Matthew Klasen/DC/USEPA/US
01/07/2011 12:53 PM

To Michael Dunn
cc Stefania Shamet
bcc
Subject Fw: Kicked out of office

Mike: Can you print this out and get this to Stef? It's really long, but I just talked to Stef and it's more productive for her to look at this version than the Kevin-commented one.

Tell her that I saw absolutely no problem with Kevin's line edits at all, and the only things we have to work through are the remaining margin comments.

Thanks,
Matt

ATTACHMENT REDACTED - DELIBERATIVE

2011-01-06 Compiled WVDEP RD Comment Responses.doc

Matt Klasen
U.S. Environmental Protection Agency
Office of Water (IO)
202-566-0780
cell (202) 380-7229

----- Forwarded by Matthew Klasen/DC/USEPA/US on 01/07/2011 12:51 PM -----

From: Stefania Shamet/R3/USEPA/US
To: Matthew Klasen/DC/USEPA/US@EPA, Christopher Hunter/DC/USEPA/US@EPA, Michael Dunn/R3/USEPA/US@EPA, Gregory Peck/DC/USEPA/US@EPA, Kevin Minoli/DC/USEPA/US@EPA
Cc: Amy Caprio/R3/USEPA/US@EPA
Date: 01/07/2011 12:49 PM
Subject: Kicked out of office

Won't have access to my email for several hours. If you need my attention -- text or call my cell (b) (6) [redacted]. If before 2:15 pm, you can email Mike Dunn and he'll be able to track me down. Should be home and on email by 4pm.

Matt -- I've printed out all of Kevin's comments and your spreadsheet and will start working through them. Greg Pond is awaiting Kevin's specific comments on his so that he can get going, if you want to send to him.

I leave you with a research proposal that I just received. As the attorney assigned to the Freshwater Biology Team, I frequently see these types of proposals. Perhaps the resulting paper could be cited in the future:

"*Differential sub-lethal and acute effects of beer, wine, and chocolate milk on early-instar Ephemeroptera in controlled indoor mesocosms*"

Carrie Traver/R3/USEPA/US
01/07/2011 01:01 PM

To Marcel Tchaou
cc Christopher Hunter
bcc
Subject Re: Fw: Info for Lemly (2006) and West Virginia Collection Permit database citation -- Fw: IMPORTANT correction - Fw: Lemley quote that needs citation/reference verification in Appendices and FD & RD

Marcel,

The Lemly 2006 reference was cited in the comment/response document (#152) I'm not sure if Chirs or Stef updated the citation in the text.

I just added the WVDNR permit database to the reference list. The fish database was already included. Ithink Frank was responding to my question if the fish database was the same as the collection permit database, and if we had a link or access to these databases.

Hope that answers your question.

carrie

Carrie,
(b) (5) [redacted]

****
Marcel K. Tchaou, Ph.D., P.E., P.H.
Environmental Engineer
Wetlands & Aquatic Resources Regulatory Branch
Office of Wetlands, Oceans and Watersheds
U.S. EPA
1200 Pennsylvania Avenue, NW (MC 4502T)
Washington, DC 20460
202-566-1904

Info for Lemly (2006) and West Virginia Collection Permit database citation -- Fw: IMPORTANT correction - Fw: Lemley quote that needs citation/reference verification in Appendices and FD & RD

Carrie/Marcel:

Here is Frank Borsuk's responses to two identified references that I used:

(b) (5) [redacted]

[redacted]

[redacted]

[redacted]

Frank

Frank Borsuk, Ph.D.
Aquatic/Fisheries Biologist
Freshwater Biology Team
USEPA-Region 3 (Wheeling Office)
Office of Monitoring & Assessment (3EA50)
Environmental Assessment & Innovation Division
1060 Chapline Street, Suite 303
Wheeling, WV 26003-2995
304-234-0241 Phone
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borsuk.frank@epa.gov

Please visit our website at http://epa.gov/reg3esd1/3ea50.htm

----- Forwarded by Frank Borsuk/R3/USEPA/US on 01/06/2011 12:15 PM -----

[IM [IMAGE]

AGE] Frank Borsuk/R3/USEPA/US

From:

[IMAGE] [IMAGE] Margaret Passmore/R3/USEPA/US@EPA, Regina Poeske/R3/USEPA/US@EPA

To:

[IMAGE] [IMAGE] borsuk.frank@epa.gov

Cc:

[IMAGE] [IMAGE] 12/13/2010 04:43 PM

Date:

[IMAGE] [IMAGE] IMPORTANT correction - Fw: Lemley quote that needs citation/reference verification in Appendices and FD & RD

Subject:

(b) (5) [redacted]

[redacted]

[redacted]

[redacted]

p.s. The best way to get ahold of me is by cell (b) (6) [redacted]

Frank

Please visit our website at http://epa.gov/reg3esd1/3ea50.htm

- palmer_etal_2010_mountaintop.pdf

SCIENCE AND REGULATION

Mountaintop Mining Consequences

Damage to ecosystems and threats to human health and the lack of effective mitigation require new approaches to mining regulation.

M. A. Palmer,[1,2] E. S. Bernhardt,[3] W. H. Schlesinger,[4] K. N. Eshleman,[1] E. Foufoula-Georgiou,[5] M. S. Hendryx,[6] A. D. Lemly,[7] G. E. Likens,[4] O. L. Loucks,[8] M. E. Power,[9] P. S. White,[10] P. R. Wilcock[11]

There has been a global, 30-year increase in surface mining (*1*), which is now the dominant driver of land-use change in the central Appalachian ecoregion of the United States (*2*). One major form of such mining, mountaintop mining with valley fills (MTM/VF) (*3*), is widespread throughout eastern Kentucky, West Virginia (WV), and southwestern Virginia. Upper elevation forests are cleared and stripped of topsoil, and explosives are used to break up rocks to access buried coal (fig. S1). Excess rock (mine "spoil") is pushed into adjacent valleys, where it buries existing streams.

Despite much debate in the United States (*4*), surprisingly little attention has been given to the growing scientific evidence of the negative impacts of MTM/VF. Our analyses of current peer-reviewed studies and of new water-quality data from WV streams revealed serious environmental impacts that mitigation practices cannot successfully address. Published studies also show a high potential for human health impacts.

Ecological Losses, Downstream Impacts

The extensive tracts of deciduous forests destroyed by MTM/VF support some of the highest biodiversity in North America, including several endangered species. Burial of headwater streams by valley fills causes permanent loss of ecosystems that play critical roles in ecological processes such as nutrient cycling and production of organic matter for downstream food webs; these small Appalachian streams also support abundant aquatic organisms, including many endemic species (*5*). Many studies show that when more than 5 to 10% of a watershed's area is affected by anthropogenic activities, stream biodiversity and water quality suffer (*6*, *7*). Multiple watersheds in WV

already have more than 10% of their total area disturbed by surface mining (table S1).

Hydrologic flow paths in Appalachian forests are predominantly through permeable soil layers. However, in mined sites, removal of vegetation, alterations in topography, loss of topsoil, and soil compaction from use of heavy machinery reduce infiltration capacity and promote runoff by overland flow (*8*). This leads to greater storm runoff and increased frequency and magnitude of downstream flooding (*9*, *10*).

Water emerges from the base of valley fills containing a variety of solutes toxic or damaging to biota (*11*). Declines in stream biodiversity have been linked to the level of mining disturbance in WV watersheds (*12*). Below valley fills in the central Appalachians, streams are characterized by increases in pH, electrical conductivity, and total dissolved solids due to elevated concentrations of sulfate (SO_4), calcium, magnesium, and bicarbonate ions (*13*). The ions are released as coal-generated sulfuric acid weathers carbonate rocks. Stream water SO_4 concentrations are closely linked to the extent of mining in these watersheds (*11*, *14*). We found that significant linear increases in the concentrations of metals, as well as decreases in multiple measures of biological health, were associated with increases in stream water SO_4 in streams below mined sites (see the chart on page 149). Recovery of biodiversity in mining waste-impacted streams has not been documented, and SO_4 pollution is known to persist long after mining ceases (*14*).

Conductivity, and concentrations of SO_4 and other pollutants associated with mine runoff, can directly cause environmental degradation, including disruption of water and ion balance in aquatic biota (*12*). Elevated SO_4 can exacerbate nutrient pollution of downstream rivers and reservoirs by increasing nitrogen and phosphorus availability through internal eutrophication (*15*, *16*). Elevated SO_4 can also increase microbial production of hydrogen sulfide, a toxin for many aquatic plants and organisms (*17*). Mn, Fe, Al, and Se can become further concentrated in stream sediments, and Se bioaccumulates in organisms (*11*) (figs. S1 and S2).

A survey of 78 MTM/VF streams found that 73 had Se water concentrations greater than the 2.0 μg/liter threshold for toxic bioaccumulation (*18*). Se levels exceed this in many WV streams (see the chart on page 149). In some freshwater food webs, Se has bioaccumulated to four times the toxic level; this can cause teratogenic deformities in larval fish (fig. S2) (*19*), leave fish with Se concentrations above the threshold for reproductive failure (4 ppm), and expose birds to reproductive failure when they eat fish with Se >7 ppm (*19*, *20*). Biota may be exposed to concentrations higher than in the water since many feed on streambed algae that can bioconcentrate Se as much as 800 to 2000 times that in water concentrations (*21*).

Potential for Human Health Impacts

Even after mine-site reclamation (attempts to return a site to premined conditions), groundwater samples from domestic supply wells have higher levels of mine-derived chemical constituents than well water from unmined areas (*22*). Human health impacts may come from contact with streams or exposure to airborne toxins and dust. State advisories are in effect for excessive human consumption of Se in fish from MTM/VF affected waters. Elevated levels of airborne, hazardous dust have been documented around surface mining operations (*23*). Adult hospitalizations for chronic pulmonary disorders and hypertension are elevated as a function of county-level coal production, as are rates of mortality; lung cancer; and chronic heart, lung, and kidney disease (*24*). Health problems are for women and men, so effects are not simply a result of direct occupational exposure of predominantly male coal miners (*24*).

Mitigation Effects

Reclamation of MTM/VF sites historically has involved planting a few grass and herb species (*20*, *25*). Compared with unmined

[1]University of Maryland Center for Environmental Science, Cambridge, MD 21613, USA. [2]University of Maryland, College Park, MD 20742, USA. [3]Duke University, Durham, NC 27708, USA. [4]Cary Institute of Ecosystem Studies, Millbrook, NY 12545, USA. [5]University of Minnesota, Minneapolis, MN 55414, USA. [6]West Virginia University, Morgantown, WV 26506, USA. [7]Wake Forest University, Winston Salem, NC 27109, USA. [8]Miami University, Oxford, OH 45056, USA. [9]University of California at Berkeley, Berkeley, CA 94720, USA. [10]University of North Carolina at Chapel Hill, Chapel Hill, NC 27599, USA. [11]Johns Hopkins University, Baltimore, MD 21218, USA.

*Author for correspondence. E mail: mpalmer@umd.edu

Downloaded from www.sciencemag.org on March 9, 2010

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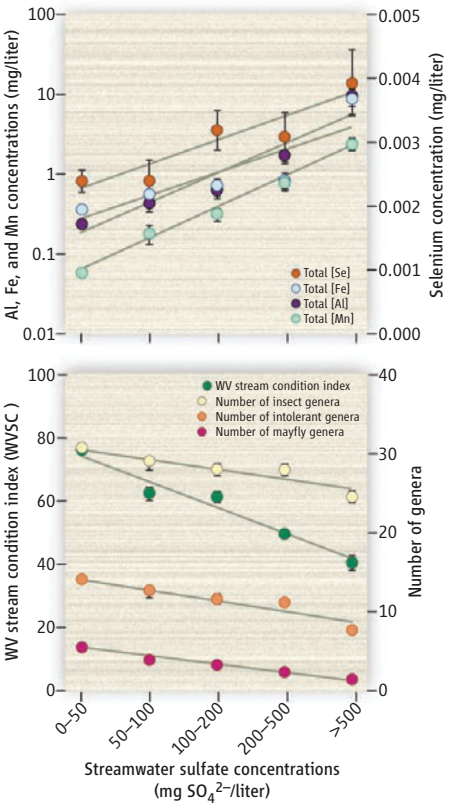

Mining effects on stream chemistry and biota. Sulfate concentrations reflect amount of mining in watershed. (**Top**) Average concentrations of manganese, iron, aluminum, and selenium. (**Bottom**) Stream invertebrate community metrics in relation to sulfate concentrations for 1058 WV streams (methods in table S2). Regressions all statistically significant (table S3).

sites, reclaimed soils characteristically have higher bulk density, lower organic content, low water-infiltration rates, and low nutrient content (*8*, *25*). Many reclaimed areas show little or no regrowth of woody vegetation and minimal carbon (C) storage even after 15 years (*26*). Decreased forest productivity may be related to the type of surface material (e.g., brown versus gray sandstone) used in the reclamation (*27*). In reclaimed forests, projected C sequestration after 60 years is only about 77% of that in undisturbed vegetation in the same region (*28*). Mined areas planted to grassland sequester much less. Since reclamation areas encompass >15% of the land surface in some regions (*29*) (table S1), significant potential for terrestrial C storage is lost.

Mitigation plans generally propose creation of intermittently flowing streams on mining sites and enhancement of streams offsite. Stream creation typically involves building channels with morphologies similar to unaffected streams; however, because they are on or near valley fills, the surrounding topography, vegetation, soils, hydrology, and water chemistry are fundamentally altered from the premining state. U.S. rules have considered stream creation a valid form of mitigation while acknowledging the lack of science documenting its efficacy (*30*). Senior officials of the U.S. Army Corps of Engineers (ACOE) have testified that they do not know of a successful stream creation project in conjunction with MTM/VF (*31*).

A Failure of Policy and Enforcement

The U.S. Clean Water Act and its implementing regulations state that burying streams with materials discharged from mining should be avoided. Mitigation must render nonsignificant the impacts that mining activities have on the structure and function of aquatic ecosystems. The Surface Mining Control and Reclamation Act imposes requirements to minimize impacts on the land and on natural channels, such as requiring that water discharged from mines will not degrade stream water quality below established standards.

Yet mine-related contaminants persist in streams well below valley fills, forests are destroyed, headwater streams are lost, and biodiversity is reduced; all of these demonstrate that MTM/VF causes significant environmental damage despite regulatory requirements to minimize impacts. Current mitigation strategies are meant to compensate for lost stream habitat and functions but do not; water-quality degradation caused by mining activities is neither prevented nor corrected during reclamation or mitigation.

Clearly, current attempts to regulate MTM/VF practices are inadequate. Mining permits are being issued despite the preponderance of scientific evidence that impacts are pervasive and irreversible and that mitigation cannot compensate for losses. Considering environmental impacts of MTM/VF, in combination with evidence that the health of people living in surface-mining regions of the central Appalachians is compromised by mining activities, we conclude that MTM/VF permits should not be granted unless new methods can be subjected to rigorous peer review and shown to remedy these problems. Regulators should no longer ignore rigorous science. The United States should take leadership on these issues, particularly since surface mining in many developing countries is expected to grow extensively (*32*).

References and Notes

1. World Coal Institute, www.worldcoal.org.
2. K. L. Saylor, *Land Cover Trends: Central Appalachians* [U.S. Department of the Interior, U.S. Geological Survey (USGS), Washington, DC, 2008]; http://landcovertrends.usgs.gov/east/eco69Report.html.
3. MTM/VF refers to surface mining operations that remove coal seams running through a mountain, ridge, or hill; it may also refer more broadly to large scale surface mining, including area or contour mining in steep terrain that disposes of excess rock in heads of hollows or valleys with streams.
4. Debates are conspicuous because of recent high profile federal court cases [e.g., (*33*)], widely publicized exchanges between the U.S. Environmental Protection Agency (EPA) and the ACOE over permitting decisions, advocacy by non governmental organizations, and protests by miners.
5. J. L. Meyer *et al.*, *J. Am. Water Resour. Assoc.* **43**, 86 (2007).
6. J. D. Allan, *Annu. Rev. Ecol. Evol. Syst.* **35**, 257 (2004).
7. This 5 to 10% issue is based on studies done on many nonmining types of land use change. Thus far, EPA has not done mining specific studies on this "threshold" issue (percentage of watershed mined versus impacts on streams) despite many calls for such data.
8. T. L. Negley, K. N. Eshleman, *Hydrol. Process.* **20**, 3467 (2006).
9. B. C. McCormick, K. N. Eshleman, J. L. Griffith, P. A. Townsend, *Water Resour. Res.* **45**, W08401 (2009).
10. J. R. Ferrari, T. R. Lookingbill, B. McCormick, P. A. Townsend, K. N. Eshleman, *Water Resour. Res.* **45**, W04407 (2009).
11. K. S. Paybins *et al.*, *USGS Circular* 1204 (2000); http://pubs.water.usgs.gov/circ1204/.
12. G. J. Pond, M. E. Passmore, F. A. Borsuk, L. Reynolds, C. J. Rose, *J. N. Am. Benthol. Soc.* **27**, 717 (2008).
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15. N. F. Caraco, J. J. Cole, G. E. Likens, *Nature* **341**, 316 (1989).
16. S. B. Joye, J. T. Hollibaugh, *Science* **270**, 623 (1995).
17. M. E. van der Welle, J. G. Roelofs, L. P. Lamers, *Sci. Total Environ.* **406**, 426 (2008).
18. EPA, *Stream Chemistry Report*, part 2 (EPA Region 3, Philadelphia, PA, 2002); http://www.epa.gov/region3/mtntop/pdf/appendices/d/stream chemistry/MTMVFChemistryPart2.pdf.
19. A. D. Lemly, *Selenium Assessment in Aquatic Ecosystems: A Guide for Hazard Evaluation and Water Quality Criteria* (Springer, New York, 2002).
20. EPA, *Mountaintop Mining/VF Final Programmatic Environmental Impact Statement* (EPA Region 3, Philadelphia, PA, 2005); http://www.epa.gov/region3/mtntop/index.htm.
21. J. M. Conley, D. H. Funk, D. B. Buchwalter, *Environ. Sci. Technol.* **43**, 7952 (2009).
22. S. McAuley, M. D. Kozar, *USGS Report* 5059 (2006); http://pubs.usgs.gov/sir/2006/5059/pdf/sir2006 5059.pdf.
23. M. K. Ghose, S. R. Majee, *Environ. Monit. Assess.* **130**, 17 (2007).
24. M. Hendryx, M. M. Ahern, *Public Health Rep.* **124**, 541 (2009).
25. Mining industry and government organizations recently signed a statement of intent to promote reforestation approaches that improve reclamation [see, e.g., (*34*)]; however, adoption of recommendations is voluntary. Reforestation of a mined site to premined conditions has not been demonstrated.
26. J. A. Simmons *et al.*, *Ecol. Appl.* **18**, 104 (2008).
27. P. Emerson, J. Skousen, P. Ziemkiewicz, *J. Environ. Qual.* **38**, 1821 (2009).
28. B. Y. Amichev, A. J. Burger, J. A. Rodrigue, *For. Ecol. Manage.* **256**, 1949 (2008).
29. P. A. Townsend *et al.*, *Remote Sens. Environ.* **113**, 62 (2009).
30. EPA and ACOE, *Fed. Regist.* **73**, 10 (2008).
31. U.S. District Court, Civil Action No. 3:05 0784, transcript, vol. 3, pp. 34 45; http://palmerlab.umd.edu/MTM/US District Court Civil Action Official transcript Volume III.pdf.
32. A. P. Chikkatur, A. D. Sagar, T. L. Sankar, *Energy* **34**, 942 (2009).
33. U.S. Court of Appeals for the 4th District, *Ohio Valley Environmental Coalition* et al. vs. *U.S. ACOE* et al., case 07 1255.
34. Appalachian Regional Reforestation Initiative, www.arri.osmre.gov/FRApproach.shtm.

35. This is contribution no. 4368 of the University of Maryland Center for Environmental Science.

Supporting Online Material

www.sciencemag.org/cgi/content/full/327/5962/148/DC1

10.1126/science.1180543

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Published by AAAS

Matthew Klasen/DC/USEPA/US
01/07/2011 02:09 PM

To Gregory Peck
cc
bcc
Subject Oct 8 House Dems letter to LPJ on Spruce & signatories

For OCIR's purposes based on our 1 pm meeting, attached is a summary of the October 8 letter to the Administrator with respect to Spruce. (b) (5) [redacted]

Also attached is the letter itself.

Thanks,
Matt

2011-01-07 Signatories of 10-8-10 House Letter to EPA re MTM, Spruce.docx

EPA Mountaintop Removal Letter 10-8-10.pdf

Document Withheld-FOIA(b)(5)

Matt Klasen
U.S. Environmental Protection Agency
Office of Water (IO)
202-566-0780
cell (202) 380-7229

Congress of the United States
Washington, DC 20515

October 8, 2010

The Honorable Lisa P. Jackson
Administrator
U.S. Environmental Protection Agency
1200 Pennsylvania Avenue, NW
Washington, DC 20460

Dear Administrator Jackson,

We write in support of the actions that the Environmental Protection Agency has taken recently to protect the public and the environment from the devastating effects of surface coal mining in Appalachia. Although we continue to support Congressional action to pass the Clean Water Protection Act as the ultimate protection against mountaintop removal and valley fills, the interim administration actions that the EPA has taken under your leadership represent significant progress for communities struggling in the shadow of mining and for the environment.

As you know, surface mining in the steep slopes of Appalachia has disrupted the biological integrity of an area about the size of Delaware, buried approximately 2,000 miles of streams with mining waste, and contaminated downstream areas with toxic and bioaccumulative selenium. Protections required by federal laws, such as the Clean Water Act, were not enforced, and key rules, such as the Clean Water Act's definition of fill material, were changed for the benefit of the coal mining industry.

The guidance your agency issued on April 1 for improving EPA review of surface mining operations under the Clean Water Act, the National Environmental Policy Act and the Environmental Justice Executive Order marks a long-needed assertion of EPA oversight based on recent, peer-reviewed research. When scientific research shows that surface mining routinely violates downstream water quality standards, it is critical for EPA to ensure that states and mining companies are aware of the pollution levels that cause harm, that discharge permits incorporate adequate safeguards, and that the permits are enforced.

We are also pleased that EPA's guidance commits to ensure that potential impacts on low-income Appalachian communities are considered in permit decision-making processes. This action will breathe life into the long-overlooked Executive Order 12898, which requires federal agencies to make environmental justice part of their mission.

In addition to this policy guidance, we applaud EPA's proposed veto of the Clean Water Act permit for Spruce No. 1 Mine in West Virginia. One of the largest surface mines in Appalachia, it would bury more than seven miles of headwater streams, directly impact 2,278 acres of forestland, and degrade water quality in streams adjacent to the mine. This proposed veto, an extremely rare action in the history of the Clean Water Act, demonstrates the EPA's seriousness in curtailing mountaintop removal.

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The ultimate success of the new guidance depends upon effective implementation by EPA and its regional offices. Mining companies and some state agencies may reject this guidance, but we strongly urge the EPA to carry it out aggressively. In addition Congress must act to pass laws, such as the Clean Water Protection Act, which makes these protections more permanent. Nothing less will protect Appalachia from the devastation of mountaintop removal mining.

We appreciate the strong leadership you have shown in basing EPA's new policies soundly on the latest science and taking action needed to implement the nation's environmental and public health laws.

Sincerely,

FRANK PALLONE, JR.
Member of Congress

EARL BLUMENAUER
Member of Congress

CAROLYN C. KILPATRICK
Member of Congress

DORIS O. MATSUI
Member of Congress

DEBBIE WASSERMAN SCHULTZ
Member of Congress

WILLIAM L. OWENS
Member of Congress

FORTNEY PETE STARK
Member of Congress

RAÚL M. GRIJALVA
Member of Congress

HENRY A. WAXMAN
Member of Congress

JOHN A. YARMUTH
Member of Congress

DIANA DEGETTE
Member of Congress

HOWARD L. BERMAN
Member of Congress

MAXINE WATERS
Member of Congress

BETTY MCCOLLUM
Member of Congress

DENNIS J. KUCINICH
Member of Congress

LYNN C. WOOLSEY
Member of Congress

JESSE L. JACKSON, JR.
Member of Congress

JARED POLIS
Member of Congress

LOIS CAPPS
Member of Congress

KEITH ELLISON
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JAMES P. MORAN
Member of Congress

JOHN LEWIS
Member of Congress

LAURA RICHARDSON
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TAMMY BALDWIN
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STEVE COHEN
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RUSH D. HOLT
Member of Congress

LLOYD DOGGETT
Member of Congress

BARNEY FRANK
Member of Congress

ELEANOR HOLMES NORTON
Member of Congress

GERALD E. CONNOLLY
Member of Congress

CAROL SHEA-PORTER
Member of Congress

MIKE QUIGLEY
Member of Congress

Gregory Peck/DC/USEPA/US
01/07/2011 02:22 PM

To Christopher Hunter
cc Brian Frazer, David Evans, Denise Keehner, Jim Pendergast, Karyn Wendelowski, Kevin Minoli, Matthew Klasen, Stefania Shamet, Betsaida Alcantara
bcc
Subject Re: Spruce Fact Sheet

Please see revised Fact Sheet and Press release based on comments thus far. (b) (5) [redacted]

Thanks,
Greg

ATTACHMENTS REDACTED - DELIBERATIVE

Mining Spruce Draft Fact Sheet JAN 07 11.doc Mining Spruce DRAFT Press Release JAN 05 11 v. 2.docx

Christopher Hunter | Thanks Greg, A couple of small changes in redli... | 01/07/2011 12:23:36 PM

From: Christopher Hunter/DC/USEPA/US
To: Gregory Peck/DC/USEPA/US@EPA
Cc: Brian Frazer/DC/USEPA/US@EPA, Denise Keehner/DC/USEPA/US@EPA, Karyn Wendelowski/DC/USEPA/US@EPA, Kevin Minoli/DC/USEPA/US@EPA, Matthew Klasen/DC/USEPA/US@EPA, Stefania Shamet/R3/USEPA/US@EPA, David Evans/DC/USEPA/US@EPA, Jim Pendergast/DC/USEPA/US@EPA
Date: 01/07/2011 12:23 PM
Subject: Re: Spruce Fact Sheet

Thanks Greg,
A couple of small changes in redline, and 2 points I want to highlight. The original Spruce mine may have the been the largest mine ever proposed in WV, but that's no longer the case with current design, which is why I used the phrase "among the largest" earlier. And by my count Spruce will be the 13th 404c action, not 14th as stated.

