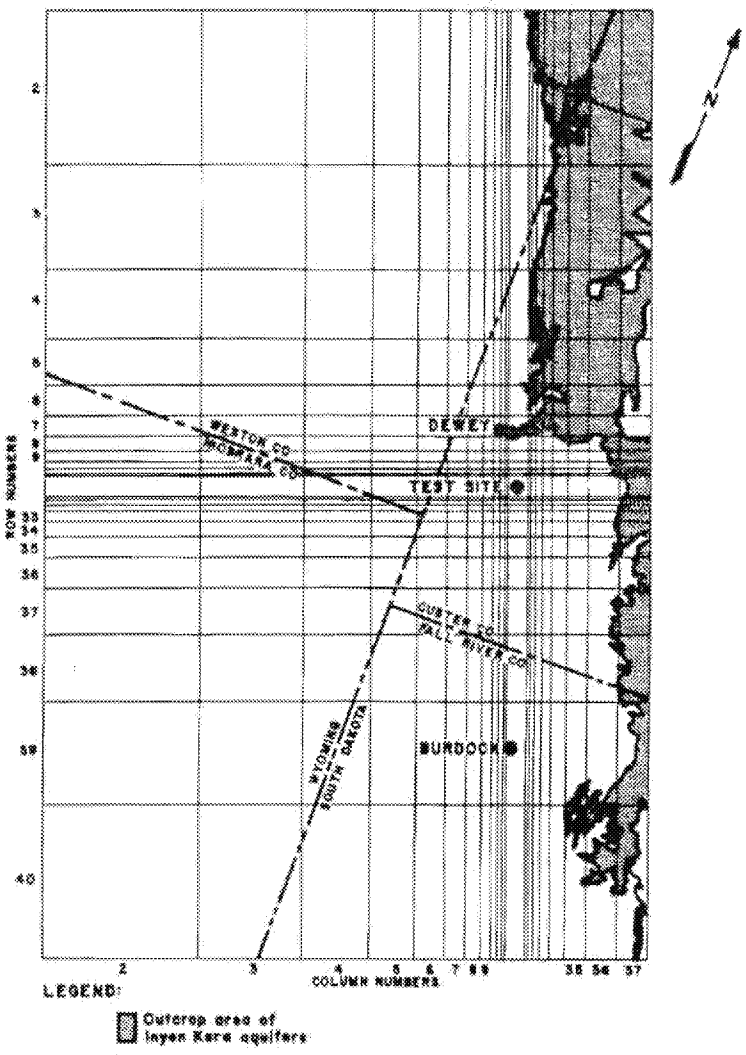


Figure 4: Ground-Water Model Grid

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whether the fault alone could account for late drawdown trends. The Fuson aquitard was assigned a uniform $K'_v$ of $10^{-4}$ ft/d. The Fall River aquifer was represented by uniform T and S values of 400 gpd/ft and $10^{-4}$ respectively, based on the results of the Burdock tests (Boggs and Jenkins, 1980). A simulation was then made of the 11-day Dewey aquifer test using the average pumping rate of 495 gpm in an attempt to reproduce the test results. A comparison of computed and observed s-t graphs for the Lakota observation wells is shown in Figure 5. Clearly, the barrier boundary condition created by the fault does not fully account for the observed increase in drawdown rate during the latter part of the test.

In Case II, the model was modified to account for the suspected spatial variability of transmissivity in the Lakota aquifer. Geologic evidence indicates that the test site is located in an area where the Lakota is composed of an exceptionally thick course-grained sandstone. Outside of this locality the aquifer becomes thinner and its composition changes to finer-grained sedimentary facies. These changes are particularly evident in the area east of the site. The test results indicate a local T in the immediate site area of about 4,400 gpd/ft and a regional average of about 670 gpd/ft. These T estimates were used along with areal variations in the sandstone-shale composition of the Lakota aquifer in the site vicinity to arrive at the T distribution shown in Figure 6. Exploration borehole geophysical logs were used to estimate the relative amounts of sandstone and shale in the Lakota across the site area. The horizontal hydraulic conductivity of the sandstone is estimated at approximately $5.7 \times 10^{-5}$ ft/sec based upon the near-field T estimate of 4,400 gpd/ft, an aquifer thickness of 120 feet, and the assumption that the aquifer in the immediate vicinity of the test well and closest observation wells is essentially all sandstone. The

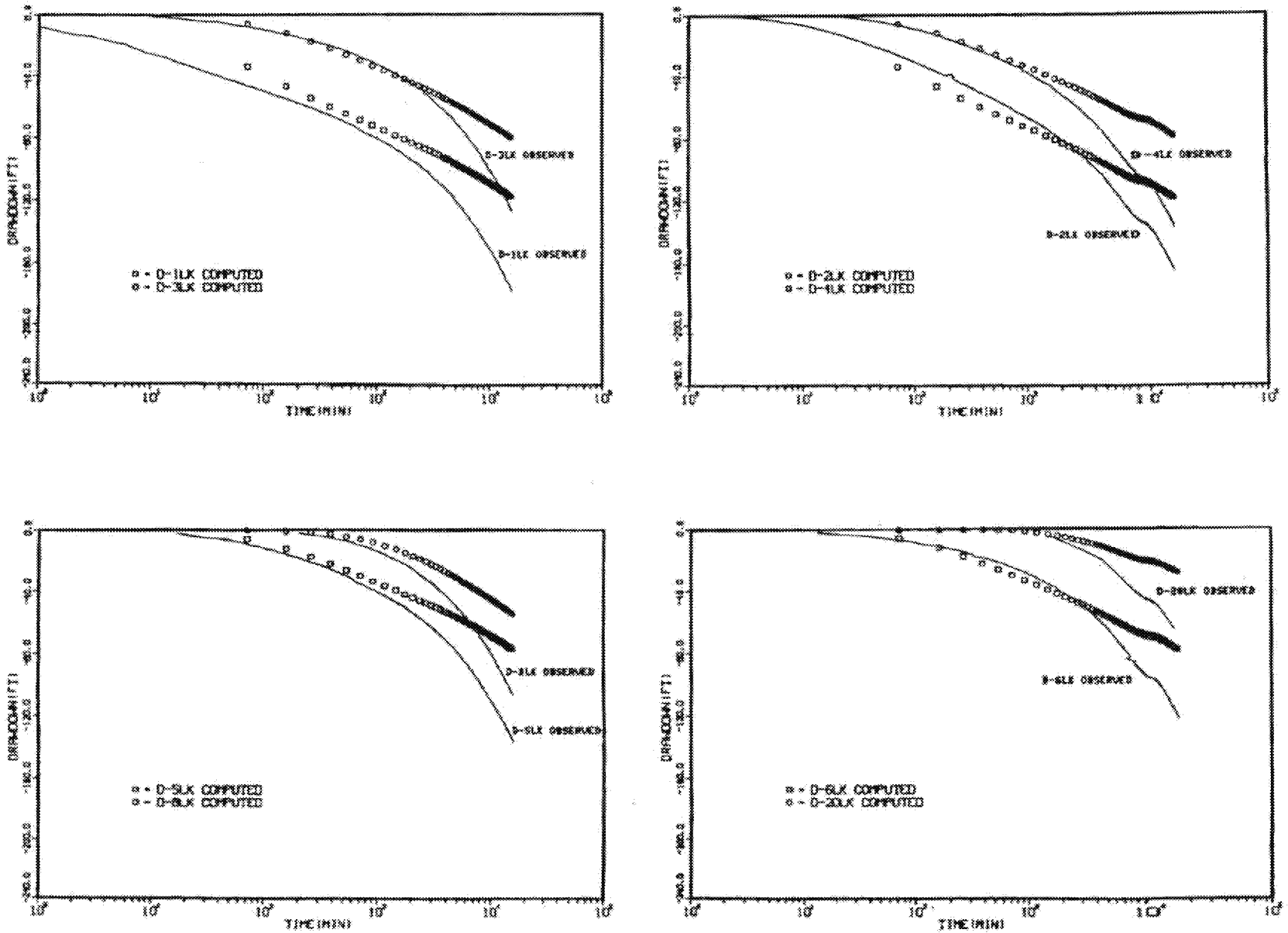


Figure 5. Comparison of Observed and Computed Drawdown, Case I



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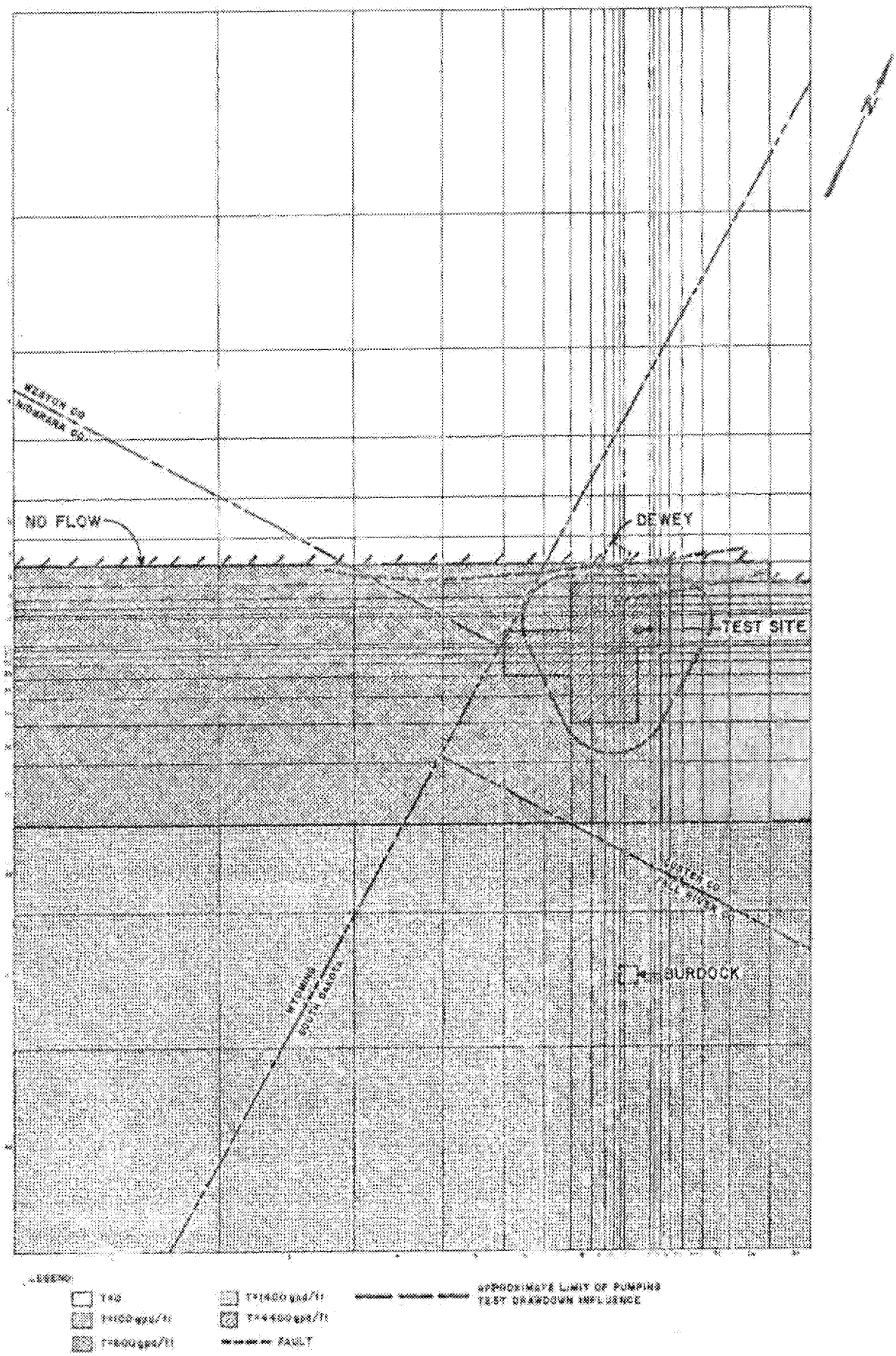


Figure 6: Transmissivity Distribution, Case II

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WKZ8

horizontal conductivity of the shale is estimated to be about $10^{-8}$ ft/sec assuming (1) the measured vertical conductivity of the Fuson shale is also representative of shale in the Lakota aquifer and (2) the ratio of horizontal to vertical conductivity is about 10:1. Given the estimated horizontal conductivities for the sandstone and shale, a representative average conductivity was computed for areas having similar aquifer sandstone-shale ratios. The representative average conductivity was computed from the geometric mean of the conductivity samples as suggested by Bouwer (1969). The transmissivity of 1,400 gpd/ft assigned to the southern portion of the model is based on results of the Burdock aquifer test. Note that although an attempt was made to assign realistic transmissivity values to the entire model region, model simulation results are mainly affected by the transmissivity distribution within the observed limits of influence of the 11-day aquifer test as indicated in Figure 6. Outside of this region the model is relatively insensitive to the assigned T values.

The Case II simulation results are shown in Figure 7. The agreement between the computed and observed drawdown trends in the Lakota wells is quite good overall. At least part of the discrepancy between observed and computed responses in these units is due to the fact that computed hydraulic heads are average values over the thickness of the aquifer or aquitard layer.

The observed drawdown trends could, perhaps, be reproduced using some alternative T distribution without the barrier boundary condition assumed for the Dewey fault. However, if the fault did not represent a barrier, substantial pressure changes should have been observed during the test in the private Lakota wells located north of the fault. These wells are located at approximately the same radial distance as observation well

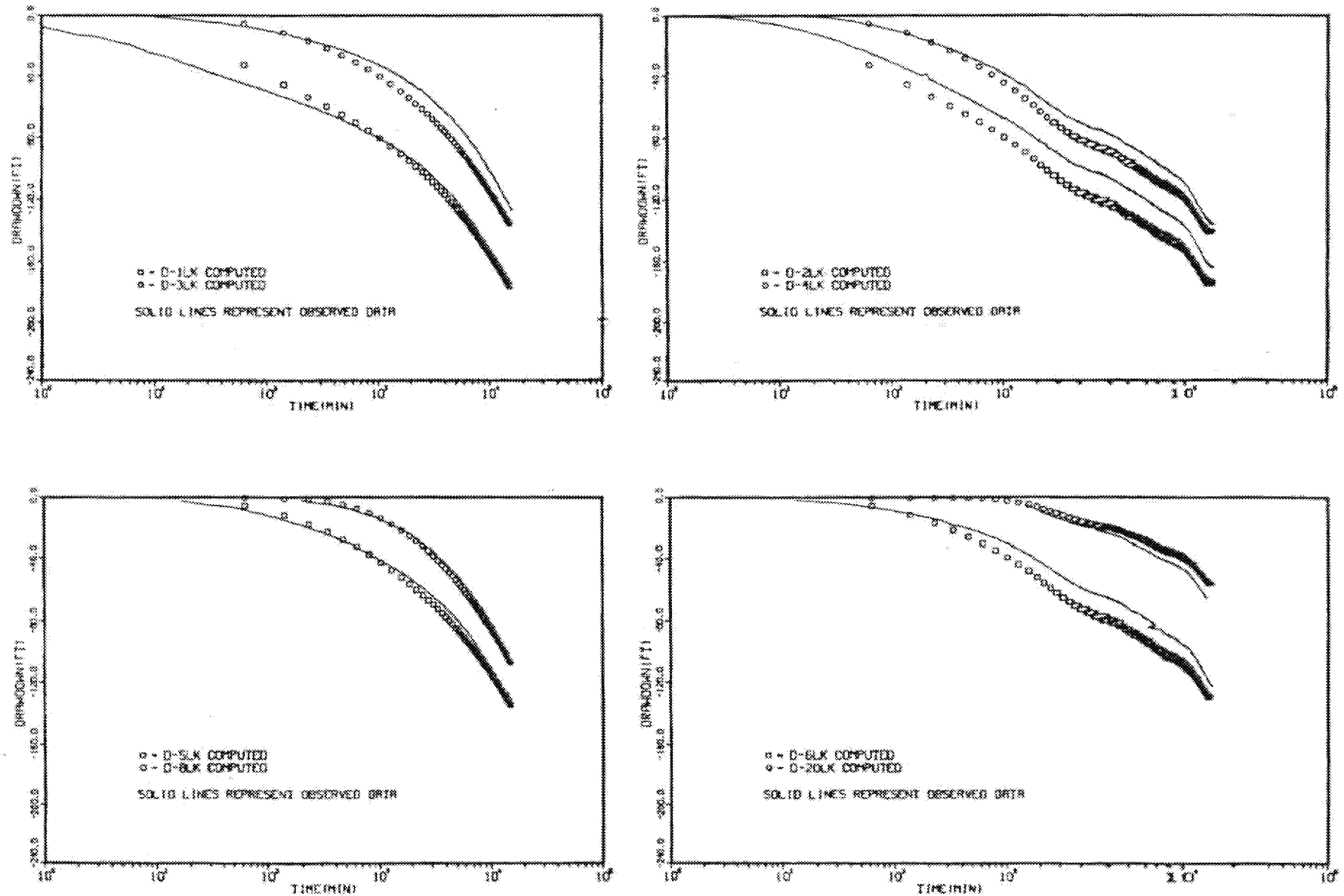


Figure 7. Comparison of Observed and Computed Drawdown, Case II

D-20LK which exhibited 66 feet of drawdown at the end of the test. As no drawdown occurred in these wells, it is concluded that the Dewey fault represents a hydrogeologic barrier.

The Case II simulation results support the concept of the Lakota as a patchy aquifer of relatively low-transmissivity overall but having within it localized zones of substantially higher transmissivity. The proposed mine site lies within one of these high transmissivity localities. Although the T distribution used in the Case II model is based upon reasonable assumptions, it is considered only an approximation of actual conditions in the test site area. Nevertheless, this approximation is adequate for assessing long-term mine depressurization impacts. The significance of the Case II model result is that it provides an interpretation of the test results which is consistent with what is known or suspected about the hydrogeologic conditions in the site region.

## CONCLUSIONS

Hydrogeologic investigations in the Dewey area indicate that the proposed mine site lies within an area where the Lakota Formation is composed of relatively thick permeable sandstone. The transmissivity of the Lakota aquifer in this locality is estimated to be approximately 4,400 gpd/ft. Storativity of the aquifer is about $10^{-4}$. Outside of this area the Lakota transmissivity decreases substantially. The variation in transmissivity over the region is consistent with geologic evidence of thinning of the Lakota sandstone away from the test site and a change to finer-grained sand and shale facies. The significance of this condition is that long-term mine depressurization rates and drawdown response in the Dewey vicinity will be

governed by the lower transmissivity material. As a result, dewatering rates will be lower and the areal extent of drawdown impacts smaller than if the higher transmissivity prevailed.

There is evidence that hydraulic communication between the Fall River and Lakota aquifers occurred during the Dewey test. However, the degree of interconnection between these units is substantially less than that observed at the Burdock test site. The vertical hydraulic conductivity of the intervening Fuson aquitard estimated from the Dewey test data is approximately $10^{-4}$ ft/d. This value is about an order of magnitude lower than the estimate obtained at Burdock. The difference is somewhat surprising in that the Fuson aquitard is thinner in the Dewey area than at Burdock. A possible explanation may be that the direct avenues of hydraulic communication (e.g., numerous open pre-TVA exploration boreholes) believed to exist at Burdock, are not present in the Dewey area.

Evaluation of the drawdown responses recorded in test wells and private wells during the aquifer test and review of existing subsurface geologic data indicates that the Dewey fault zone acts as a hydrogeologic barrier to horizontal ground-water movement between the Inyan Kara aquifers located on opposite sides of the fault zone. Some upward vertical recharge to the Inyan Kara may occur in the fault zone as suggested by Gott, et al. (1968). However, rate of recharge from this source must be relatively small, otherwise recharge effects would be apparent in the aquifer test results and in the configuration of the steady-state potentiometric surface. It is expected that the fault will significantly reduce mining drawdown impacts on ground-water supplies located north of the fault zone.

## RECOMMENDATIONS REGARDING FUTURE GROUND-WATER IMPACT ASSESSMENT

Because of the likelihood of adverse effects on some existing ground-water supplies in the vicinity of the proposed mining operations, the most accurate and credible method of analysis should be utilized in the ground-water assessment. Hydrogeologic conditions in the site region are complex due to hydrologic boundaries (e.g., aquifer outcrop zone and the Dewey fault) and heterogeneity of the aquifer system. Under such conditions simple analytical methods cannot be applied with an acceptable level of confidence. Thus, development of a numerical model capable of handling these complexities will be necessary. We recommend that the ground-water assessment model be developed along the following lines:

1. The three-layer conceptual model of the Inyan Kara Group described previously in this report and used in interpretation of the Burdock aquifer test should be incorporated into the model used for impact assessment. At some point during the long-term mine depressurization simulations, the three hydrogeologic units comprising the Inyan Kara may begin responding as a single unit (i.e., same magnitude of drawdown in each unit). However, for purposes of estimating mine dewatering requirements and short-term water mitigation planning, it is recommended that the Inyan Kara be treated separately in the model.

2. The modeled region should extend to the Inyan Kara outcrop area to the east and to the Dewey fault zone to the north. The location of the western and southern boundaries of the model are uncertain at this time but must extend beyond the influence of pumping stresses. Some experimentation will probably be necessary to establish the proper location of these boundaries.

3. The model should be calibrated by adjustment of hydraulic parameters to reproduce the existing steady-state potentiometric surface shown in Figure 1. The hydraulic properties for the Inyan Kara units measured at the Dewey and Burdock test sites should be held constant in the calibration process, while parameter adjustments are made in other areas to obtain a reasonable match between the computed and observed potentiometric levels. An estimate of net ground-water recharge can be obtained from the calibrated model by assigning observed potentiometric head values to the model nodes which lie within the aquifer recharge (outcrop) area. The aquifer recharge fluxes may be incorporated directly into the model to more accurately represent drawdown conditions in the outcrop areas during mine depressurization simulations.

4. Significant pumping stresses on the Inyan Kara aquifers other than the TVA mining operations should be identified and incorporated into the model.

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Trescott, P. C., 1975, "Documentation of Finite-Difference Model for Simulation of Three-Dimensional Ground-Water Flow," USGS Open File Report 75-438.

Walton, W. C., 1970, Groundwater Resource Evaluation, McGraw-Hill, New York.