Chris
[attachment "Mining Spruce Draft Fact Sheet JAN 07 11 - CH.doc" deleted by Gregory Peck/DC/USEPA/US]

Chris Hunter
U.S. Environmental Protection Agency
Office of Wetlands, Oceans, & Watershed
(202) 566-1454
hunter.christopher@epa.gov

Gregory Peck | When you have a chance, please review the atta... | 01/07/2011 12:03:48 PM

From: Gregory Peck/DC/USEPA/US
To: Nancy Stoner/DC/USEPA/US@EPA, Matthew Klasen/DC/USEPA/US@EPA, Denise Keehner/DC/USEPA/US@EPA, Brian Frazer/DC/USEPA/US@EPA, Christopher Hunter/DC/USEPA/US@EPA, Stefania Shamet/R3/USEPA/US@EPA, Kevin Minoli, Karyn Wendelowski/DC/USEPA/US@EPA
Date: 01/07/2011 12:03 PM
Subject: Spuce Fact Sheet

When you have a chance, please review the attached Fact Sheet we'll be using as part of the communications materials to summarize the Spruce Final Determination.

Steph - please don't forget to send me the R3 comments on the draft PR - thanks.

Greg

[attachment "Mining Spruce Draft Fact Sheet JAN 07 11.doc" deleted by Christopher Hunter/DC/USEPA/US]

Denise Keehner/DC/USEPA/US

01/07/2011 02:32 PM

To Gregory Peck

cc Brian Frazer, Christopher Hunter, Karyn Wendelowski, Kevin Minoli, Matthew Klasen, Nancy Stoner, Stefania Shamet

bcc

Subject Re: Spuce Fact Sheet: Somre Recommended Edits adn A Question

ATTACHMENT REDACTED - DELIBERATIVE

Mining Spruce Draft Fact Sheet JAN 07 11dkedits.doc

Gregory Peck	When you have a chance, please review the atta...	01/07/2011 12:03:48 PM

From: Gregory Peck/DC/USEPA/US
To: Nancy Stoner/DC/USEPA/US@EPA, Matthew Klasen/DC/USEPA/US@EPA, Denise Keehner/DC/USEPA/US@EPA, Brian Frazer/DC/USEPA/US@EPA, Christopher Hunter/DC/USEPA/US@EPA, Stefania Shamet/R3/USEPA/US@EPA, Kevin Minoli, Karyn Wendelowski/DC/USEPA/US@EPA
Date: 01/07/2011 12:03 PM
Subject: Spuce Fact Sheet

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Steph - please don't forget to send me the R3 comments on the draft PR - thanks.

Greg

[attachment "Mining Spruce Draft Fact Sheet JAN 07 11.doc" deleted by Denise Keehner/DC/USEPA/US]

Matthew Klasen/DC/USEPA/US
01/07/2011 02:52 PM

To "Travis Loop"
cc
bcc
Subject Fw: Spruce Fact Sheet

Matt Klasen
U.S. Environmental Protection Agency
Office of Water
(202) 566-0780
Cell (202) 380-7229
Gregory Peck

----- Original Message -----
From: Gregory Peck
Sent: 01/07/2011 02:22 PM EST
To: Christopher Hunter
Cc: Brian Frazer; David Evans; Denise Keehner; Jim Pendergast; Karyn Wendelowski; Kevin Minoli; Matthew Klasen; Stefania Shamet; Betsaida Alcantara
Subject: Re: Spruce Fact Sheet

Please see revised Fact Sheet and Press release based on comments thus far. (b) (5) [redacted]

Thanks,
Greg

ATTACHMENTS REDACTED - DELIBERATIVE

Mining Spruce Draft Fact Sheet JAN 07 11.doc Mining Spruce DRAFT Press Release JAN 05 11 v. 2.docx

Christopher Hunter Thanks Greg, A couple of small changes in redli... 01/07/2011 12:23:36 PM

From: Christopher Hunter/DC/USEPA/US
To: Gregory Peck/DC/USEPA/US@EPA
Cc: Brian Frazer/DC/USEPA/US@EPA, Denise Keehner/DC/USEPA/US@EPA, Karyn Wendelowski/DC/USEPA/US@EPA, Kevin Minoli/DC/USEPA/US@EPA, Matthew Klasen/DC/USEPA/US@EPA, Stefania Shamet/R3/USEPA/US@EPA, David Evans/DC/USEPA/US@EPA, Jim Pendergast/DC/USEPA/US@EPA
Date: 01/07/2011 12:23 PM
Subject: Re: Spruce Fact Sheet

Thanks Greg,
A couple of small changes in redline, and 2 points I want to highlight. The original Spruce mine may have the been the largest mine ever proposed in WV, but that's no longer the case with current design, which is why I used the phrase "among the largest" earlier. And by my count Spruce will be the 13th 404c action, not 14th as stated.

Chris
[attachment "Mining Spruce Draft Fact Sheet JAN 07 11 - CH.doc" deleted by Gregory Peck/DC/USEPA/US]

Chris Hunter
U.S. Environmental Protection Agency

Office of Wetlands, Oceans, & Watershed
(202) 566-1454
hunter.christopher@epa.gov

Gregory Peck	When you have a chance, please review the atta...	01/07/2011 12:03:48 PM

From: Gregory Peck/DC/USEPA/US
To: Nancy Stoner/DC/USEPA/US@EPA, Matthew Klasen/DC/USEPA/US@EPA, Denise Keehner/DC/USEPA/US@EPA, Brian Frazer/DC/USEPA/US@EPA, Christopher Hunter/DC/USEPA/US@EPA, Stefania Shamet/R3/USEPA/US@EPA, Kevin Minoli, Karyn Wendelowski/DC/USEPA/US@EPA
Date: 01/07/2011 12:03 PM
Subject: Spuce Fact Sheet

When you have a chance, please review the attached Fact Sheet we'll be using as part of the communications materials to summarize the Spruce Final Determination.

Steph - please don't forget to send me the R3 comments on the draft PR - thanks.

Greg

[attachment "Mining Spruce Draft Fact Sheet JAN 07 11.doc" deleted by Christopher Hunter/DC/USEPA/US]

Matthew Klasen/DC/USEPA/US
01/07/2011 02:52 PM

To "Travis Loop"
cc "Gregory Peck"
bcc
Subject Fw: Qs and As -- comments by close of weekend (COW) please

Here are the Qs and As. I think Greg is making edits to the release. I'll send you the two-page fact sheet, too.

Matt Klasen
U.S. Environmental Protection Agency
Office of Water
(202) 566-0780
Cell (202) 380-7229
Matthew Klasen

----- Original Message -----
From: Matthew Klasen
Sent: 01/07/2011 02:41 PM EST
To: Christopher Hunter; Brian Frazer; Jim Pendergast; Kevin Minoli; Karyn Wendelowski; Stefania Shamet; Michael Dunn; David Evans
Cc: Gregory Peck; Denise Keehner; Nancy Stoner
Subject: Fw: Qs and As -- comments by close of weekend (COW) please

Hi everyone,

In prep for a meeting earlier this afternoon w/ OEA and OCIR on communications and rollout, we pulled together the following Qs and As. These incorporate (I think) all the major contentions in the recent Hill letters, as well as earlier additions from Jim, Brian T., and Chris.

Please take a look and let me know if you have comments/edits by the end of the weekend. We'll then take the updated draft, make sure the question wording and responses are formatted consistent with AO expectations, and send up an updated version to them Monday.

(b) (6) [redacted]

Thanks,
Matt

Matt Klasen
U.S. Environmental Protection Agency
Office of Water
(202) 566-0780
Cell (202) 380-7229
Matthew Klasen

----- Original Message -----
From: Matthew Klasen
Sent: 01/07/2011 12:37 PM EST
To: Gregory Peck
Subject: Qs and As

Here they are. Want to take a quick look or want me to just go ahead and print?

Thanks,
Matt

ATTACHMENT REDACTED - DELIBERATIVE

[redacted]011 [redacted] 07 Draft [redacted]Spr[redacted]e Q&As.doc

---

Matt Klasen
U.S. Environmental Protection Agency
Office of Water (IO)
202-566-0780
cell (202) 380-7229

Betsy Behl/DC/USEPA/US
01/07/2011 05:36 PM

To Gregory Peck
cc Christopher Hunter, Ephraim King, Joe Beaman, Karyn Wendelowski, Kevin Minoli, Lynn Zipf, Matthew Klasen, stoner.nancy, Charles Delos, Jim Hanlon
bcc
Subject Re: Spruce selenium response -- need your input on support for the 4 ppm whole body threshold

Greg:

(b) (5) [redacted]

Betsy

Gregory Peck | Betsy and Joe: Hope you both are enjoying your... | 01/02/2011 12:46:05 PM

From: Gregory Peck/DC/USEPA/US
To: Betsy Behl/DC/USEPA/US@EPA, Joe Beaman/DC/USEPA/US@EPA
Cc: Matthew Klasen/DC/USEPA/US@EPA, Lynn Zipf/DC/USEPA/US@EPA, stoner.nancy@epa.gov, Ephraim King/DC/USEPA/US@EPA, Karyn Wendelowski/DC/USEPA/US@EPA, Kevin Minoli/DC/USEPA/US@EPA, Frank Borsuk/R3/USEPA/US@EPA, Christopher Hunter/DC/USEPA/US@EPA
Date: 01/02/2011 12:46 PM
Subject: Spruce selenium response -- need your input on support for the 4 ppm whole body threshold

Betsy and Joe:

Hope you both are enjoying your 2011 so far. Thanks again for your help a couple weeks ago in pulling together some selenium-related responses to comments on the Spruce #1 veto. (b) (5) [redacted]

[redacted]

Please give Matt or me a call if you have any questions. We're coming close to the finish line on the Spruce Final Determination and would appreciate a response as soon as you get a chance to review and talk with appropriate folks in your group.

Thanks,
Greg

(b) (5)

To: Stefania Shamet/R3/USEPA/US@EPA, John Forren/R3/USEPA/US@EPA, Margaret Passmore/R3/USEPA/US@EPA, borsuk.frank@epa.gov
From: Frank Borsuk/R3/USEPA/US
Date: 12/29/2010 11:21AM
Cc: Matthew Klasen/DC/USEPA/US@EPA, Christopher Hunter/DC/USEPA/US@EPA, David Rider/R3/USEPA/US@EPA, David Kargbo/R3/USEPA/US@EPA
Subject: Response Supplement #67 Selenium - Support for the 4 ppm whole body threshold

Stef:

(b) (5)

(b) (5)

(b) (5)

Frank Borsuk, Ph.D.
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Freshwater Biology Team
USEPA-Region 3 (Wheeling Office)
Office of Monitoring & Assessment (3EA50)
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Please visit our website at http://epa.gov/reg3esd1/3ea50.htm

Hamilton_2003.pdf Peterson et al 2009 selenium.pdf

Environ. Sci. Technol. **2009**, *43*, 3919–3925

How Might Selenium Moderate the Toxic Effects of Mercury in Stream Fish of the Western U.S.?

SPENCER A PETERSON,*,† NICHOLAS V.C. RALSTON,‡ DAVID V PECK,† JOHN VAN SICKLE,† J. DAVID ROBERTSON,§ VICKIE L. SPATE,§ AND J. STEVEN MORRIS§

National Health and Environmental Effects Research Laboratory, Western Ecology Division, U.S. Environmental Protection Agency, Corvallis, Oregon 97333, Energy and Environmental Research Center, University of North Dakota, 15 North 23rd Street, Stop 9018, Grand Forks, North Dakota 58202-9018, and Department of Chemistry and Research Reactor, Room 209A, University of Missouri, Research Park Drive, Columbia, Missouri 65211

Received November 12, 2008. Revised manuscript received March 11, 2009. Accepted March 17, 2009.

The ability of selenium (Se) to moderate mercury (Hg) toxicity is well established in the literature. Mercury exposures that might otherwise produce toxic effects are counteracted by Se, particularly when Se:Hg molar ratios approach or exceed 1. We analyzed whole body Se and Hg concentrations in 468 fish representing 40 species from 137 sites across 12 western U.S. states. The fish samples were evaluated relative to a published wildlife protective Hg threshold (0.1 μg Hg·g^{-1} wet wt.), the current tissue based methylmercury (MeHg) water quality criterion (WQC) for the protection of humans (0.3 μg Hg·g^{-1} wet wt.) and to presumed protections against Hg toxicity when Se:Hg molar ratios are >1. A large proportion (56%) of our total fish sample exceeded the wildlife Hg threshold, whereas a smaller, but significant proportion (12%), exceeded the MeHg WQC. However, 97.5% of the total fish sample contained more Se than Hg (molar ratio >1) leaving only 2.5% with Se:Hg ratios <1. All but one of the fish with Se:Hg <1, were of the genus *Ptychochelius* (pikeminnow). Scientific literature on Se counteracting Hg toxicity and our finding that 97.5% of the freshwater fish in our survey have sufficient Se to potentially protect them and their consumers against Hg toxicity suggests that Se in fish tissue (Se:Hg molar ratio) must be considered when assessing the potential toxic effects of Hg.

Introduction

Selenium is an essential nutrient for all life forms that have nervous systems, but Se can be toxic when present at high levels in the environment. There is no physiological requirement for Hg, but it bioaccumulates in the aquatic food chain and fish are the chief exposure route for wildlife and humans. In fish, MeHg constitutes 95–97% of the total Hg in fish filets (*1*). Therefore, since total Hg is more easily measured in fish tissue, total Hg measurements are recommended for fish surveys by EPA (*2*).

At high exposures, Se and Hg can each be individually toxic, but evidence supports the 1971 observation by Parizek et al. (*3*) that co-occurring Se and Hg antagonistically reduce each other's toxic effects. In 1972, Ganther et al. (*4*) found that tuna containing an ~1:1 molar ratio of Se:Hg reduced toxic effects of MeHg. He attributed the reduced toxicity to Se in the tuna. Various hypotheses for the Se protective mechanism have been proposed (*5, 6*). One of the most comprehensive involves formation of highly stable organic MeHg-selenocysteine (MeHg-SeCys) that forms in the brain and nervous systems of Hg stressed organisms (*7*). This form and its products are highly stable, thus making the Se biologically unavailable (*8, 9*). Sequestration (deactivation) of Se by high concentrations of MeHg inhibits normal selenoenzyme antioxidant activities that result in the adverse effects associated with Hg toxicity. However, during Hg stress, redistribution of Se from somatic cells and dietary sources to preferentially supply the brain replaces some of the Se lost to HgSe and MeHg-SeCys formation. This reduces the toxic effects by maintaining selenium-dependent enzymes (selenoenzymes) required for brain function and protein synthesis (*10, 11*).

Methylmercury is, by biochemical definition, an irreversible inhibitor of selenoenzymes since it transfers from the thiol of cysteine to the selenol of selenocysteine at the enzymes active site (*7, 12*). Since selenocysteine is a critical component of protein synthesis and must be formed de novo during each cycle of cellular protein synthesis (*7, 12*) inhibition of its formation critically impairs cell metabolism. Based on rat (*7, 13*) and mice studies (*14*), MeHg toxicity appears to occur when molar concentrations of MeHg exceed those of Se and covalent bonding of MeHg to the Se of selenocysteine occurs, thereby irreversibly inhibiting Se-dependent enzymes (*7, 13*). In adult onset, molar surpluses of Se over Hg (Se:Hg molar ratio >1) tend to protect the brains of Hg-stressed organisms. Fetal and young organisms are at much greater risk of toxicity from Hg exposure because the rapid rate of cell division in these organisms requires a steady supply of Se. Watanabe et al. (*14*) demonstrated that in utero Se nutritional status affects MeHg neurotoxicity. Additionally, Ralston et al. (*7*) found that neurofunctional defects (hind leg crossing) can be stabilized, and growth impairments in young rats can be reversed by increasing the amount of Se in their diets, even while maintaining high MeHg exposures.

Peterson et al. (*15*) showed that total Hg (THg) in fish filets exceed that in whole fresh water fish (0.185 μg THg·g^{-1} wet wt. in whole fish = 0.3 μg THg·g^{-1} wet wt. in fish filet). If, as Gather (*4*) suggested, the molar ratio of Se:Hg in fish filet is ~1 it follows that the mass of Se in filet might be approximately the same or greater than that of Hg. Harris et al. (*16*) and Korbas et al. (*17*), recently determined that various forms of Se complex with MeHg in fish filets, making the 95–97% of MeHg in fish tissue (*1*) less toxic to the fish and presumably to consumers (*4*) of the fish than previously thought. Harris et al. (*16*) indicated that zebrafish larvae are 20 times less sensitive to cystine-bound MeHg [MeHg(Cys)], the predominant form of MeHg found in fish tissue, than they are to MeHgCl, that is commonly used in toxicity tests. This was corroborated when Cabañero et al. (*18*) discovered that fish tissue maintains the MeHg(Cys) association after passing through an artificial digestion process. The MeHg(Cys) does not dissociate into toxic MeHg forms as previously suspected.

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‡ University of North Dakota.
§ University of Missouri.

10.1021/es803203g CCC: $40.75 © 2009 American Chemical Society
Published on Web 04/14/2009

Selenium's effect in counteracting Hg toxicity increases throughout Se's nutritionally relevant range and has been demonstrated in all insect, fish, bird, and mammal species tested to date (*13*). However, effects remain controversial. A review of adult effects resulting from fetal exposure in MeHg exposed animal models by Newland et al. (*6*) suggests that diets rich in Se do not uniformly protect against MeHg's effects. The review by Yang et al. (*5*) points out that "a large number of scientific studies have provided strong evidence of the protective role of Se in preventing the detrimental effect of CH_3Hg^+." Ralston et al. (*7*) found that MeHg toxicity in rats could not be predicted from tissue MeHg content alone, but that toxicity was directly related to the Hg:Se molar ratios in the tissue. Thus, it appears that selenium-dependent protection against Hg-toxicity depends not on Hg concentrations per se, but rather on the total mass ratio of Se to Hg. Ganther (*4*) first mentioned the Se:Hg molar ratio of 1:1 as protective against Hg toxicity in fish. Luten et al. (*19*) drew a similar conclusion relative to both freshwater and marine fish.

Since the evidence indicates that Se:Hg molar ratios influence the toxicity of either element and that these ratios are useful in interpretation of toxicity, we developed the fish tissue data in this paper from that perspective. The purpose of this paper is to describe the Se:Hg molar ratios in whole stream fish (n = 468) collected from 137 sites across 12 western U.S. states and to relate those ratios to a published wildlife methylmercury (MeHg) consumption threshold (0.1 μg Hg·g^{-1} wet wt.) (*20*). In addition, we comment on these molar ratios relative to the current methylmercury (MeHg) water quality criterion (WQC) for protection of humans (0.3 μg Hg·g^{-1} wet wt.) (*21*) and on potential fish tissue Se toxicity.

Materials and Methods

Procedures for sample site selection, Hg analysis, Hg quality assurance, and quality control (QA/QC), and results of fish tissue Hg analyses were reported previously (*15*). Each is described briefly as follows.

Probability Sample Design. For Se analysis, we selected 468 freeze-dried samples that previously had been analyzed for Hg (*15*). All piscivores (n = 206) were analyzed, since those fish commonly contain the highest Hg concentrations and are among commonly sought game fish. Presumably they pose the greatest potential risk of Hg toxicity relative to fish reproduction or consumption by other fish. In addition, we analyzed a random sampling (n = 262) of the remaining nonpiscivorous fish.

Stream and river sampling sites were drawn from Arizona, California, Colorado, Idaho, Montana, Nevada, North Dakota, Oregon, South Dakota, Utah, Washington, and Wyoming, on a probability basis, from the perennial stream network appearing on the 1:100, 000-scale digital line graph database of the United States Geological Survey (*22*−*24*). At each site, up to nine individual fish (three individuals from up to three different piscivore and nonpiscivore species) could be collected, but not all sites yielded fish.

Sample Collection and Processing for Hg Analyses. We collected fish from streams and rivers according to wadeable and nonwadeable electrofishing protocols (*25, 26*). Fish were wrapped in aluminum foil, double-bagged in resealable freezer bags, and shipped on ice to the laboratory within 36 h of being caught (*25, 26*). At the laboratory, they were inspected for condition and stored frozen at −20 °C until processing (*15*).

Freeze-Dried Sample Preparation. A second set of wet homogenate subsamples were freeze-dried for Se analysis at the same time the above samples were prepared. Since Se analysis by Instrumental Neutron Activation Analysis (INAA) requires a very small, but uniformly mixed sample, the freeze-dried samples were prepared according to a procedure prescribed by the University of Missouri Research Reactor. The full procedure is described in the Supporting Information (Methods -Se Sample Preparation).

Mercury Analysis. All Hg analyses were done on frozen wet homogenate samples by combustion atomic absorption spectrometry (CAAS) using a direct mercury analyzer (Milestone DMA80; Milestone, Monroe, CT or LECO model AMA 254; LECO Corporation, St. Joseph, MI) and EPA Method 7473 (*27*). Samples were analyzed in triplicate, and reanalyzed if the relative standard deviation (RSD) exceeded ±5%. The result for each sample was reported as the mean wet weight Hg concentration. All Hg analyses were performed within time frames that assured against nondegradation and/or changes in the Hg content of fish tissue (*28*).

Mercury Detection Limit and Quality Assurance. The analytical method detection limit (MDL) was calculated using the method of Taylor (*29*) as published in 1986 by the U.S. EPA in 40 CFR Part 136, Appendix B, Revision 1.11. The MDL was based on repeated analyses between 2000 and 2004 (n = 875) of a low-level standard (NIST 2976 mussel tissue) and expressed as μg Hg·g^{-1} wet wt. (assuming a water content of 70% for the mussel species used for the standard (*30*)). The MDL was calculated to be 0.015 μg Hg·g^{-1}wet wt.

We assessed analytical precision using 376 duplicate analyses of fish tissue homogenate samples within a single sample batch. Precision expressed as relative percent difference of duplicate measurements was 6.4%. We assessed systematic error of our Hg analyses by repeated analyses of two standard reference materials (SRMs) during sample analytical runs: a high-level SRM (DORM-2 dogfish tissue; Institute for National Measurement Standards (INMS), Ottawa, ON, Canada) and a low-level SRM (NIST 2976 mussel tissue; National Institute of Standards & Technology (NIST), Gaithersburg, MD). For the DORM-2 SRM (certified as 4.64 ± 0.26 μg Hg ·g^{-1}dry wt.), the mean measured value was 4.58 μg Hg·g^{-1} dry wt. (n = 1099, SD = 0.33 μg Hg·g^{-1} dry wt., relative standard deviation [RSD] = ±7.3%), indicating a small negative bias (−1.2%). For the low-level NIST 2976 SRM (certified as 0.061 ± 0.004 μg Hg·g^{-1} dry wt.), the mean measured value was 0.070 μg Hg·g^{-1} dry wt. (n = 876, SD = 0.021 μg Hg·g^{-1} dry wt., RSD = ±29.8%), indicating a positive bias (14.8%) at lower concentrations.

Selenium Analysis. All Se analyses were performed on freeze-dried fish homogenate samples by standard comparator INAA according to the analysis protocol of the University of Missouri Research Reactor (*31*−*33*). The procedure is described briefly in Supporting Information Methods: Se Analysis.

Selenium Limit of Quantitation and Quality Assurance. The limit of quantitation (LOQ) for the INAA Se analysis of fish homogenate under this protocol is on the order of 2 ng, which on a 0.025 g sample yields a fractional mass LOQ of 0.08 μg·g^{-1} dry wt. The LOQ is based on 10 times the square root of the integrated baseline over an energy range of 160.2−163.7 keV. In gamma-ray spectroscopy, the standard deviation of the background for the measurement is the square root of the number of counts in the integrated baseline and the LOQ is 10 times one standard deviation of the background (*34*).

SRM NIST (1577 Bovine Liver; ca. 30 mg per sample) was used as an external quality control standard for the INAA measurements for two reasons. First, INAA Se analyses require small sample masses (30 mg). Thus, the 250 mg DORM-2 masses recommended by both NIST and National Research Council of Canada are incompatible with the INAA method. Second, DORM-2 and bovine liver standards behave identically relative to the INAA method. The certified value for Se in SRM 1577 is 1.1 ± 0.1 μg Se·g^{-1} dry wt. Analysis of replicate

TABLE 1. Mass and Molar Concentrations of Mercury and Selenium and Surplus Se Concentrations in Various Fish Groups[a]

fish group (n) mean total length (mm) (minimum, maximum)	mercury mean concentration (minimum, maximum)		selenium mean concentration (minimum, maximum)		surplus Se concentration (μmol Se/g wet wt.) mean (std. error)
	μg Hg·g^{-1} wet wt	μmol Hg ·g^{-1} wet wt	μg Se·g^{-1} wet wt	μmol Se·g^{-1} wet wt	
Non-Piscivores					
suckers (106)327 (190, 480)	0.114 (0.012, 0.468)	0.0006 (0.0001, 0.0023)	0.556 (0.112, 3.196)	0.0070 (0.0014, 0.0405)	0.0065 (0.0008)
trout and salmon (89)264 (198, 480)	0.090 (0.012, 0.662)	0.0005 (0.0001, 0.0033)	0.798 (0.080, 4.150)	0.0101 (0.0010, 0.0526)	0.0096 (0.0010)
whitefish (23)324 (235, 515)	0.088 (0.013, 0.321)	0.0004 (0.0001, 0.0016)	1.082 (0.075, 1.890)	0.0137 (0.0061, 0.1231)	0.0133 (0.0013)
carp (19)356 (180, 630)	0.067 (0.010, 0.231)	0.0003 (<0.0001, 0.0012)	1.2893 (0.453, 5.460)	0.0163 (0.0057, 0.0691)	0.0160 (0.0036))
bullheads (14)193 (165, 220)	0.115 (0.031, 0.413)	0.0006 (0.0002, 0.0021)	0.522 (0.196, 1.079)	0.0066 (0.0025, 0.0137)	0.0060 (0.0011)
other nonpiscivores (11)231 (165, 390)	0.176 (0.083, 0.285)	0.0009 (0.0004, 0.0014)	0.637 (0.274, 1.352)	0.0081 (0.0035, 0.0171)	0.0072 (0.0016)
all non-piscivores (262)296 (165, 630)	**0.103 (0.010, 0.662)**	**0.0005 (0.0000, 0.0033)**	**0.740 (0.075, 5.460)**	**0.0094 (0.0010, 0.0691)**	**0.0089 (0.0006)**
Piscivores					
pikeminnows (59)318 (142, 560)	0.368 (0.053, 1.040)	0.0018 (0.0003, 0.0052)	0.320 (0.093, 1.144)	0.0040 (0.0012, 0.0145)	0.0022 (0.0004)
walleye & sauger (50)348 (135, 570)	0.244 (0.026, 0.587)	0.0012 (0.0001, 0.0029)	0.478 (0.243, 1.102)	0.0061 (0.0031, 0.0140)	0.0048 (0.0004)
bass (48)262 (138, 485)	0.186 (0.042, 0.665)	0.0009 (0.0002, 0.0033)	0.570 (0.096, 1.869)	0.0072 (0.0012, 0.0237)	0.0063 (0.0007)
pike (30)353 (122, 640)	0.170 (0.042, 0.397)	0.0008 (0.0002, 0.0020)	0.360 (0.142, 0.638)	0.0046 (0.0024, 0.0081)	0.0037 (0.0004)
large catfish (14)401 (280, 610)	0.148 (0.049, 0.307)	0.0007 (0.0002, 0.0015)	0.657 (0.434, 1.013)	0.0083 (0.0055, 0.0128)	0.0076 (0.0006)
other piscivores (5)385 (265, 600)	0.221 (0.119, 0.3759)	0.0011 (0.0006, 0.0019)	0.607 (0.518, 0.719)	0.0077 (0.0066, 0.0091)	0.0066 (0.0007)
all piscivores (206)325 (122, 640)	**0.248 (0.026, 1.040)**	**0.0012 (0.0001, 0.0052)**	**0.452 (0.093, 1.869)**	**0.0057 (0.0012, 0.0237)**	**0.0045 (0.0002)**

[a] Surplus Selenium is the Difference in Molar Concentrations of Se and Hg.

SRM samples ($n = 61$) yielded a mean value of 1.08 μg Se·g^{-1} dry wt. (SD = 0.063 μg Se·g^{-1} dry wt., RSD = ±5.8%).

Effect of Measurement Precision on Se Exceedance of Hg. We explored the effect of Se and Hg measurement precision estimates, based on standard reference materials, relative to Se molar concentration of individual fish exceeding the Hg molar concentration. After conversion to wet weight molar concentrations, the precision estimates (standard deviations) of measured and certified values for the DORM-2 SRM (for Hg) and of the NIST 1577 SRM (for Se) were equal to 0.00020 μmol Hg·g^{-1} wet wt. and 0.00022 μmol Se·g^{-1} wet wt., respectively.

We assumed that the Se and Hg measurements were unbiased and independent, and modeled the true (but unknown) difference in molar concentration between Se and Hg as a normally distributed random variable, with mean equal to the measured difference, and standard deviation $\sqrt{(0.00020^2 + 0{,}00022^2)} = 0.00030\ \mu\text{mol}\cdot\text{g}^{-1}$ wet wt. With these assumptions, the true mean difference has a ≥90% probability of exceeding zero (Se molar concentration > Hg molar concentration) if the measured difference exceeds 1.28 × 0.00030 = 0.00038 μmol·g^{-1} wet wt., where 1.28 is the 90th percentile of the standard normal distribution. Thus, we considered any fish having a measured difference (Se-Hg) exceeding 0.00038 μmol·g^{-1} wet wt. to have true Se exceeding true Hg, i.e., Se:Hg > 1. However, we did not adjust concentration statistics of Se, Hg, their difference, or their ratio for measurement precision.

Results and Discussion

Fish Samples. Selenium analyses were performed on 468 fish of 40 different species from 137 sites (some with multiple fish samples) across 12 western U.S. states (Figure 1). Fish included all of the piscivores (n = 206) analyzed previously for Hg by Peterson et al. (*15*) and a random sampling of the remaining nonpiscivores ($n = 262$) from that original sampling of 2707 large fish. As expected, the mean Hg concentration for all piscivores in Table 1 (**Bold Summary**) is greater (more than double) than the mean for all nonpiscivores. The mean Se concentration is greater for all nonpiscivores than for all piscivores. Mean Hg concentrations (μg·g^{-1} wet wt.) by fish group in Table 1 indicate all of the piscivore groups pose a toxicity risk relative to the wildlife threshold of 0.1 μg Hg·g^{-1} wet wt., but the nonpiscivore groups present a mixed picture. Several individual pikeminnow, walleye, sauger, bass, and pike exceed the MeHg WQC (0.3 μg·g^{-1} wet wt. for filet) as it relates to whole fish Hg concentrations (≥0.185 μg·g^{-1}) (*15*). Based on an assessment using the MeHg WQC many individual fish in our sample likely would be recommended for limited or nonconsumption by either wildlife or humans.

Selenium: Mercury Molar Ratios. Based on Se soil concentrations across our study area ranging from 0.17 to 0.74 μg·g^{-1} dry wt (*35*), we expected to see many fish types and regions in the western U.S. with fish Se:Hg molar ratios <1. However, there is a general geographic pattern of Se:Hg molar ratios >1 (surplus Se), but surplus Se is not uniformly present in all fish (Figure 2 and Supporting Information Table S1).

Figure 2 suggests that Se:Hg molar ratios might decline with increasing fish size, possibly reducing Se protection in larger fish. We tested this by linear regression of surplus Se against total fish length for piscivores and nonpiscivores. The relationship for piscivores is poor ($r^2 = 0.085$) and the one for nonpiscivores is worse ($r^2 = 0.0004$). We conclude from this that Se protection against Hg toxicity in larger fish probably remains intact. The proportion of piscivores with Se:Hg <1 (11 of 206) was substancially greater than that of nonpiscivores (1 of 262 fish; $P < 0.001$, for Fisher's exact test of the difference between proportions).

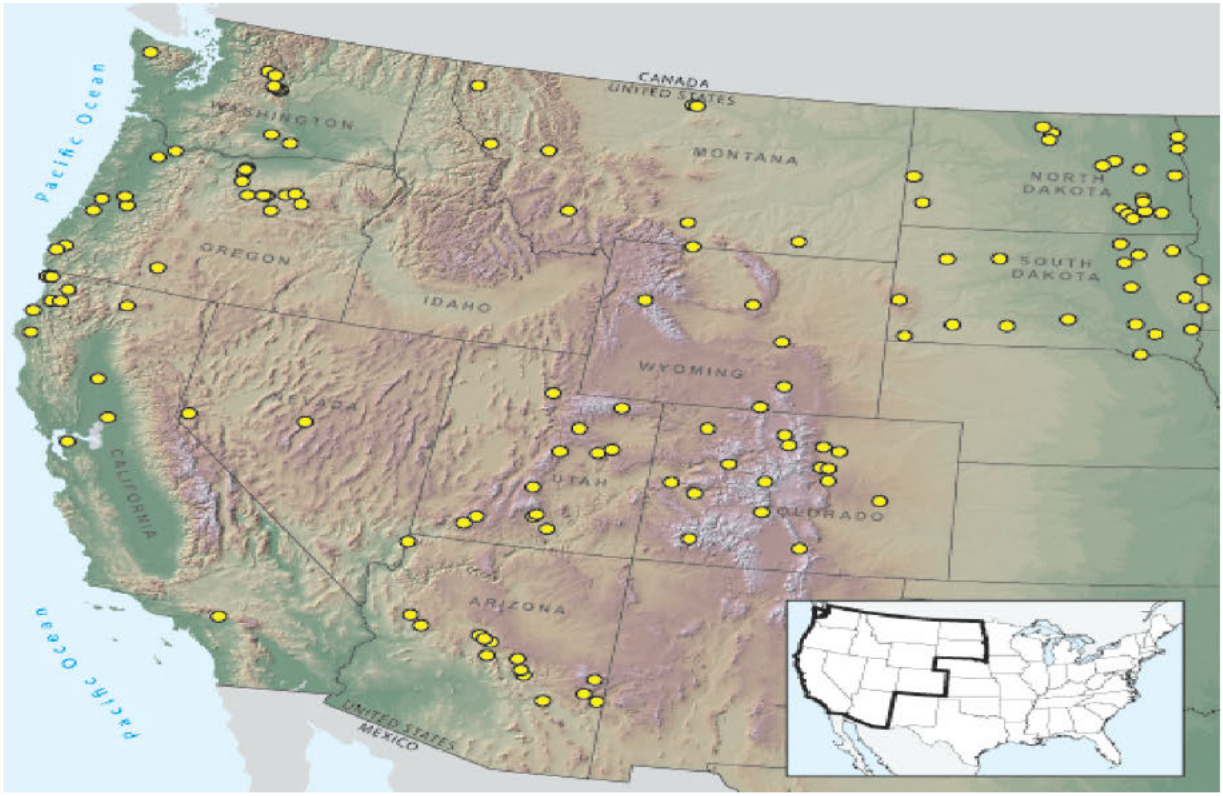

FIGURE 1. Location of probability based sites where fish tissue samples were collected for Hg and Se analysis.

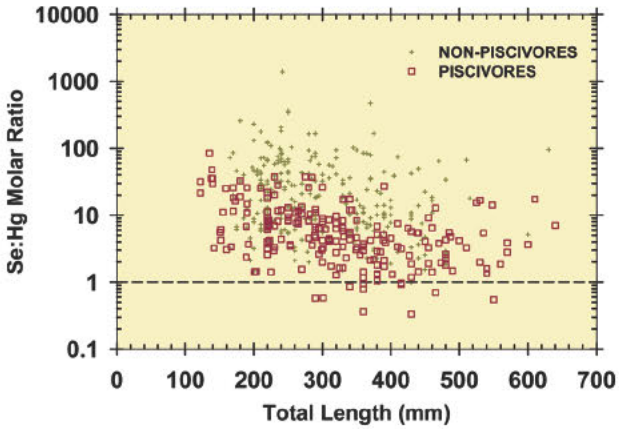

FIGURE 2. Molar ratio of selenium to mercury relative to fish size. The horizontal dotted line is the Se:Hg, 1:1 line.

Pikeminnows. All of the fish in Figure 2 that have a Se:Hg molar ratio <1 were pikeminnows (*Ptychocheilus spp.*), except the one largescale sucker (*Catostomus macrocheilus*), ranging in total length from about 300 to about 550 mm. There were 23 smaller and one larger pikeminnows with a Se:Hg molar ratio >1. This suggests that some combination of fish species, fish size and possibly environment might play a role in determining Se:Hg ratios. Northern pikeminnows represent the top of the freshwater aquatic food chain and are known to be voracious piscivores (*36*). Zimmerman (*36*) found that the stomach of pikeminnows, relative to their total weight (index of feeding (IF)) was more than twice that of smallmouth bass (*Micropterus dolomieu*). This perhaps increases Hg bioaccumulation in large pikeminnows over other piscivores due to the potential uptake from the large stomach mass. However, since pikeminnow size alone appears not to control Se:Hg molar ratios, other factors must contribute. Pikeminnows having a molar ratio of Se:Hg < 1 came from seven sites: five in Oregon, one in Montana, and one in Washington. This suggests that local or regional environmental factors such as, wetland extent (*37*), forested regions (*38*), agricultural areas (*39*), and/or several water quality variables including pH, alkalinity, DOC, and SO_4 (*40–43*) might contribute to a molar surplus of Hg relative to Se. Zimmerman (*36*) suggested that some combination of these factors do influence the chemical burdens of fish with his finding that northern pikeminnow had significantly higher IF values in the Snake River than in the Columbia River and that stomach fullness, while significantly greater in summer than in spring in the unimpounded lower Columbia River, did not differ between seasons in the impounded reaches of the Columbia and Snake Rivers.

Mercury vs Selenium. High Hg concentrations in fish tissue from our samples were found only when Se concentrations in the same tissue were low (Figure 3). This is consistent with Belzile et al. (*44*) who found reduced bioaccumulation of Hg in all lake trophic levels (including young-of-the-year fish) downwind from the Sudbury, Ontario smelters. They concluded "Selenium plays an important role in limiting the whole-body assimilation of Hg at lower levels of the aquatic food chain." Bioaccumulation differs from, but is not entirely unrelated to, Hg toxicity potential. Concentration gradients in our study are not as well-defined geographically as those at Sudbury, but our results do suggest that fish species and environmental variability influence Se:Hg molar ratios in freshwater fish.

Mercury Criteria vs Se:Hg Molar Ratios. Peterson et al. (*15*) estimated the proportion of stream length across the western U.S. where the total Hg in fish tissue exceeded the wildlife threshold (*20*) and the current MeHg WQC (*21*). Those estimates are accurate relative to the wildlife and human health benchmarks for Hg alone, however, they likely exaggerate Hg toxicity potentials relative to an assessment based on Se:Hg molar ratios.

Considering all fish in our sample ($n = 468$), 56% exceeded the wildlife Hg threshold (0.1 μg Hg g^{-1} wet wt.) (*20*) and 12% exceeded the MeHg WQC (0.3 μg Hg g^{-1} wet wt.) (*21*). When

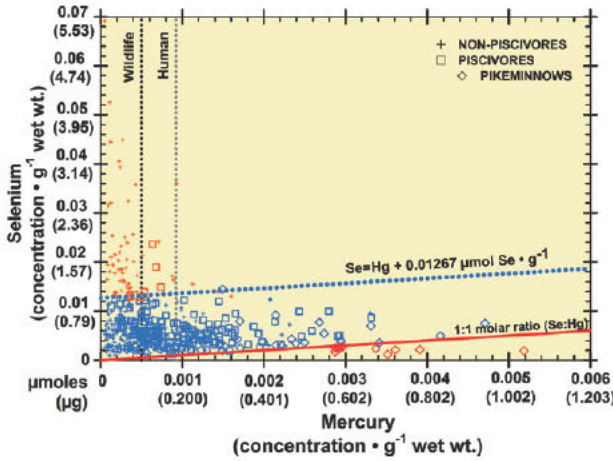

FIGURE 3. Selenium and mercury concentrations in whole fish tissue. The vertical dotted, line closest to the *y*-axis represents the 0.1 μg Hg·g^{-1} wet wt. whole fish wildlife threshold (*20*). The vertical dotted line to the right is drawn at 0.185 μg Hg·g^{-1} wet wt. whole fish (equals 0.3 μg Hg·g^{-1} wet wt. of filet), which represents the human health filet tissue based water quality criterion (*21*). The angled red line near the bottom of the figure is the Se:Hg, 1:1 line. The dotted blue line above and parallel to the 1:1 line is drawn at 4 μg Se·g^{-1} dry wt. = 1.0 μg Se·g^{-1} (wet wt.) = 0.01267 μmol Se·g^{-1} wet wt. above the 1:1 line and represents the surplus Se level (or toxic effect threshold (TET)) where fish exhibit reproductive failure (*49*). Fish shown in red below the Se:Hg, 1:1 line have a surplus of Hg. Fish shown in blue, between the red dashed 1:1 line and the blue dotted Se TET-line, presumably are protected from Hg toxicity by surplus Se. Fish shown in orange, above the blue dotted line, have surplus Se above the Se TET, and their consumers might risk Se toxic effects.

examined by major feeding groups, 33% of the nonpiscivores ($n = 262$) and 84% of the piscivores ($n = 206$), respectively, exceeded the wildlife Hg threshold. Five percent of the nonpiscivores and 25% of the piscivores exceeded the MeHg WQC. Based on Hg concentrations alone, a large proportion of the fish in our sample would exceed the MeHg WQC and possibly be unfit for consumption. However, if we consider that a molar ratio surplus of Se:Hg >1 in fish might be sufficient to prevent Hg toxicity in the fish and consumers of the fish (*4*), only 12 samples (those below the 1:1 line in Figure 3) would be considered unsuitable for wildlife consumption. By allowing for Se and Hg measurement uncertainty and applying that to the 1:1 line in Figure 3, only one more fish with a Hg molar surplus was added to the group. Thus, based on their Se:Hg molar ratios, 13 fish (2.7% of our total sample) might pose Hg toxicity problems for wildlife consumers. However, if we assess the potential toxicity of the 13 fish with Hg surplus (Hg >Se) based on the current MeHg WQC of 0.3 μg Hg · g^{-1} wet wt., only 6 of the 13 fish have that amount or more Hg > their 1:1 Se:Hg molar ratio. Thus, potential Hg toxicity in our entire fish sample might be no more than seven (1.3% of our sample). Since all of these fish are northern pikeminnows, this could be important to northwestern Native Americans because they commonly consume northern pikeminnows. Here we have compared the Hg surplus, relative to the Se:Hg ratio in whole fish to a human consumption criterion. We realize that such a comparison might not be directly pertinent to those human consumers of western U.S. fish who eat only the filet tissue. This discrepancy emphasizes the need to know the Se:Hg ratios in fish filet as well as in whole fish tissue.

The Se:Hg molar ratios in freshwater fish tissue have not been reported extensively. However, it has become more common for marine species. Kaneko and Ralston (*45*) reported Se:Hg >1 in filet of all marine fish except mako shark. Luten et al. (*19*) reported similar results for marine fish filets. However, all of their freshwater fish species (pike, perch and pike-perch; $n = 21$) exhibited Se:Hg molar ratios of <1. This is in near total contrast to our results, which is not surprising, since theirs was a European study and the soils of north-central Europe and the Scandinavian countries are depauperate of Se (*46*). This likely contributes to the high Hg levels relative to the low Se levels observed in their freshwater fish (*47*). Kehrig et al. (*48*) measured Se and Hg in hepatic and muscle tissue of four fish species in a tropical estuary. They found the Se:Hg molar ratios were >1 (5 to 70 times >) in both tissue types of all fish. Because reports of Se:Hg ratios in freshwater fish are rare and because geographic regions differ, more documentation is needed. This is particularly true for regions of the eastern U.S. and for lakes and reservoirs that might produce Se:Hg fish tissue ratios considerably different from the ones we report here for stream fish of the western U.S.

Potential Se Toxicity. Small amounts of Se are required by all cells of virtually all forms of animal life, but Se levels above certain threshold limits can be harmful. Lemly's (*49*) whole body 4.0 μg Se·g^{-1} dry wt. (1.0 μg·g^{-1} wet wt., or 0.01267 μmol·g^{-1} wet wt.) toxic effect threshold (TET) is the concentration at which fish experience reproductive failure and juvenile mortality. This TET is widely cited in the literature. Thus, we used this benchmark to assess Se toxicity potential in our fish sample. There are 456 fish in Figure 3 that have a Se:Hg molar ratio >1. Presumably, all of these fish are protected against Hg toxicity. However, there are 68, or 15% of the 456 fish that have Se concentrations that exceed the Lemly (*49*) TET of 1.0 μg Se·g^{-1} wet wt. above the 1:1 line. This raises potential selenium toxicity (selenosis) concerns for those fish and their consumers. Thus, in our sample there are ~6 times more fish in the potential Se toxicity category than those in the potential Hg toxicity category.

Our finding that nearly all (97.5%) of the freshwater fish in our survey have sufficient Se to potentially protect them and their consumers against Hg toxicity suggests that consideration of Se–Hg interactions might improve our understanding of risks associated with fish tissue Hg toxicity. Several researchers (*13, 19, 45, 50*) recommend measuring Se concurrently with Hg in fish tissue and considering the Se–Hg interaction. The focus of future research should be on the Se protective mechanism itself, on the effects of co-occurring Se and Hg, and on establishing the Se:Hg molar ratios of whole fish vs filets in streams, lakes and reservoirs in various geographic settings.

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Supporting Information Available

Table S1 lists all fish groups analyzed, their mercury and selenium concentrations and the selenium surpluses for each group. Additionally, details of the fish tissue sample preparation method and the selenium neutron activation analysis are described. This material is available free of charge via the Internet at http://pubs.acs.org.

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Commentary

Review of residue-based selenium toxicity thresholds for freshwater fish

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Abstract

A variety of guidelines have been proposed in recent years for linking selenium concentrations in the whole body of fish or in diet with adverse effects in fish. Diverging viewpoints seem to be forming separating groups supporting either the low selenium guidelines proposed by the government and academic researchers or the high selenium guidelines proposed by other researchers. Recently, an article was published that reviewed selected studies and recommended guidelines for selenium concentrations in the whole body of fish and in diet that were higher than those proposed by other researchers ($\approx 4\,\mu g/g$ in whole body and 3 4 $\mu g/g$ in diet). That article also recommended separating guidelines for coldwater fish ($6\,\mu g/g$ in whole body and $11\,\mu g/g$ in diet) and warmwater fish ($9\,\mu g/g$ in whole body and $10\,\mu g/g$ in diet). The approaches, information, and guidelines presented in the article are reviewed and problems in their interpretation and conclusions are discussed. The majority of the selenium literature supports a whole body threshold of $4\,\mu g/g$ in fish and $3\,\mu g/g$ in diet.
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Keywords: Selenium; Diet; Fish; Threshold; Tissue based criteria

1. Introduction

The criteria for selenium in the aquatic ecosystem has become a controversial topic in recent years as evidenced by debate articles in the journal *Human and Ecological Risk Assessment* (Chapman, 1999; Lemly, 1999a; Hamilton, 1999; Ohlendorf, 1999; DeForest et al., 1999; Fairbrother et al., 1999), response articles (Skorupa, 1999; Fairbrother et al., 2000), and debates at national scientific meetings, i.e., "Selenium in the Environment: A Ticking Time Bomb or No Big Deal?" (SETAC, 1999). There seems to be a divergence between academia or government-backed articles proposing low-selenium criteria (SWRCBC, 1987; UCC, 1988; DuBowy, 1989; Skorupa and Ohlendorf, 1991; Pease et al., 1992; Peterson and Nebeker, 1992; Lemly, 1993a, 1996; Maier and Knight, 1994; Engberg, 1999; Skorupa, 1998; USDOI, 1998) and nongovernmental articles proposing high criteria (Canton and Van Derveer, 1997; Van Derveer and Canton, 1997; Canton, 1999; DeForest et al., 1999; Adams et al., 2000; Brix et al., 2000).

The US Environmental Protection Agency (USEPA) is currently in the process of revising the selenium chronic criterion for the protection of aquatic life (C. Delos and K. Sappington, USEPA, written communications), which was established in 1987 (USEPA, 1987). One step in the USEPA revision process was a peer consultation workshop on the bioaccumulation and aquatic toxicology of selenium, held to discuss the technical issues underlying the freshwater aquatic life chronic criterion (USEPA, 1998). The nine-member peer review group was composed of representatives from federal agencies, academia, private consultants, and industry. The subjects of interest in the workshop included the potential development of a water-based criterion, a tissue-based criterion, and a sediment-based criterion. The general consensus of the peer review group was that the relationship between water-borne and sediment selenium concentrations to the tissue accumulation of selenium was poor because of the importance of dietary exposure in determining the potential for chronic effects. Consequently, there has been recent interest in promoting a tissue-based criterion

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or threshold (DeForest et al., 1999; Brix et al., 2000; Hamilton, 2002).

2. Critique of a tissue-based selenium threshold paper

A recent article by DeForest et al. (1999) reviewed the proposed residue-based toxicity thresholds for freshwater fish. Similar information was given in Brix et al. (2000). They proposed whole-body thresholds of 9 μg/g (all given as dry weight) for warmwater fish and 6 μg/g for larval coldwater anadromous fish, ovary threshold of 17 μg/g for warmwater fish, and fish dietary thresholds of 10 μg/g for warmwater fish and 11 μg/g for larval coldwater anadromous fish. These values are substantially different from those proposed by Maier and Knight (1994; 4.5 μg/g in tissue and 4 μg/g in diet), Lemly (1993a, 1996; 4 μg/g in whole body, 10 μg/g in ovary, and 3 μg/g in diet), and Hamilton (2002; 4 μg/g in tissue).