# APPENDIX A

## SEMILOGARITHMIC TIME-DRAWDOWN GRAPHS

FIGURE A-1: DRAWDOWN GRAPH FOR WELL D-PW

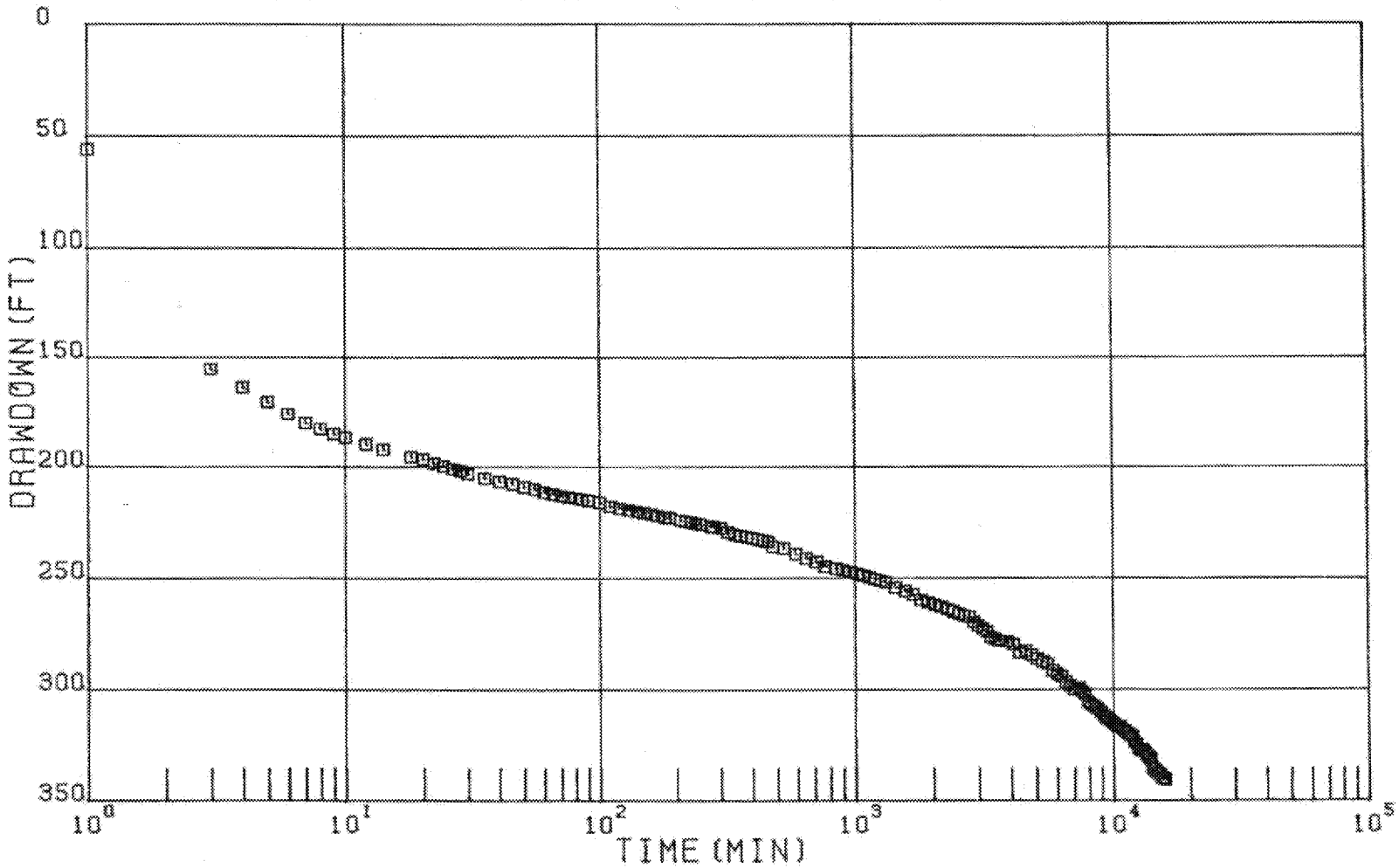


FIGURE A-2: DRAWDOWN GRAPH FOR D-1 WELL GROUP

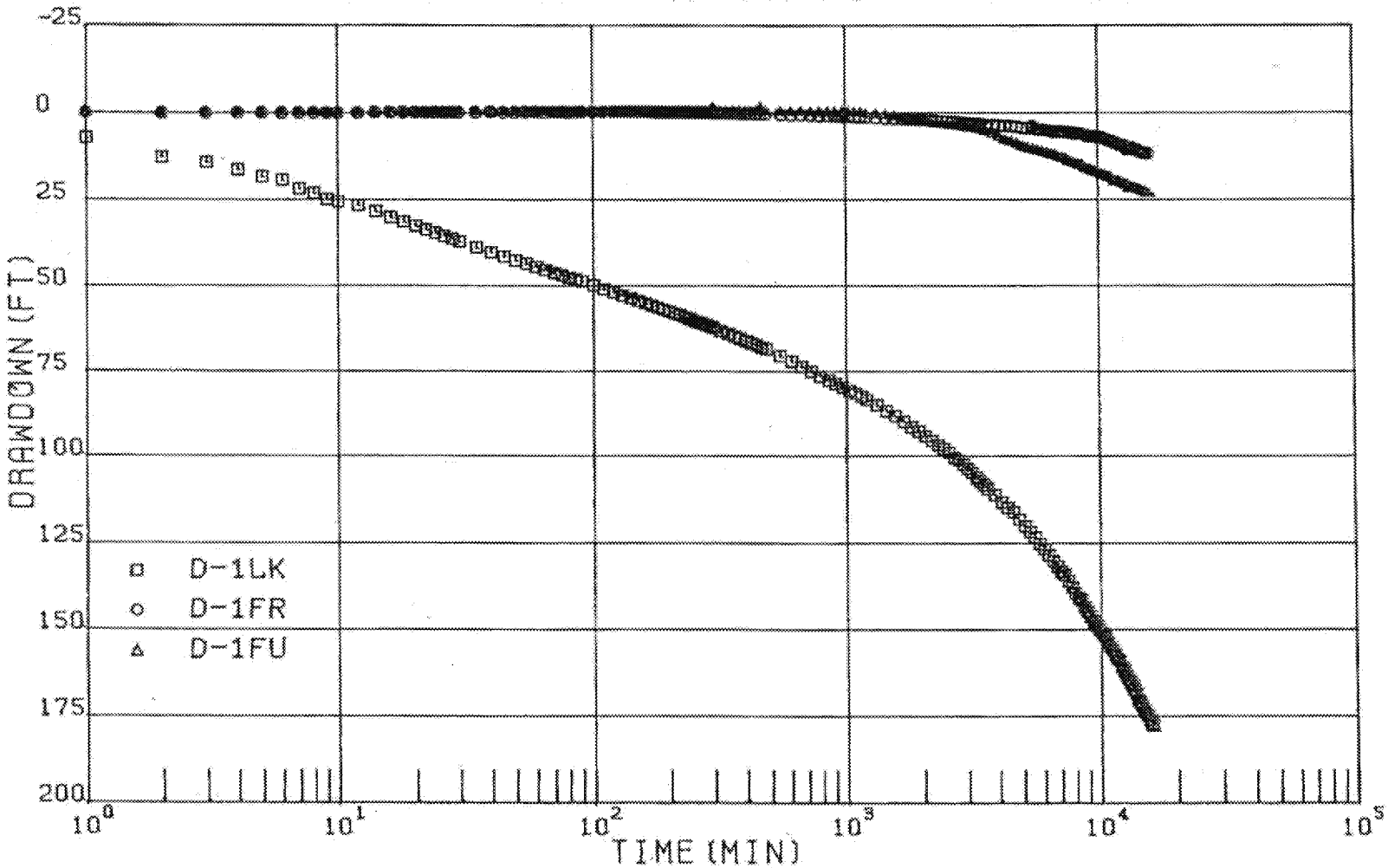


FIGURE A-3: DRAWDOWN GRAPH FOR WELL D-2LK

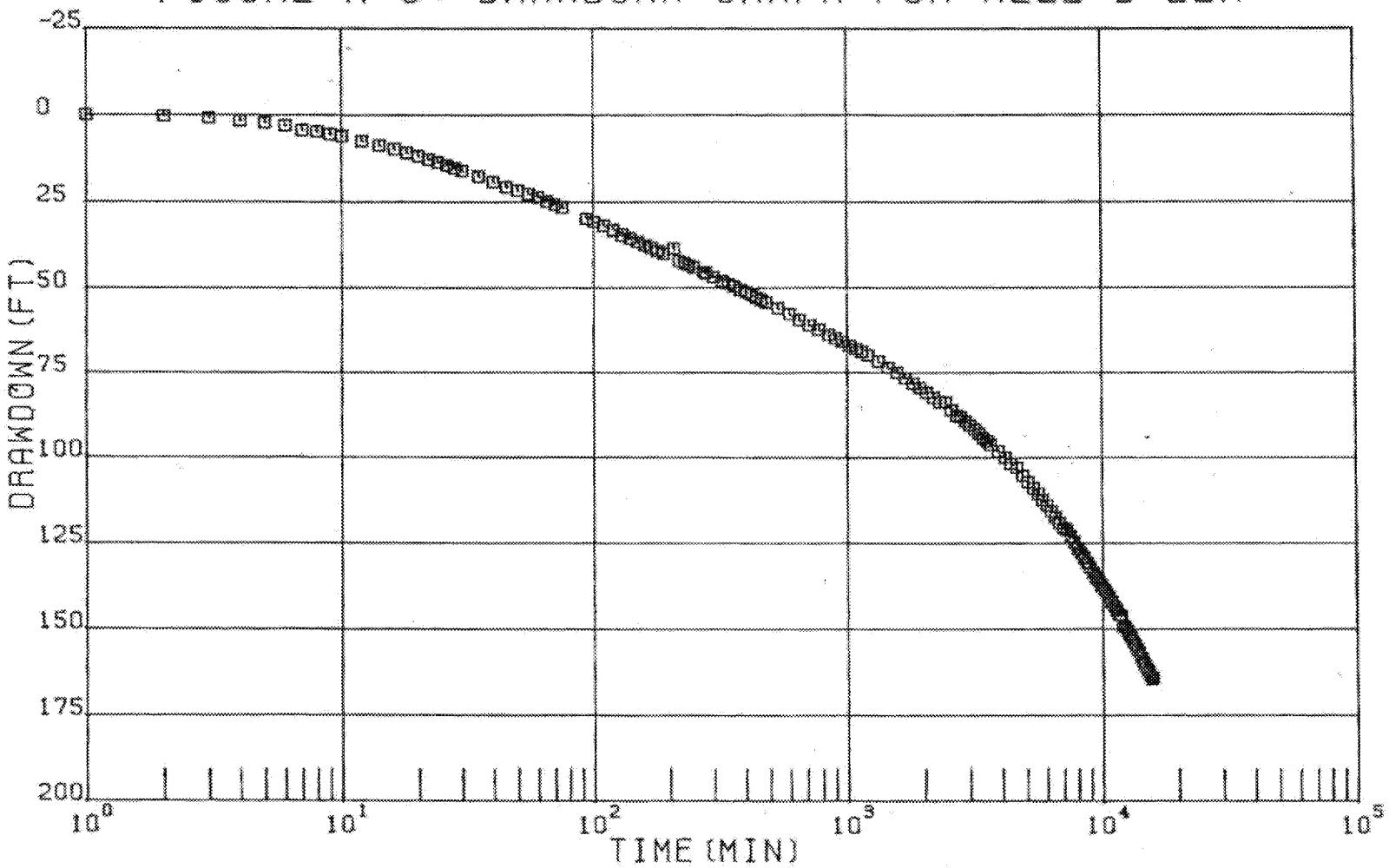


FIGURE A-4: DRAWDOWN GRAPH FOR D-3 WELL GROUP

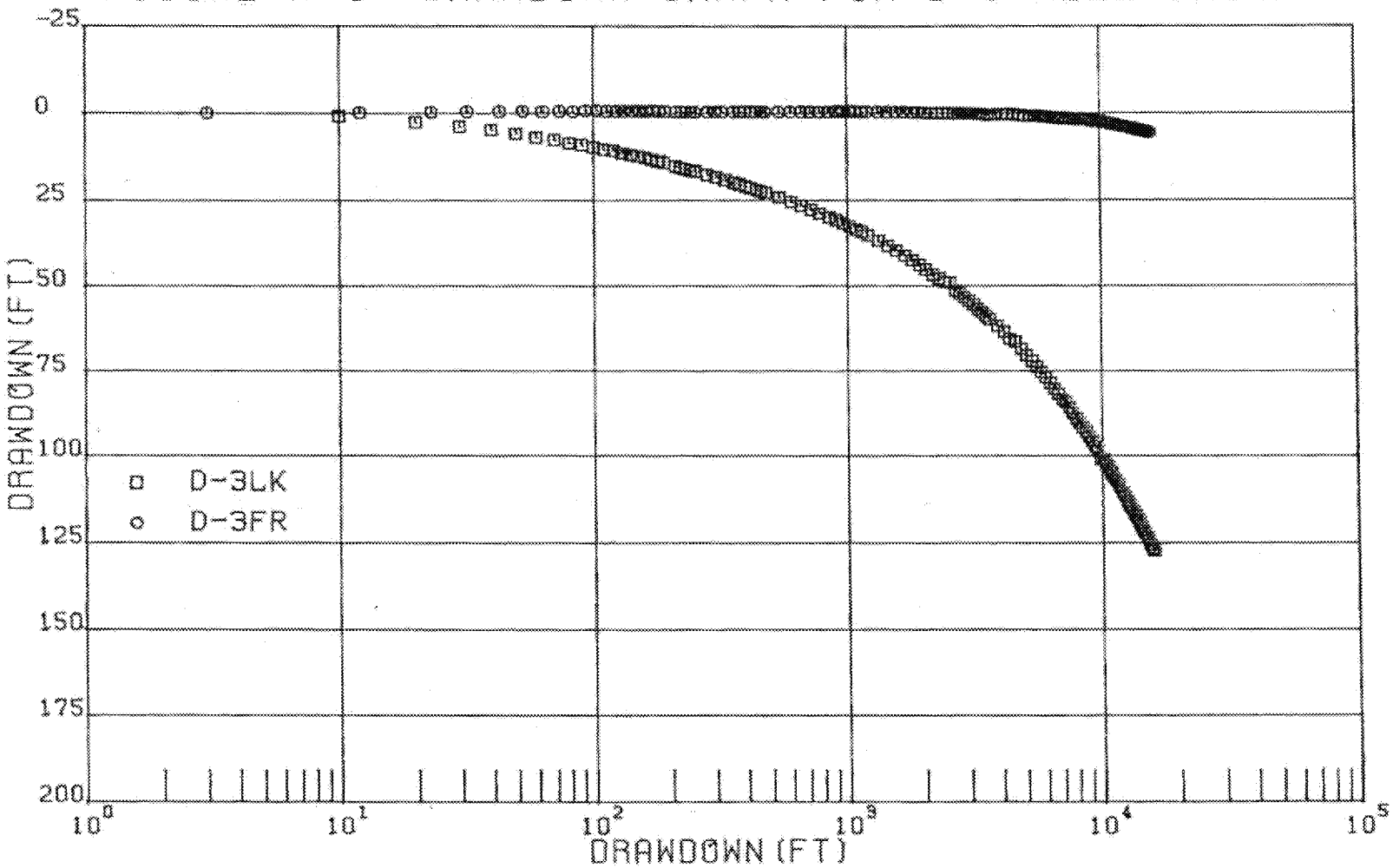


FIGURE A-5: DRAWDOWN GRAPH FOR D-4 WELL GROUP

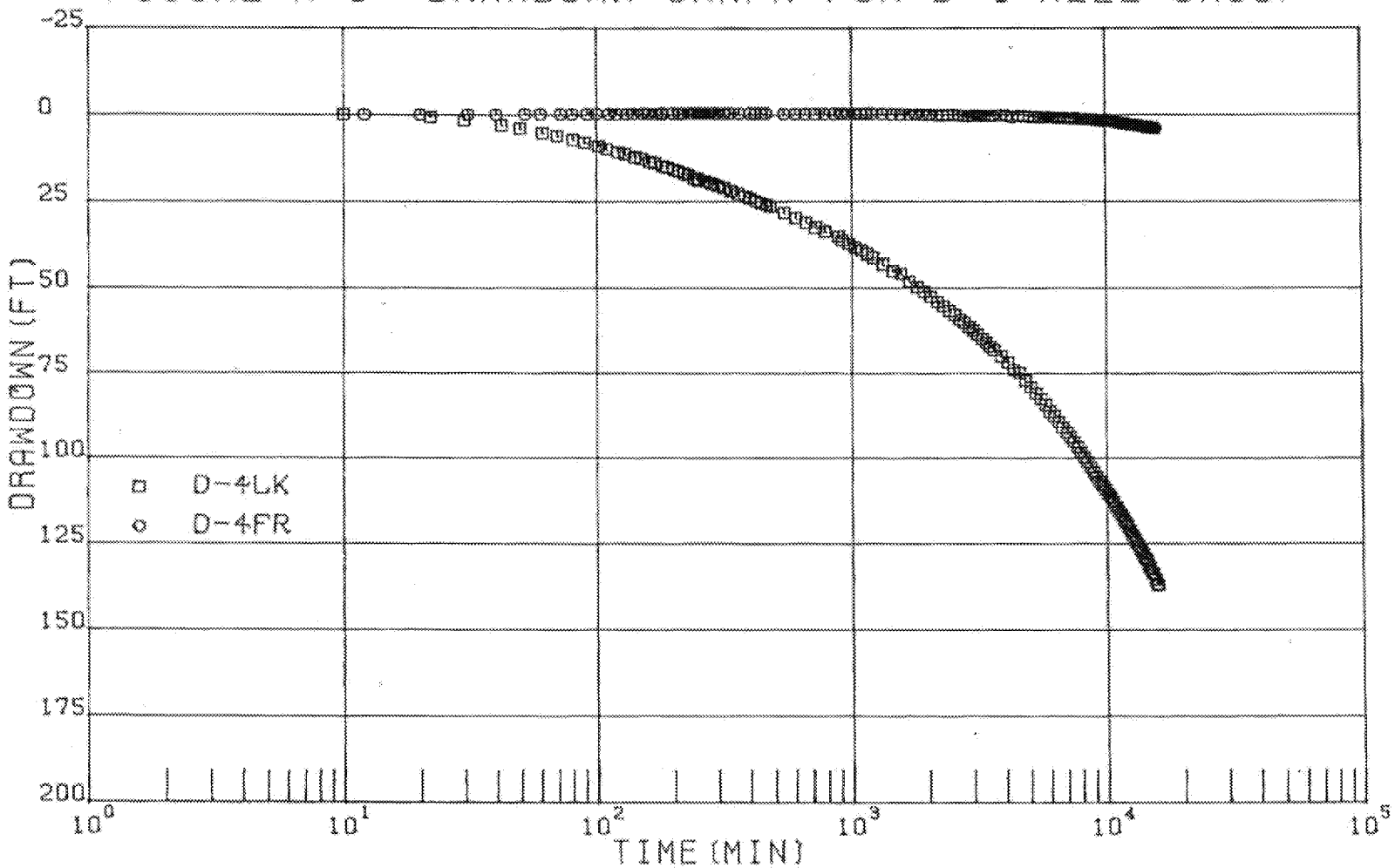


FIGURE A-6: DRAWDØWN GRAPH FØR WELL D-5LK

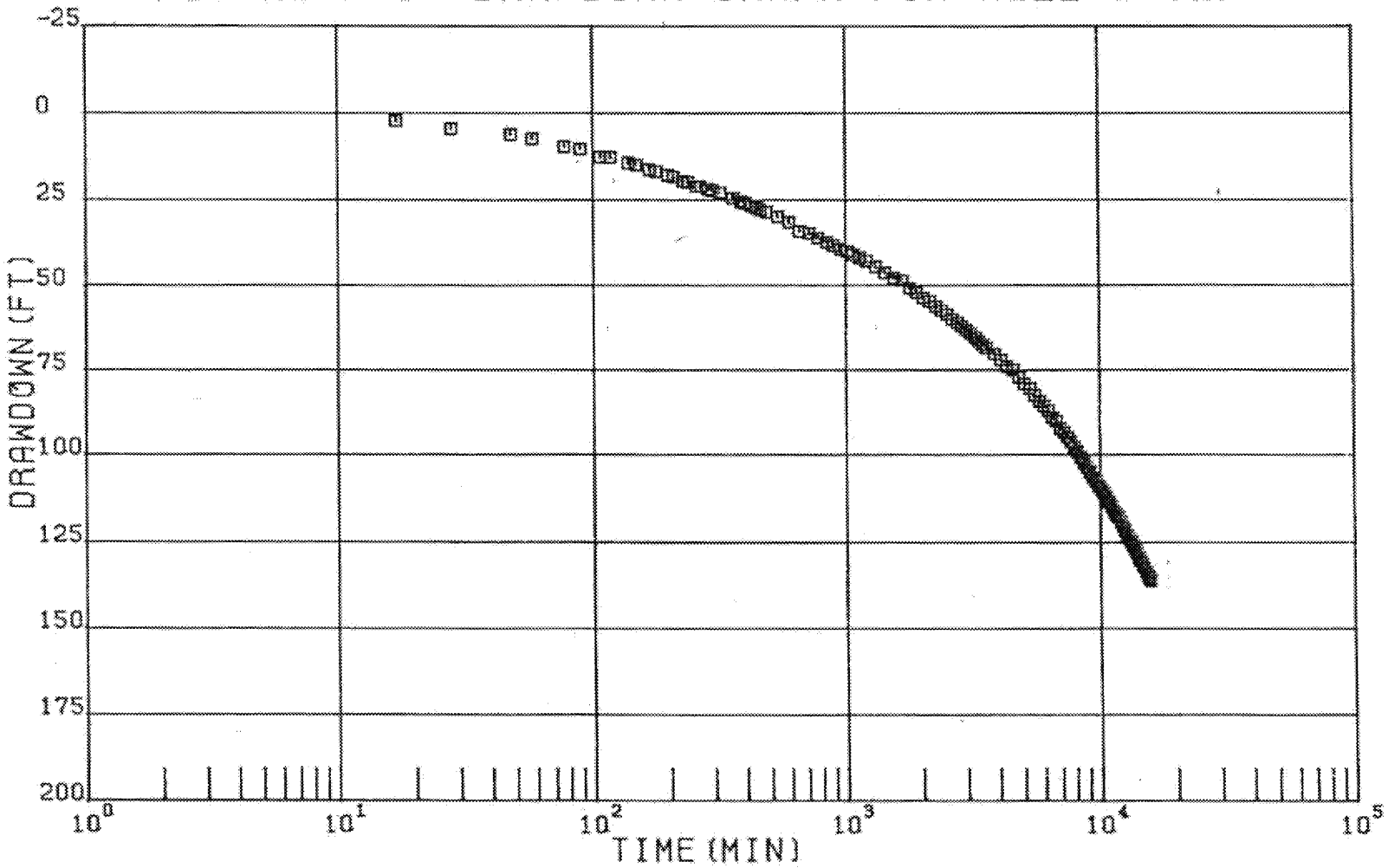


FIGURE A-7: DRAWDOWN GRAPH FOR WELL D-6LK

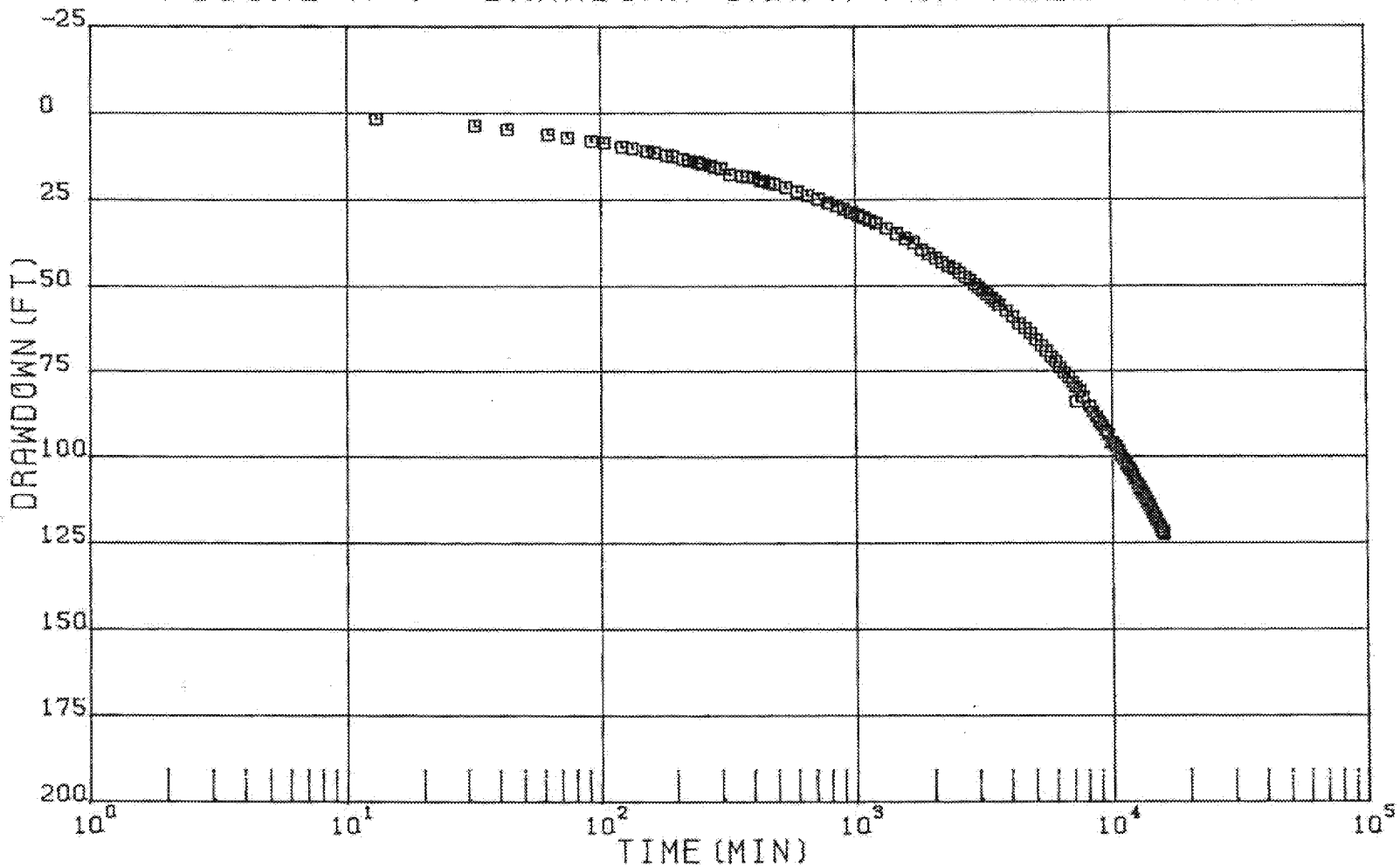


FIGURE A-8: DRAWDØWN GRAPH FØR WELL D-8LK

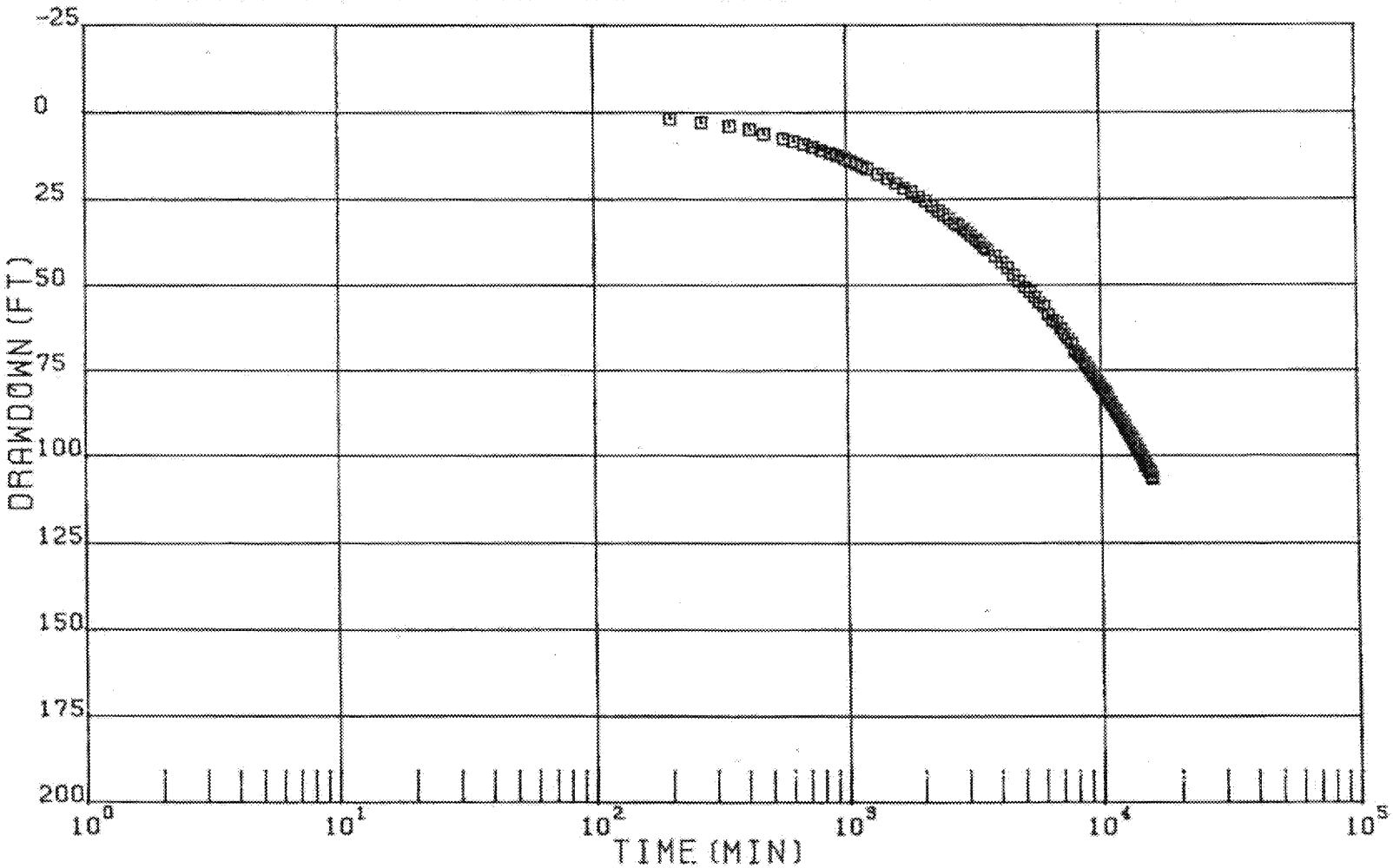
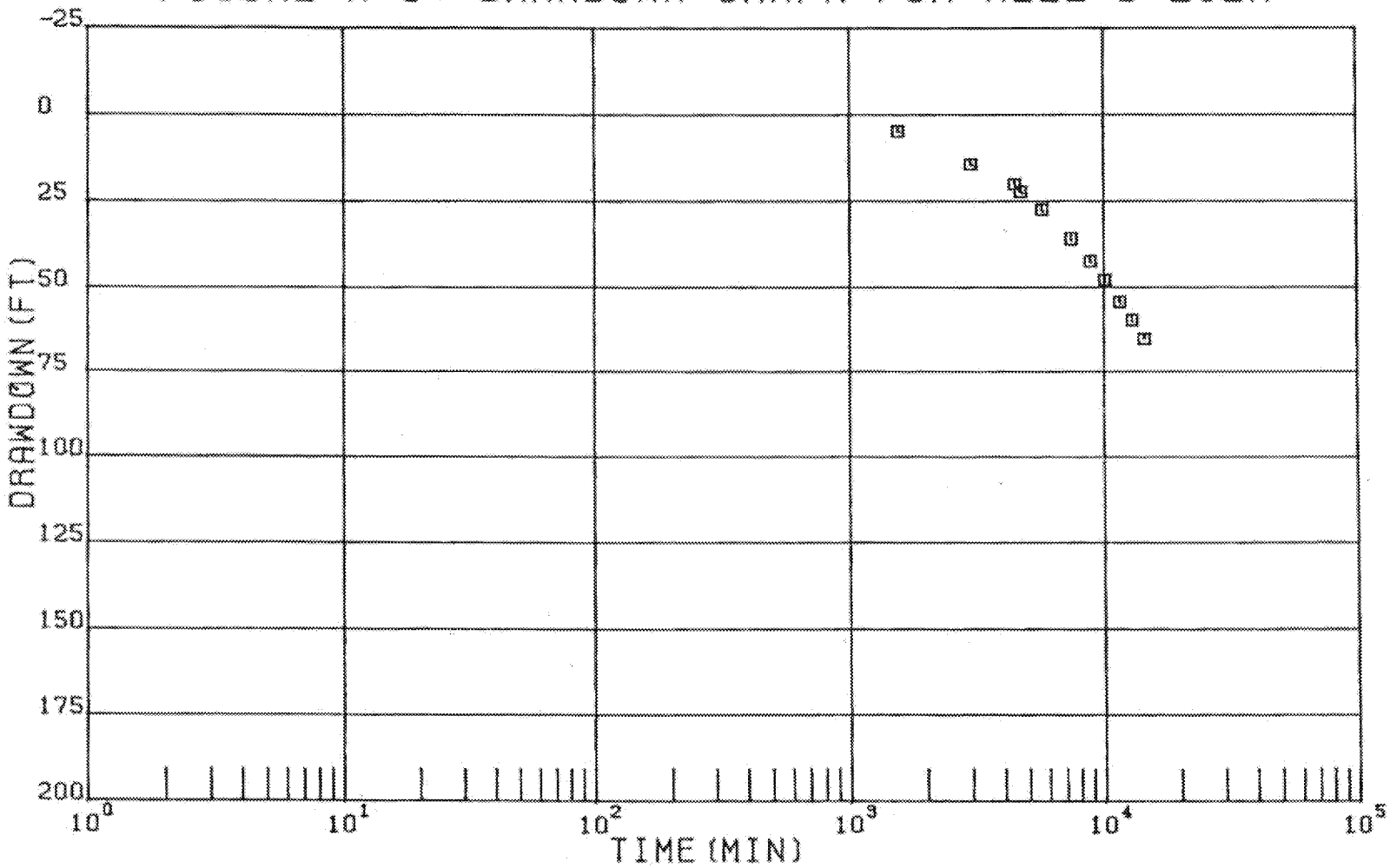


FIGURE A-9: DRAWDOWN GRAPH FOR WELL D-20LK



# APPENDIX B

## LOGARITHMIC TIME-DRAWDOWN GRAPHS

FIGURE B-1: DRAWDOWN GRAPH FOR WELL D-PW

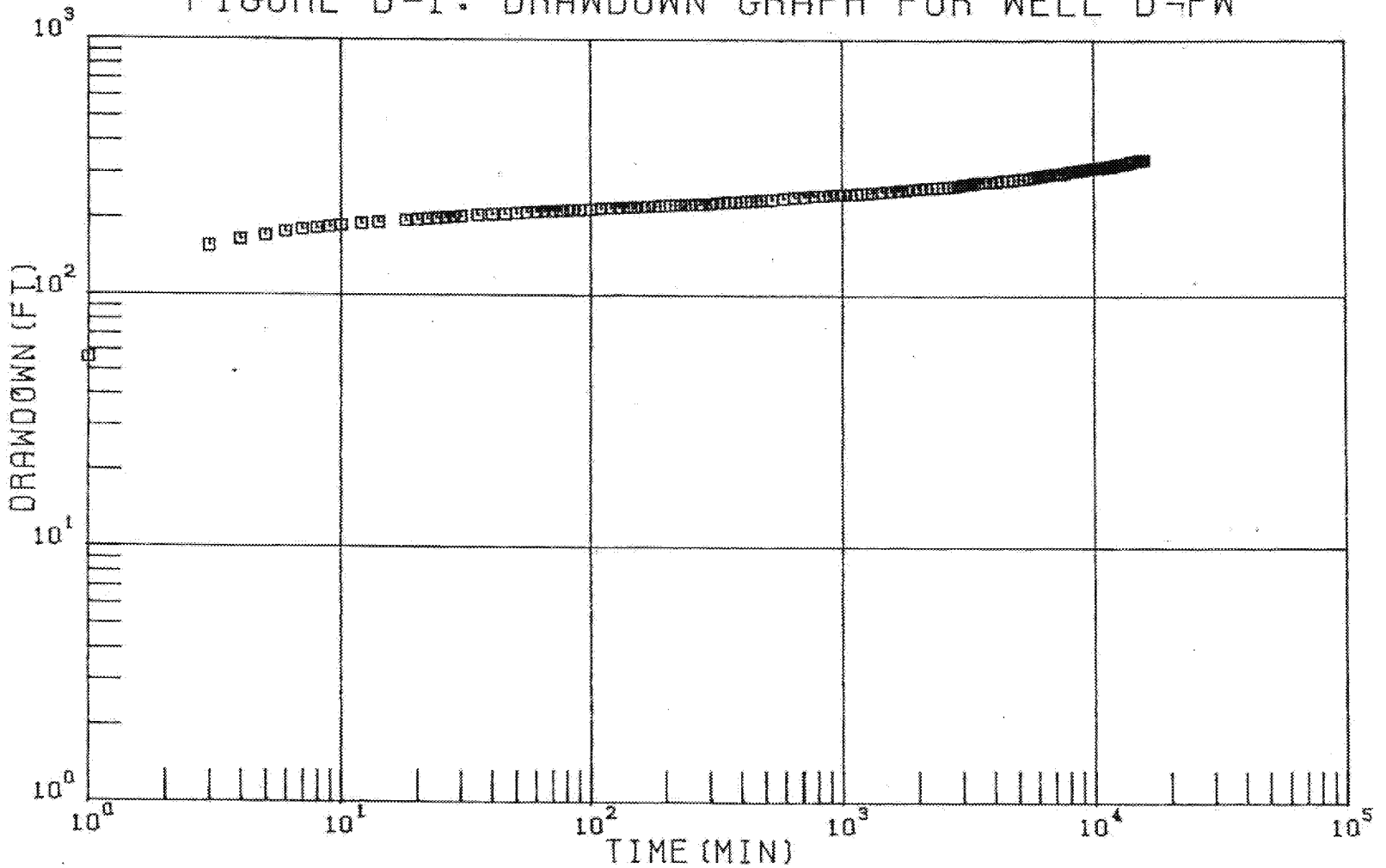





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FIGURE B-2: DRAWDOWN GRAPH FOR D-1 WELL GROUP