The DeForest et al. (1999) article seems to have fallen short of their objective of critically reviewing the proposed tissue-based thresholds for freshwater fish because they excluded the results of water-borne studies and selectively discussed results from dietary studies. Their review focused primarily on Lemly (1993a) and they correctly cite several errors in two summary tables. Those errors were corrected in Lemly (1996), which they do not cite. They also did not include information from the review article on selenium toxicology by Maier and Knight (1994) in their review. Maier and Knight (1994) independently proposed threshold concentrations for selenium effects that were similar to those of Lemly (1993a, 1996).

2.1. Errors in Lemly (1993a)

Despite the errors in Lemly (1993a), the proposed tissue-based thresholds were still supported unchanged in Lemly (1996). The residue-based thresholds proposed by DeForest et al. (1999) seem overly high and are not supported by the majority of the selenium literature. The review by Deforest et al. (1999) seems to be incomplete and does not include important articles that further supported the thresholds proposed by Lemly (1996).

Numerous authors cite Lemly (1993a) as the first comprehensive review of the selenium literature and proposal of selenium residue-based thresholds. Few authors cite Lemly (1996), which has conclusions similar to those of Lemly (1993a), but different supporting data in Tables 1 and 2, which had similar supporting citations between the two publications. No one in their publications has noted the difference in values given in Tables 1 and 2 in those two publications (Tables 1 and 2).

2.2. Additional articles supporting Lemly's proposed values

Several articles not cited in Lemly (1993a, 1996) or published later support the 4 μg/g whole-body concentration for toxic effects in fish (Hilton and Hodson, 1983; Cleveland et al., 1993; Lemly, 1993b; Hamilton et al., 1996,2001a, b) (Table 3). This effect concentration in the whole body was supported by Skorupa et al. (1996), who proposed 4–6 μg/g, and Maier and Knight (1994) who proposed 4.5 μg/g.

Likewise, several articles not cited in Lemly (1993a, 1996) or published later support the 3-μg/g dietary toxicity threshold for fish (Cleveland et al., 1993; Lemly, 1993b; Hamilton et al., 1996, 2001a, b) (Table 4). These articles report effect concentrations of 4.6–6.5 μg/g, which suggests a threshold concentration at a lower concentration, i.e., conservatively <4.6 μg/g. Those articles lend further support to the 3 μg/g threshold of effects suggested by Hilton et al. (1980), Lemly (1993a, 1996) and Skorupa et al. (1996) and the 4 μg/g threshold suggested by Maier and Knight (1994).

2.3. Information not cited in Deforest et al.

DeForest et al. (1999) cited selenium contamination problems at Belews Lake, North Carolina, Hyco Reservoir, North Carolina, and Kesterson Reservoir, California, but did not cite selenium contaminant problems at Sweitzer Lake, Colorado (Barnhart, 1957; Birkner, 1978; Butler et al., 1989, 1991, 1994, 1996) or Martin Lake, Texas (Sorensen, 1991).

Similarly, DeForest et al. (1999) cited Van Derveer and Canton (1997) as demonstrating that fish in lotic systems in Colorado were not at risk at water selenium concentrations of approximately 30 μg/L. However, they failed to mention that the articles by Canton and Van Derveer (1997) and Van Derveer and Canton (1997) had incorrectly interpretated exposure survey reports as being exposure-response studies, ignored the importance of the water-borne entry of selenium in aquatic food webs, overlooked key studies from the extensive body of selenium literature, and failed to consider the offstream consequences of proposing high instream selenium standards (Hamilton and Lemly, 1999). Offstream concerns of selenium contamination have also been discussed in Skorupa (1998) and Lemly (1999b). These offstream concerns about selenium contamination were substantiated by Radtke et al. (1988) and Radtke and Kepner (1990), who concluded that elevated selenium concentrations in sediment and biota in the backwaters of the lower Colorado River were carried by water from the upper Colorado River basin and not derived from local agricultural or industrial sources.

DeForest et al. (1999) chose to disregard the results of the SLD diet despite the more realistic exposure scenario

Table 1
Selenium concentrations in tissue associated with toxic effects in fish and aquatic organisms

Species[a]	Tissue	Lemly (1993a) selenium concentration (μg/g)[b]	Lemly (1996) selenium concentration (μg/g)[b]	Effect	Reference
Rainbow trout	Whole body	3	2	Blood changes	Hodson et al. (1980)
	Liver	12	51	Blood changes	Hodson et al. (1980)
	Whole body	5	5	Mortality	Hilton et al. (1980)
	Whole body	4	1	Mortality	Hunn et al. (1987)
Chinook salmon	Whole body	9.5	20	Reduced smolting	Hamilton et al. (1986)
	Whole body	3	2	Reduced growth	Hamilton et al. (1990)
	Whole body	10	5	Mortality	Hamilton et al. (1990)
Fathead minnow	Whole body	6	5	Reduced growth	Ogle and Knight (1989)
	Ovaries	15	24	Reproductive failure	Schultz and Hermanutz (1990)
	Whole body	8	16	Reproductive failure	Schultz and Hermanutz (1990)
Striped bass	Skeletal muscle	14	14	Mortality	Coughlan and Velte (1989)
	Whole body	NG[c]	2	Mortality	Saiki et al. (1992)
Bluegill	Skeletal muscle	20	20	Mortality	Finley (1985)
	Liver	32	34	Mortality	Finley (1985)
	Carcass	8	24	Reproductive failure	Gillespie and Baumann (1986)
	Ovaries	12	23	Reproductive failure	Gillespie and Baumann (1986)
	Whole body	5	5	Mortality	USFWS (1990)
	Whole body	16	19	Reproductive failure	Coyle et al. (1993)
	Ovaries	30	34	Reproductive failure	Coyle et al. (1993)
	Eggs	40	42	Reproductive failure	Coyle et al. (1993)
	Ovaries	10	18	Reproductive failure	Hermanutz et al. (1992)
	Skeletal muscle	10	16	Reproductive failure	Hermanutz et al. (1992)
	Liver	22	29	Reproductive failure	Hermanutz et al. (1992)
	Whole body	12	18	Reproductive failure	Hermanutz et al. (1992)
	Whole body	15	15	Teratogenic defects	Lemly (1993c)
Green alga	Whole organism	20	20	Reduced cell replication	Foe and Knight (1986)
Cyanobacterium	Whole organism	700	394	Reduced chlorophyll a	Kiffney and Knight (1990)
Cladoceran	Whole organism	20	15	Reduced weight	Ingersoll et al. (1990)
	Whole organism	30	32	Reproductive failure	Ingersoll et al. (1990)
Aquatic birds	Liver	10	NG	Reproductive failure	Skorupa et al. (in press)
	Eggs	3	NG	Reproductive failure	Skorupa et al. (in press)

[a] Rainbow trout (*Oncorhynchus mykiss*), Chinook salmon (*Oncorhynchus tshawytscha*), fathead minnow (*Pimephales promelas*), striped bass (*Morone saxatilis*), bluegill (*Lepomis macrochirus*), green alga (*Selenastrum capricornutum*), cyanobacterium (*Anabaena flosaquae*), cladoceran (*Daphnia magna*).
[b] Selenium concentrations on a dry weight basis.
[c] Not given in Lemly (1993a).

compared to the selenomethionine- (SEM) based diet in the studies with chinook salmon (*Oncorhynchus tshawytscha*) (Hamilton et al., 1990). Although there were differences in the diet formulation between the SLD-based diet and the SEM-based diet, reduced survival occurred in both dietary selenium exposures at 9.6 μg/g, and the whole-body selenium residues were remarkably similar (6.5 μg/g in the SLD diet and 5.4 μg/g in the SEM diet). Other adverse effects from the two diets were also similar between the two diets. The slight reduction in growth that occurred earlier and at slightly lower dietary concentrations in the SLD diets compared to the SEM diets was a minor discussion point in Hamilton et al. (1990).

DeForest et al. (1999) cited Brown (1997) to imply that pesticide residues in western mosquitofish (*Gambusia affinis*) used in the San Luis Drain (SLD) diet tested in Hamilton et al. (1990) may have influenced the results of dietary exposures with chinook salmon. The possibility of confounding effects from pesticides or other

Table 2
Concentrations of selenium known to be toxic in the diets of fish and wildlife

Species	Lemly (1993a) dietary selenium concentration (μg/g)[a]	Lemly (1996) dietary selenium concentration (μg/g)[a]	Effect	Reference
Rainbow trout	9	9	Mortality	Goettl and Davies (1978)
	>3	13	Mortality	Hilton et al. (1980)
	10	11	Kidney damage	Hilton and Hodson (1983)
Chinook salmon	6.5	6.5	Mortality	Hamilton et al. (1989)
	5	5	Reduced growth	Hamilton et al. (1990)
Fathead minnow	20	20	Reduced growth	Ogle and Knight (1989)
Striped bass	35	39	Mortality	Coughlan and Velte (1989)
Bluegill	50	54	Mortality	Finley (1985)
	6.5	6.5	Mortality	USFWS (1990)
	NG[b]	5	Mortality	Lemly (1993b)
	13	13	Reproductive failure	Woock et al. (1987)
	16	33[c]	Reproductive failure	Coyle et al. (1993)
Mallard duck[d]	>4	11	Reproductive failure	Heinz et al. (1987)
	>4	9	Reproductive failure	Heinz et al. (1989)

[a] Selenium concentrations on a dry weight basis.
[b] Not given in Lemly (1993a).
[c] Exposure included 10 μg/L in water.
[d] Mallard duck (*Anas platyrhynchos*).

Table 3
Selenium concentrations in tissue associated with toxic effects in fish

Exposure route, species	Tissue	Selenium concentration (μg/g)	Effect	Reference
Diet				
Rainbow trout	Carcass	4.0 4.5	Kidney damage and reduced weight	Hilton and Hodson (1983)
Fathead minnow	Whole body	43 61	Reduced growth	Bennett et al. (1986)
Bluegill	Whole body	25	Mortality	Bryson et al. (1984)
	Whole body	4.3[a]	Mortality	Cleveland et al. (1993)
	Whole body	7.9	Mortality	Lemly (1993b)
Channel catfish	Muscle	3.5	Reduced growth	Gatlin and Wilson (1984)
Razorback sucker	Whole body	3.6 8.7	Mortality	Hamilton et al. (1996)
	Whole body	5.4	Mortality	Hamilton et al. (2001a)
	Whole body	6.1	Mortality	Hamilton et al. (2001b)
Water				
Bluegill	Whole body	5.1[b]	Mortality	Cleveland et al. (1993)
Razorback sucker	Whole body	5.9	Reduced growth	Hamilton et al. (2000)
Bonytail	Whole body	9.4	Reduced growth	Hamilton et al. (2000)

[a] Derived from Fig. 3 in Cleveland et al. (1993).
[b] Derived from Fig. 2 in Cleveland et al. (1993).

contaminants in Kesterson studies has been explored, but none have been reported (i.e., Moore et al., 1990; Ohlendorf et al., 1993). Nevertheless, the toxicity of water from the SLD to fish has been reported and linked to high concentrations of major ions present in atypical ratios, to high concentrations of sulfates, or to both (Saiki et al., 1992).

In fact, in several other selenium contaminant studies, concerns about the influence of other interacting chemicals have been expressed, but none confirmed. For example, Sorensen (1986) stated that "Fish kills [at Belews Lake, NC, and Martin Lake, TX] were considered a direct result of selenium release into the main basin of the lakes because several hundred

Table 4
Selenium concentrations known to be toxic in the diets of fish

Species	Dietary selenium concentration (μg/g)	Effect	Reference
Fathead minnow	55 70[a]	Reduced growth	Bennett et al. (1986)
Bluegill	45[b]	Mortality	Bryson et al. (1984)
	6.5[c]	Mortality	Cleveland et al. (1993)
	5.1[d]	Mortality	Lemly (1993b)
Razorback sucker	2.4 5.1[e]	Mortality	Hamilton et al. (1996)
	4.6[f]	Mortality	Hamilton et al. (2001a)
	4.6[f]	Mortality	Hamilton et al. (2001b)

[a] Rotifers fed selenium laden algae.
[b] Burrowing mayfly nymphs (*Hexagenia limbata*) collected from Belews Lake, North Carolina.
[c] Selenomethionine incorporated into an Oregon moist pellet diet.
[d] Exposure included water borne exposure to 4.8 μg/L selenium and winter stress (4c).
[e] Zooplankton collected from Sheppard Bottom ponds 1, 3, and 4 at Ouray NWR, Utah.
[f] Zooplankton collected from three sites near Grand Junction, Colorado.

analyses for metals, metalloids, physiochemical parameters, and pesticides provided essentially negative results except for sufficiently high levels of selenium in the water (about 5 μg/L) to warrant concern." Others have reached similar conclusions concerning fishery problems at Belews Lake (Lemly, 1985), water and biota collected from Kesterson Reservoir area, California (Saiki and Lowe, 1987), trace elements in fish from the Merced River, and from Salt Slough, San Joaquin Valley, California (Nakamoto and Hassler, 1992), studies of Hyco Reservoir, North Carolina (Bryson et al., 1984; Gillespie and Baumann, 1986), and phosphate-mining activities in the Blackfoot River watershed of southeastern Idaho (Watson, 1998).

2.4. Water-borne versus dietary exposure

DeForest et al. (1999) did not include results from water-borne studies, but rather limited their analyses to dietary studies. In doing so, they eliminated several studies that relate directly to the tissue threshold of 4 μg/g suggested by Lemly (1993a, 1996), 4.5 μg/g of Maier and Knight (1994), and 4 μg/g of Hamilton (2002). For example, they discard the results of Hunn et al. (1987), who reported adverse effects in rainbow trout (*Oncorhynchus mykiss*), with 5.2 μg/g (assuming 75% moisture) in the whole body because it was a water-borne exposure.

Critically reviewing a residue-based toxicity threshold should include consideration of the results of water-borne studies. A selenium residue in a fish is the result of all exposures, dietary, water-borne, and sedimentary. The exposure routes are concurrent and inseparable. For example, four studies with young fall chinook salmon used different test waters and exposure routes, but had remarkably similar results based on whole-body selenium residues (Hamilton et al., 1986, 1990; Hamilton and Wiedmeyer, 1990). In separate dietary studies, fish were exposed to either SEM in a commercially prepared diet or to the same diet made with fish meal containing elevated concentrations of naturally incorporated seleno-compounds, and reduced growth occurred in fish with whole-body residues of 4.0–5.4 μg/g (Hamilton et al., 1990). In separate water-borne studies, fall chinook salmon were exposed to water-borne selenium in two different water qualities and adverse effects (reduced growth and survival) occurred in fish with whole-body residues of 3.8–4.9 μg/g (Hamilton et al., 1986; Hamilton and Wiedmeyer, 1990). Even though the routes of exposure were different in these studies, a common whole-body selenium residue of 4–5 μg/g was associated with the same adverse effects.

The convergence of adverse effects from water-borne and dietary exposures with a variety of fish suggests that once tissue selenium concentrations reach a critical threshold, regardless of the route of exposure, adverse effects will occur. This supposition is supported by results from several studies, including Hodson et al. (1980), where rainbow trout were exposed to 53 μg/L of selenium for 308 days, but no effects were observed on the survival, growth, condition factor, or several blood and plasma measurements because whole-body selenium residues were only 1.8 μg/g. Hamilton and Wiedmeyer (1990) found no effects on mortality or growth of 2-g fall chinook salmon exposed to water-borne selenium concentrations as high as 140 μg/L for 60 days in a blended brackish water (~1‰ salinity) because whole-body selenium residues were only 1.3 μg/g. Bertram and Brooks (1986) reported no effects on fathead minnow (*Pimephales promelas*) exposed to 7.3 μg/g in the diet and 43.5 μg/L in water for 56 days because whole-body

residues were only 2.2 μg/g. These water-borne and combined diet and water-borne exposure studies help define the upper end of the no-effect tissue threshold (1.3–2.2 μg/g) and the lower end of the effect tissue threshold (3.8–4.0 μg/g). Consequently, a threshold tissue concentration of 4 μg/g would seem reasonable.

DeForest et al. (1999) discussed their supposition that water-borne exposures result in mortality at lower whole-body selenium concentration than dietary exposures, and used Cleveland et al. (1993) as their focal point. The authors did not mention that the water-borne study was conducted with 5-month-old fish and the dietary study with 3-month-old fish, which may have influenced the data interpretation. More importantly, the selenium residue at day 60 linked to reduced mortality in the water-borne study was 4.3 μg/g and in the diet study was 5.1 μg/g. These values are very close to each other, especially considering no standard deviation or standard error was given in Cleveland et al. (1993) for readers to judge the variation of the values. If toxicity were observed at 4.3 and 5.1 μg/g, then some concentration less than these would approach the toxic effects threshold. Consequently, the data in Cleveland et al. (1993) would also support a proposed threshold of 4 μg/g. URS (2000) used a USEPA procedure (Stephan et al., 1985) with data from Cleveland et al. (1993) to calculate a whole-body toxicity threshold for selenium of 3.4 μg/g for the dietary study and 3.3 μg/g for the water-borne study. Thus, they revealed, contrary to DeForest et al. (1999), that there was no difference between water-borne and dietary exposure of bluegill (*Lepomis macrochirus*).

2.5. Coldwater fish versus warmwater fish

Another flaw in the supposition of DeForest et al. (1999) that coldwater fish are more sensitive to selenium toxicity than warmwater fish is that they reviewed selected literature and not a more complete set of selenium publications. The result is that they recommend 6 μg/g as the whole-residue threshold for coldwater fish and 9 μg/g as the threshold for warmwater fish. Several studies in Tables 1 and 3 reveal that whole-body selenium residues of 4–6 μg/g cause adverse effects regardless of whether fish were coldwater or warmwater and regardless of the route of exposure (Hilton et al., 1980; Hilton and Hodson, 1983; Hunn et al., 1987; Hamilton et al., 1990, 1996, 2001a, b; USFWS, 1990; Cleveland et al., 1993; Lemly, 1993a, b, c). DeForest et al. (1999) have not provided an adequate foundation for differentiating the importance of whole-body selenium residues between coldwater fish and warmwater fish. If 4–6 μg/g causes adverse effects in fish, then some concentration lower should be selected as the threshold concentration, i.e., 4 μg/g, not 6 or 9 μg/g as proposed by DeForest et al. (1999).

Two other publications mention the possible differences between coldwater fish and warmwater fish (USDOI, 1998; URS, 2000). Table 32 in USDOI (1998), citing Lemly (1996), gives the no-effect selenium concentration for whole-body residues as <3 μg/g in warmwater fish and <2 μg/g in coldwater fish; the level of concern as 3–4 μg/g and 2–4 μg/g, respectively; and toxicity threshold as >4 μg/g for warmwater and coldwater fish. Although Lemly (1996) does not differentiate between warmwater and coldwater fish, USDOI (1998) cited Lemly (1996) and reported a slight difference in guideline values between warmwater and coldwater fish. Even so, the values in USDOI (1998) were less than those of DeForest et al. (1999), but similar to those reported by others (Maier and Knight, 1994; Hamilton, 2002). USDOI (1998) did not discuss the basis for suggesting a difference between warmwater and coldwater fish in their sensitivity to selenium toxicity.

URS (2000) also suggests the selenium literature has some evidence of coldwater fish being more sensitive to selenium than warmwater fish. They followed the USEPA method (Stephan et al., 1985) employed by DeForest et al. (1999) to calculate the selenium tissue threshold as the geometric mean of the no observable effect concentration (NOEC) and the lowest observable effect concentration (LOEC). Application of the procedure to day 60 data for bluegill from Cleveland et al. (1993) yielded a whole-body toxicity threshold of 3.4 μg/g in their dietary study. Using day 90 data for chinook salmon from Hamilton et al. (1990), URS (2000) reported a whole-body toxicity threshold of 1.5 μg/g. Thus, they concluded there was evidence of differences in sensitivity between warmwater fish (3.4) and coldwater fish (1.5).

However, URS (2000) seems to have used inappropriate data for chinook salmon in their calculation. They note that growth of chinook salmon was reduced at 30 and 60 days of exposure to the 3.2 μg/g SLD diet and then use the whole-body selenium residue at day 90 for that treatment in the USEPA method calculation (i.e., NOEC 0.8 μg/g and LOEC 2.7 μg/g). At day 90, growth was not reduced in the 3.2-μg/g diet treatment, but was reduced in the 5.6-μg/g diet treatment. For day 60 data (NOEC 0.9 μg/g, LOEC 3.3 μg/g) the geometric mean whole-body toxicity threshold is 1.7 for chinook salmon. If day 60 data from Hamilton et al. (1990) were used in the comparison, one might still conclude there was a difference in sensitivity between coldwater fish with a threshold of 1.7 and warmwater fish with a threshold of 3.4 (Cleveland et al., 1993). However, if day 90 data were used, there would be no difference between coldwater fish with a whole-body toxicity threshold of 3.3 (NOEC 2.7 μg/g, LOEC 4.0 μg/g; Hamilton et al., 1990) and warmwater fish with a threshold of 3.9 (NOEC 3.3 μg/g, LOEC 4.6 μg/g; Cleveland et al., 1993). Considering the incongruity between day 60 and day 90

data from these two studies, there seems to be little support for differentiating sensitivity to selenium toxicity between coldwater and warmwater fish.

2.6. Diet selenium threshold

DeForest et al. (1999) proposed a dietary selenium threshold of 11 μg/g for coldwater fish and 10 μg/g for warmwater fish. The available information suggests similar sensitivity between coldwater fish and warmwater fish to dietary selenium toxicity. Tables 2 and 4 reveal that 4.6–6.5 μg/g dietary selenium causes adverse effects in fish regardless of whether they are coldwater species or warmwater species (Hamilton et al., 1989, 1990, 2001a, b; USFWS, 1990; Cleveland et al., 1993; Lemly, 1993a, b). If these dietary concentrations cause adverse effects in fish, primarily mortality, then a lower concentration must be selected as a dietary threshold concentration, i.e., 3 μg/g.

Professional judgment is an important consideration in the interpretation of data that can be frequently difficult and complex, conflicting or ambiguous, or incomplete (USEPA, 1992). Over 20 years ago, Hilton and colleagues conducted several selenium toxicity studies in the late 1970s and early 1980s and, based on their scientific judgment, they hypothesized that >3 μg/g dietary selenium would be harmful to fish over the long term (Hilton et al., 1980). Research in the late 1980s through the early 2000s has substantiated the speculation of John Hilton and colleagues.

3. Divergence of selenium thresholds

Much of the controversy in recent years concerning the selenium criterion for aquatic life and the dichotomy in proposed toxicity thresholds has been between government/academia published papers and nongovernmental papers. It is incumbent on federal government scientists to be an advocate for the environment on behalf of the general public as stated in the mission statement of the US Department of the Interior. Some may state this is a biased position. The chief biologist of the National Biological Service (NBS), and later the Biological Resources Division of the US Geological Survey, Dennis Fenn noted that the line is thin between judgment informed by sound scientific data and speculative judgment based on little data and much personal interest (Fenn and Milton, 1997); yet he concluded NBS scientists must be advocates for the environment (Fenn and Milton, 1997; Fenn, 1997). As Fenn stated, a basic premise of the scientific method is that the scientist has no vested interest in the outcome of the observations.

DeForest et al. (1999) have attempted to critically evaluate selenium thresholds for fish. Others have attempted similar critical evaluations of thresholds using limited datasets for fish (Brix et al., 2000) and birds (Adams et al., 1998, 2000; Fairbrother et al., 1999). Skorupa (1999) critiqued the article by Fairbrother et al. (1999) and noted the selective use of data from several studies that resulted in higher selenium threshold values for birds than proposed by government researchers. Fairbrother et al. (2000), in turn, responded to Skorupa (1999). Skorupa (personal communication) had similar comments on the draft of Adams et al. (1998). Articles that use limited datasets do little to enhance the body of knowledge about selenium. In contrast, to meet our responsibilities as federal researchers for stewardship of our natural resources for the benefit of our citizens, it is incumbent on us to ensure that the full range of relevant information is acquired and presented to the public. This responsibility requires us to not only point out deficiencies of selective information presented in scientific papers such as DeForest et al. (1999) and Brix et al. (2000), yet work to complement their data with the widest possible range of data.

Arguments in the articles by DeForest et al. (1999), Brix et al. (2000), Fairbrother et al. (1999), and Adams et al. (1998) for high threshold values were supported by statistics. However, Skorupa (1999) pointed out how selective use of data points can lead to the arrival at erroneous conclusions. Many of the concerns raised in this critique of DeForest et al. (1999) match those expressed by Stoto (1990) who noted that errors in conclusions could result from incomplete and inaccurate reporting of data, i.e., incomplete and inaccurate review of the selenium literature.

4. Conclusions

DeForest et al. (1999) and Brix et al. (2000) have used selective data to present high toxicity threshold for selenium in the tissue and diet of fish. They have cited older literature containing errors (Lemly, 1993a) while omitting later literature with corrected values (Lemly, 1996), excluded data from publications based on minor justifications, and overlooked key studies from the extensive body of selenium literature. The proposed high-selenium thresholds by DeForest et al. (1999) and Brix et al. (2000) does not stand on equal footing with reviews of more extensive datasets by USDOI (1998), Lemly (1996), Maier and Knight (1994), and Hamilton (2002). Recent studies continue to support the dietary selenium threshold of 3 μg/g and the whole-body selenium threshold of 4 μg/g for fish.