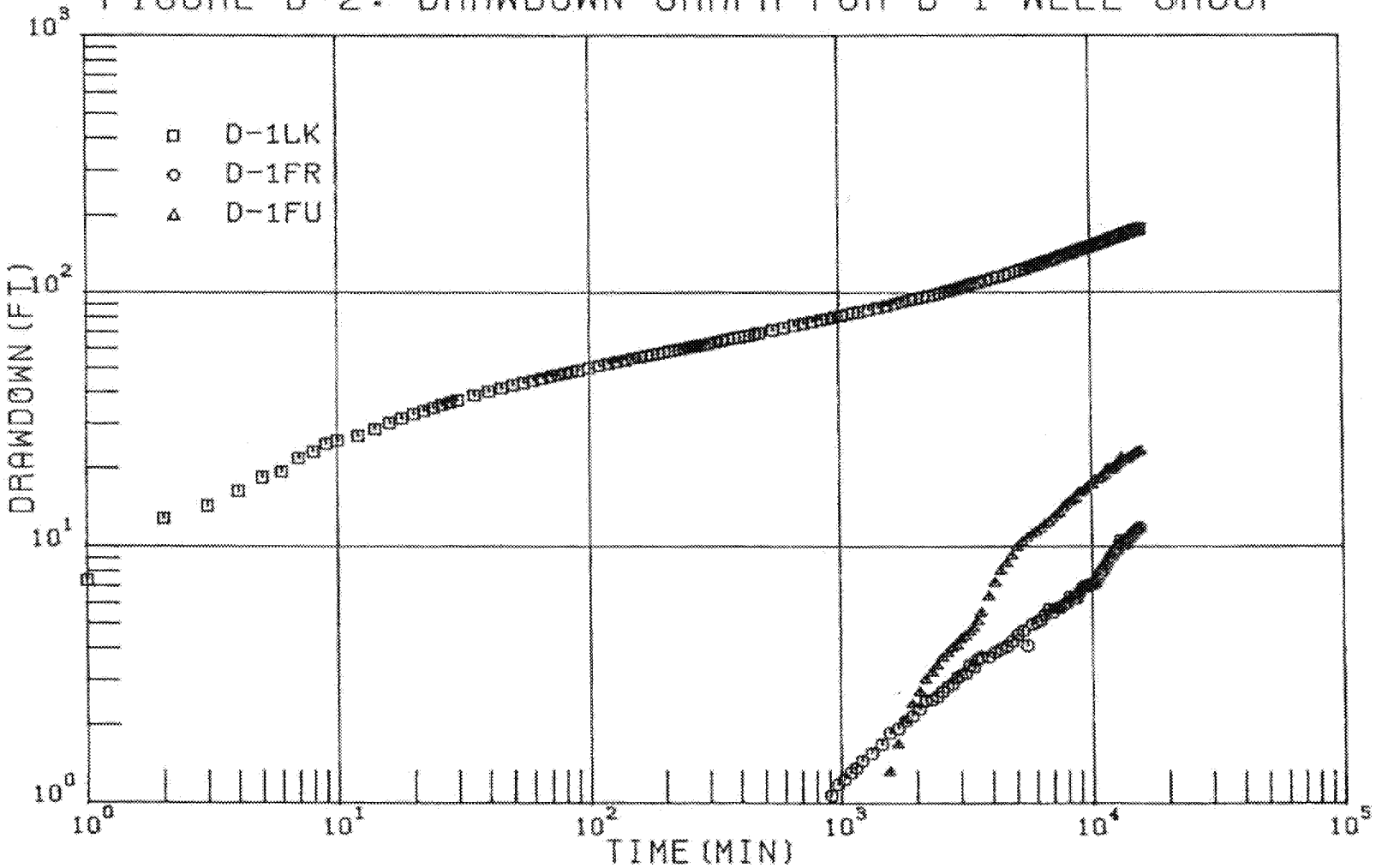


FIGURE B-3: DRAWDOWN GRAPH FOR WELL D-2LK

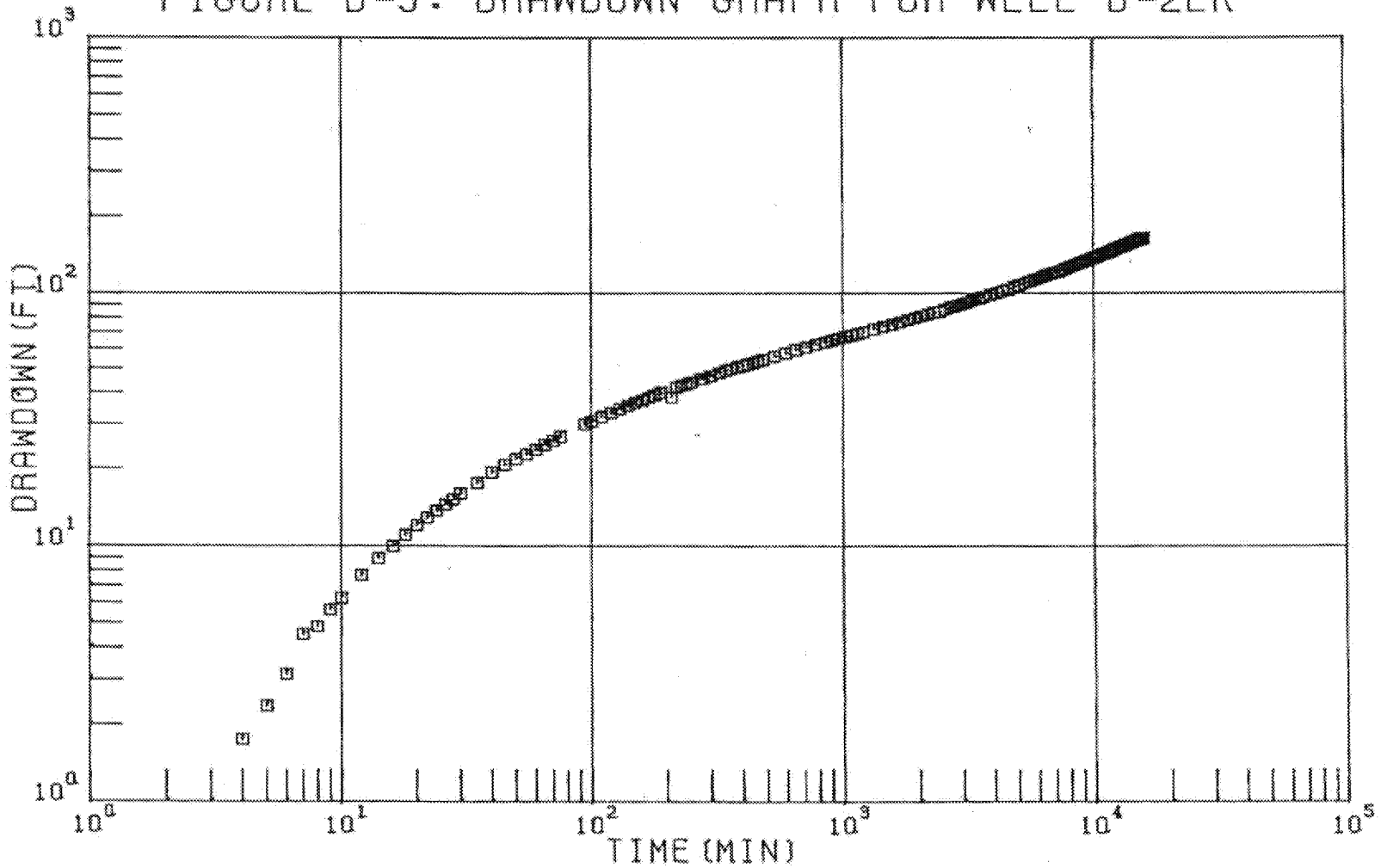


FIGURE B-4: DRAWDOWN GRAPH FOR D-3 WELL GROUP

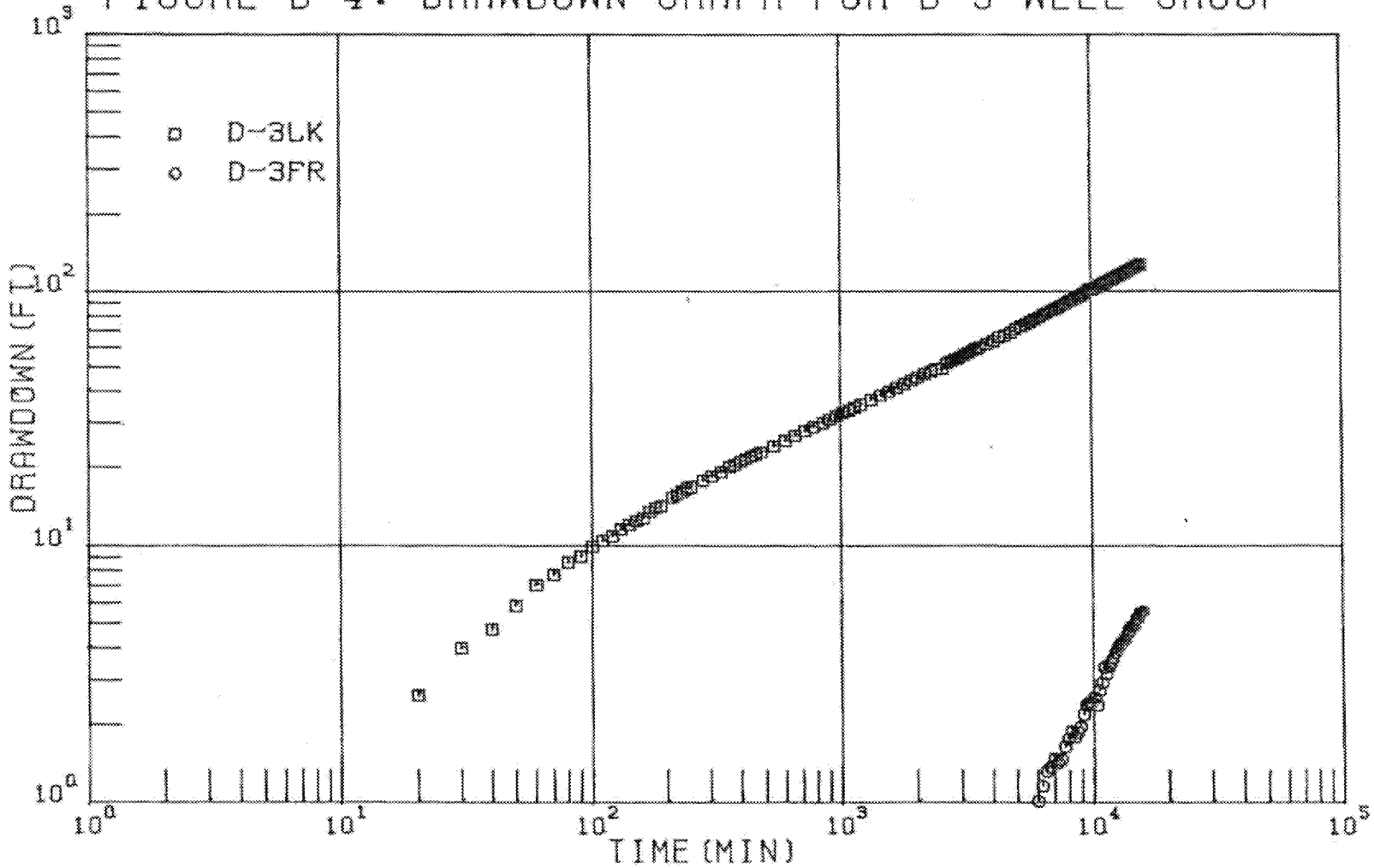


FIGURE B-5: DRAWDOWN GRAPH FOR D-4 WELL GROUP

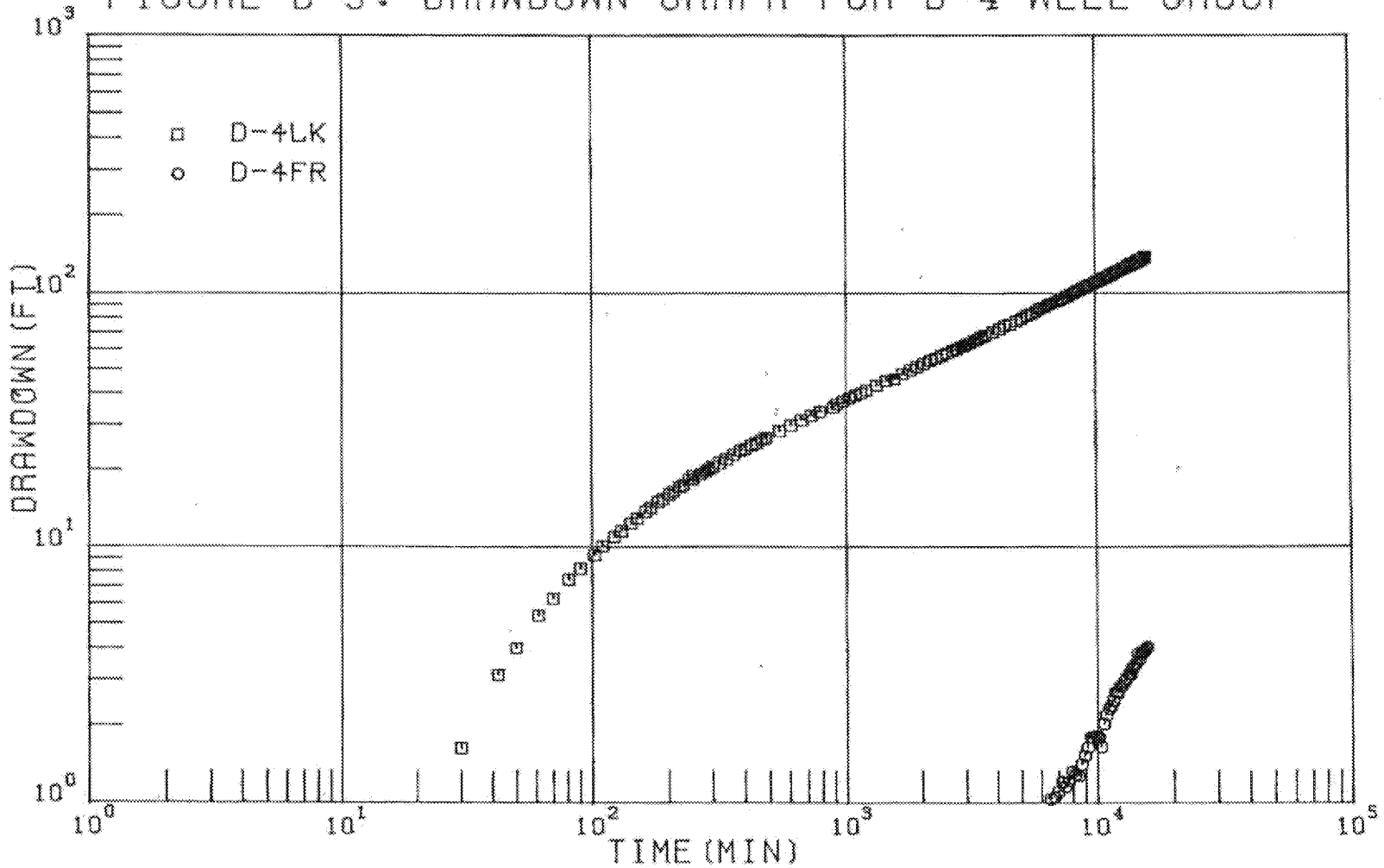


FIGURE B-6: DRAWDØWN GRAPH FØR WELL D-5LK

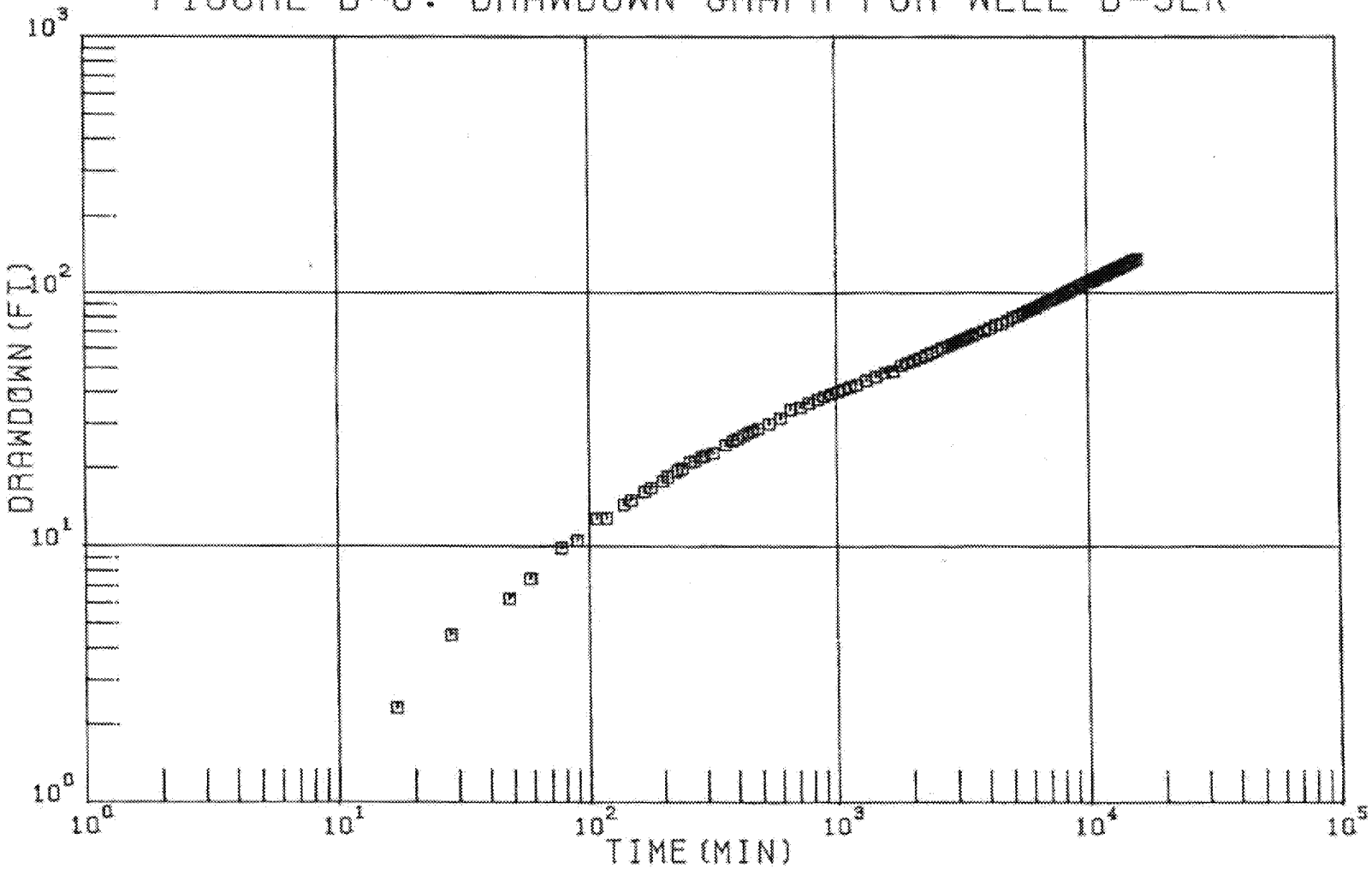


FIGURE B-7: DRAWDØWN GRAPH FØR WELL D-6LK

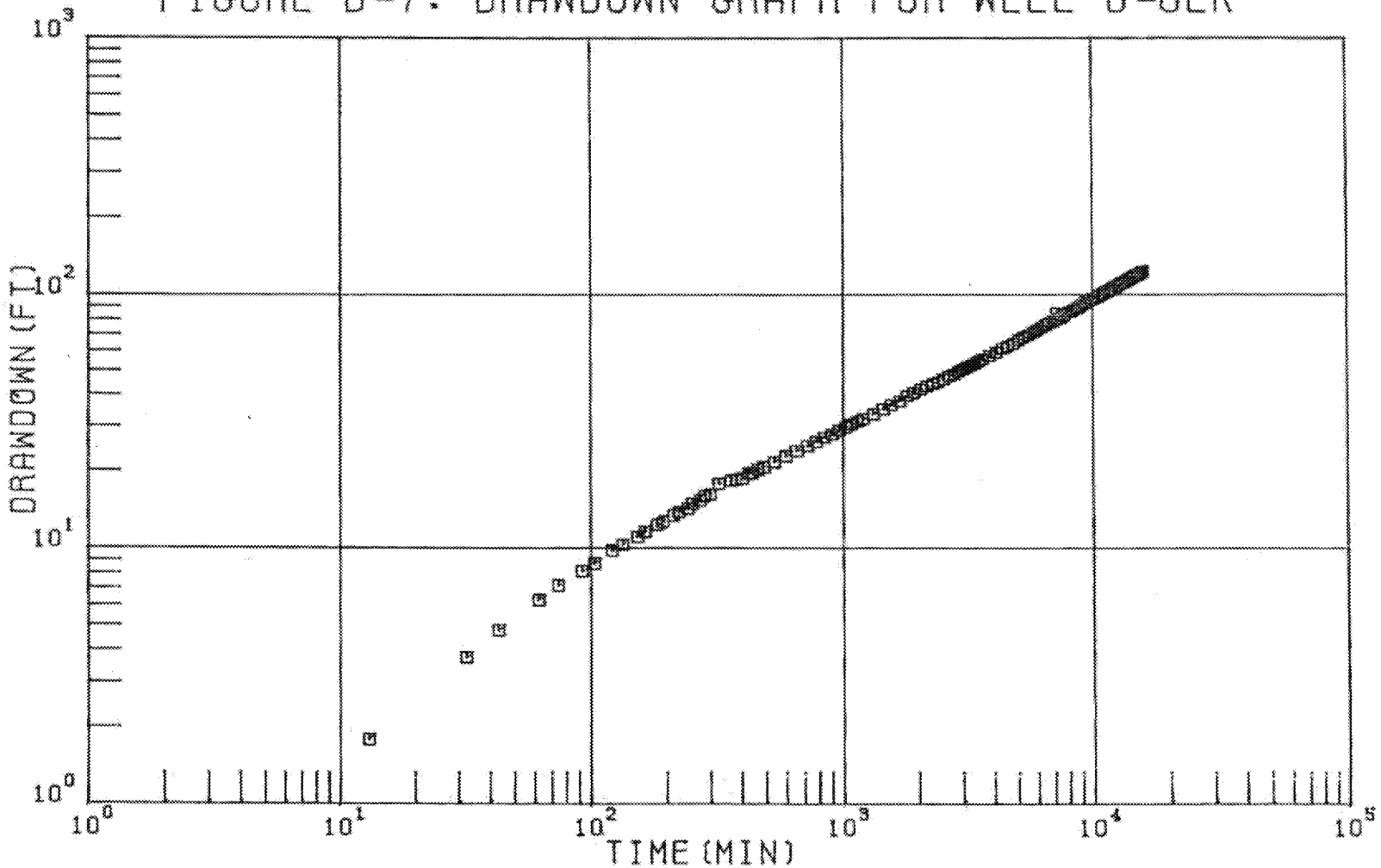


FIGURE B-8: DRAWDØWN GRAPH FØR WELL D-8LK

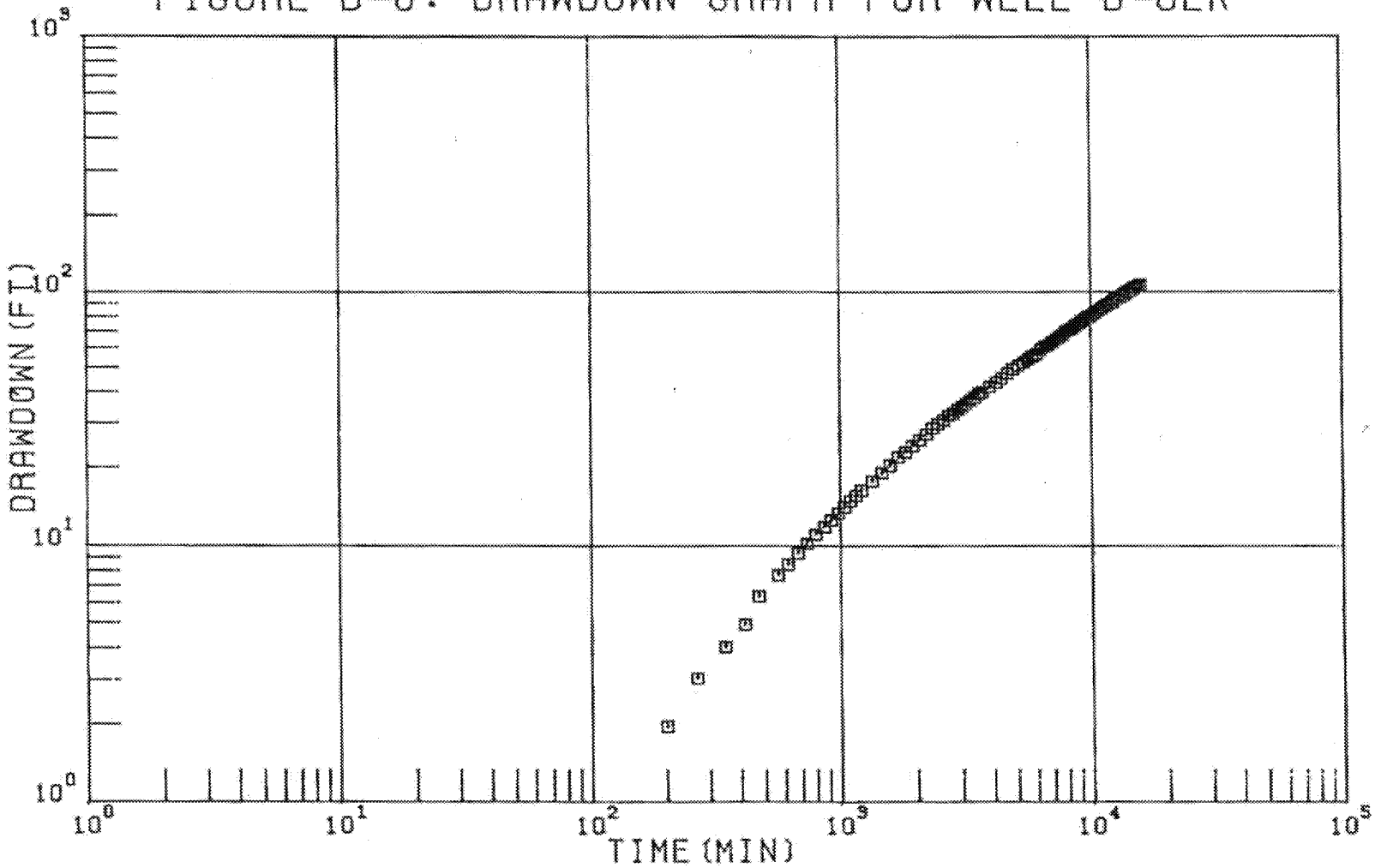
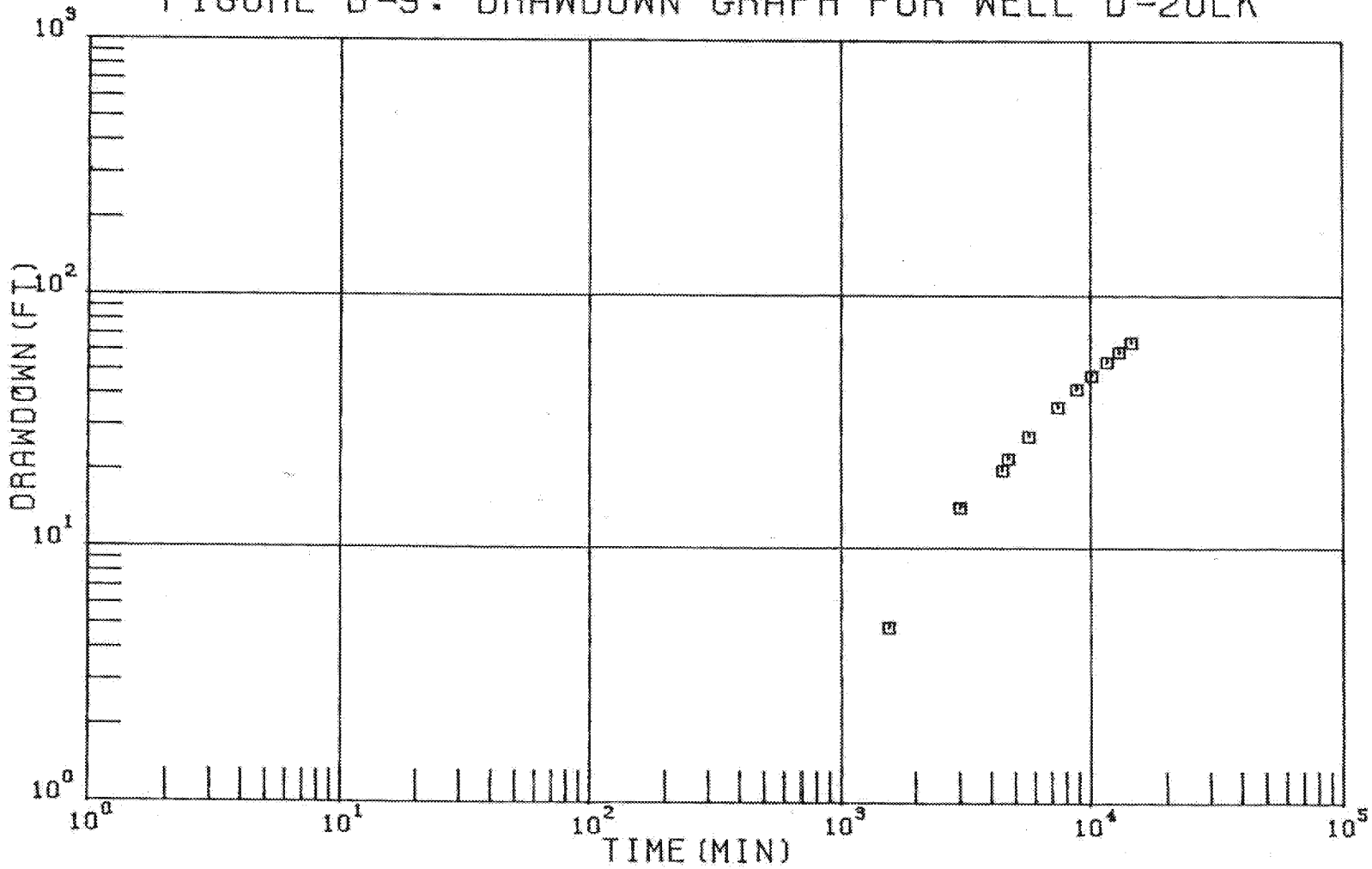


FIGURE B-9: DRAWDØWN GRAPH FØR WELL D-20LK



# APPENDIX C

## SEMILOGARITHMIC TIME-RESIDUAL DRAWDOWN GRAPHS

FIGURE C-1: RECØVERY GRAPH FØR WELL D-PW

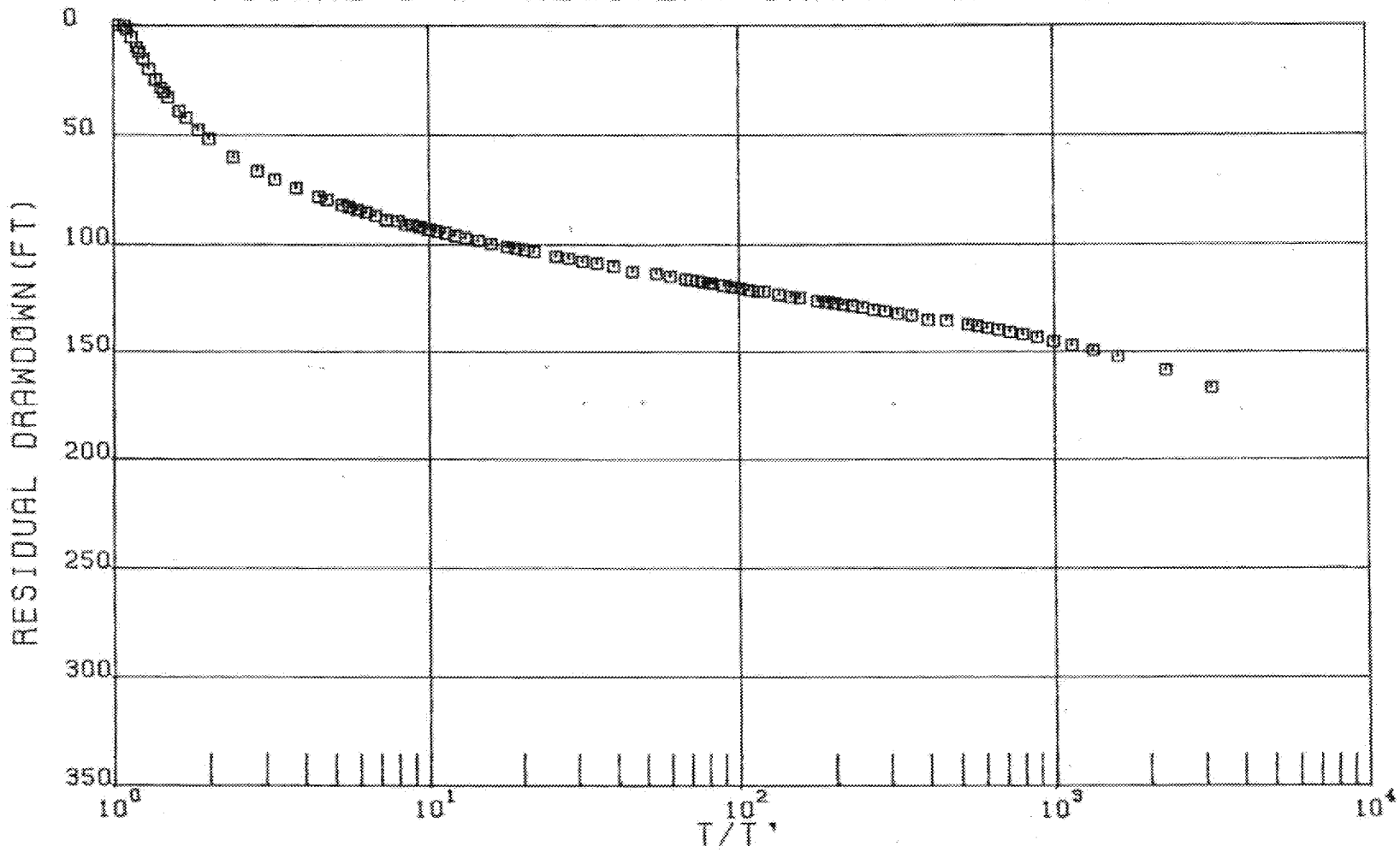





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FIGURE C-2: RECOVERY GRAPH FOR D-1 WELL GROUP

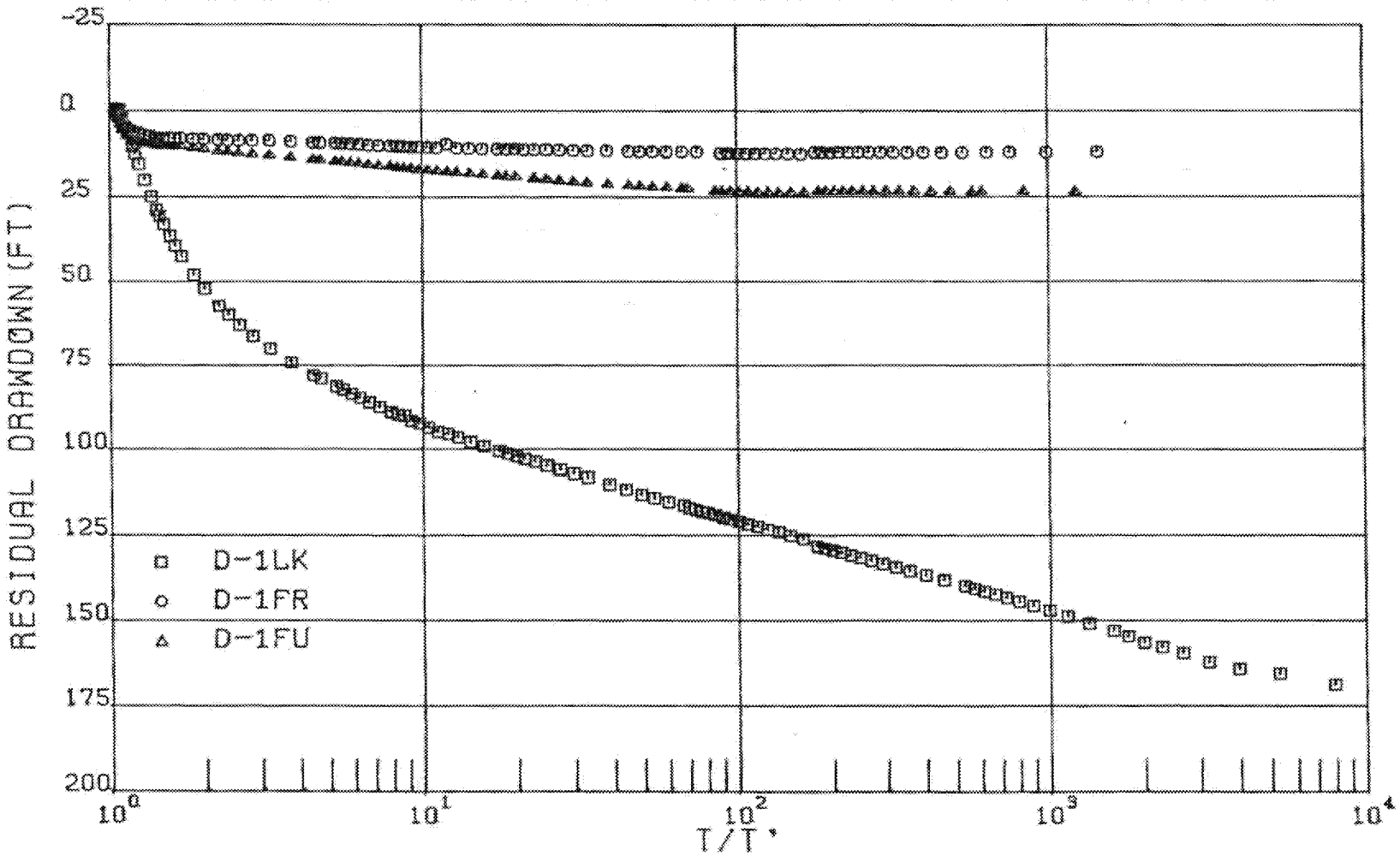

FIGURE C-3: RECOVERY GRAPH FOR WELL D-2LK

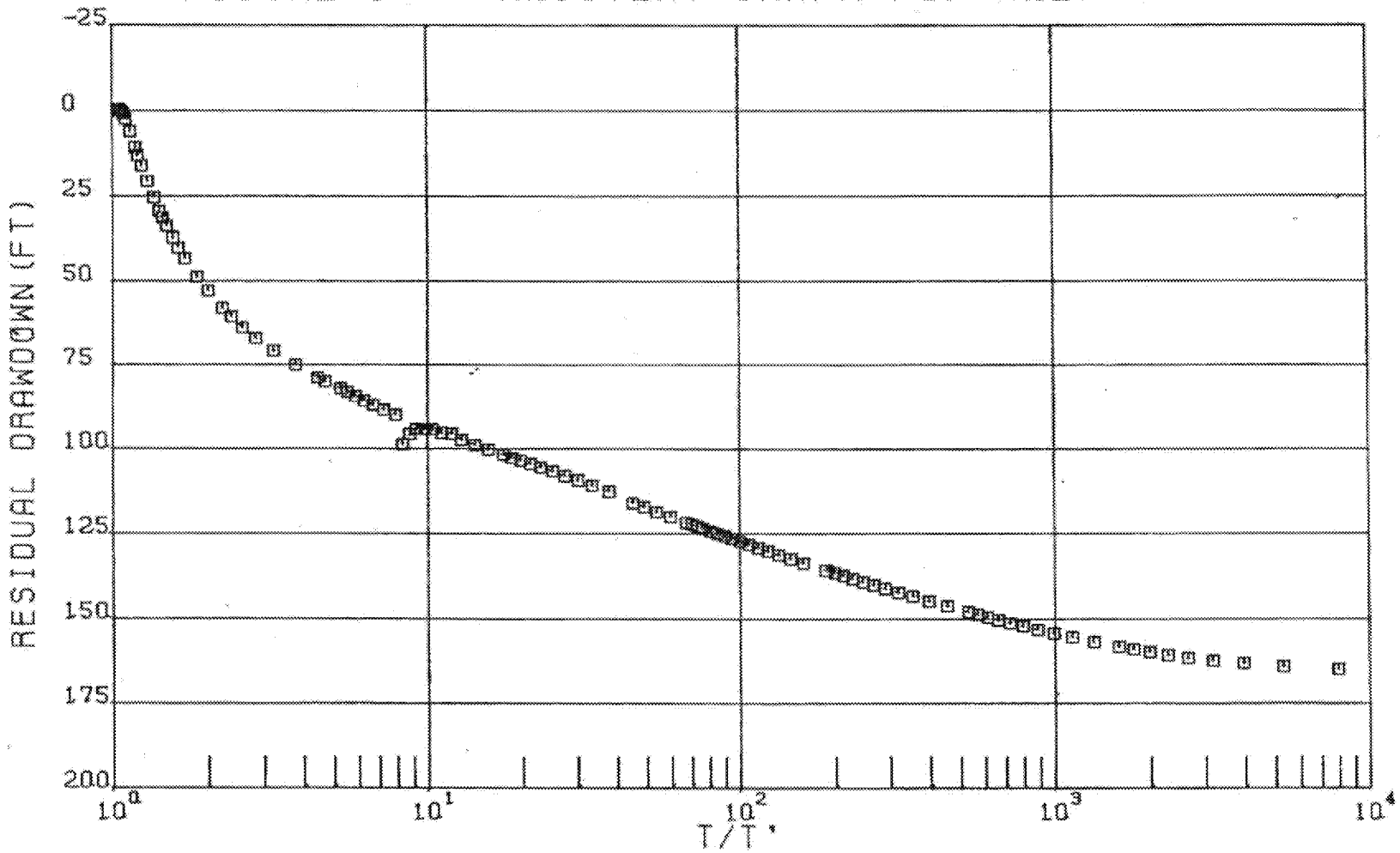

FIGURE C-4: RECOVERY GRAPH FOR D-3 WELL GROUP

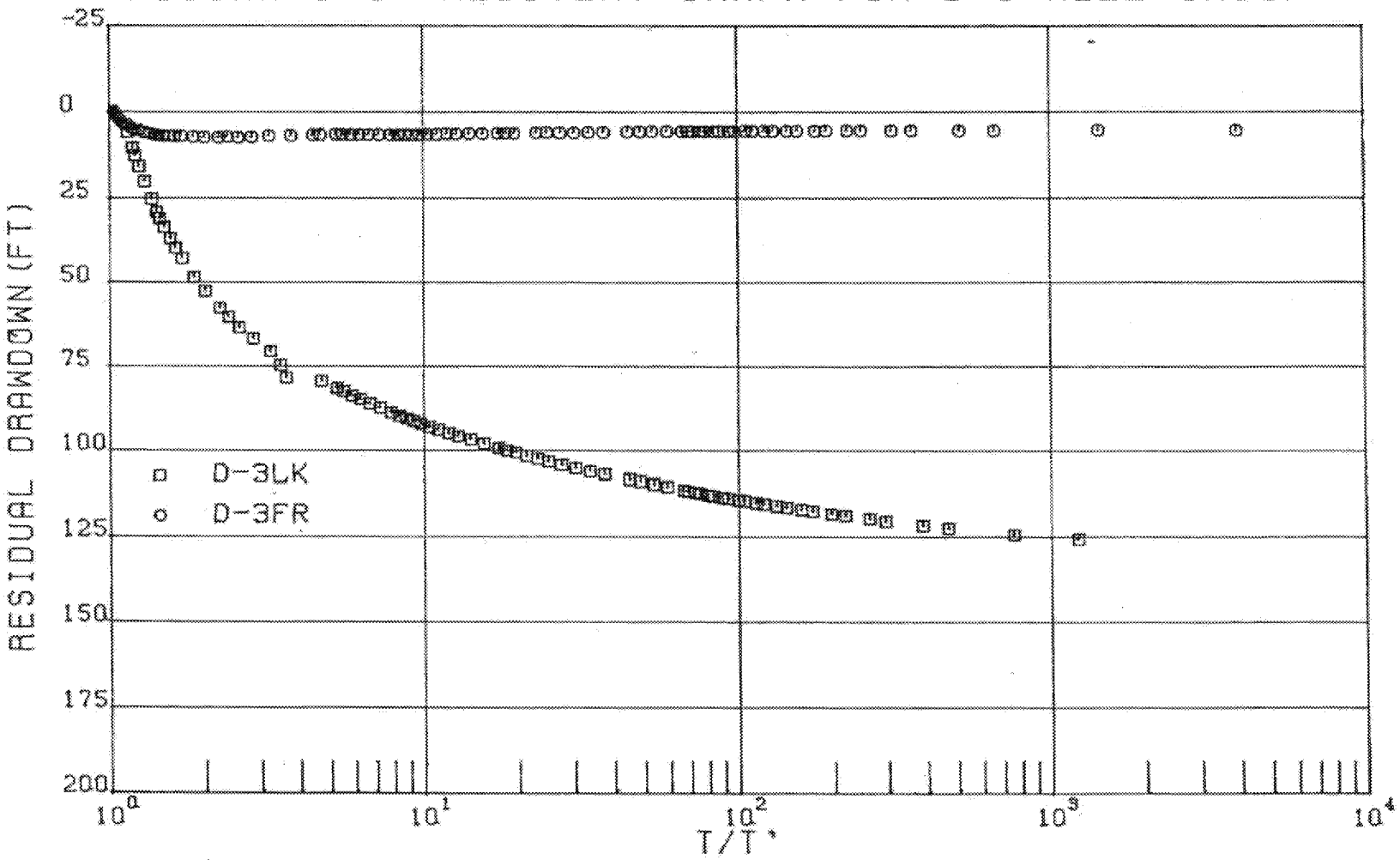

FIGURE C-5: RECØVERY GRAPH FØR D-4 WELL GRØUP

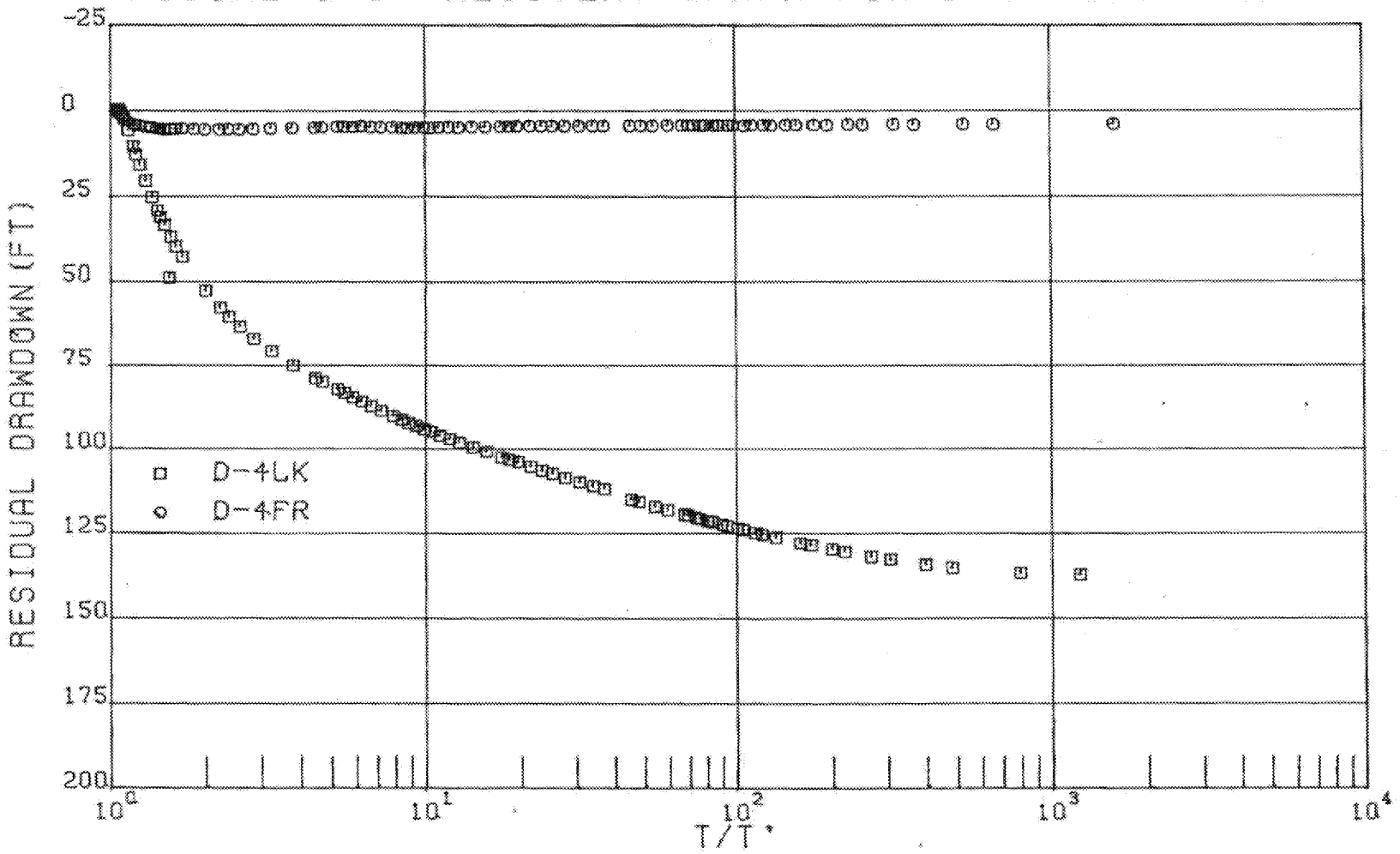

FIGURE C-6: RECØVERY GRAPH FØR WELL D-5LK

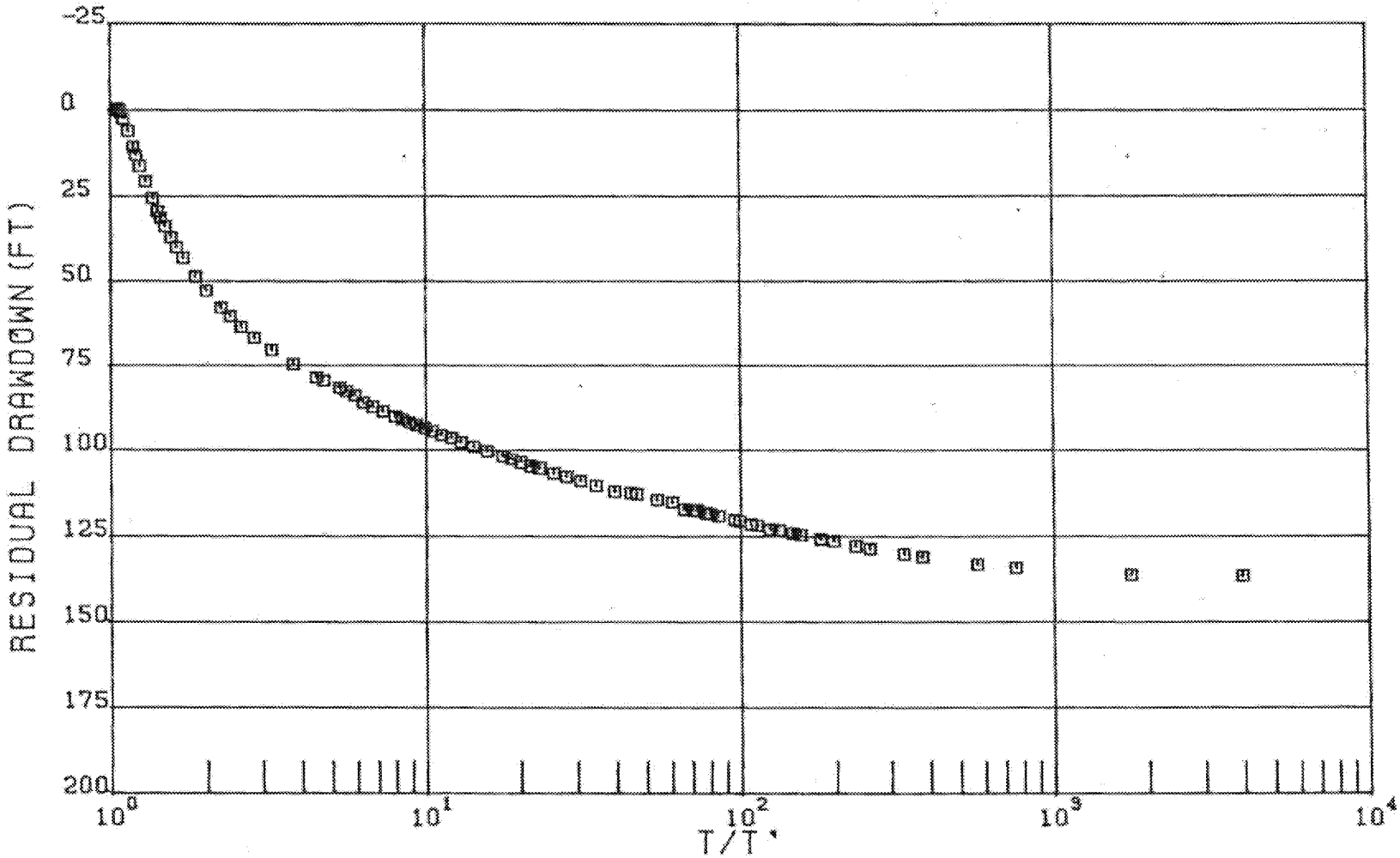




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FIGURE C-7: RECOVERY GRAPH FOR WELL D-6LK