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Christopher Hunter/DC/USEPA/US
01/07/2011 06:03 PM

To Jim Pendergast
cc
bcc
Subject Re: Daily Spruce Update

ATTACHMENT REDACTED - DELIBERATIVE

Revised Spruce 404c Executive Summary.doc

Chris Hunter
U.S. Environmental Protection Agency
Office of Wetlands, Oceans, & Watershed
(202) 566-1454
hunter.christopher@epa.gov

Jim Pendergast | can you forward me the new exec summary? Da... | 01/07/2011 06:01:21 PM

From: Jim Pendergast/DC/USEPA/US
To: Christopher Hunter/DC/USEPA/US@EPA
Date: 01/07/2011 06:01 PM
Subject: Re: Daily Spruce Update

can you forward me the new exec summary?

Daily Spruce Update

Daily Spruce Update

Christopher Hunter to: Denise Keehner 01/07/2011 05:45 PM

Cc: David Evans, Brian Frazer, Jim Pendergast

(b) (5) [redacted] Here is a revised schedule and status update.

(b) (5) [redacted]

(b) (5)

Matthew Klasen/DC/USEPA/US
01/08/2011 09:42 AM

To Greg Pond
cc Margaret Passmore, Stefania Shamet, Christopher Hunter
bcc
Subject Re: Follow-ups after Kevin's comments (118A, 119A, 124A, and 136A)

Thanks Greg; those edits should do it. I'll plug those into the main doc (with perhaps a few minor tweaks).

Attached are the current draft answers for 146A and 148A. Stef probably has a more updated version of 146A; that's one of the 14 responses in the whole batch we didn't give Kevin quite yet. But the tables should be updated; take a look.

Chris: See below for Greg's note about PD #78, and I've attached the file that Greg attached.

Thanks,
Matt

Matt Klasen
U.S. Environmental Protection Agency
Office of Water (IO)
202-566-0780
cell (202) 380-7229

-----Greg Pond/R3/USEPA/US wrote: -----

To: Matthew Klasen/DC/USEPA/US@EPA
From: Greg Pond/R3/USEPA/US
Date: 01/08/2011 08:00AM
Cc: Margaret Passmore/R3/USEPA/US@EPA, Stefania Shamet/R3/USEPA/US@EPA
Subject: Re: Follow-ups after Kevin's comments (118A, 119A, 124A, and 136A)

Hi Matt,

Ok, here are my edits. Hope these help.

(See attached file: 2010-01-08 Follow-ups for Maggie and Greg (118A, 119A, 124A, 136A)__GP edits.docx)

Also, in PD response #78, when I re-did the FFG analysis, this response never got fixed.

(See attached file: PD #78 fix.doc)

ALSO, could you send me our Response #146A and 148A to make sure the corrected FFG tables are there?

Greg

Greg Pond

Office of Monitoring and Assessment
U.S. EPA Region 3
1060 Chapline Street, Suite 303
Wheeling, WV 26003-2995
(p) 304-234-0243
(f) 304-234-0260
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Website: http://epa.gov/reg3esd1/3ea50.htm

Matthew Klasen---01/08/2011 01:26:38 AM---Hey Maggie and Greg, [Stef may have already followed up with you on these responses since this (yes

From: Matthew Klasen/DC/USEPA/US
To: Margaret Passmore/R3/USEPA/US@EPA, Greg Pond/R3/USEPA/US@EPA
Cc: Stefania Shamet/R3/USEPA/US@EPA
Date: 01/08/2011 01:26 AM
Subject: Follow-ups after Kevin's comments (118A, 119A, 124A, and 136A)

Hey Maggie and Greg,

[Stef may have already followed up with you on these responses since this (yesterday) morning -- if so, ignore this note.]

I thought you both would be best to respond to a few of Kevin's substantive comments generated during his review of our RD comment responses. I've attached the four comments/ response (including Kevin's comments) that I thought you would be best to respond to. Comment numbers are 118A, 119A, 124A, and 136A.

To summarize Kevin's comments (shown in the margins of the attachment) :
(b) (5)
[redacted]

Let me know if you have any questions about these. I don't expect these four responses to take much time at all -- and responses in Track Changes format would be great.

Thanks for your amazing help throughout this process!

Ciao,
Matt

Matt Klasen
U.S. Environmental Protection Agency
Office of Water (IO)
202-566-0780
cell (202) 380-7229[attachment "2010-01-08 Follow-ups for Maggie and Greg (118A, 119A, 124A, 136A).docx" deleted by Greg Pond/R3/USEPA/US]

[attachment "2010-01-08 Follow-ups for Maggie and Greg (118A, 119A, 124A, 136A)__GP edits.docx" removed by Matthew Klasen/DC/USEPA/US]

[attachment "PD #78 fix.doc" removed by Matthew Klasen/DC/USEPA/US] - 2010-01-08 146A, 148A for Greg Pond.docx - PD #78 fix.doc

ATTACHMENTS REDACTED - DELIBERATIVE

Nancy Stoner/DC/USEPA/US
01/08/2011 10:02 AM

To "Travis Loop"
cc
bcc
Subject Fw: Oct 8 House Dems letter to LPJ on Spruce & signatories

This is just fyi
Gregory Peck

----- Original Message -----
From: Gregory Peck
Sent: 01/07/2011 02:32 PM EST
To: David McIntosh
Cc: Nancy Stoner; Bob Sussman; Betsaida Alcantara; Kevin Minoli; Denise Keehner
Subject: Fw: Oct 8 House Dems letter to LPJ on Spruce & signatories

David:

For OCIR's purposes based on our 1 pm meeting, attached is a summary of the October 8 letter to the Administrator with respect to Spruce. (b) (5) [redacted]

Also attached is the letter itself.

Best,
Greg

2011-01-07 Signatories of 10-8-10 House Letter to EPA re MTM, Spruce.docx EPA Mountaintop Removal Letter 10-8-10.pdf

Document Withheld-FOIA(b)(5)

Congress of the United States
Washington, DC 20515

October 8, 2010

The Honorable Lisa P. Jackson
Administrator
U.S. Environmental Protection Agency
1200 Pennsylvania Avenue, NW
Washington, DC 20460

Dear Administrator Jackson,

We write in support of the actions that the Environmental Protection Agency has taken recently to protect the public and the environment from the devastating effects of surface coal mining in Appalachia. Although we continue to support Congressional action to pass the Clean Water Protection Act as the ultimate protection against mountaintop removal and valley fills, the interim administration actions that the EPA has taken under your leadership represent significant progress for communities struggling in the shadow of mining and for the environment.

As you know, surface mining in the steep slopes of Appalachia has disrupted the biological integrity of an area about the size of Delaware, buried approximately 2,000 miles of streams with mining waste, and contaminated downstream areas with toxic and bioaccumulative selenium. Protections required by federal laws, such as the Clean Water Act, were not enforced, and key rules, such as the Clean Water Act's definition of fill material, were changed for the benefit of the coal mining industry.

The guidance your agency issued on April 1 for improving EPA review of surface mining operations under the Clean Water Act, the National Environmental Policy Act and the Environmental Justice Executive Order marks a long-needed assertion of EPA oversight based on recent, peer-reviewed research. When scientific research shows that surface mining routinely violates downstream water quality standards, it is critical for EPA to ensure that states and mining companies are aware of the pollution levels that cause harm, that discharge permits incorporate adequate safeguards, and that the permits are enforced.

We are also pleased that EPA's guidance commits to ensure that potential impacts on low-income Appalachian communities are considered in permit decision-making processes. This action will breathe life into the long-overlooked Executive Order 12898, which requires federal agencies to make environmental justice part of their mission.

In addition to this policy guidance, we applaud EPA's proposed veto of the Clean Water Act permit for Spruce No. 1 Mine in West Virginia. One of the largest surface mines in Appalachia, it would bury more than seven miles of headwater streams, directly impact 2,278 acres of forestland, and degrade water quality in streams adjacent to the mine. This proposed veto, an extremely rare action in the history of the Clean Water Act, demonstrates the EPA's seriousness in curtailing mountaintop removal.

PRINTED ON RECYCLED PAPER

The ultimate success of the new guidance depends upon effective implementation by EPA and its regional offices. Mining companies and some state agencies may reject this guidance, but we strongly urge the EPA to carry it out aggressively. In addition Congress must act to pass laws, such as the Clean Water Protection Act, which makes these protections more permanent. Nothing less will protect Appalachia from the devastation of mountaintop removal mining.

We appreciate the strong leadership you have shown in basing EPA's new policies soundly on the latest science and taking action needed to implement the nation's environmental and public health laws.

Sincerely,

FRANK PALLONE, JR.
Member of Congress

EARL BLUMENAUER
Member of Congress

CAROLYN C. KILPATRICK
Member of Congress

DORIS O. MATSUI
Member of Congress

DEBBIE WASSERMAN SCHULTZ
Member of Congress

WILLIAM L. OWENS
Member of Congress

FORTNEY PETE STARK
Member of Congress

RAÚL M. GRIJALVA
Member of Congress

HENRY A. WAXMAN
Member of Congress

JOHN A. YARMUTH
Member of Congress

DIANA DEGETTE
Member of Congress

HOWARD L. BERMAN
Member of Congress

MAXINE WATERS
Member of Congress

BETTY MCCOLLUM
Member of Congress

DENNIS J. KUCINICH
Member of Congress

LYNN C. WOOLSEY
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JESSE L. JACKSON, JR.
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JARED POLIS
Member of Congress

LOIS CAPPS
Member of Congress

KEITH ELLISON
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JAMES P. MORAN
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JOHN LEWIS
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LAURA RICHARDSON
Member of Congress

TAMMY BALDWIN
Member of Congress

THOMAS S.P. PERRIELLO
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BOB FILNER
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MAURICE D. HINCHEY
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DAVID WU
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CHELLIE PINGREE
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PATRICK J. KENNEDY
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JERRY MCNERNEY
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DONNA F. EDWARDS
Member of Congress

LINDA T. SANCHEZ
Member of Congress

JUDY CHU
Member of Congress

BARBARA LEE
Member of Congress

JAMES P. MCGOVERN
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STEVE COHEN
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DENNIS MOORE
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RUSH D. HOLT
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LLOYD DOGGETT
Member of Congress

BARNEY FRANK
Member of Congress

ELEANOR HOLMES NORTON
Member of Congress

GERALD E. CONNOLLY
Member of Congress

CAROL SHEA-PORTER
Member of Congress

MIKE QUIGLEY
Member of Congress

Nancy Stoner/DC/USEPA/US
01/08/2011 10:03 AM

To "Travis Loop"
cc
bcc
Subject Fw: Spuce Fact Sheet: Somre Recommended Edits adn A Question

Denise Keehner

----- Original Message -----
From: Denise Keehner
Sent: 01/07/2011 02:32 PM EST
To: Gregory Peck
Cc: Brian Frazer; Christopher Hunter; Karyn Wendelowski; Kevin Minoli; Matthew Klasen; Nancy Stoner; Stefania Shamet
Subject: Re: Spuce Fact Sheet: Somre Recommended Edits adn A Question

ATTACHMENT REDACTED - DELIBERATIVE

Mining Spruce Draft Fact Sheet JAN 07 11dkedits.doc

Gregory Peck | When you have a chance, please review the atta... | 01/07/2011 12:03:48 PM

From: Gregory Peck/DC/USEPA/US
To: Nancy Stoner/DC/USEPA/US@EPA, Matthew Klasen/DC/USEPA/US@EPA, Denise Keehner/DC/USEPA/US@EPA, Brian Frazer/DC/USEPA/US@EPA, Christopher Hunter/DC/USEPA/US@EPA, Stefania Shamet/R3/USEPA/US@EPA, Kevin Minoli, Karyn Wendelowski/DC/USEPA/US@EPA
Date: 01/07/2011 12:03 PM
Subject: Spuce Fact Sheet

When you have a chance, please review the attached Fact Sheet we'll be using as part of the communications materials to summarize the Spruce Final Determination.

Steph - please don't forget to send me the R3 comments on the draft PR - thanks.

Greg

[attachment "Mining Spruce Draft Fact Sheet JAN 07 11.doc" deleted by Denise Keehner/DC/USEPA/US]

Karyn Wendelowski/DC/USEPA/US
01/08/2011 12:44 PM

To Gregory Peck
cc Christopher Hunter, Kevin Minoli, Matthew Klasen, Stefania Shamet
bcc
Subject Executive summary

(b) (5) [redacted]

ATTACHMENT REDACTED - DELIBERATIVE

Revised Spruce 404c Executive summary kw edits.doc

Christopher Hunter/DC/USEPA/US

01/08/2011 01:09 PM

To Matthew Klasen

cc

bcc

Subject WVDEP Responses

Hi Matt,
minor cleanup edits from me on the WVDEP responses.

Thanks

Chris Hunter
U.S. Environmental Protection Agency
Office of Wetlands, Oceans, & Watershed
(202) 566-1454

hunter.christopher@epa.gov - 2011-01-06 Compiled WVDEP RD Comment Responses - CH.doc

ATTACHMENT REDACTED - DELIBERATIVE

Kevin Minoli/DC/USEPA/US
01/08/2011 01:09 PM

To Matthew Klasen
cc Christopher Hunter, Gregory Peck, Karyn Wendelowski, Stefania Shamet
bcc
Subject Re: 181A-200A (almost the last numbered batch)

ATTACHMENT REDACTED - DELIBERATIVE

Just a few very minor edits on these. 2011-07-07 181A-200A for Kevin.ksm.docx
181A-200A (almost the last numbered batch)

181A-200A (almost the last numbered batch)

Matthew Klasen to: Kevin Minoli 01/07/2011 05:14 PM

Cc: Christopher Hunter, Gregory Peck, Karyn Wendelowski, Stefania Shamet

---

Hey Kevin,

Given your imminent departure for the evening, I've split up the last batch into two sub-batches. This is 181A-200A (13 pages), which you can review in its entirety.

I'll follow up tonight or tomorrow AM with the final set to get us through the whole numbering system, and we'll follow up incrementally with the small group of questions that we withheld from your review until we nail down better answers.

Thanks,
Matt

Matt Klasen
U.S. Environmental Protection Agency
Office of Water (IO)
202-566-0780
cell (202) 380-7229

-----Kevin Minoli/DC/USEPA/US wrote: -----

To: Matthew Klasen/DC/USEPA/US@EPA
From: Kevin Minoli/DC/USEPA/US
Date: 01/07/2011 04:16PM
Cc: Christopher Hunter/DC/USEPA/US@EPA, Gregory Peck/DC/USEPA/US@EPA, Karyn Wendelowski/DC/USEPA/US@EPA, Stefania Shamet/R3/USEPA/US@EPA
Subject: Re: 140A-180A (with four exceptions

Here are my comments on these. There really are just a few. Bring on the last batch!

(See attached file: 2011-01-06 140A-180A for Kevin.ksm.docx)

Matthew Klasen---01/06/2011 06:06:42 PM---OK -- and here are 140A-180A. Four of them aren't ready for your final review (146A, 150A, 154A, an

From: Matthew Klasen/DC/USEPA/US
To: Kevin Minoli/DC/USEPA/US@EPA
Cc: Christopher Hunter/DC/USEPA/US@EPA, Gregory Peck/DC/USEPA/US@EPA, Karyn Wendelowski/DC/USEPA/US@EPA, Stefania Shamet/R3/USEPA/US@EPA
Date: 01/06/2011 06:06 PM
Subject: 140A-180A (with four exceptions

OK -- and here are 140A-180A. Four of them aren't ready for your final review (146A, 150A, 154A, and 165A). But we have good answers (I think) to each of these except 150A, so they're probably worth your time to read. These four comments/responses are highlighted in teal .

Note that this is the first "ORD-heavy" batch, beginning with 140A. I'm suggesting adding the boilerplate language in the text before 140A, and then each of the benchmark-focused responses that follows references parts of that language.

Thanks,
Matt

[attachment "2011-01-06 140A-180A for Kevin.docx" deleted by Kevin Minoli/DC/USEPA/US]

Matt Klasen
U.S. Environmental Protection Agency
Office of Water (IO)
202-566-0780
cell (202) 380-7229

Kevin Minoli---01/06/2011 05:52:57 PM---Here are my edits. No big issues from me. Thanks.

From: Kevin Minoli/DC/USEPA/US
To: Matthew Klasen/DC/USEPA/US@EPA
Cc: Christopher Hunter/DC/USEPA/US@EPA, Gregory Peck/DC/USEPA/US@EPA, Karyn Wendelowski/DC/USEPA/US@EPA, Stefania Shamet/R3/USEPA/US@EPA
Date: 01/06/2011 05:52 PM
Subject: Re: 114A-139A

Here are my edits. No big issues from me. Thanks.

[attachment "2011-01-06 114A-139A for Kevin.ksm.docx" deleted by Matthew Klasen/DC/USEPA/US]

Matthew Klasen---01/06/2011 12:33:05 PM---Hey Kevin, Here's another batch for you. Not too many

questions here (only 25), but lots of text, a

From: Matthew Klasen/DC/USEPA/US
To: Kevin Minoli/DC/USEPA/US@EPA
Cc: Gregory Peck/DC/USEPA/US@EPA, Stefania Shamet/R3/USEPA/US@EPA, Karyn Wendelowski/DC/USEPA/US@EPA, Christopher Hunter/DC/USEPA/US@EPA
Date: 01/06/2011 12:33 PM
Subject: 114A-139A

Hey Kevin,

Here's another batch for you. Not too many questions here (only 25), but lots of text, and very technical macroinvertebrate answers.

(b) (5) [redacted]

Stef: I kept 140 for the next batch because it's the first one that directly references the ORD report, so I'm going to take a shot at the preface language on that one, consistent with the group's conversation this morning.

Thanks,
Matt

[attachment "2011-01-06 114A-139A for Kevin.docx" deleted by Kevin Minoli/DC/USEPA/US]

Matt Klasen
U.S. Environmental Protection Agency
Office of Water (IO)
202-566-0780
cell (202) 380-7229

[attachment "2011-01-06 140A-180A for Kevin.ksm.docx" removed by Matthew Klasen/DC/USEPA/US][attachment "2011-07-07 181A-200A for Kevin.docx" deleted by Kevin Minoli/DC/USEPA/US]

Kevin Minoli/DC/USEPA/US
01/08/2011 02:33 PM

To Matthew Klasen
cc Christopher Hunter, Gregory Peck, Karyn Wendelowski, Stefania Shamet
bcc
Subject Re: 201A-242A (last numbered batch of RD responses)

And here are my comments on this batch.

ATTACHMENT REDACTED - DELIBERATIVE

2011-01-08 201A-242A for Kevin.ksm.docx

In going back through everything I realized I never commented on 96-150 on the PD comments (they came in while I was in Vermont and I lost track of them). If I get you comments on those by the end of the weekend can they still be added in? Sorry about that.
201A-242A (last numbered batch of RD responses)

201A-242A (last numbered batch of RD responses)

Matthew Klasen to: Kevin Minoli 01/08/2011 12:57 AM

Cc: Gregory Peck, Stefania Shamet, Karyn Wendelowski, Christopher Hunter

---

Hey Kevin,

Here are the last of the RD comment responses for your review (201A-242A -- 22 pages), representing the final batch of the numbering scheme. With this email, we've sent you 331 of the 345 total RD responses. You've already reviewed and sent back your comments on 276 of them.

Note that in this batch, I've flagged **201A-204A**, **212A-213A**, and **242A** as not yet ready for your review (again, in our favorite teal color).

Over the next couple days, we'll follow up with:
- Draft answers to these seven;
- Draft answers to the seven others we haven't given you to review (from earlier batches); and
- Revised responses to the comments you've asked to see again.

Let me know if you have any questions, and looking forward to our extra-special weekend check-in tomorrow morning.

Thanks,
Matt

Matt Klasen
U.S. Environmental Protection Agency
Office of Water (IO)
202-566-0780
cell (202) 380-7229[attachment "2011-01-08 201A-242A for Kevin.docx" deleted by Kevin Minoli/DC/USEPA/US]

Matthew Klasen/DC/USEPA/US
01/08/2011 03:07 PM

To Christopher Hunter
cc
bcc
Subject Re: RD Responses

Hey Chris,

Sorry for the delay (but back in the work business again).

Attached is the most recent draft. Nothing has changed in the first section (I don't think) if you've already started, but there are updates in the 100s range.

Just keep a running list of the things you've checked and let me know so I can delete the margin comments. I'll incorporate the most recent edits we got from Kevin this afternoon and send you the most recent version after that.

Thanks,
Mat

Matt Klasen
U.S. Environmental Protection Agency
Office of Water (IO)
202-566-0780
cell (202) 380-7229

-----Christopher Hunter/DC/USEPA/US wrote: -----

To: Matthew Klasen/DC/USEPA/US@EPA
From: Christopher Hunter/DC/USEPA/US
Date: 01/08/2011 01:11PM
Subject: RD Responses

Hi Matt,
I was going to work in reverse and start reviewing the RD comments and work my way back to the PD comments and revise them based on that. Should I use the version from yesterday morning, or do you have another version you'd like me to use?

Chris

Chris Hunter
U.S. Environmental Protection Agency
Office of Wetlands, Oceans, & Watershed
(202) 566-1454
hunter.christopher@epa.gov - 2011-01-06 Compiled H&W RD Comment Responses.docx

ATTACHMENT REDACTED - DELIBERATIVE

Gregory Peck/DC/USEPA/US
01/08/2011 05:14 PM

To Lynn Zipf, Betsy Behl
cc Matthew Klasen
bcc
Subject Fw: Spruce selenium response -- need your input on support for the 4 ppm whole body threshold

Lynn/Betsy - can we schedule a call with you all and Region 3 Monday to discuss this? Very important issue for the Spruce veto. Say 10:30? Thanks

Greg

From: Betsy Behl/DC/USEPA/US
To: Gregory Peck/DC/USEPA/US@EPA
Cc: Christopher Hunter/DC/USEPA/US@EPA, Ephraim King/DC/USEPA/US@EPA, Joe Beaman/DC/USEPA/US@EPA, Karyn Wendelowski/DC/USEPA/US@EPA, Kevin Minoli/DC/USEPA/US@EPA, Lynn Zipf/DC/USEPA/US@EPA, Matthew Klasen/DC/USEPA/US@EPA, stoner nancy@epa.gov, Charles Delos/DC/USEPA/US@EPA, Jim Hanlon/DC/USEPA/US@EPA
Date: 01/07/2011 05:36 PM
Subject: Re: Spruce selenium response -- need your input on support for the 4 ppm whole body threshold

---

Greg:

(b) (5) [redacted]

Betsy

Gregory Peck---01/02/2011 12:46:05 PM---Betsy and Joe: Hope you both are enjoying your 2011 so far. Thanks again for your help a couple wee

From: Gregory Peck/DC/USEPA/US
To: Betsy Behl/DC/USEPA/US@EPA, Joe Beaman/DC/USEPA/US@EPA
Cc: Matthew Klasen/DC/USEPA/US@EPA, Lynn Zipf/DC/USEPA/US@EPA, stoner.nancy@epa.gov, Ephraim King/DC/USEPA/US@EPA, Karyn Wendelowski/DC/USEPA/US@EPA, Kevin Minoli/DC/USEPA/US@EPA, Frank Borsuk/R3/USEPA/US@EPA, Christopher Hunter/DC/USEPA/US@EPA
Date: 01/02/2011 12:46 PM
Subject: Spruce selenium response -- need your input on support for the 4 ppm whole body threshold

---

Betsy and Joe:

Hope you both are enjoying your 2011 so far. Thanks again for your help a couple weeks ago in pulling together some selenium-related responses to comments on the Spruce #1 veto. (b) (5) [redacted]

[redacted]

Please give Matt or me a call if you have any questions. We're coming close to the finish line on the Spruce Final Determination and would appreciate a response as soon as you get a chance to review and talk with appropriate folks in your group.

Thanks,
Greg

(b) (5) [redacted]

[redacted]

[redacted]

To: Stefania Shamet/R3/USEPA/US@EPA, John Forren/R3/USEPA/US@EPA, Margaret Passmore/R3/USEPA/US@EPA, borsuk.frank@epa.gov
From: Frank Borsuk/R3/USEPA/US

Date: 12/29/2010 11:21AM
Cc: Matthew Klasen/DC/USEPA/US@EPA, Christopher Hunter/DC/USEPA/US@EPA, David Rider/R3/USEPA/US@EPA, David Kargbo/R3/USEPA/US@EPA
Subject: Response Supplement #67 Selenium - Support for the 4 ppm whole body threshold

(b)
(5)

(See attached file: Hamilton_2003.pdf) (See attached file: Peterson et al 2009 selenium.pdf)

Hamilton

(b)
(5)

(b) (5)

[redacted]

[redacted]

Aquatic/Fisheries Biologist
Freshwater Biology Team
USEPA-Region 3 (Wheeling Office)
Office of Monitoring & Assessment (3EA50)
Environmental Assessment & Innovation Division
1060 Chapline Street, Suite 303
Wheeling, WV 26003-2995
304-234-0241 Phone
304-234-0260 Fax
borsuk.frank@epa.gov

Please visit our website at http://epa.gov/reg3esd1/3ea50.htm

(See attached file: Hamilton_2003.pdf) (See attached file: Peterson et al 2009 selenium.pdf)

[attachment "Hamilton_2003.pdf" removed by Matthew Klasen/DC/USEPA/US]
[attachment "Peterson et al 2009 selenium.pdf" removed by Matthew Klasen/DC/USEPA/US]

Kevin Minoli/DC/USEPA/US
01/08/2011 06:32 PM

To Matthew Klasen
cc Christopher Hunter, Gregory Peck, Karyn Wendelowski, Stefania Shamet
bcc
Subject Kevin's Edits to 96-150 for the PD

Hey Matt- As I mentioned in my not earlier, I realized I had never sent my comments on Responses 96-150 of the PD comments. Here they are. Please let me know if there is a problem with making this changes.