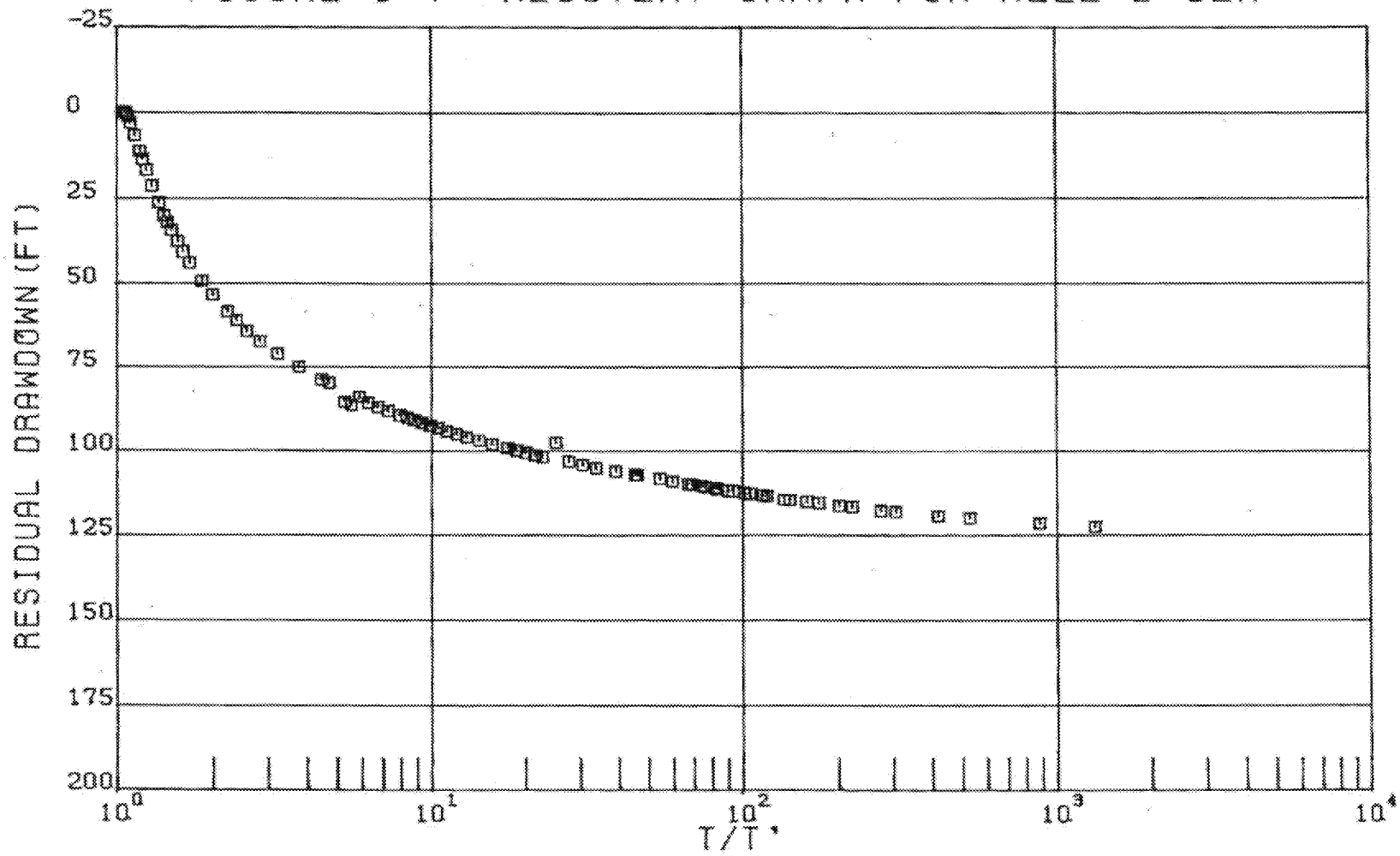

FIGURE C-8: RECØVERY GRAPH FØR WELL D-8LK

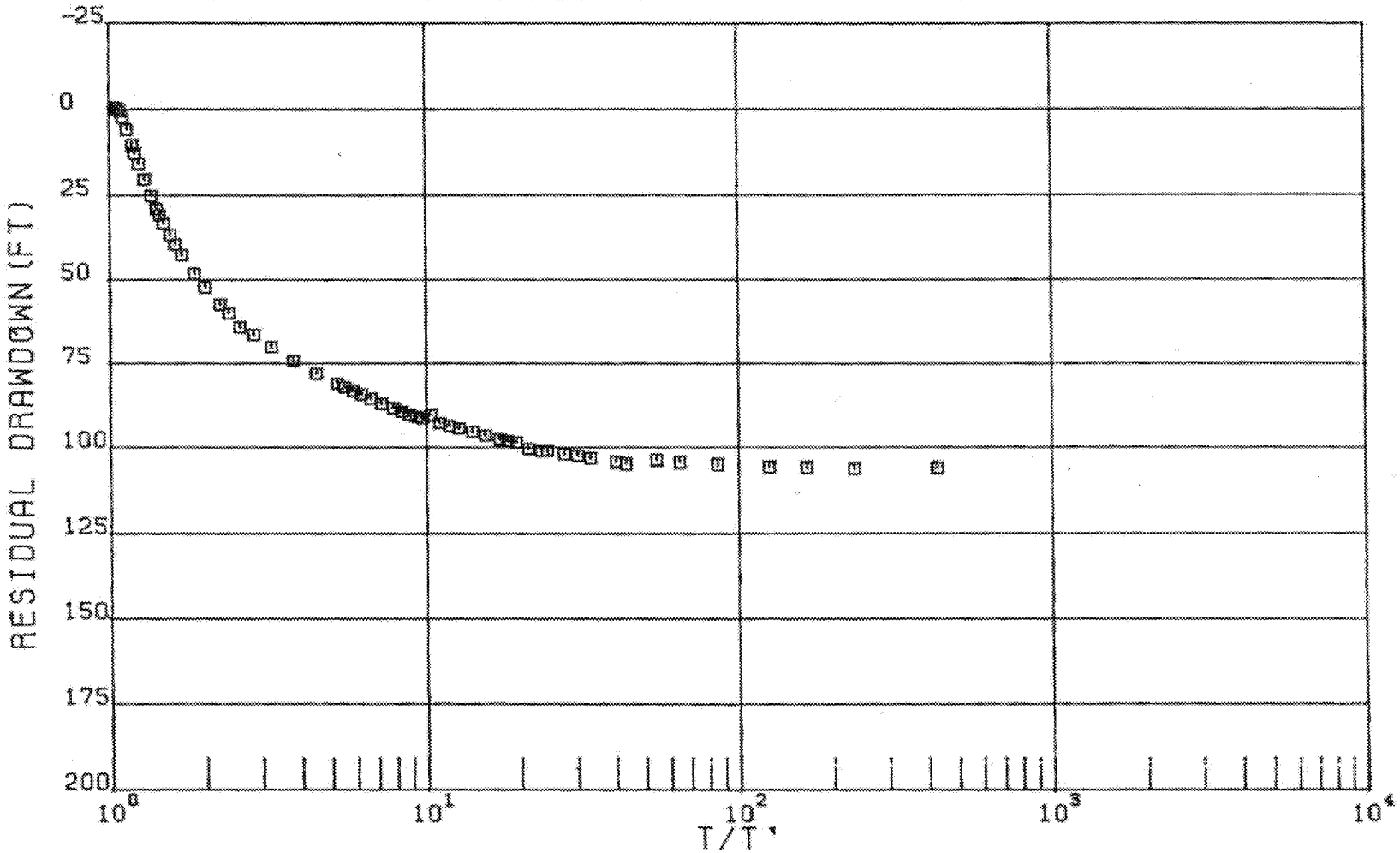




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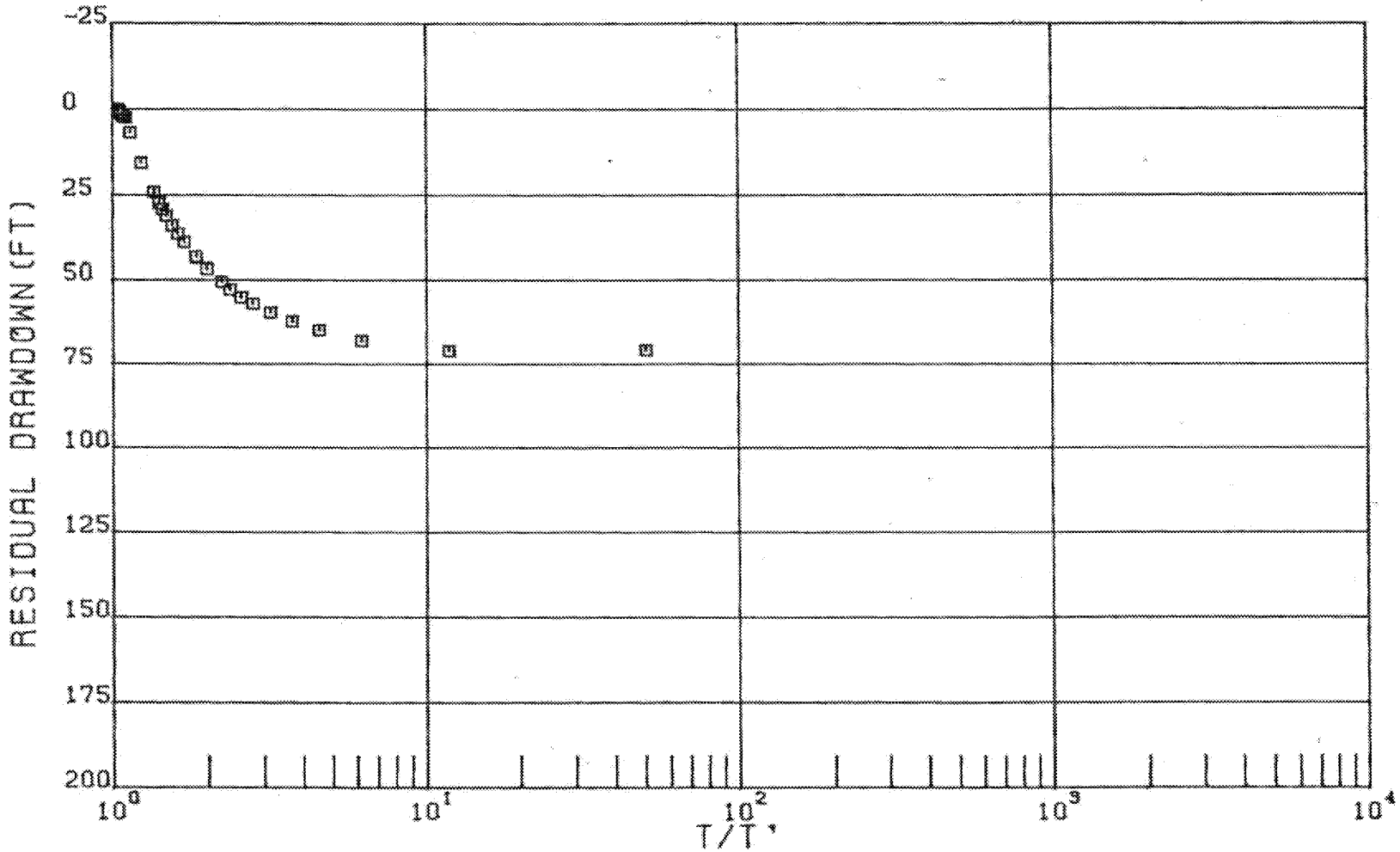
FIGURE C-9: RECØVERY GRAPH FØR WELL D-20LK



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# In-situ recovery uranium mining in the United States: Overview of production and remediation issues

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In 2007, in-situ recovery (ISR) methods produced about 95% of U.S. production of 4.53 million pounds. Eleven new and five expansion ISR applications or letters of intent were filed with the U.S. Nuclear Regulatory Commission for the period from 2007-2009. ISR mining can be conducted in water-saturated, permeable, hydrologically confined sandstone beds where the uranium is soluble. Contamination of ground water during and after ISR operations has become a major issue for nearby residents, and for local, county and state governments. Colorado has raised ISR mining requirements and established a burden of proof that operations can return water quality to baseline conditions. Similar concerns are affecting mining plans in Wyoming, Texas, New Mexico, South Dakota, and Nebraska. Major issues affecting restoration at ISR mining operations include the following:

- Baseline water quality: Is the water presently potable or suitable for livestock or irrigation? What parts of the local aquifer should be sampled to establish baseline? What sampling methods are required to establish water quality conditions?
- Control of fluid flow during operations: How much hydrologic understanding of the ore zone is necessary to avoid flow problems?
- Ground-water restoration: To what standard should the ground water be restored? How long should monitoring occur after mining is completed?
- Ground-water restoration:What technologies work or might work?

To date, no remediation of an ISR operation in the United States has successfully returned the aquifer to baseline conditions. Often at the end of monitoring, contaminants continue to increase by reoxidation and resolubilization of species reduced during remediation; slow contaminant movement from low to high permeability zones; and slow desorption of contaminants adsorbed to various mineral phases. New remediation technologies are being examined, including bioremediation and monitored natural attenuation. Bioremediation can occur through addition of a carbon source such as acetate or molasses to augment the natural bacterial population which can induce simultaneous reduction and precipitation of uranium in solution. Bioremediation experiments are presently being conducted at U.S. Department of Energy sites in western states. Monitored natural attenuation suggest that ground-water flow that created the deposit moved from an oxidized zone through the orebody to a reduced zone. Re-establishment of ground-water flow after mining should move contaminants from the mined orebody into the reduced zone where natural processes can reduce the contaminants and remove them from the ground water. Questions: 1) Is current ground-water hydrology suitable? 2) What is the reducing capacity of the reduced zone? 3) Do kinetics of reduction reactions in the reducing zone vs. speed of ground water flow? 4) Effects of heterogeneity in mining zone and reducing zone? 5) Can all analytes of concern be attenuated? 6) Monitored attenuation- can the limited time frame preferred by operators be achieved?

# Technical Paper

# Excursions of Mining Solution at the Kingsville Dome In-situ Leach Uranium Mine

by George Rice

Hydrologist, GRGwH

## Abstract

In-situ leach (ISL) uranium mining differs from conventional mining in that it does not require excavation of ore. Instead, uranium is mobilized by injecting leaching fluids into a groundwater-saturated ore body. The uranium enriched groundwater (mining solution) is then brought to the surface through extraction wells. Approximately 1 to 3 percent more water is extracted from a uranium production well field than is injected. The purpose of this "bleed" is to prevent the escape of mining solution (excursions) by maintaining a hydraulic gradient toward the extraction wells.

The Kingsville Dome Mine is 13 km southeast of Kingsville, Texas. ISL mining began in 1988 and continued intermittently until 2009. The mine covers 864 ha and is divided into three production areas. This paper focuses on production area three (PA-3).

The bleed at PA-3 did not contain the increased pressures caused by injection of leaching fluids. A hydraulic gradient was rapidly established between the injection wells and the mine boundary, as shown by a rise in water levels in monitor wells surrounding PA-3. This gradient drove mining solution beyond the mine boundary. These excursions affected a well on the Garcia property, approximately 300 m down gradient of the mine. Since mining began, uranium concentrations in the Garcia well have increased from less than 200 µg/L, to more than 600 µg/L. This is the first time that contaminants in an off-site domestic well have been linked to ISL uranium mining in the United States of America.

## In-situ leach uranium mining

In-situ leach (ISL) uranium mining differs from conventional mining in that it does not require excavation of ore. Instead, uranium is mobilized by injecting leaching fluids into a groundwater-saturated ore body (figure 1). The uranium-enriched groundwater (mining solution) is brought to the surface through extraction wells and routed to a processing plant where the uranium is removed. The uranium-depleted solution is then re-injected into the ore body. This cycle of injection and extraction continues as long as the ore body contains economically recoverable amounts of uranium.



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Leaching fluids typically consist of water, oxidants (e.g., oxygen, hydrogen peroxide), and complexing agents (e.g., carbonates, sulfates) (NRC 2007). The oxidants convert uranium from the relatively insoluble $U^{+4}$ state to the soluble $U^{+6}$ state. The complexing agents combine with the oxidized uranium to form anionic or neutral complexes that remain in solution (e.g., $UO_2(CO_3)_3^{4-}$, $UO_2(SO_4)_3^{4-}$) (Charbeneau 1984). Uranium ore usually contains other toxic constituents such as radium, arsenic, molybdenum, and selenium (NRC 2007). These are also mobilized during ISL mining.

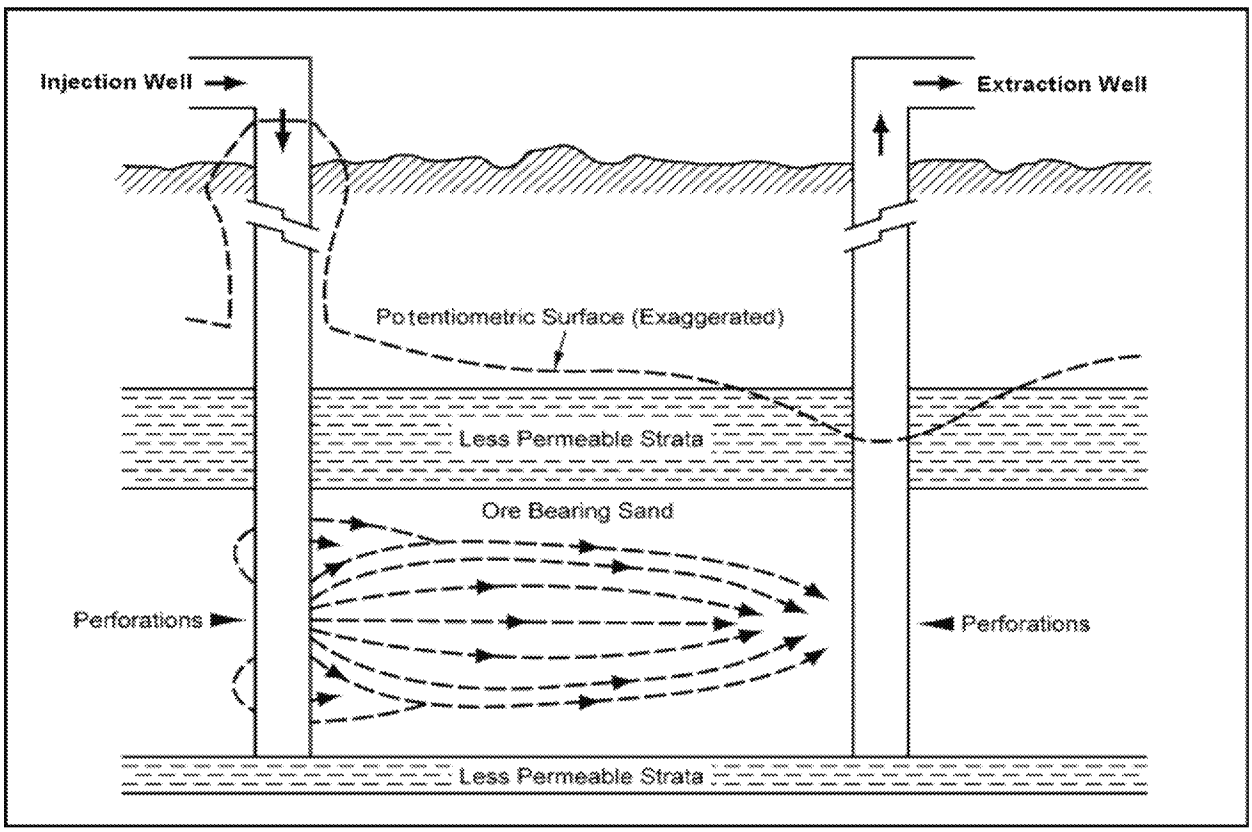


***Figure 1. Schematic Cross Section, Injection and Extraction Wells (adapted from NRC 2009)***

Most ISL mining occurs in fluvial sandstone aquifers (Staub et al. 1986). These fluvial systems are heterogeneous and anisotropic, consisting of interbedded clays, silts, sands, and gravels. They contain paleochannels that act as preferential flow paths, and overbank deposits that impede flow.

Injection and extraction wells are organized in patterns. Figure 2 shows a 5-spot pattern. Other patterns, e.g., 7-spot, are also used. A uranium production well field will usually contain a series of patterns arranged to follow the form of the uranium ore body. Well fields are grouped in production areas, and production areas are surrounded by a ring of monitor wells (NRC 2009).

Approximately 1 to 3 percent more water is extracted from a production area well field than is injected. The purpose of this "bleed" is to prevent the escape (excursion) of mining solution by maintaining a hydraulic gradient toward the extraction wells. An excursion is the flow of mining solution beyond the monitor well ring.

Figure 2 is an idealized depiction of groundwater flow. In practice, excursions are initiated when mining solution flows beyond the capture zones of extraction wells. This may be caused by failure to balance injection and extraction rates, failure to maintain sufficient bleed rates, or when mining solution is diverted by paleochannels.



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After mining at a production area is completed, groundwater is supposed to be restored to its pre-mining quality (Texas Administrative Code, Title 30, §331.107). However, groundwater restoration after ISL mining is difficult. The United States Geological Survey reviewed 22 uranium production areas in Texas (USGS 2009). Toxic constituents (e.g., uranium, arsenic, selenium) had been restored to their pre-mining levels at only two of them. In no case had all constituents, including non-toxic constituents such as calcium and sulfate, been restored to their pre-mining levels (USGS 2009). Nonetheless, the Texas Commission on Environmental Quality (TCEQ) considers groundwater restoration to be complete at all 22 production areas (USGS 2009).