Thanks, Kevin

ATTACHMENT REDACTED - DELIBERATIVE

PD Comments 96-150 From Kevin.doc

Christopher Hunter/DC/USEPA/US
01/09/2011 11:31 AM

To Karyn Wendelowski
cc Matthew Klasen, Minoli.Kevin, Peck.Gregory, "Stefania Shamet"
bcc
Subject Re: Fw: Qs and As -- comments by close of weekend (COW) please

My comments on top of Karyn's. Thanks

Chris Hunter
U.S. Environmental Protection Agency
Office of Wetlands, Oceans, & Watershed
(202) 566-1454
hunter.christopher@epa.gov

-----Karyn Wendelowski/DC/USEPA/US wrote: -----

To: Matthew Klasen/DC/USEPA/US@EPA
From: Karyn Wendelowski/DC/USEPA/US
Date: 01/08/2011 02:21PM
Cc: Hunter.Christopher@epamail.epa.gov, Minoli.Kevin@epamail.epa.gov, Peck.Gregory@epamail.epa.gov, "Stefania Shamet" <Shamet.Stefania@epamail.epa.gov>
Subject: Re: Fw: Qs and As -- comments by close of weekend (COW) please

I think these look good, here are a few edits:

Fw: Qs and As -- comments by close of weekend (COW) please

Matthew Klasen to: Hunter.Christopher, Frazer.Brian, Pendergast.Jim, Minoli.Kevin, Karyn Wendelowski, Stefania Shamet, Michael Dunn, David Evans 01/07/11 02:41 PM

cc: Peck.Gregory, Keehner.Denise, "Nancy Stoner"

Hi everyone,

In prep for a meeting earlier this afternoon w/ OEA and OCIR on communications and rollout, we pulled together the following Qs and As. These incorporate (I think) all the major contentions in the recent Hill letters, as well as earlier additions from Jim, Brian T., and Chris.

Please take a look and let me know if you have comments/edits by the end of the weekend. We'll then take the updated draft, make sure the question wording and responses are formatted consistent with AO expectations, and send up an updated version to them Monday.

(b) (6) [redacted]

Thanks,
Matt

Matt Klasen
U.S. Environmental Protection Agency
Office of Water
(202) 566-0780
Cell (202) 380-7229

----- Original Message -----
From: Matthew Klasen
Sent: 01/07/2011 12:37 PM EST
To: Gregory Peck
Subject: Qs and As

Here they are. Want to take a quick look or want me to just go ahead and print?

Thanks,
Matt

[attachment "2011-01-07 Draft Spruce Q&As.doc" deleted by Karyn Wendelowski/DC/USEPA/US]

Matt Klasen
U.S. Environmental Protection Agency
Office of Water (IO)
202-566-0780
cell (202) 380-7229

[attachment "2011-01-07 Draft Spruce Q&A kw edits.doc" removed by Christopher Hunter/DC/USEPA/US] - 2011-01-07 Draft Spruce Q&A kw and ch edits.doc

ATTACHMENT REDACTED - DELIBERATIVE

Matthew Klasen/DC/USEPA/US
01/09/2011 01:28 PM

To: Christopher Hunter
cc:
bcc:
Subject: Fw: Re: For 9:30: Rough spreadsheet of comments with remaining to-dos from the Minoli-reviewed bunch

Hey Chris,

I'd added these to my spreadsheet on Friday but didn't follow up with folks yet. I was planning to send a couple around now, but wanted to make sure you haven't followed up yourself (?)

Let me know -- thanks!

mk

Matt Klasen
U.S. Environmental Protection Agency
Office of Water (IO)
202-566-0780
cell (202) 380-7229

-----Forwarded by Matthew Klasen/DC/USEPA/US on 01/09/2011 01:27PM -----

To: Matthew Klasen/DC/USEPA/US@EPA
From: Christopher Hunter/DC/USEPA/US
Date: 01/07/2011 10:24AM
Subject: Re: For 9:30: Rough spreadsheet of comments with remaining to-dos from the Minoli-reviewed bunch

Here are the outstanding comments from the PD responses.

Thanks
(See attached file: PD Comment to do.docx)

Chris Hunter
U.S. Environmental Protection Agency
Office of Wetlands, Oceans, & Watershed
(202) 566-1454
hunter.christopher@epa.gov

Matthew Klasen---01/07/2011 09:29:28 AM---Let's talk about this briefly at 9:30, and I can explain. Basically, these are all the questions t

From: Matthew Klasen/DC/USEPA/US
To: Gregory Peck/DC/USEPA/US@EPA, Brian Frazer/DC/USEPA/US@EPA, David

Evans/DC/USEPA/US@EPA, Jim Pendergast/DC/USEPA/US@EPA, Christopher Hunter/DC/USEPA/US@EPA, Palmer Hough/DC/USEPA/US@EPA, Kevin Minoli/DC/USEPA/US@EPA, Karyn Wendelowski/DC/USEPA/US@EPA, Stefania Shamet/R3/USEPA/US@EPA, Margaret Passmore/R3/USEPA/US@EPA, Greg Pond/R3/USEPA/US@EPA, Michael Dunn/R3/USEPA/US@EPA

Date: 01/07/2011 09:29 AM

Subject: For 9:30: Rough spreadsheet of comments with remaining to-dos from the Minoli-reviewed bunch

---

Let's talk about this briefly at 9:30, and I can explain.

Basically, these are all the questions that Kevin has reviewed that still have substantive margin comments. Some will be very easy to answer; others will take a bit more time. I'll plan to send the actual drafts after 9:30.

Thanks,
Matt

[attachment "Status Table.pdf" deleted by Christopher Hunter/DC/USEPA/US]

Matt Klasen
U.S. Environmental Protection Agency
Office of Water (IO)
202-566-0780

cell (202) 380-7229 - PD Comment to do.docx

ATTACHMENT REDACTED - DELIBERATIVE

Matthew Klasen/DC/USEPA/US
01/09/2011 04:53 PM

To Kevin Minoli, Karyn Wendelowski
cc Stefania Shamet, Christopher Hunter
bcc
Subject Legal follow-up on #103A

Kevin and Karyn,

I'm trying to troubleshoot some specific responses to comments and had a legal follow-up from Kevin's comments.

(b) (5) Deliberative Process Privilege and Attorney-Client Privilege [redacted]

Let me know if the response below will do the trick or whether we also need something new. For reference, the old answer just said "See Responses #169 and 170."

Thanks,
Matt

(b) (5) Deliberative Process Privilege and Attorney-Client Privilege [redacted]

Matt Klasen
U.S. Environmental Protection Agency
Office of Water (IO)
202-566-0780
cell (202) 380-7229

Stefania Shamet/R3/USEPA/US
01/10/2011 06:12 AM

To Matthew Klasen
cc
bcc
Subject 146A, 150A, 151A, 154A

A VERY frustrating morning with glitches on not one, but two computers. 74A and 79A require me to look at the mine plan and the TED in more detail to confirm that we are talking about the same thing in terms of mine plan,etc. Try as I might, I could not get those to come up on EITHER computer this morning, so I'll hunt down hard copies when I get to the office. 288A and 302A require looking at the CMP and SMCRA permit. (b) (5) [redacted]

You'll see my earlier email to Maggie asking her to expand a little on 86A.

Attached are 146A, 150A, 151A, and154A. Note that as to 146A, I think one of my emails got lost in the shuffle. I thought Greg Pond's last stab at it did what we needed it to do.

ATTACHMENT REDACTED - DELIBERATIVE

146A 150A 151A 154A.doc

Christopher Hunter/DC/USEPA/US
01/10/2011 07:44 AM

To Matthew Klasen
cc
bcc
Subject Re: Fw: Re: For 9:30: Rough spreadsheet of comments with remaining to-dos from the Minoli-reviewed bunch

Here are the remaining PD comments to check into. Kevin addressed #132 in his comments, so I took that one out.

Chris

ATTACHMENT REDACTED - DELIBERATIVE

Remaining PD Comments.docx

Chris Hunter
U.S. Environmental Protection Agency
Office of Wetlands, Oceans, & Watershed
(202) 566-1454
hunter.christopher@epa.gov

Matthew Klasen | OK thanks. I'll farm out the rest of these in the m... | 01/09/2011 07:00:59 PM

From: Matthew Klasen/DC/USEPA/US
To: Christopher Hunter/DC/USEPA/US@EPA
Date: 01/09/2011 07:00 PM
Subject: Re: Fw: Re: For 9:30: Rough spreadsheet of comments with remaining to-dos from the Minoli-reviewed bunch

---

OK thanks. I'll farm out the rest of these in the morning once I have a bit more context (though the dates in #81 are correct for the causal assessment).

I think we're doing well on RD comments; I've farmed out everything so far, with most of them either being Stef follow-ups or OST, which hopefully we'll deal with tomorrow morning.

In terms of trying to get everything wrapped up and signature ready by Wed COB, maybe we shoot for a several-hour cross-reference / proofreading session on the PD comments and RD comments on Tuesday sometime? Assuming the OST discussions tomorrow go well, I think we should have all the RD comments answered, reviewed by Kevin, and set by mid-day Tuesday.

Thanks,
Matt

Matt Klasen
U.S. Environmental Protection Agency
Office of Water (IO)
202-566-0780
cell (202) 380-7229

-----Christopher Hunter/DC/USEPA/US wrote: -----

To: Matthew Klasen/DC/USEPA/US@EPA
From: Christopher Hunter/DC/USEPA/US
Date: 01/09/2011 04:30PM

Subject: Re: Fw: Re: For 9:30: Rough spreadsheet of comments with remaining to-dos from the Minoli-reviewed bunch

I don't have a current electronic draft with me, I'll get it to you first thing in the morning.

Chris

Chris Hunter
U.S. Environmental Protection Agency
Office of Wetlands, Oceans, & Watershed
(202) 566-1454
hunter.christopher@epa.gov

-----Matthew Klasen/DC/USEPA/US wrote: -----

To: Christopher Hunter/DC/USEPA/US@EPA
From: Matthew Klasen/DC/USEPA/US
Date: 01/09/2011 03:41PM
Subject: Re: Fw: Re: For 9:30: Rough spreadsheet of comments with remaining to-dos from the Minoli-reviewed bunch

OK, I'll start sending them around. Can you send me the current PD comment draft for context on some of these ((b) (5) Deliberative Process Privilege and Attorney-Client Privilege [redacted]

Thanks,
Matt

Matt Klasen
U.S. Environmental Protection Agency
Office of Water (IO)
202-566-0780
cell (202) 380-7229

-----Christopher Hunter/DC/USEPA/US wrote: -----

To: Matthew Klasen/DC/USEPA/US@EPA
From: Christopher Hunter/DC/USEPA/US
Date: 01/09/2011 02:44PM
Subject: Re: Fw: Re: For 9:30: Rough spreadsheet of comments with remaining to-dos from the Minoli-reviewed bunch

Nope, there were a couple others I handled, but these were the ones I couldn't respond to.

Thanks

Chris Hunter
U.S. Environmental Protection Agency
Office of Wetlands, Oceans, & Watershed
(202) 566-1454
hunter.christopher@epa.gov

-----Matthew Klasen/DC/USEPA/US wrote: -----

To: Christopher Hunter/DC/USEPA/US@EPA
From: Matthew Klasen/DC/USEPA/US

Date: 01/09/2011 01:28PM
Subject: Fw: Re: For 9:30: Rough spreadsheet of comments with remaining to-dos from the Minoli-reviewed bunch

Hey Chris,

I'd added these to my spreadsheet on Friday but didn't follow up with folks yet. I was planning to send a couple around now, but wanted to make sure you haven't followed up yourself (?)

Let me know -- thanks!

mk

Matt Klasen
U.S. Environmental Protection Agency
Office of Water (IO)
202-566-0780
cell (202) 380-7229
-----Forwarded by Matthew Klasen/DC/USEPA/US on 01/09/2011 01:27PM -----

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From: Christopher Hunter/DC/USEPA/US
Date: 01/07/2011 10:24AM
Subject: Re: For 9:30: Rough spreadsheet of comments with remaining to-dos from the Minoli-reviewed bunch

Here are the outstanding comments from the PD responses.

Thanks
(See attached file: PD Comment to do.docx)

Chris Hunter
U.S. Environmental Protection Agency
Office of Wetlands, Oceans, & Watershed
(202) 566-1454
hunter.christopher@epa.gov

Matthew Klasen---01/07/2011 09:29:28 AM---Let's talk about this briefly at 9:30, and I can explain. Basically, these are all the questions t

From: Matthew Klasen/DC/USEPA/US
To: Gregory Peck/DC/USEPA/US@EPA, Brian Frazer/DC/USEPA/US@EPA, David Evans/DC/USEPA/US@EPA, Jim Pendergast/DC/USEPA/US@EPA, Christopher Hunter/DC/USEPA/US@EPA, Palmer Hough/DC/USEPA/US@EPA, Kevin Minoli/DC/USEPA/US@EPA, Karyn Wendelowski/DC/USEPA/US@EPA, Stefania Shamet/R3/USEPA/US@EPA, Margaret Passmore/R3/USEPA/US@EPA, Greg Pond/R3/USEPA/US@EPA, Michael Dunn/R3/USEPA/US@EPA
Date: 01/07/2011 09:29 AM

Subject: For 9:30: Rough spreadsheet of comments with remaining to-dos from the Minoli-reviewed bunch

---

Let's talk about this briefly at 9:30, and I can explain.

Basically, these are all the questions that Kevin has reviewed that still have substantive margin comments. Some will be very easy to answer; others will take a bit more time. I'll plan to send the actual drafts after 9:30.

Thanks,
Matt

[attachment "Status Table.pdf" deleted by Christopher Hunter/DC/USEPA/US]

Matt Klasen
U.S. Environmental Protection Agency
Office of Water (IO)
202-566-0780
cell (202) 380-7229

[attachment "PD Comment to do.docx" removed by Christopher Hunter/DC/USEPA/US]

Matthew Klasen/DC/USEPA/US
01/10/2011 08:56 AM

To Gregory Peck
cc
bcc
Subject Fw: Spruce selenium response -- need your input on support for the 4 ppm whole body threshold

This should work. If they could find a room, that would be great.

Matt Klasen
U.S. Environmental Protection Agency
Office of Water (IO)
202-566-0780
cell (202) 380-7229
----- Forwarded by Matthew Klasen/DC/USEPA/US on 01/10/2011 08:56 AM -----

From: Betsy Behl/DC/USEPA/US
To: Gregory Peck/DC/USEPA/US@EPA
Cc: Lynn Zipf/DC/USEPA/US@EPA, Matthew Klasen/DC/USEPA/US@EPA
Date: 01/10/2011 08:45 AM
Subject: Re: Fw: Spruce selenium response -- need your input on support for the 4 ppm whole body threshold

Greg: Would 11 be alright? I have a mandatory management meeting I need to attend from 10-11.

Gregory Peck | Lynn/Betsy - can we schedule a call with you all... | 01/08/2011 05:15:00 PM

From: Gregory Peck/DC/USEPA/US
To: Lynn Zipf/DC/USEPA/US@EPA, Betsy Behl/DC/USEPA/US@EPA
Cc: Matthew Klasen/DC/USEPA/US@EPA
Date: 01/08/2011 05:15 PM
Subject: Fw: Spruce selenium response -- need your input on support for the 4 ppm whole body threshold

Lynn/Betsy - can we schedule a call with you all and Region 3 Monday to discuss this? Very important issue for the Spruce veto. Say 10:30? Thanks

Greg

From: Betsy Behl/DC/USEPA/US
To: Gregory Peck/DC/USEPA/US@EPA
Cc: Christopher Hunter/DC/USEPA/US@EPA, Ephraim King/DC/USEPA/US@EPA, Joe Beaman/DC/USEPA/US@EPA, Karyn Wendelowski/DC/USEPA/US@EPA, Kevin Minoli/DC/USEPA/US@EPA, Lynn Zipf/DC/USEPA/US@EPA, Matthew Klasen/DC/USEPA/US@EPA, stoner nancy@epa.gov, Charles Delos/DC/USEPA/US@EPA, Jim Hanlon/DC/USEPA/US@EPA
Date: 01/07/2011 05:36 PM
Subject: Re: Spruce selenium response -- need your input on support for the 4 ppm whole body threshold

Greg:

(b) (5)

Betsy

Gregory Peck---01/02/2011 12:46:05 PM---Betsy and Joe: Hope you both are enjoying your 2011 so far. Thanks again for your help a couple wee

From: Gregory Peck/DC/USEPA/US
To: Betsy Behl/DC/USEPA/US@EPA, Joe Beaman/DC/USEPA/US@EPA
Cc: Matthew Klasen/DC/USEPA/US@EPA, Lynn Zipf/DC/USEPA/US@EPA, stoner.nancy@epa.gov, Ephraim King/DC/USEPA/US@EPA, Karyn Wendelowski/DC/USEPA/US@EPA, Kevin Minoli/DC/USEPA/US@EPA, Frank Borsuk/R3/USEPA/US@EPA, Christopher Hunter/DC/USEPA/US@EPA
Date: 01/02/2011 12:46 PM
Subject: Spruce selenium response -- need your input on support for the 4 ppm whole body threshold

---

Betsy and Joe:

(b) (5)

Thanks,
Greg

(b) (5)

(b) (5)

To: Stefania Shamet/R3/USEPA/US@EPA, John Forren/R3/USEPA/US@EPA, Margaret Passmore/R3/USEPA/US@EPA, borsuk.frank@epa.gov
From: Frank Borsuk/R3/USEPA/US
Date: 12/29/2010 11:21AM
Cc: Matthew Klasen/DC/USEPA/US@EPA, Christopher Hunter/DC/USEPA/US@EPA, David Rider/R3/USEPA/US@EPA, David Kargbo/R3/USEPA/US@EPA
Subject: Response Supplement #67 Selenium - Support for the 4 ppm whole body threshold

Stef:

(b) (5)

(b) (5)

(b) (5)

[redacted]

Frank Borsuk, Ph.D.
Aquatic/Fisheries Biologist
Freshwater Biology Team
USEPA-Region 3 (Wheeling Office)
Office of Monitoring & Assessment (3EA50)
Environmental Assessment & Innovation Division
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borsuk.frank@epa.gov

Please visit our website at http://epa.gov/reg3esd1/3ea50.htm

(See attached file: Hamilton_2003.pdf) (See attached file: Peterson et al 2009 selenium.pdf)

[attachment "Hamilton_2003.pdf" removed by Matthew Klasen/DC/USEPA/US]
[attachment "Peterson et al 2009 selenium.pdf" removed by Matthew Klasen/DC/USEPA/US]

Matthew Klasen/DC/USEPA/US
01/10/2011 09:53 AM

To Travis Loop
cc
bcc
Subject Fw: spuce mine materials

Hey Travis,

Did you have comments on the Qs & As too? My note assumed you did, but I took a closer look at the attachments and I don't see them below.

Thanks,
Matt

Matt Klasen
U.S. Environmental Protection Agency
Office of Water (IO)
202-566-0780
cell (202) 380-7229
----- Forwarded by Matthew Klasen/DC/USEPA/US on 01/10/2011 09:27 AM -----

From: Travis Loop <tloop@chesapeakebay.net>
To: Nancy Stoner/DC/USEPA/US@EPA, Gregory Peck/DC/USEPA/US@EPA, Matthew Klasen/DC/USEPA/US@EPA
Date: 01/10/2011 08:58 AM
Subject: spuce mine materials

(b) (6) [redacted]

[redacted]

[redacted]

[redacted]

[redacted]

(b) (6) [redacted]

[redacted]

Travis Loop

Office of Water

U.S. Environmental Protection Agency

office: 202.564.0183

cell: 443.510.1571

Mining Spruce DRAFT Press Release JAN 05 11 v. 2 TL edits.docx Mining Spruce Draft Fact Sheet JAN 07 11dkedits TL edits.doc

---

ATTACHMENTS REDACTED - DELIBERATIVE

Betsy Behl/DC/USEPA/US	To	Gregory Peck, "Joe Beaman"
01/10/2011 10:54 AM	cc	
	bcc	
	Subject	Re: Fw: Spruce selenium response -- need your input on support for the 4 ppm whole body threshold

My office? 5233H
to ----------\Sent by EPA Wireless E-Mail Services.
Gregory Peck

----- Original Message -----
From: Gregory Peck
Sent: 01/10/2011 09:53 AM EST
To: Betsy Behl
Cc: Lynn Zipf; Matthew Klasen
Subject: Re: Fw: Spruce selenium response -- need your input on support for the 4 ppm whole body threshold
Betsy

Lets keep 11 this morning - do you have a room we can use?

Thanks,
Greg

Betsy Behl	Greg: Would 11 be alright? I have a mandatory...	01/10/2011 08:45:31 AM

From:	Betsy Behl/DC/USEPA/US
To:	Gregory Peck/DC/USEPA/US@EPA
Cc:	Lynn Zipf/DC/USEPA/US@EPA, Matthew Klasen/DC/USEPA/US@EPA
Date:	01/10/2011 08:45 AM
Subject:	Re: Fw: Spruce selenium response -- need your input on support for the 4 ppm whole body threshold

Greg: Would 11 be alright? I have a mandatory management meeting I need to attend from 10-11.

Gregory Peck	Lynn/Betsy - can we schedule a call with you all...	01/08/2011 05:15:00 PM

From:	Gregory Peck/DC/USEPA/US
To:	Lynn Zipf/DC/USEPA/US@EPA, Betsy Behl/DC/USEPA/US@EPA
Cc:	Matthew Klasen/DC/USEPA/US@EPA
Date:	01/08/2011 05:15 PM
Subject:	Fw: Spruce selenium response -- need your input on support for the 4 ppm whole body threshold

Lynn/Betsy - can we schedule a call with you all and Region 3 Monday to discuss this? Very important issue for the Spruce veto. Say 10:30? Thanks

Greg

From:	Betsy Behl/DC/USEPA/US
To:	Gregory Peck/DC/USEPA/US@EPA
Cc:	Christopher Hunter/DC/USEPA/US@EPA, Ephraim King/DC/USEPA/US@EPA, Joe Beaman/DC/USEPA/US@EPA, Karyn Wendelowski/DC/USEPA/US@EPA, Kevin Minoli/DC/USEPA/US@EPA, Lynn Zipf/DC/USEPA/US@EPA, Matthew Klasen/DC/USEPA/US@EPA, stoner nancy@epa.gov, Charles

Delos/DC/USEPA/US@EPA, Jim Hanlon/DC/USEPA/US@EPA
Date: 01/07/2011 05:36 PM
Subject: Re: Spruce selenium response -- need your input on support for the 4 ppm whole body threshold

---

Greg:

(b) (5) [redacted]

Betsy

Gregory Peck---01/02/2011 12:46:05 PM---Betsy and Joe: Hope you both are enjoying your 2011 so far. Thanks again for your help a couple wee

From: Gregory Peck/DC/USEPA/US
To: Betsy Behl/DC/USEPA/US@EPA, Joe Beaman/DC/USEPA/US@EPA
Cc: Matthew Klasen/DC/USEPA/US@EPA, Lynn Zipf/DC/USEPA/US@EPA, stoner.nancy@epa.gov, Ephraim King/DC/USEPA/US@EPA, Karyn Wendelowski/DC/USEPA/US@EPA, Kevin Minoli/DC/USEPA/US@EPA, Frank Borsuk/R3/USEPA/US@EPA, Christopher Hunter/DC/USEPA/US@EPA
Date: 01/02/2011 12:46 PM
Subject: Spruce selenium response -- need your input on support for the 4 ppm whole body threshold

---

Betsy and Joe:

Hope you both are enjoying your 2011 so far. Thanks again for your help a couple weeks ago in pulling together some selenium-related responses to comments on the Spruce #1 veto. (b) (5) [redacted]

Thanks,
Greg

(b) (5)

To: Stefania Shamet/R3/USEPA/US@EPA, John Forren/R3/USEPA/US@EPA, Margaret Passmore/R3/USEPA/US@EPA, borsuk.frank@epa.gov
From: Frank Borsuk/R3/USEPA/US
Date: 12/29/2010 11:21AM
Cc: Matthew Klasen/DC/USEPA/US@EPA, Christopher Hunter/DC/USEPA/US@EPA, David Rider/R3/USEPA/US@EPA, David Kargbo/R3/USEPA/US@EPA
Subject: Response Supplement #67 Selenium - Support for the 4 ppm whole body threshold

Stef:

(b) (5)

(b) (5)

(b) (5)

[redacted]

Frank Borsuk, Ph.D.
Aquatic/Fisheries Biologist
Freshwater Biology Team
USEPA-Region 3 (Wheeling Office)
Office of Monitoring & Assessment (3EA50)
Environmental Assessment & Innovation Division
1060 Chapline Street, Suite 303
Wheeling, WV 26003-2995
304-234-0241 Phone
304-234-0260 Fax
borsuk.frank@epa.gov

Please visit our website at http://epa.gov/reg3esd1/3ea50.htm

(See attached file: Hamilton_2003.pdf) (See attached file: Peterson et al 2009 selenium.pdf)

[attachment "Hamilton_2003.pdf" removed by Matthew Klasen/DC/USEPA/US]
[attachment "Peterson et al 2009 selenium.pdf" removed by Matthew Klasen/DC/USEPA/US]

Matthew Klasen/DC/USEPA/US
01/10/2011 01:13 PM

To Margaret Passmore
cc Greg Pond, John Forren, Stefania Shamet
bcc
Subject Re: 86A

Hi Maggie,

I'll add in all the cross-refs you suggested; I forgot to do so last week. I'm assuming no updates to the version you sent out on the 2nd?

Thanks,
Matt

Matt Klasen
U.S. Environmental Protection Agency
Office of Water (IO)
202-566-0780
cell (202) 380-7229

Margaret Passmore Hi Stef, (b) (5) [redacted] 01/10/2011 07:50:11 AM

From: Margaret Passmore/R3/USEPA/US
To: Stefania Shamet/R3/USEPA/US@EPA
Cc: John Forren/R3/USEPA/US@EPA, Matthew Klasen/DC/USEPA/US@EPA, Greg Pond/R3/USEPA/US@EPA
Date: 01/10/2011 07:50 AM
Subject: Re: 86A

Hi Stef,

(b) (5) [redacted]

[redacted]

[redacted]

[redacted]

(b) (5)

[redacted]

How much do valley fills influence headwater streams?

Kyle J. Hartman*, Michael D. Kaller, John W. Howell & John A. Sweka
Division of Forestry, Wildlife and Fisheries Program, West Virginia University, 322 Percival Hall,
Morgantown, WV 26506-6125, USA

(*Author for correspondence: Tel.: +1-304-293-2941 Ext. 2494, Fax: +1-304-293-2441, E-mail: hartman@wvu.edu)
Received 23 September 2003; accepted 28 April 2004
Key words: valley fill, macroinvertebrate metrics, mining, Ephemeroptera, specific conductance

Abstract
Valley fill mining has the potential to alter headwater stream habitat in many areas in the eastern United
States. In valley fill mining, overburden is removed to expose underlying coal seams. The overburden is
then deposited in the adjacent valley. The deposited overburden from mining increases sedimentation,
increases stream conductivity, and alters hydrologic regimes downstream of the fill. Changes in downstream
communities are not well documented. However, it was suspected the increased sedimentation and conductivity
would have deleterious effects upon the downstream macroinvertebrate communities. In southern
West Virginia, four pairs of streams, each consisting of a fill and a reference stream, were selected as
representative of watersheds experiencing valley fill mining. Stream pairs were selected for similar environmental
conditions, with one stream having a valley fill in its headwaters. Each stream was sampled by
replicate Surber samples (n ¼ 9 per stream). Water chemistry and sediment measurements also were taken
at each location. Valley fill streams experienced significantly higher specific conductance ($p<0.01$), but did
not have elevated levels of fine sediment. Fills exhibited elevated levels of Na, K, Mn, Mg, Ca, Ni and Fe
relative to reference streams. Additionally, valley fill streams demonstrated significantly lower densities of
Ephemeroptera, Coleoptera, Odonata, Non-insects, Scrapers, and Shredders ($p<0.03$) than reference
streams. Further, Ephemeroptera richness was negatively related to specific

conductivity and many of the
richness metrics were negatively related to metals, both of which were
generally elevated in fill streams. It
appears that at the minimum, valley fills increase specific conductance and
metals in streams and this or
some other unqualified factors structure the macroinvertebrate community
downstream of the valley fill.
**However, given the level of disturbance in valley fills, it is surprising how
little differences existed between
fills and reference stream biota.**

Table 1. Summary of water quality characteristics in the study streams

Stream	Type	pH	SE	Tempera-ture	SE	Dissolved oxygen (mg/l)	SE	Specific conductance (muhm/s)	S
Atkins Creek	Fill	7.4	0.3	14.8	0.3	13.0	0.3	1479.0	[illegible]
	Reference	7.0	0.2	15.0	0.8	12.6	0.3	133.0	[illegible]
Hill Fork	Fill	7.5	0.2	10.0	0.7	13.0	0.3	502.0	[illegible]
Big Buck Fork	Reference	6.7	0.3	13.2	1.2	13.4	0.2	160.1	[illegible]
Rockhouse Creek	Fill	7.2	0.3	12.8	0.6	9.3	0.3	1024.3	1[illegible]
Bend Branch	Reference	6.5	0.3	15.2	0.3	11.4	0.2	47.6	[illegible]
Sugar Tree Creek	Fill	7.5	0.5	17.6	0.3	9.1	0.5	1198.6	[illegible]
	Reference	6.5	0.2	16.2	0.6	8.5	0.4	259.7	[illegible]

Mean values followed by the standard error for each water quality parameter for three sites in each stream are listed.

Table 5. Results of Wilcoxon 2 Sample test for comparisons of invertebrate metrics in fill and reference streams

Metric	Mean score (fill)	Mean score (ref.)	$Pr > \|Z\|$
Coleoptera density	27.1	41.2	0.0027
Diptera density	33.2	33.9	0.8772
Ephemeroptera density	26.6	41.8	0.0009
Odonata density	29.9	37.8	0.0282
Plecoptera density	31.6	35.8	0.3742
Trichoptera density	35.5	31.1	0.3629
Total density	31.7	35.7	0.4062
EPT density	32.3	35.0	0.5579
Chironomidae density	33.0	34.1	0.8317
Non-insect density	28.9	39.0	0.0337
Collector density	32.7	34.5	0.6992
Scraper density	27.5	40.7	0.0034
Shredder density	28.0	40.2	0.0102

Sample sizes were 33 and 36 for reference and fills, respectively.

Table 6. Summary of correlation between mean aquatic macroinvertebrate metrics and mean water quality measure for each stream

Metric	Variable	Pearson's	
		R	*p*
Ephemeroptera richness	Ca	−0.8224	0.0122
Ephemeroptera richness	Cu	−0.9762	0.0001
Ephemeroptera richness	Fe	−0.8360	0.0097
Ephemeroptera richness	Mn	−0.7367	0.0371
Ephemeroptera richness	Ni	−0.8604	0.0061
EPT richness	Ca	−0.7070	0.0499
EPT richness	Mn	−0.7959	0.0181
EPT richness	Ni	−0.7257	0.0416
Plecoptera richness	Cd	−0.7436	0.0345
Trichoptera richness	Sb	0.8430	0.0086
% Ephemeroptera	Cu	−0.8300	0.0108
% Ephemeroptera	Ni	−0.7458	0.0336
% Non-insects	Cr	−0.7475	0.0330
% Non-insects	Sb	−0.7316	0.0391
% Trichoptera	Sb	0.8199	0.0127

Only those metrics which were significantly correlated with a water quality parameter are presented, all others are $p > 0.05$.

Margaret Passmore
Freshwater Biology Team
Office of Monitoring and Assessment (3EA50)
Environmental Assessment and Innovation Division
USEPA Region 3
1060 Chapline Street, Suite 303
Wheeling, WV 26003-2995
(p) 304-234-0245
(f) 304-234-0260
passmore.margaret@epa.gov

Visit our website at http://epa.gov/reg3esd1/3ea50.htm

Stefania Shamet Hi Maggie. (b) (5) [redacted] 01/10/2011 05:29:38 AM

From: Stefania Shamet/R3/USEPA/US
To: Margaret Passmore/R3/USEPA/US@EPA
Cc: John Forren/R3/USEPA/US@EPA, Matthew Klasen/DC/USEPA/US@EPA
Date: 01/10/2011 05:29 AM
Subject: 86A

(b) (5) [redacted]

(b) (5)

Kevin Minoli/DC/USEPA/US
01/10/2011 01:51 PM

To Matthew Klasen
cc Christopher Hunter, Gregory Peck, Karyn Wendelowski, Stefania Shamet
bcc
Subject Re: Draft responses to Corps 2009 and 2010 letters (#11A and footnote)

Hey Matt- Yes I do think we should have a response. Here are my edits.

ATTACHMENT REDACTED - DELIBERATIVE

2011-01-10 Response #11A re Corps 9-30-09 and 11-29-10 letters.ksm.docx

Matthew Klasen (b) (5) [redacted]. 01/10/2011 12:04:52 PM

From: Matthew Klasen/DC/USEPA/US
To: Christopher Hunter/DC/USEPA/US@EPA
Cc: Gregory Peck/DC/USEPA/US@EPA, Karyn Wendelowski/DC/USEPA/US@EPA, Kevin Minoli/DC/USEPA/US@EPA, Stefania Shamet/R3/USEPA/US@EPA
Date: 01/10/2011 12:04 PM
Subject: Re: Draft responses to Corps 2009 and 2010 letters (#11A and footnote)

OK -- (b) (5) [redacted]

Thanks,
Matt

Matt Klasen
U.S. Environmental Protection Agency
Office of Water (IO)
202-566-0780
cell (202) 380-7229

Christopher Hunter (b) (5) [redacted] 01/10/2011 11:32:57 AM

From: Christopher Hunter/DC/USEPA/US
To: Matthew Klasen/DC/USEPA/US@EPA
Cc: Karyn Wendelowski/DC/USEPA/US@EPA, Gregory Peck/DC/USEPA/US@EPA, Kevin Minoli/DC/USEPA/US@EPA, Stefania Shamet/R3/USEPA/US@EPA
Date: 01/10/2011 11:32 AM
Subject: Re: Draft responses to Corps 2009 and 2010 letters (#11A and footnote)

(b) (5) [redacted]

Chris Hunter
U.S. Environmental Protection Agency
Office of Wetlands, Oceans, & Watershed
(202) 566-1454
hunter.christopher@epa.gov

Matthew Klasen	Hi everyone, I took a shot at writing up a draft re...	01/10/2011 09:08:31 AM

From: Matthew Klasen/DC/USEPA/US
To: Christopher Hunter/DC/USEPA/US@EPA, Karyn Wendelowski/DC/USEPA/US@EPA, Kevin Minoli/DC/USEPA/US@EPA, Gregory Peck/DC/USEPA/US@EPA, Stefania Shamet/R3/USEPA/US@EPA
Date: 01/10/2011 09:08 AM
Subject: Draft responses to Corps 2009 and 2010 letters (#11A and footnote)

Hi everyone,

I took a shot at writing up a draft response to the WVDEP 9-30-09 letter, consistent with our discussion on Saturday morning and a couple follow-up messages. The more I drafted the response, the more it seemed appropriate to rely upon references to the FD rather than responses to comments, given the fact that the letter came in a long time ago.

(b) (5)
[redacted]

Let me know your thoughts when you get a chance. I know this is wordier than I expected on Saturday (thinking that just cross-referencing would make sense), but I think it better does the job, given the significant attention that H&W paid to this letter.

Thanks,
Matt

[attachment "2011-01-10 Response #11A re Corps 9-30-09 and 11-29-10 letters.docx" deleted by Christopher Hunter/DC/USEPA/US]

Matt Klasen
U.S. Environmental Protection Agency
Office of Water (IO)
202-566-0780
cell (202) 380-7229

Matthew Klasen/DC/USEPA/US
01/10/2011 01:55 PM

To Lynn Zipf
cc Gregory Peck, Joe Beaman, Betsy Behl
bcc
Subject Add'l Spruce OST reviews (in addition to fish tissue)

Hi Lynn,

We had a good discussion this morning with Betsy and Joe on the fish tissue Se issues, and we're well on our way to getting that resolved.

There are three other Spruce responses that we'd like OST review of to make sure there aren't any problematic programmatic or policy statements.

Responses are attached, and they address the following:
(b) (5)
[redacted]

I'm guessing Joe or Betsy is the right person to review the first group, but not sure who is right for the second one. Can you let me know whether these looks OK after forwarding to the appropriate folks? COB today would be great, and again, the goal is just to ensure we're not overstepping policy- or program-wise with our specific responses on Spruce.

Happy to help explain more by phone if that would help.

Thanks,
Matt

ATTACHMENT REDACTED - DELIBERATIVE

2011-01-10 99A, 100A, 147A for OST.docx

Matt Klasen
U.S. Environmental Protection Agency
Office of Water (IO)
202-566-0780
cell (202) 380-7229

Bette Conway/R3/USEPA/US
01/10/2011 02:46 PM

To Linda Boornazian
cc
bcc
Subject Fw: Revised pros and cons and combined Wheeling comments re WV Guidance

Linda, I believe Stef mentioned sending this to you during our meeting today.... FYI,

Bette Conway
EPA Region III
Water Protection Division
NPDES Permits Branch
1650 Arch Street, (3WP41)
Philadelphia PA 19103
Ph: 215-814-5744
Fax: 215-814-2301
conway.bette@epa.gov

----- Forwarded by Bette Conway/R3/USEPA/US on 01/10/2011 02:45 PM -----

From: Stefania Shamet/R3/USEPA/US
To: John Pomponio/R3/USEPA/US@EPA, Michael Dunn/R3/USEPA/US@EPA, John Forren/R3/USEPA/US@EPA, Jeffrey Lapp/R3/USEPA/US@EPA, Jessica Martinsen/R3/USEPA/US@EPA, Margaret Passmore/R3/USEPA/US@EPA, Greg Pond/R3/USEPA/US@EPA, Amy Bergdale/R3/USEPA/US@EPA, Jon Capacasa/R3/USEPA/US@EPA, Larry Merrill/R3/USEPA/US@EPA, Evelyn MacKnight/R3/USEPA/US@EPA, Francisco Cruz/R3/USEPA/US@EPA, Bette Conway/R3/USEPA/US@EPA, Cheryl Atkinson/R3/USEPA/US@EPA
Cc: Nina Rivera/R3/USEPA/US@EPA, Douglas Frankenthaler/R3/USEPA/US@EPA, Stephen Field/R3/USEPA/US@EPA, Marcia Mulkey/R3/USEPA/US@EPA, Jessica Greathouse/R3/USEPA/US@EPA
Date: 08/19/2010 06:10 AM
Subject: Revised pros and cons and combined Wheeling comments re WV Guidance

---

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INTERNAL DELIBERATIONS
DO NOT RELEASE

(b) (5) Deliberative Process Privilege and Attorney-Client Privilege [redacted]

[redacted]

[redacted]

WV Guidance pros and cons.doc WVDEP guidance_PBT_081310_FBT combined.doc

ATTACHMENT REDACTED - ATTORNEY-CLIENT AND DELIBERATIVE

Marcel Tchaou/DC/USEPA/US
01/10/2011 02:59 PM

To Christopher Hunter
cc
bcc
Subject Fw: Because a day without yet MORE refrences for Spruce would be like a day w/o sunshine ....

****

Marcel K. Tchaou, Ph.D., P.E., P.H.
Environmental Engineer
Wetlands & Aquatic Resources Regulatory Branch
Office of Wetlands, Oceans and Watersheds
U.S. EPA
1200 Pennsylvania Avenue, NW (MC 4502T)
Washington, DC 20460
202-566-1904

----- Forwarded by Marcel Tchaou/DC/USEPA/US on 01/10/2011 02:59 PM -----

From: Stefania Shamet/R3/USEPA/US
To: Marcel Tchaou/DC/USEPA/US@EPA, Carrie Traver/R3/USEPA/US@EPA
Date: 01/10/2011 02:32 PM
Subject: Because a day without yet MORE refrences for Spruce would be like a day w/o sunshine ....

----- Forwarded by Stefania Shamet/R3/USEPA/US on 01/10/2011 02:30 PM -----

From: David Kargbo/R3/USEPA/US
To: Jeffrey Lapp/R3/USEPA/US@EPA
Cc: Christopher Hunter/DC/USEPA/US@EPA, Dave Campbell/R3/USEPA/US@EPA, David Rider/R3/USEPA/US@EPA, Frank Borsuk/R3/USEPA/US@EPA, John Forren/R3/USEPA/US@EPA, Kevin Minoli/DC/USEPA/US@EPA, Margaret Passmore/R3/USEPA/US@EPA, Matthew Klasen/DC/USEPA/US@EPA, Stefania Shamet/R3/USEPA/US@EPA, Stephen Field/R3/USEPA/US@EPA, John Pomponio/R3/USEPA/US@EPA
Date: 01/06/2011 06:24 PM
Subject: Comments on materials handling Plan for Spruce

Jeff;

Per your request, please see my comments on the materials handling Plan for Spruce. The referenced articles are attached.

Tomorrow id my compress day but I'll be checking my email if you need any additional help.

Dave. WORD ATTACHMENT REDACTED - DELIBERATIVE

Comments on MHP_Kargbo.doc
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Topic WQ-4

White Paper Topic: Prediction and Treatment of Selenium

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Date: October 21, 2005

A FRAMEWORK FOR SELENIUM STUDIES IN THE APPALACHIAN PLATEAUS

Introduction

A recent Environmental Impact Study (EIS) on the effects of mountaintop coal mining in West Virginia showed that concentrations of selenium (Se) in small streams and sediment ponds receiving drainage from valley fills can exceed the aquatic wildlife standard of 5 micrograms per liter (µg/L). Deleterious impacts of this finding have not been observed in the Appalachian Plateaus, but can be implied from other research.

During the past 20 years, scientists from the U.S. Geological Survey (USGS) and the U.S. Fish and Wildlife Service (USFWS) have collaborated on studies to understand the occurrence and impacts of Se in the environment. Initial studies were conducted during 1982-85 at the Kesterson Reservoir, National Wildlife Management Area in the Central Valley of California, where Se leached by irrigation of desert soils caused severe health problems for aquatic wildlife. Studies at Kesterson Reservoir led to the development of the Department of Interior Irrigation Drainage Program in 1985 to investigate impacts of irrigation drainage throughout the western United States.

Se is an essential micronutrient for animals, but it is also known to be the most toxic to mammals of all biologically essential elements; fish and birds are very sensitive to Se contamination in an aquatic environment. Se is passed from parents to offspring in eggs and, during critical stages of development and growth, is substituted for sulfur in amino acids that form structural and functional proteins. As Se exposure increases, toxic effects can range from suppression of the immune system, to reduced juvenile growth, to embryo mortality, to mass wasting in adults, to teratogenesis (lethal or sub-lethal deformities) in juveniles, to juvenile mortality, and finally to adult mortality.

Previous studies have shown that predators are more at risk than their prey. Aquatic organisms strongly bioaccumulate Se, maybe up to thousands of times the water concentration, but are unaffected by residues in their tissues that can cause reproductive failure when consumed by predator fish and aquatic birds. Bioaccumulation in aquatic food chains is the most important rout for the transfer of toxic levels of Se to upper trophic level species, including humans. However, some forage plants accumulate Se from contaminated soils or wastes and are toxic when ingested by grazing animals.

Although there is a significant body of scientific literature on the occurrence and impacts of Se, most of the studies have been in the western United States where climatic conditions generally are drier and there is less biodiversity. This paper will present a framework for investigating Se in the Appalachian Plateaus region of the eastern United States.

SELENIUM RESULTS FROM THE EIS ON MOUNTAINTOP COAL MINING AND OTHER STUDIES

Selenium in Stream Water and Bottom Sediments

Se was analyzed in 213 stream-water samples as part of the EIS; 66 samples, all collected downstream from valley fills, exceeded the aquatic wildlife standard of 5 µg/L. The median concentration of Se detected at EIS sites downstream from valley fills was 11.7 µg/L while the median concentration for un-mined sites was below the detection limit of 3 µg/L. Subsequent sampling by the West Virginia Department of Environmental Protection (WVDEP) detected Se in 126 of 909 stream-water samples and resulted in nine streams being placed on West Virginia's 2002 303(d) list; four are in the Coal River Basin (Beech Creek, Left Fork Beech Creek, Rockhouse Creek, and Buffalo Fork) where 121 of the 126 Se detections occurred, four are in the Guyandotte River Basin, and one is in the Gualey River Basin. During July 2002 through June 2003 all 11 samples from Left Fork Beech Creek exceeded the 5 µg/L Se aquatic-wildlife standard; all four samples collected during February through June 2002 exceeded 35 µg/L (WVDEP). Se detections were most common during low flow; 95 of 126 detections were associated with total suspended solids concentrations (TSS) of 5 milligrams per liter (mg/L) or less; the highest seven Se concentrations were associated with TSS < 3 mg/L. In contrast, when TSS exceeded 50 mg/L (indicating overland runoff) there were only three associated detections of Se.

An ongoing study by West Virginia University (WVU) determined that most (90%) of the Se in water samples from the Mud River is selenate (SeO_4^{2-}) while a Se in water from a sediment pond at the toe of a valley fill was less oxidized, with about 70% selenate. Selenate is generally mobile and occurs in the dissolved state in water.

Se concentrations in ten bottom-sediment samples collected by the USFWS from the Coal River Basin ranged from < 0.229 to 1.49 parts per million (ppm), with a median concentration of 0.416 ppm. Se concentrations in four bottom-sediment samples from the Mud River Basin ranged from < 0.0679 to 0.192 ppm. Se concentrations in 52 fine-grained (< 63 micrometers) bottom-sediment samples collected during the USGS National Water-Quality Assessment (NAWQA) of the Kanawha-New River Basin ranged from 0.3 ppm to 2.4 ppm, with a medium concentration of 0.95 ppm. Correlation analyses showed that bottom-sediment Se concentrations were related to the percent of the basin occupied by quarries, coal strip mines, and gravel pits ($r^2 = 0.529$) and to mean annual coal production during 1980-95 ($r^2 = 0.271$).

Sources of Selenium

Se is often associated with organic-rich deposits including coal and black shale, both of which are present in the Pennsylvanian-age rocks that occur at or near the surface in the Appalachian Plateaus province. Available data on the geochemistry of Pennsylvanian-age coal beds show that those very beds that are included in the mountaintop mining sequence (Clarion, Brookville, No. 5 block, Stockton, Coalburg, and Winifrede) have high concentrations of Se; median concentrations in these coal beds range from about 4.5 to 7 ppm and concentrations exceeding 10 ppm have been observed. Of course, during mountaintop mining, this sequence of coals is removed and, therefore, cannot be the source of Se detected in streams draining valley fills during the EIS.

If a specific rock stratum in the mountaintop mining sequence is enriched in Se, then the release of Se to the environment probably could be controlled by materials handling protocols. However, preliminary geochemical analyses of core sections collected through a joint program by the U.S. Geological Survey (USGS), the West Virginia Geological and Economic Survey (WVGES), and WVU indicate that the entire mountaintop mining geologic interval is enriched with Se and that coarser-grained siltstone has the highest concentrations. If these preliminary results indicating enrichment of Se throughout the mountaintop mining sequence hold true, then controlling the release of Se by materials-handling protocols would be problematic. Se may be enriched in wastes from coal-washing operations and in coal ash from power generation.

Selenium in Aquatic Wildlife

Se concentrations in 16 whole-body composite fish samples (ten creek chub, five blacknose dace, and one bluegill) collected by USFWS from ten sites in the Coal River Basin ranged from 0.845 to 6.89 ppm, dry weight; the median concentration was 3.59 ppm. Se concentrations in seven whole-body composite fish samples (five creek chub and two blacknose dace) collected by USFWS from four sites in the Mud River Basin ranged from < 0.481 to 6.85 ppm, dry weight; the median concentration was 4.13 ppm. Se concentrations in 27 fish-liver samples (19 rock bass, six common carp, one smallmouth bass, and one white sucker) collected from 19 sites during the USGS Kanawha-New River NAWQA ranged from 1.7 to 15 ppm, dry weight; the median concentration was 5.8 ppm. Correlation analysis showed a relation between Se concentrations in livers of Rock bass and stream-bottom sediment (r^2 = 0.568).

QUESTIONS CONCERNING THE OCCURRENCE AND IMPACTS OF SELENIUM IN THE APPALACHIAN PLATEUS

There are many unanswered questions about the occurrence of Se and its impacts on Appalachian Plateaus ecosystems:

1. What are the relations among rock strata and Se enrichment?
2. Are there other trace elements of concern associated with this geologic interval?
3. What is the geographic extent of the Se-enriched geologic interval?
4. What are the background concentrations of Se in streams draining the enriched area?
5. Have land disturbances in the enriched area released Se to the aquatic environment?
6. What is the amount of Se available for leaching from fill materials?
7. What processes (physical, chemical, and microbiological) control the leaching of Se?
8. What is the rate of Se leaching and does this rate decline through time?
9. Are there quantifiable relations between land disturbances (location, extent, and age) and the occurrence of Se in the aquatic environment?
10. What are the concentrations and loads of Se in water from underground mines?
11. What are concentrations of Se in waters from coal-washing operations?
12. What are Se concentrations in leachate from coal ash from power plants?
13. Can we predict the occurrence and transport of Se in the aquatic environment?

Impacts of Selenium

1. What are the food-web pathways for Se in the Appalachian Plateaus?
2. Are there any quantifiable Se impacts to aquatic wildlife in the mountaintop coal-mining area where aquatic-wildlife standards for Se in water have been exceeded?
3. Are there likely to be impacts to aquatic wildlife as land disturbances continue?
4. Are there quantifiable impacts to grazing animals; is there potential for impacts?
5. Can we predict impacts of Se on aquatic or terrestrial wildlife?