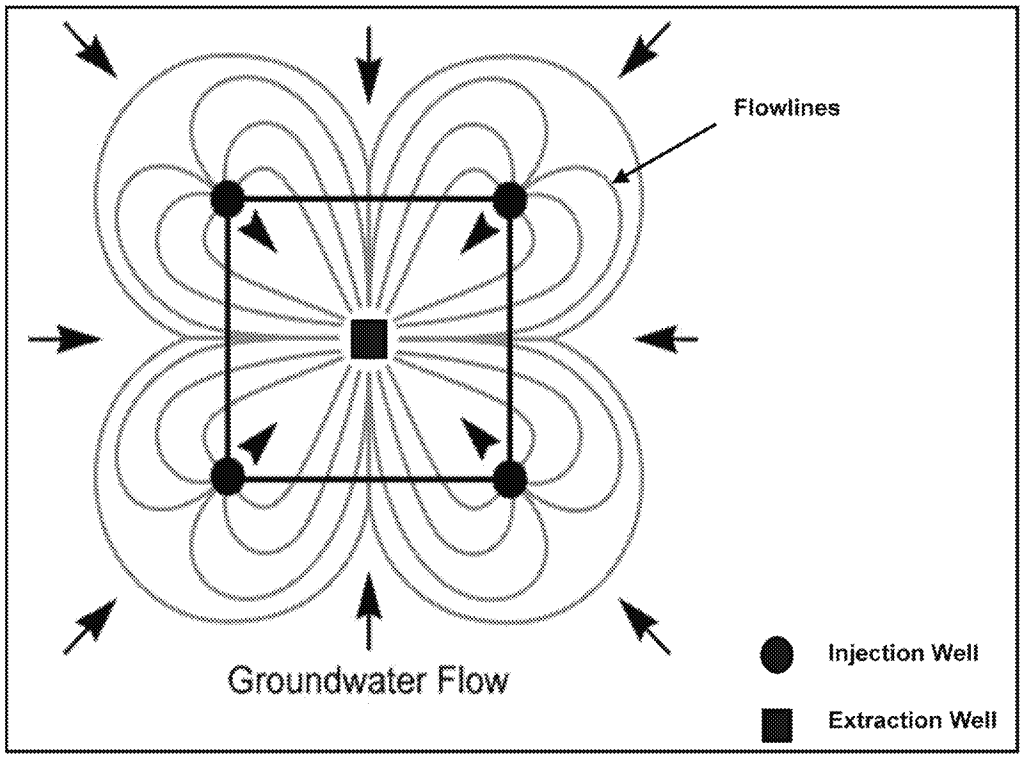


***Figure 2. Schematic, 5-spot Injection-Extraction Well Pattern*** *(Adapted from NRC 2009)*

# ISL mining at Kingsville Dome

The Kingsville Dome (KVD) mine is owned and operated by Uranium Resources Inc. (URI). The mine is in Kleberg County, Texas, approximately 13 km southeast of Kingsville (figure 3). ISL mining began in 1988 and continued intermittently until 2009. The area licensed for mining covers 864 ha (TBRC 1985) and is divided into three production areas (PAs) (figure 4). This paper focuses on PA-3. Unless otherwise noted, all of the site-specific data regarding the KVD mine was obtained from documents submitted by URI to the TCEQ or its predecessor agencies.

There are domestic wells near the mine. All of them are monitored for uranium and other constituents associated with ISL mining. Two of them, the Garcia wells, are directly down gradient of PA-3 (figure 4).



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The ore occurs in the Goliad Aquifer, a fluvial deposit consisting of interbedded clay, silt, and sand (Rice 2006). The ore is found between about 150 m and 225 m below land surface. The principal uranium minerals are believed to be uraninite ($UO_2$) and coffinite ($U(SiO_4)(OH)_4$) (McKnight 2006).

The groundwater is confined (Rice 2006) and generally flows toward the northwest (TBRC 1985). The current flow direction is not the natural direction. Under natural conditions, groundwater flowed southeast, toward the coast. However, pumpage in the vicinity of Kingsville reversed the hydraulic gradient and groundwater now flows toward Kingsville (Rettman 1983). Local groundwater flow directions vary. Calculated flow rates range from about 0.3 m/yr to 100 m/yr (Rice 2006). This range reflects the heterogeneity of the fluvial deposits. It should be noted that these flow rates are for non-mining conditions. During mining, local flow rates may be much higher due to the steep gradients caused by the operation of injection and extraction wells.

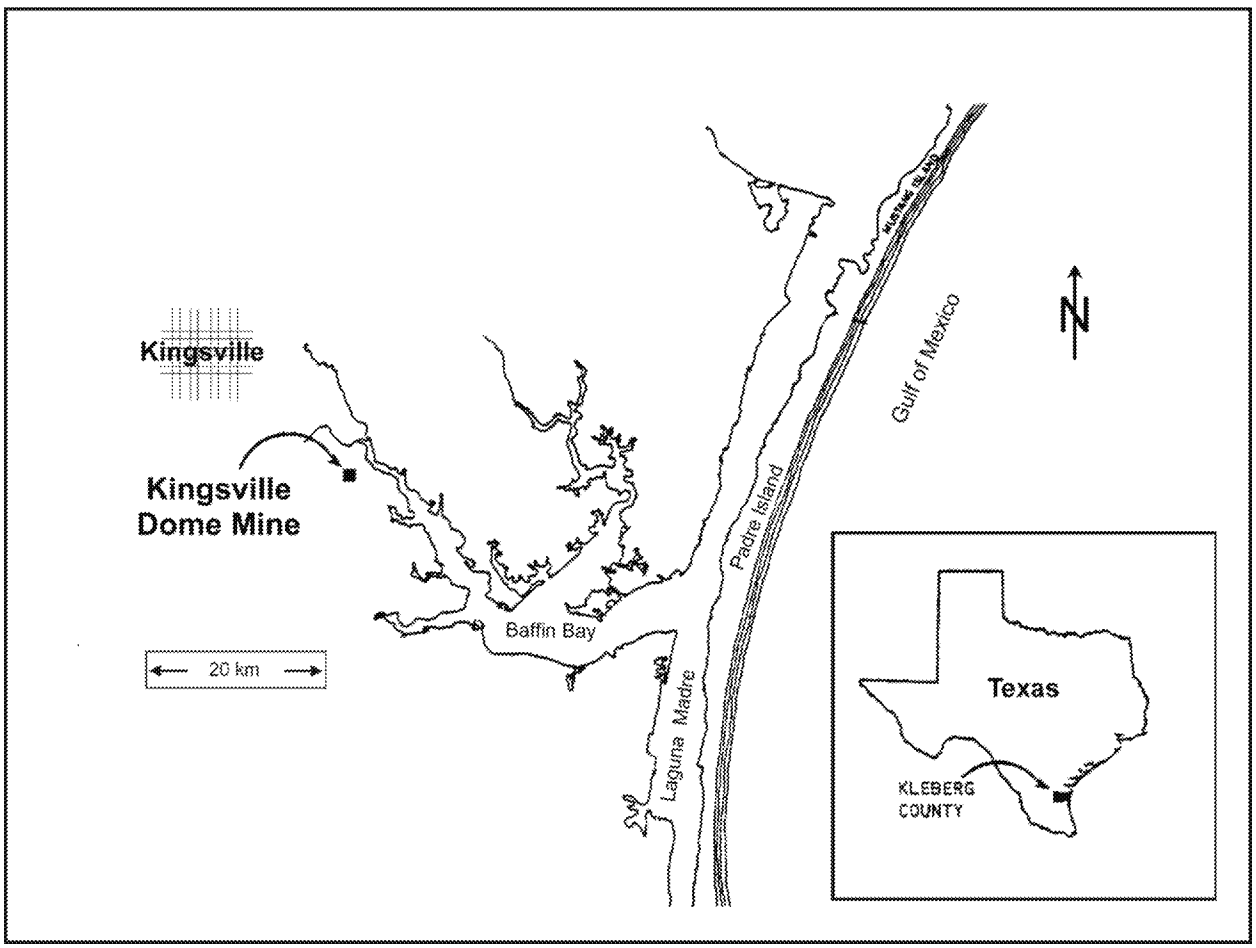


*Figure 3. Mine Location Map*

The leaching fluid used at the KVD mine is oxygenated water. Table 1 shows typical concentrations of constituents in the mining solution. URI uses a computerized model to adjust injection and extraction rates, but the model does not account for aquifer heterogeneities (Grant 2006). URI maintains a bleed of approximately one percent. The bleed is supposed to continue until groundwater restoration is completed, but URI has not always maintained the bleed as required (TCEQ 2003).



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**Table 1 Concentrations of Constituents in a Typical Mining Solution at the KVD Mine***

| pH | Electrical cond. | Uranium | Chloride | Calcium | Bicarb-onate | Sulfate | Molyb-denum |
|---|---|---|---|---|---|---|---|
| (SU) | (µmhos/cm) | (µg/L) | (mg/L) | (mg/L) | (mg/L) | (mg/L) | (mg/L) |
| 6.6 | 4000 | 80,000 | 600 | 400 | 800 | 1200 | 10 |

**URI analysis of mining solution from extraction wells. It may be a mixture of mining solutions from many extraction wells. Data from Mark Pelizza of URI, 2005.*

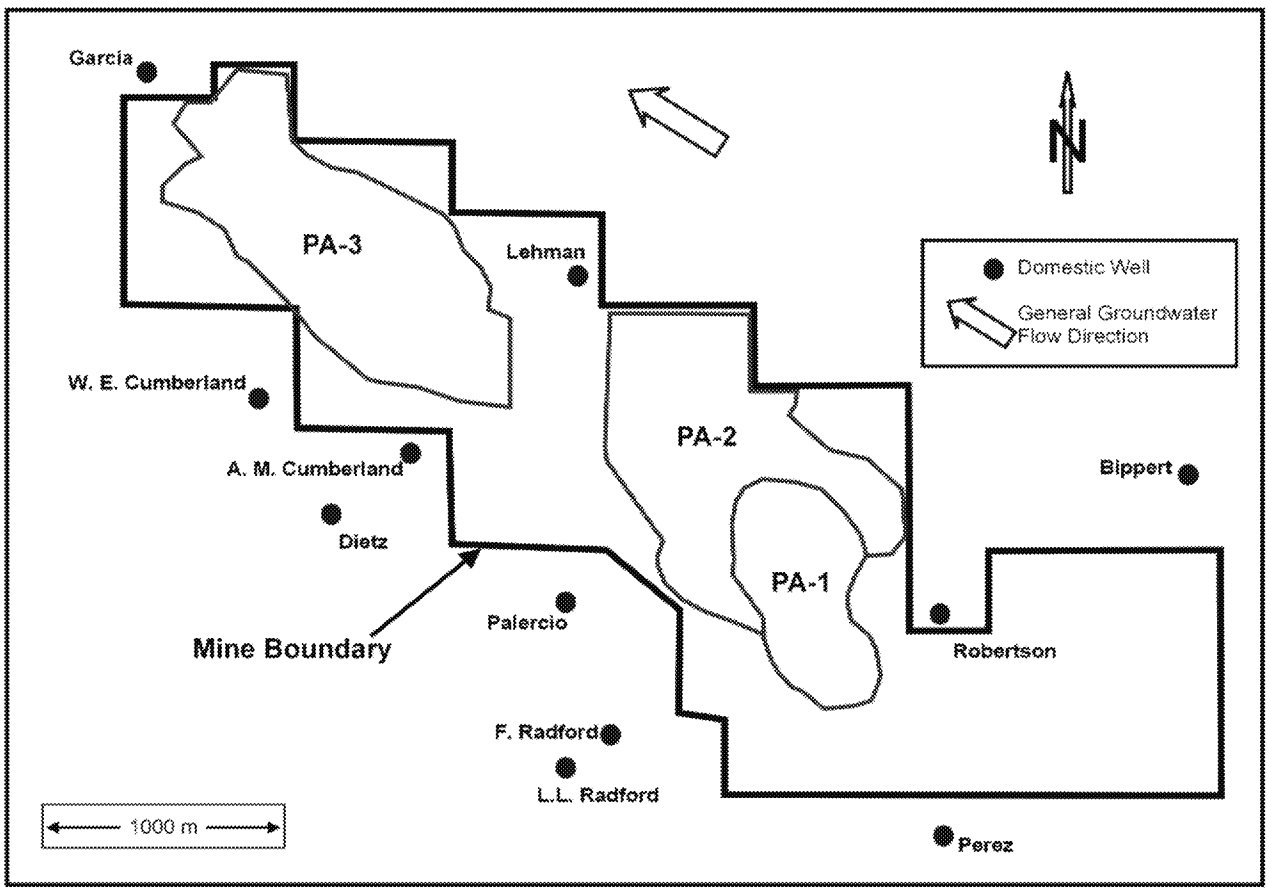


***Figure 4. KVD Mine Map***

## The Effects of Mining on Hydraulic Gradients at PA-3

Excursions are driven by hydraulic gradients. During mining at PA-3, the hydraulic gradients driving excursions were the result of the injection of leaching fluids.

PA-3 covers 151 ha. Mining at PA-3 first began in June 1998 and was suspended in June 1999. During this first period, uranium was produced from well fields 9 and 10 (figure 5). Mining resumed in January 2007 and was



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suspended again in June 2009. During this second period, uranium was produced from well fields 13, 14, 15a, 16a, 16b, 17a and 17b. Well field 15b was installed but was not used to produce uranium (Van Horn 2012). Well field injection rates ranged from about 1400 L/min to 5000 L/min (TCEQ 2008; URI 1999). Complete well field injection data are not available. A request to URI for additional data was refused (URI 2012b).

PA-3 is surrounded by a ring of 49 monitor wells. Water levels have been measured in all the monitor wells, but the lengthiest records are from seven wells monitored under an agreement between URI and Kleberg County. Beginning in 2005, water levels were measured in wells MW-78, MW-83, MW-85, MW-89, MW-97, MW-102, and MW-125. Water levels in these wells were measured quarterly when mining was not taking place, and twice a month during mining. Water levels from these seven wells are used in the discussion below.

The injection of leaching fluids had a rapid effect on water levels in the monitor wells. The effect can be seen by comparing water levels before, during, and after mining. Water levels rose an average of 1.7 m in the year after the resumption of mining (table 2), and fell an average of 2.3 m in the year after the suspension of mining (table 3). Figure 6 shows water levels in two monitor wells for the one year periods immediately before and after mining resumed.

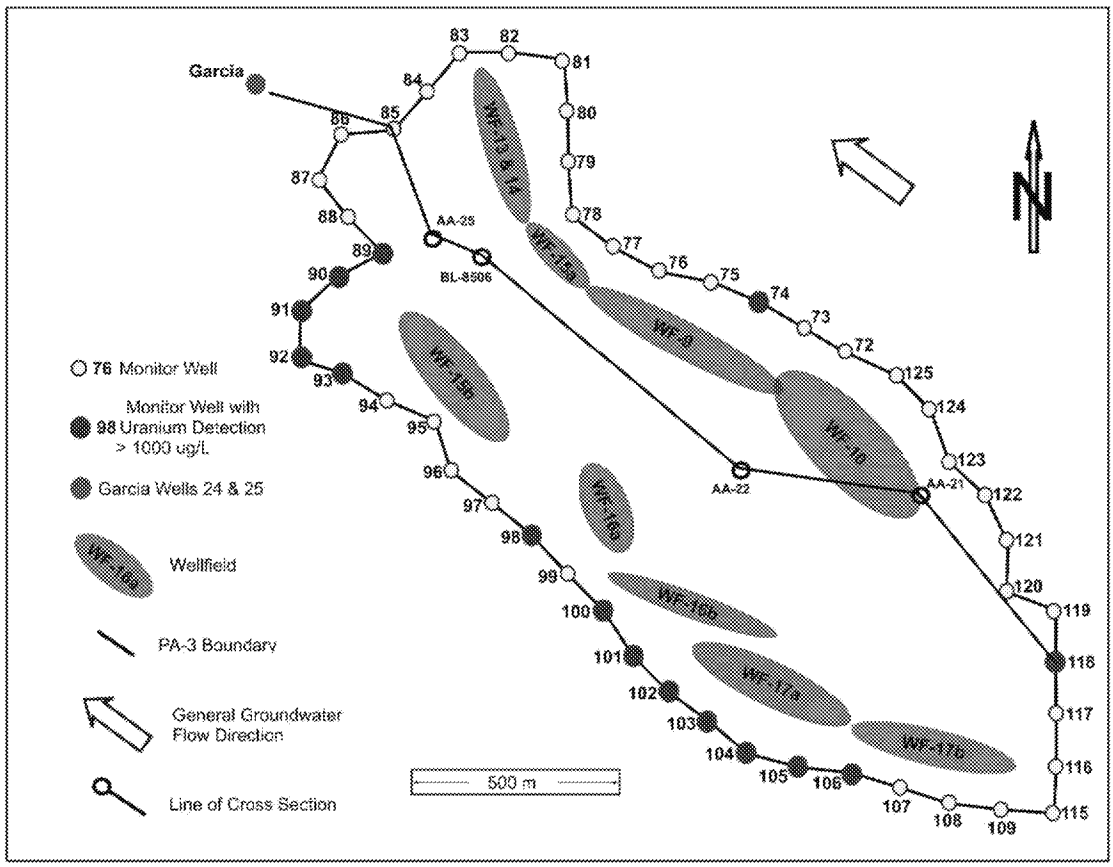


*Figure 5. PA-3, Well Fields and Monitor Wells*

**Table 2 Water Level Rises in Response to Resumption of Mining***



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| Well ID | Average depth to water in the year before mining resumed (Dec 2005 – Dec 2006, m btoc**) | Average depth to water in the year after mining resumed (Jan 2007 – Dec 2007, m btoc) | Average rise in water level in year after mining resumed (m) |
|---|---|---|---|
| MW-78 | 36.21 | 34.53 | 1.68 |
| MW-83 | 39.40 | 37.29 | 2.11 |
| MW-85 | 40.45 | 37.77*** | 2.68 |
| MW-89 | 37.69 | 36.67 | 1.02 |
| MW-97 | 36.80 | 35.61 | 1.19 |
| MW-102 | 37.28 | 35.84 | 1.44 |
| MW-125 | 34.06 | 32.37 | 1.69 |
| | | **Average of all wells:** | 1.67 |

** URI, 2012a. The average bleed rate during the year preceding mining was 62 L/min (URI 2007a, no pumping for restoration appears to have occurred during this period). The average bleed rate during the first three quarters of mining was 67.8 L/min (URI 2007b and 2008). There was no bleed during the remaining period of mining.*

*** btoc: below top of casing.*

**** With outlier removed. The outlier (56.48 m Aug 13, 2007) was approximately 18 m lower than any other measurement (URI 2012a). The average depth without removing the outlier was 38.58 m.*

**Table 3 Water Level Declines in Response to Suspension of Mining***

| Well ID | Average depth to water in the year before mining suspended (June 2008 – May 2009 m btoc) | Average depth to water in the year after mining suspended (June 2009 – May 2010 m btoc) | Average decline in water level in year after mining suspended (m) |
|---|---|---|---|
| **MW-78** | 35.27 | 37.71 | 2.44 |
| **MW-83** | 37.47 | 40.27 | 2.80 |
| **MW-85** | 39.45 | 42.00 | 2.55 |
| **MW-89** | 37.08 | 39.46 | 2.38 |
| **MW-97** | 36.44 | 38.60 | 2.16 |
| **MW-102** | 36.90 | 38.79 | 1.89 |
| **MW-125** | 33.27 | 35.38 | 2.11 |
| | | **Average of all wells:** | 2.33 |

** URI 2012a. The average pumping rate (bleed plus restoration) during the year following mining was 428 L/min (URI 2010).*

This rapid effect on water levels is to be expected. In a confined aquifer, changes in head are quickly propagated in response to the extraction or injection of water (Kruseman and De Ridder 1976). A similar response was seen during a pumped aquifer test at the KVD mine. In that test, water levels more than 1200 m from the pumped well began dropping less than ten hours after pumping began (TBRC 1985).

The rise in water levels shows that the bleed did not contain the increased pressures caused by injecting leaching fluids. The increased pressures were propagated beyond the monitor well ring, creating a gradient between the



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injection wells and monitor wells. Mining solution flowed down this gradient, toward the monitor wells. This resulted in excursions.

## Excursions at PA-3

Excursions are monitored by measuring the concentrations of uranium and chloride, and the value of electrical conductivity (EC) at the monitor well ring. Monitor wells are sampled quarterly when mining is not taking place, and twice a month during mining.

Excursions at PA-3 are most readily identified by increases in uranium concentrations. This is because the concentration of uranium in the mining solution is more than 1000 times greater than the groundwater background concentration, while the concentration of chloride and the value of EC are only about two times greater than background (table 4).

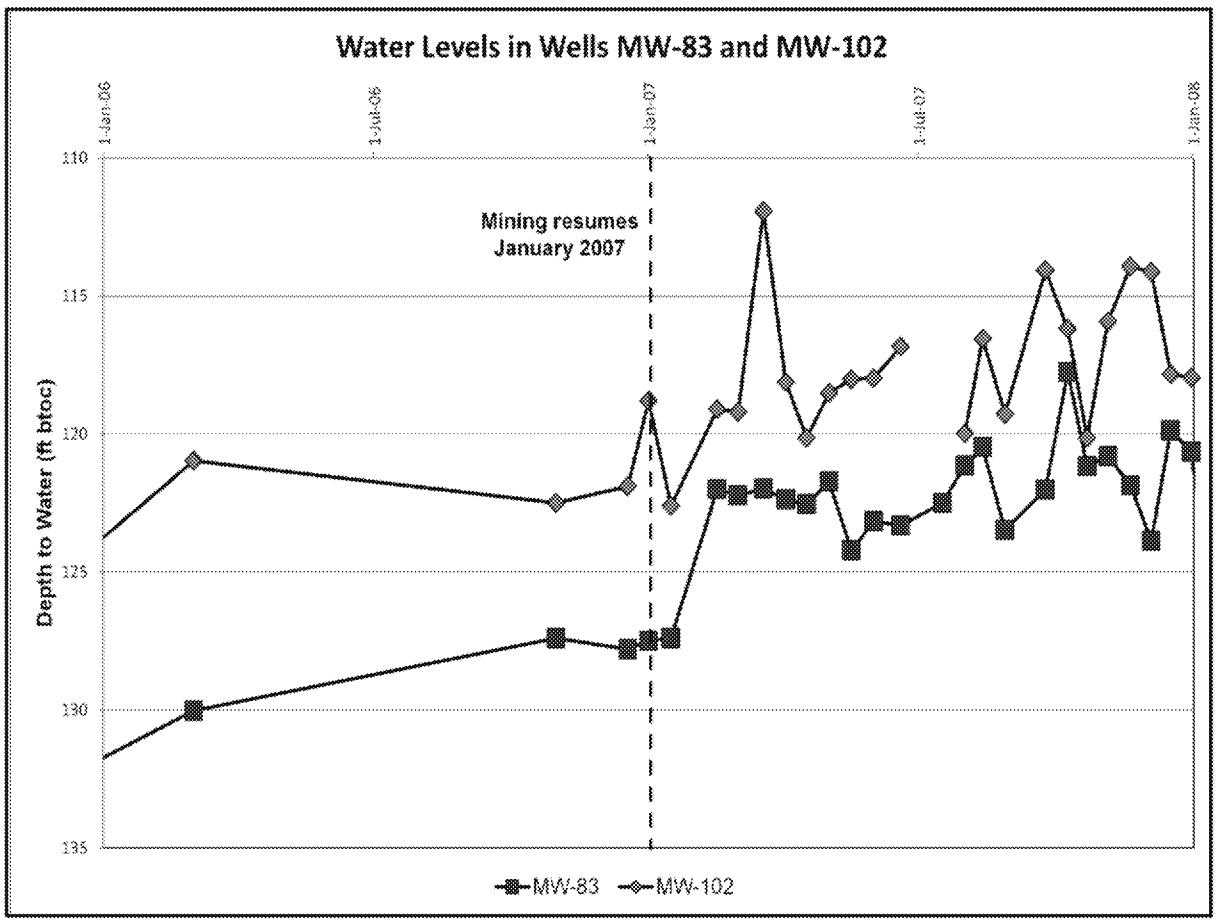


*Figure 6. Response of Water Levels to Injection of Leaching Fluids*



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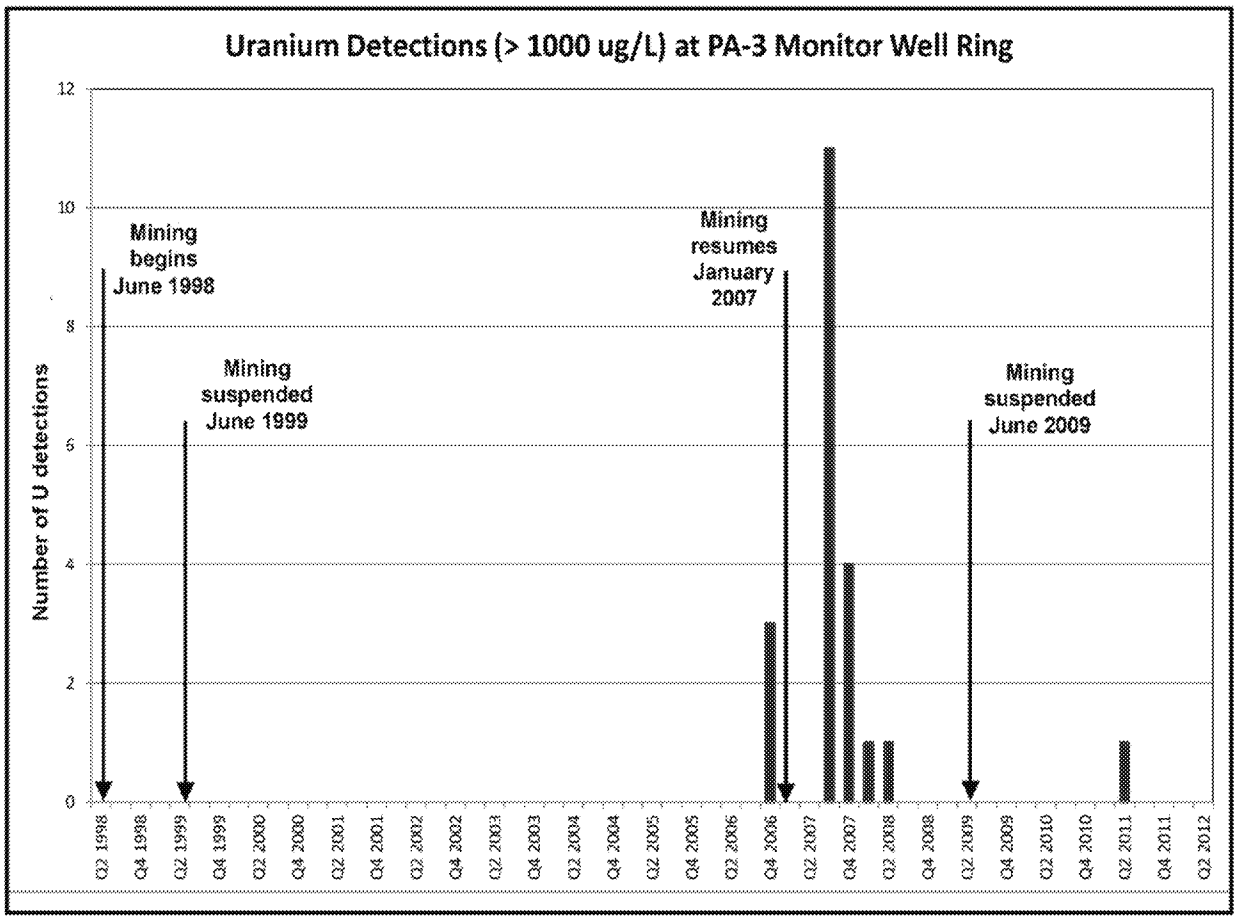


*Figure 7. Timeline of Uranium Detections at PA-3*

**Table 4 . Uranium, Chloride, and EC Values In Mining Solution and Background Groundwater at PA-3**

| Parameter | Typical mining solution value | Range of background values* | Average background values* | Ratio of mining solution value to average background value | EPA drinking water standard** |
|---|---|---|---|---|---|
| **Uranium (µg/L)** | 80,000 | < 0.001 - 187 | 41 | 1950 | 30 µg/L |
| **Chloride (mg/L)** | 600 | 214 - 443 | 282 | 2.1 | 250 mg/L |
| **EC (µmhos/cm)** | 4000 | 1600 - 2590 | 2017 | 2.0 | NA |

** Pre-mining values in monitor well ring surrounding PA-3 (URI 1997).*

*** The uranium standard is a primary maximum contaminant level (MCL). MCLs are health-based and legally enforceable. The chloride standard is a non-enforceable secondary standard based on aesthetic effects (e.g., taste, odor) (EPA, 2009). NA: not applicable.*



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Given the values in table 4, a mixture of 2% mining solution and 98% background groundwater would have the following values of uranium, chloride, and EC.

Uranium: 0.02 (80,000 μg/L) + 0.98 (41 μg/L) = 1640 μg/L
Chloride: 0.02 (600 mg/L) + 0.98 (282 mg/L) = 288 mg/L
EC: 0.02 (4000 μmhos/cm) + 0.98 (2017 μmhos/cm) = 2057 μmhos/cm

Thus, a mixture of several percent mining solution with background groundwater could be readily identified by the increase in uranium concentrations, but the chloride and EC values would be difficult to distinguish from background values.

At least two factors act to reduce concentrations in the sampled mining solution. As the mining solution travels from the well field to the monitor well ring, hydrodynamic dispersion dilutes the concentrations of uranium and other constituents. There is also an apparent reduction in concentrations resulting from the design of the monitor wells. The well screens are 30 m long. Therefore, a plume of mining solution that is less than 30 m thick will be diluted by native groundwater when it is pumped from the well.

It should be noted that it is not necessary for uranium to travel from the well fields to the monitor well ring in order to increase uranium concentrations in the monitor wells. If uranium is present in the formation near the monitor wells, uranium concentrations can be increased by the arrival of oxidizing mining solution.

Apparent excursions of mining solution have been detected 21 times at PA-3 (table 5, and figures 5 and 7). More excursions have probably occurred, but URI does not report the values of uranium concentrations that are less than 1000 μg/L (see below).

## Quality of analytical data and false positives

The uranium concentrations cited in this paper come from analyses performed by commercial laboratories and by URI's in-house laboratory. The background samples and samples from the Garcia wells were analyzed by commercial laboratories. All the monitor well samples, except the background samples, were analyzed by URI's laboratory.

There are two problems with the analyses produced by URI's laboratory. First, although TCEQ accepts the results, problems with their accuracy have been documented (Rice 2006). Second, when reporting uranium concentrations for monitor wells, URI reports only those values greater than 1000 μg/L. If a value does not meet this threshold, it is reported either as less than 1000 μg/L, or as zero. Zero is not an analytical result. It means that the concentration is below the detection limit. In this case, the detection limit appears to be about 20 μg/L (URI 2005). Thus, the uranium analyses reported by URI's laboratory fall into three groups: less than 20 μg/L, between 20 μg/L and 1000 μg/L, and greater than 1000 μg/L. The author has asked URI for the laboratory data showing uranium values below the 1000 μg/L threshold. URI refused (URI 2012b).

The problems with URI's uranium analyses raise the possibility that URI might have reported false negatives or false positives. In the absence of additional data, individual false negatives cannot be identified. But false positives may be identified by examining the circumstances associated with analytical results.



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**Table 5 Monitor Wells with Elevated Uranium Concentrations**

| Well ID | Background U concentration (µg/L) | U concentration during excursion (µg/L) | Date U detected |
|---|---|---|---|
| **MW-74** | 21 | 3200 | 11/16/06 |
| **MW-89** | 22 | 1690 | 8/17/07 |
| **MW-90** | 24 | 1320 | 8/17/07 |
| **MW-90** | 24 | 1060 | 11/27/07 |
| **MW-91** | 31 | 2140 | 8/17/07 |
| **MW-91** | 31 | 1500 | 3/5/08 |
| **MW-92** | 36 | 1670 | 8/17/07 |
| **MW-92** | 36 | 1440 | 10/11/07 |
| **MW-92** | 36 | 1300 | 4/16/08 |
| **MW-93** | 37 | 2500 | 10/11/07 |
| **MW-98** | 59 | 1100 | 4/18/11 |
| **MW-100** | 30 | 3600 | 8/17/07 |
| **MW-101** | 53 | 2520 | 8/17/07 |
| **MW-102** | 20 | 1300 | 11/7/06 |
| **MW-102** | 20 | 5170 | 8/17/07 |
| **MW-103** | 16 | 2790 | 8/17/07 |
| **MW-104** | 36 | 2140 | 8/17/07 |
| **MW-105** | 31 | 2320 | 8/17/07 |
| **MW-106** | 32 | 3900 | 11/7/06 |
| **MW-106** | 32 | 1260 | 8/17/07 |
| **MW-118** | 101 | 1170 | 10/19/07 |

*The uranium concentrations shown in table 5 would not be considered excursions by TCEQ. According to TCEQ, an excursion has not occurred unless uranium concentrations exceed 6540 µg/L (TCEQ 2006).*

Figure 7 is a timeline showing the 21 uranium detections greater than 1000 µg/L. Four of the detections may be false positives because they are inconsistent with the history of mining at PA-3. Three of the four are from samples collected in November 2006, approximately two months before mining resumed. The fourth is from a sample collected in April 2011, almost two years after mining was suspended. There are other possible explanations for these four detections. The 2006 detections could be the result of pre-mining activities (e.g., testing of injection wells), or they could represent slow-moving, remnant solution from mining that occurred in 1998 and 1999. The 2011 detection could also be the result of slow-moving solution from earlier mining. At best, these four detections are suspect.

There are several reasons to believe that the other 17 uranium detections shown in figure 7 are not false positives. First, all of them occurred during mining. Second, all of them occurred after water levels in the monitor wells rose sharply in response to mining. This rise indicates that mining solution was being driven toward the monitor wells. Third, with one exception, the 17 detections are grouped in two clusters of wells: MW-89 – MW-93 and MW-100 – MW-106 (table 5 and figure 5). If the detections were false positives, one would expect them to be distributed



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randomly around the monitor well ring. In four of the wells, values greater than 1000 μg/L were detected more than once (table 5).

A suspicious feature of the detections shown in figure 7 is that 11 of them are from samples that were collected on one day, August 17, 2007. These detections could have been the result of problems in URI's laboratory. However, there are reasons to believe that this is not the case. First, a total of 27 samples were collected on August 17, 2007. Sixteen of the analytical results from that day were below 1000 μg/L. Second, all 11 detections occurred in the two well clusters mentioned above. Third, the 11 detections are not temporally isolated. That is, they are not anomalies that were preceded and followed by non-detections. The 11 wells where the detections occurred were sampled in the two-month periods immediately before and immediately after August 17, 2007. Seventeen samples were collected in the two-month period before August 17$^{th}$. All of the results were between 20 μg/L and 1000 μg/L. Thirty samples were collected in the two-month period after August 17$^{th.}$ Twenty eight of the results were between 20 μg/L and 1000 μg/L, one result was less than 20 μg/L, and one result was more than 1000 μg/L.

Although there are problems with the uranium analyses performed by URI's laboratory, careful consideration of the data leads to the conclusion that most of the uranium detections are not false positives.

## Garcia wells

The Garcia family used to drink water from two wells on their property, W-24 and W-25 (figure 5). These wells are about 60 m apart, and less than 300 m northwest of PA-3. Both of them are completed in the Goliad Aquifer (figure 8). Their depths are approximately 180 m and 240 m (Saenz 2012a). Well W-24 is now used only to water cattle and goats, and W-25 is no longer used (Saenz 2012a).

Water from wells W-24 and W-25 has been sampled since 1996, if not earlier; the records are unclear (figure 9). Before mining began at PA-3, the average concentration of uranium was 180 μg/L. The uranium was probably due to the presence of uranium ore in the Goliad Aquifer where the Garcia wells are completed.



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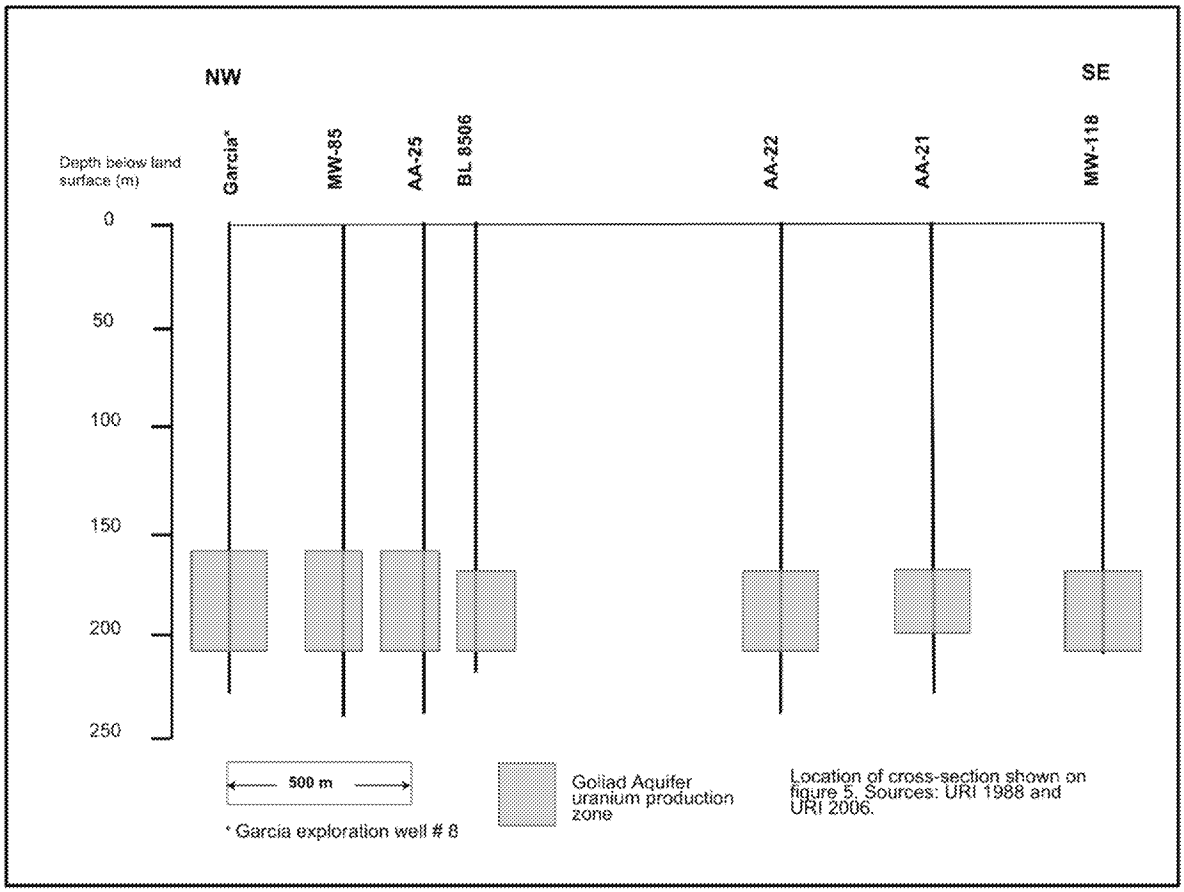


***Figure 8. Cross section through PA-3 and Garcia property***

Until late 2005, water from both Garcia wells was pumped to a single tank, and analyses were performed on samples from the tank. The only exception to this was in June 1998, when separate samples were collected from wells W-24 and W-25. The uranium concentrations were 152 µg/L and 167 µg/L, respectively. Since late 2005, W-24 has been sampled nine times and W-25 one time. The samples from W-24 had an average concentration of 670 µg/L, and the sample from W-25 had a concentration of 10.4 µg/L.

The cause of the low concentration in W-25 is unknown. W-25 no longer contains a pump. At the time it was sampled, W-25 had been unused for about two years and the sample may have been affected by deterioration of the well casing (e.g., occlusion of uranium by precipitating iron). The sample was collected by the author after purging three bore volumes. At the beginning of the purge, the water appeared to be black. When the sample was collected, the water was lightly tinted.

There are two possible causes of the increased uranium concentrations in W-24. First, concentrations in W-24 may have always been high, but were diluted in the tank by low concentrations from W-25. Second, they represent excursions from PA-3.

There are two problems with the first possibility. First, when W-24 and W-25 were individually sampled in 1998, the uranium concentrations were about equal. Second, the volume of water pumped into the tank by each well appears to have been about the same. Three horse-power pumps were installed in both wells, and when the



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storage tank was filled, both wells turned on and off at the same time. (Saenz 2012b). When the author sampled the wells in December, 2008, both wells produced water at a rate of about 35 L/min. An equal mixture of waters containing 10 µg/L and 670 µg/L uranium would contain 340 µg/L uranium. This is almost twice the average value measured in the tank between 1996 and 2005.

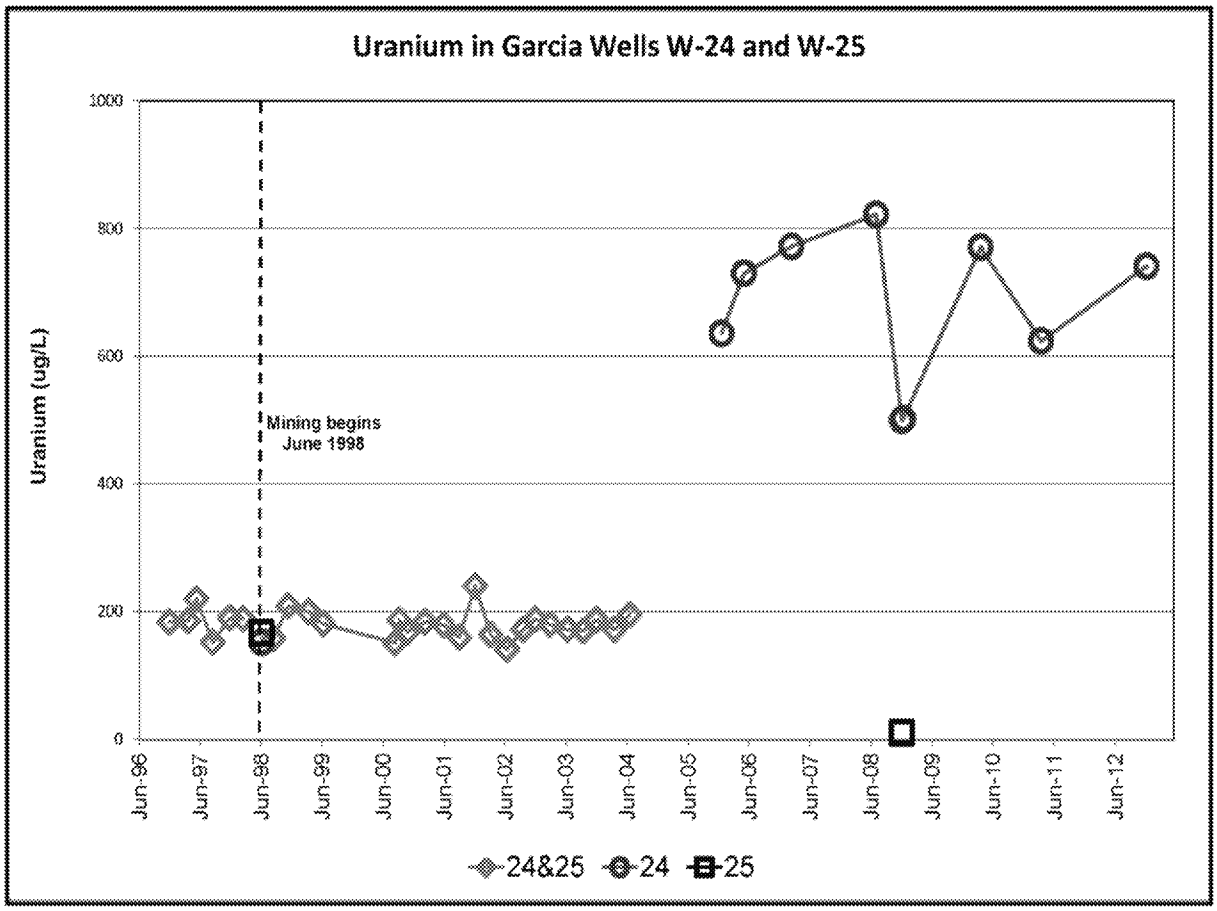


***Figure 9. Uranium Concentrations in Garcia Wells***

There is also a problem with the second possibility. The increased uranium concentrations in W-24 were first detected in late 2005, but excursions at PA-3 were not reported until 2007. However, unreported excursions, that is excursions where the uranium concentration did not reach the 1000 µg/L threshold, probably did occur. This possibility is supported by the following. First, the increased concentrations occurred after mining began at PA-3. Second, the general direction of groundwater flow from PA-3 is toward the Garcia wells, and flow may have been accelerated by pumping of the Garcia wells. Third, excursions have been detected in monitor wells less than 600 m from the Garcia wells (figure 5).

The available data indicate that the likely source of the increased uranium concentrations in the Garcia well is PA-3. To the author's knowledge, this is the first time that contaminants in an off-site domestic well have been linked to ISL uranium mining in the United States of America.



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# Conclusions

Although there are uncertainties associated with some of the available information, a conservative assessment leads to the following conclusions.

1) The injection of leaching fluids at PA-3 created a hydraulic gradient that caused mining solution to flow from injection wells, toward the monitor well ring.
2) The mining solution contained concentrations of uranium that were significantly higher than background concentrations.
3) Excursions occurred. That is, mining solution flowed beyond the monitor well ring surrounding PA-3.
4) The excursions reached the Garcia property. They caused uranium concentrations in well W-24 to increase from an average of less than 200 μg/L, to more than 600 μg/L.

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