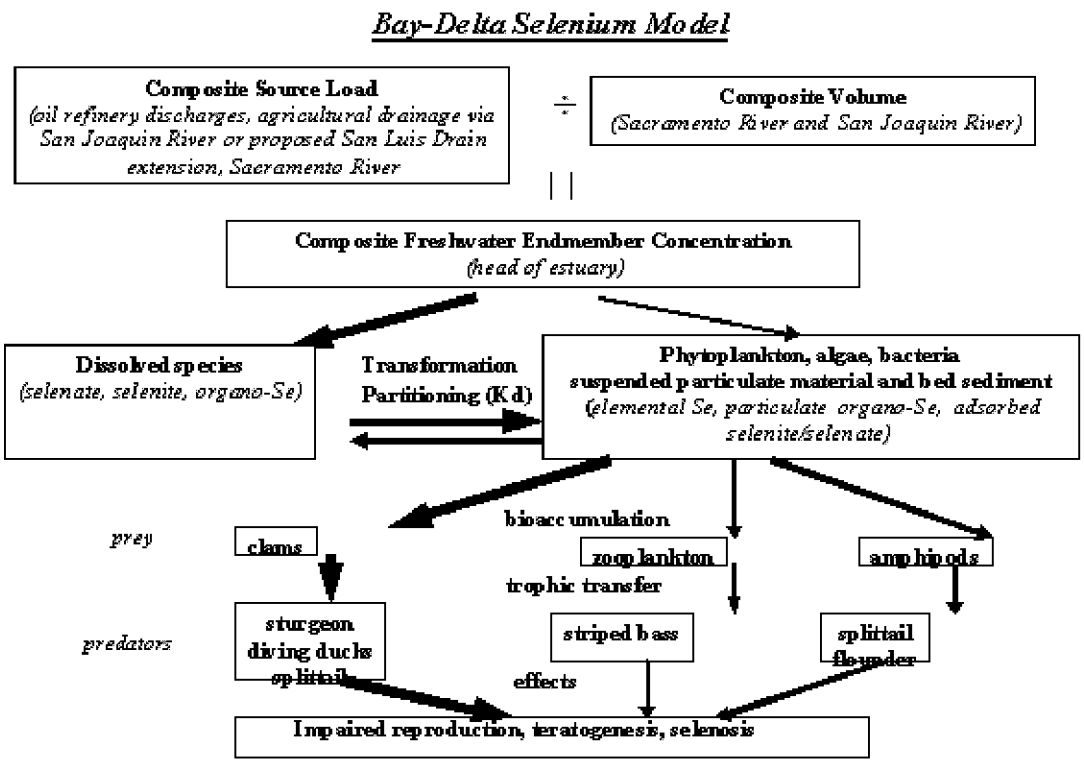
Mitigating / Remediating Selenium Impacts

1. Can Se impacts be mitigated/remediated by materials handling methods?
2. Can Se impacts be mitigated by limiting the extent of disturbances (dilution)?
3. Can Se impacts be mitigated/remediated by water treatments?

FRAMEWORK FOR INVESTIGATING SELENIUM IN THE APPALACHIAN PLATEAUS

An assessment of the occurrence and impacts of Se should:

1. Include the elements of occurrence, impacts, and mitigation discussed above.
2. Encompass the region where surface and near-surface rocks are Se enriched, probably based on coal trace-element and NURE data;
3. Include other trace elements that may be of concern in the region, as identified through a review of available data; and
4. Develop a model for predicting the occurrence and impacts of Se, like the following example for the San Francisco Bay area. A conceptual model for Se in the Appalachian Plateaus Data would be a good framework for designing scientific studies to provide necessary information.
5. Design, implement, and evaluate potential means of remediating Se contamination.



APPROACH

Phase 1 (first year)-- Develop a conceptual "Rock to Duck" Se model; assemble and evaluate available data and literature on Se in coal, rock strata, stream-bottom sediments, and tissues of aquatic and other wildlife; use available data to develop a preliminary model for predicting Se impacts, to estimate the geographic extent of Se enriched geologic sequence, and to evaluate relations among factors controlling the occurrence and impacts of Se; conduct biological impacts reconnaissance; integrate ongoing investigations; plan for Se monitoring and investigations.

Phase 2 (second through fifth years)-- Conduct data-collection activities and studies to provide information necessary to fill in gaps in describing, predicting, and mitigating the occurrence and impacts of Se; complete "Rock to Duck" Se model; report on findings.

Phase 3 (sixth through tenth year)-- Remediate; evaluate remediation; report on findings.

SUPPORT AND FUNDING

Support Pathways

1. Participating Agencies
2. DOI
3. Eastern Mine Drainage Federal Consortium
4. Mid-Atlantic Federal Partners on the Environment
5. Coal Industry

Funding Pathways

1. DOI Initiative
2. Federal Agencies- EPA, OSM, USGS, USFWS, COE, DOT, DOE (NETL)
3. State Agencies
4. Coal Industry
5. Any combination of above sources

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U.S. DEPARTMENT OF THE INTERIOR

U.S. GEOLOGICAL SURVEY

Spatial Trends in Ash Yield, Sulfur, Selenium, and Other Selected Trace Element Concentrations in Coal Beds of the Appalachian Plateau Region, U.S.A.

by

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This report is preliminary and has not been reviewed for conformity with U.S. Geological Survey editorial standards (or with the North American Stratigraphic Code). Any use of trade, product, or firm names is for descriptive purposes only and does not imply endorsement by the U.S. Government.

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Spatial Trends in Ash Yield, Sulfur, Selenium, and Other Selected Trace Element Concentrations in Coal Beds of the Appalachian Plateau Region, U.S.A.

by
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ABSTRACT

Land disturbances sometimes contribute to relative increases in deleterious substances in streams. Acid drainage in response to coal mining in certain regions of the Appalachian Plateau is one well known example. Apparent relative increases in selenium (Se) in some streams where land disturbance has occurred in the coal-producing region of the Appalachian Plateau may also be of concern. As a result of concerns regarding selenium, this report evaluates the spatial variation (both stratigraphic and regional) of selenium in coal beds in the Appalachian coal fields of Pennsylvania, Maryland, Ohio, West Virginia, Kentucky, Tennessee, and Virginia.

Analyses of selenium, ash yield, and sulfur concentrations in more than 3,000 coal samples were used to evaluate both the stratigraphic and regional variation of these parameters. The samples are from more than 70 coal beds in the Lower, Middle, and Upper Pennsylvanian Series, located in the Appalachian Plateau region of western Pennsylvania, western Maryland, eastern Ohio, throughout West Virginia, eastern Kentucky, northeastern Tennessee, and southwestern Virginia. Coal beds in the middle Middle Pennsylvanian series, from the Cedar Grove coal bed in West Virginia and the correlative Whitesburg coal bed in eastern Kentucky up through the Clarion coal bed in Pennsylvania and Ohio generally have an average selenium concentration greater than 3.9 ppm (remnant-moisture, whole-coal), an empirical observation. All coal samples from this stratigraphic interval have an average selenium concentration of 5.4 ppm. For the purposes of this report, this stratigraphic interval is referred to as "selenium greater than background" abbreviated SGB, in reference to average selenium concentrations in coal that are greater than the average for all northern and central Appalachian basin coal samples of 3.6 ppm Se.

Coal beds in the SGB stratigraphic interval generally have a median selenium concentration greater than 3.5 ppm. In contrast, coal beds that are from older strata that underlie the SGB interval (pre-SGB in this report) or from younger strata that overlie the SGB interval (post-SGB in this report) generally have median selenium concentrations that are less than 3.5 ppm. The median selenium concentrations for all coal samples from the pre-SGB, SGB, and post-SGB intervals are 2.7, 5.0, and 2.6 ppm selenium, respectively. This trend of lower-higher-lower selenium concentrations in the three stratigraphic intervals is different from the median ash yield that is 6.7, 11, and 11 percent ash on an as-received, whole-coal basis, respectively, or a

stratigraphic trend of lower-higher-higher. The stratigraphic trend in median sulfur concentration for all coal samples is lower-lower-higher with values of 0.9, 1.1, and 2.7 percent sulfur on an as-received, whole-coal basis, respectively, and is different from the trends in both selenium and ash yield. In the Appalachian Plateau region, the selenium concentrations in coal samples from the Cedar Grove/Whitesburg to Clarion (SGB) interval are almost twice those in coal samples from the older (pre-SGB) and younger (post-SGB) coal beds for thick (≥ 28 inch) as well as thin (< 28 inch) coal samples.

The different stratigraphic trends in selenium, ash yield, and sulfur concentration suggest that different processes control their concentrations in coal and that neither ash yield nor sulfur concentration can be used as a predictor for selenium concentration in coal. Whether the stratigraphic trend in selenium concentrations in eastern U.S. Pennsylvanian coal reflects a similar trend in selenium concentrations in overall Pennsylvanian strata remains unanswered.

INTRODUCTION

The practice of mountaintop coal mining (MTM) disturbs large volumes of rock. Elevated selenium concentrations reported from streams that drain areas impacted by MTM in southern West Virginia (Bryant and others, 2002; Ferreri and others, 2004; Vesper and others, 2004) and areas impacted by coal surface mining and reclamation in Ohio (Bonta and Dick, 2003) have drawn attention to the potential for increases in selenium concentrations in drainage from these Appalachian Plateau coal mining regions. The source of selenium in drainage water may be coal, although in surface mining all of the coal is removed, and the source of selenium is more likely to be the associated strata disturbed by mining operations. In underground room and pillar mining, an average of 50 percent (range 35 - 70 percent) of the coal is left in place (Wood and others, 1983). In underground longwall mining, approximately 30 percent of the coal remains. Selenium in coal left in underground mines could conceivably contribute to selenium in groundwater and streams in areas of both active and abandoned underground mines. Understanding levels and trends in selenium concentrations in coal beds and associated rocks would aid in predicting the potential for selenium mobilization as a result of coal mining and other major rock disturbance. Although study of the selenium concentrations in rocks is beyond the scope of this report, an assessment of the concentration range of selenium content in coal beds throughout the Appalachian basin is a first step toward determining whether there are any potential risks of selenium contamination from past, present, or future coal mining and utilization in the Appalachian basin.

Selenium concentration in coal varies among coal basins. The average and geometric mean concentrations of selenium in United States (U.S.) coal are reported as 2.8 and 1.8 ppm (whole-coal basis) respectively (Finkelman, 1993). Average selenium concentration in coal in the Appalachian basin, Interior province, and Powder River basin in the U.S. are reported as 3.5, 3.2, and 1.1 ppm (whole-coal basis), respectively (Finkelman and others, 1994). Gluskoter and

others (1977) calculated the enrichment factor for selenium in U.S. coal (the ratio of geometric mean selenium in coal / average selenium in crust) and showed that it is greater than the enrichment factor of all other elements. In eastern, interior, and western coal basins, selenium enrichment (whole-coal) is 68, 40, and 26, respectively (Gluskoter and others, 1977). Coal mining and utilization are major pathways that mobilize selenium into the environment (Lemly, 2004). For coal utilization purposes, selenium concentrations on a Btu basis are more meaningful than on a whole-coal basis. Se/Btu are more similar than Se/coal among the Appalachian, Interior, and Powder River basins due to a decrease in Btu values in conjunction with the decrease in selenium from the Appalachian to Interior to Powder River basin (Bragg and others, 1998). Elevated concentrations of selenium mobilized by coal mining disturbance in the Powder River basin have been observed by Dreher and Finkelman (1992).

The assumption that selenium in coal is primarily associated with pyrite (Coleman and others, 1993; Taylor and others, 1998; Diehl and others, 2004) is often made because selenium shows some chemical behavior similar to sulfur (McNeal and Balistrieri, 1989) and coal beds are reducing environments where sulfur and selenium would generally be in a reduced state and therefore less mobile. Various studies of selenium in coal and rocks associated with coal have shown that selenium substitutes for sulfur in pyrite, is associated with mineral matter, or is associated with organic matter (Kuhn and others, 1980; Cecil and others, 1981; Cahill and others, 1982; Oman and others, 1988; Naftz and Rice, 1989; Diessel, 1992; Dreher and Finkelman, 1992; Coleman and others, 1993; Taylor, 1998; Zhang and others, 2002; Hower and Robertson, 2003; Lussier and others, 2003; Diehl and others, 2004; Jenkins and Schaer, 2004). The fact that selenium may have more than one mode of occurrence in coal and coal-bearing strata and that selenium occurs in trace amounts may explain why it is difficult to demonstrate a correlation between selenium and other parameters.

The data used in this report are a subset of the U.S. Geological Survey COALQUAL database (Bragg and others, 1998; http://energy.er.usgs.gov/products/databases/CoalQual/intro.htm). Statistical data are presented herein for selenium, coal bed thickness, ash yield, sulfur (S), pyritic sulfur (Spyr), arsenic (As), mercury (Hg), and manganese (Mn). Arsenic and mercury data are included because they are trace elements in coal that are released to the environment via coal combustion and may have deleterious health effects (U.S. Environmental Protection Agency, websites: http://www.epa.gov/ttn/atw/hlthef/arsenic.html., http://www.epa.gov/safewater/arsenic.html., http://www.epa.gov/mercury/ , http://www.epa.gov/mercury/control_emissions/index.htm., http://www.epa.gov/OGWDW/dwh/t-ioc/mercury.html.). Manganese data are included in this report because manganese is released to the environment via coal mining and major rock disturbance. Manganese causes staining, an aesthetic problem, and is currently under study to determine whether there are health issues related to manganese exposure that warrant revision of manganese standards for drinking water (California Department of Health Services, 2005). In addition to selenium, only the thickness, ash yield, and sulfur data are discussed in detail in this

report.

This Open File Report focuses on selenium concentration in Pennsylvanian coal beds in the northern and central Appalachian basin coal region (fig. 1). Extensive data for selenium concentrations in coal beds, including those from the stratigraphic interval of MTM in the central Appalachian basin and the equivalent time interval in the northern Appalachian basin, are available at a regional scale (Appendix 1). Selenium, ash yield and sulfur data are examined for the average and median concentrations in each state, the distribution of concentrations in coal samples from three individual coal beds, stratigraphic trends in concentrations among coal beds, and comparison of concentrations in coal that is thicker or thinner than 28 inches. Stratigraphic trends in selenium concentration of coal beds are compared to stratigraphic trends in ash yield and sulfur concentration and are found to be dissimilar.

METHODS

Samples

Concentrations of selenium and other parameters in coal beds were obtained from the U.S. Geological Survey COALQUAL Database (Bragg and others, 1998; http://energy.er.usgs.gov/products/databases/CoalQual/intro.htm). Data from 3227 coal samples (Appendix 1) from 124 counties in western Pennsylvania, western Maryland, eastern Ohio, throughout West Virginia, eastern Kentucky, northeastern Tennessee, and southwestern Virginia in the northern and central Appalachian basin (Tully, 1996) are included in this report. Each coal sample represents the complete-bed thickness and was collected from working mines (2400 channel samples), drill cores (529 samples), or outcrops (298 weathered channel samples) in the 1970's and 1980's. The analytical methods used to determine selenium concentration were X-ray fluorescence spectroscopy (XRF) (184 samples) and instrumental neutron activation analysis (INAA) (3043 samples). Selenium concentration is reported to two significant figures on a remnant-moisture, whole-coal basis. Approximately 6 percent of the selenium values are qualified; that is, the value is greater than or less than the value reported (Bragg and others, 1998; http://energy.er.usgs.gov/products/databases/CoalQual/Docs/techinfo.pdf). In COALQUAL, selenium concentrations below the lower detection limit of the analytical method are reported as 0.7 times the detection limit. Selenium concentrations were not reported by Bragg and others (1998) for two samples, one channel and one drill core, analyzed by INAA. Additionally, selenium values for two channel samples analyzed by XRF were discarded in this report because of their exceptionally high selenium concentrations (150 ppm in the Lower Freeport coal bed in Ohio and 52 ppm in the Princess No. 9 coal bed in West Virginia), which are greater than two times the next highest value. The range of selenium concentrations of the remaining 3223 samples (fig. 1) is 0.07 to 21 ppm (Appendix 1). Ash yield and sulfur were determined by ASTM methods D3174 and D4239, respectively, and are reported to two decimal places on an as-received, whole-coal basis (ASTM, 1992). One manganese concentration, analyzed by INAA in a channel sample from the Little Raleigh coal bed in West Virginia, was discarded for this report

because of its exceptionally high value (1400 ppm) that was more than two times the next highest value (690 ppm).

Coal Bed Correlations

Coal bed samples from the COALQUAL database were correlated on an interstate basis in the northern and central Appalachian coal regions for this report (table 1). The chronostratigraphic position of each coal bed name, as used in this report, and the number of samples is given in table 2. The number of coal samples in each coal bed are listed by state (table 1) and by thickness (greater than or less than 28 inches) (table 2). Although the correlation of coal beds across county and state boundaries has uncertainty, the relative stratigraphic positions and correlations of this report are generally correct or never offset by more than one coal bed.

Correlation of coal beds from the lower Middle Pennsylvanian Pond Creek coal in eastern Kentucky and correlative coal beds in the central Appalachian basin up through the upper Middle Pennsylvanian No. 6 Block coal bed in the central Appalachian basin in southern West Virginia and the correlative Lower Kittanning coal bed in Pennsylvania in the northern Appalachian basin are summarized in Figure 2 (from Neuzil, 2001, fig. 1 and references therein).

The stratigraphic positions of the Quakertown coal bed and the Mercer coal beds in the Pottsville Formation of the northern Appalachian basin in relation to coal beds in the central Appalachian basin are uncertain because the coal beds are discontinuous and stratigraphic palynology does not resolve these coal bed correlations. Peppers (1996) places the Quakertown coal bed in Ohio in the upper Westphalian A series (western European terminology), the upper Morrowan series (midcontinent terminology), and in the lower Kanawha Formation (southern West Virginia terminology). However, the Pottsville Formation in the northern Appalachian basin does not include much of the strata in the Lower and lower Middle Pennsylvanian (Eble, 1994) and we have, therefore, placed the Quakertown coal bed in the Middle Pennsylvanian, Westphalian C, or Atokan (table 2), which is higher than Peppers' (1996) placement.

Peppers (1996) correlates the Upper Mercer coal bed in Ohio with the Upper No. 5 Block coal bed in southern West Virginia and the Lower Mercer coal bed in Ohio with the Stockton coal bed in southern West Virginia. Although the Upper and Lower Mercer coal beds may correlate with the No. 5 Block and Stockton coal beds, in this report we will consider these northern and central Appalachian basin coal beds separately because the stratigraphic correlations are uncertain (tables 1 and 2).

Correlation of the Brookville and Clarion coal beds in the upper Middle Pennsylvanian Allegheny Formation in the northern Appalachian basin to coal beds in the central Appalachian basin is uncertain (Neuzil, 2001). The Brookville and Clarion coal beds may correlate with the No. 5 Block coal zone (Rice, and others, 1994) or they may be above the No. 5 Block coal zone (Blake, 1992; Eble, 1994). In this report the northern Appalachian basin Brookville and Clarion

coal beds are placed stratigraphically above the No. 5 Block coal bed in the central Appalachian basin and are considered separately (tables 1 and 2).

Coal bed samples collected in the central Appalachian basin in counties in southern West Virginia and eastern Kentucky that were designated by northern Appalachian basin coal bed names (Appendix 1), such as Upper Kittanning and Lower Kittanning, have been correlated to central Appalachian basin coal bed names through discussions with Bascombe M. Blake Jr. (WVGES), Donald R. Chesnut Jr. (KGS retired), and Cortland F. Eble (KGS) (Neuzil, 2001, Appendix 2).

Statistical Analyses and Terminology

Statistical analyses were conducted as follows. First, the average, standard deviation, minimum, lower quartile, median, upper quartile, and maximum were calculated for selenium, thickness, ash yield, sulfur, pyritic sulfur, arsenic, mercury, and manganese for all coal bed samples within each state, treating the northern and southern West Virginia coal fields separately (table 3). Second, the distribution of selenium (fig. 3a), ash yield (fig. 3b), and sulfur (fig. 3c) concentration values were calculated for each of three coal beds (Pond Creek, Coalburg, and Pittsburgh) that have a large sample population, more than 100 samples. The Pond Creek, Coalburg, and Pittsburgh coal beds span the lower Middle to Upper Pennsylvanian stratigraphic interval (fig. 2 and table 2) and have been studied in detail (Neuzil, 2001; Ruppert and others, 2001; Tewalt and others, 2001). Third, the geometric mean, average, standard deviation, minimum, lower quartile, median, upper quartile, and maximum were calculated for selenium and other parameters for each coal bed with 5 or more samples in the Appalachian Plateau region (table 4a). Finally, the same statistical parameters were also calculated for coal bed samples greater than and less than 28 inches thick, if there were 5 or more samples in a coal bed in the thickness category (tables 4b and 4c).

The terms median, midspread, and lower and upper quartiles as used herein are clarified as follows. Consider the values of a given parameter (for example, the selenium concentration) of a sample population (for example, each sample in a coal bed) and sort these values into ascending order. The median is the value of the middle sample, which is at the 50th percentile of the sample population. The midspread is the range of values from the lower to the upper quartile, which is the range from the 25th to 75th percentile of the ascending order sample population. The values for half of the samples fall within the midspread. One quarter of the samples have a value less than the lower quartile, and one quarter of the samples have a value greater than the upper quartile. When a sample population has a normal distribution, the median and geometric mean will be equal to the average. If a sample population has a normal distribution, 30 random samples from that sample population are generally considered a large enough sample set to statistically represent the entire sample population (Drennan, 1996). A larger sample set, for example >100 samples, may appear more convincing. However, statistical values (average, median, geometric mean, lower quartile, and upper quartile) calculated from a larger sample population will not be

significantly different from those calculated from 30 random samples (Drennan, 1996).

RESULTS and DISCUSSION

Regional Distribution of Selenium

The latitude and longitude locations of 3223 coal samples with selenium data are shown in Figure 1. The sample locations reflect the general extent of coal resources in the northern and central Appalachian basin (Tully, 1996). The density of sample locations is not uniform throughout the basin because deep coal in the middle of the basin is under represented. The subset of 809 samples with elevated selenium concentrations that are greater than the upper quartile for the entire Appalachian basin (> 4.5 ppm Se) are shown in red in Figure 1. Samples with elevated selenium have a geographic distribution that is similar to the distribution of all coal samples (fig.1). To examine geographic variability, one can consider the selenium concentration in all coal samples within each state. All of the coal samples in Pennsylvania, Maryland, and Ohio are located within the northern Appalachian basin and all of the coal samples in Kentucky, Tennessee, and Virginia are within the central Appalachian basin. Therefore, we will consider the northern and southern West Virginia coal fields separately. The average and median selenium concentration in coal in each state ranges from a low of 2.5 and 1.7 ppm, respectively, in northern West Virginia, to a high of 4.2 and 3.8 ppm, respectively, in eastern Kentucky (table 3). The increase from low to high selenium values by state, for either average or median selenium concentration, is approximately a factor of two, and reflects the stratigraphic variability of selenium.

Selenium Concentrations in Coal Beds

The selenium concentration in coal beds with more than 30 samples ranges from a low average and median in the Pittsburgh coal bed of 1.7 and 1.4 ppm Se, respectively, to a high average and median in the No. 5 Block coal bed of 7.1 and 6.4 ppm Se, respectively (table 4a). The increase from low to high selenium values by coal bed, for either average or median selenium concentration, is approximately a factor of four.

Selenium Distribution Within Coal Beds

When a sample population has a normal distribution, the average will be close to the median value. If a sample population has a log normal distribution, the geometric mean will be close to the value of the median. Histograms illustrating the distribution of selenium concentrations in 3 coal beds, which each have a large sample population of more than 100 samples, appear to be close to normal with a tail of high values (fig. 3a). The average, median, and geometric mean selenium values are plotted for coal beds that each have more than 30 samples (fig. 4a), a sufficiently large random sample set if the sample population has a normal distribution. For most coal beds in the Appalachian basin the average, median, and geometric mean values for selenium concentration are quite close. This is consistent with each coal bed having a nearly normal distribution of selenium concentrations and indicates that these three

statistical parameters (average, median, and geometric mean) are all useful for understanding stratigraphic trends in selenium concentration in the Appalachian Plateau region coal beds. For coal beds with more than 30 samples, the average selenium concentration is greater than the median, except in the Waynesburg coal bed, and the average is slightly greater than the geometric mean in all cases. This confirms that each coal bed has no more than a few high values of selenium (Appendix 1). For example, only 6 of the 31 coal beds with more than 30 samples have a maximum selenium value that is more than 10 ppm greater than the upper quartile selenium value (table 4a). The median and midspread of selenium concentration in each coal bed with 30 or more samples are illustrated in Figure 5a. There is a considerable range in selenium concentrations in each coal bed throughout the Pennsylvanian (figs. 3a and 5a and tables 4a, 4b, and 4c).

Selenium in Thick and Thin Coal

The top and bottom layers of a coal bed often have higher ash yield or pyrite content compared to the rest of the coal bed (Gluskoter and others, 1977; Cecil and others, 1981; Taylor and others, 1998). If an element is enriched in the top and bottom layers of a coal bed, then thin areas of coal beds would have a greater overall concentration of the element than thick areas as a result of the greater proportion of "surface" coal and less dilution by the lower concentration in the middle of the coal bed. In order to determine whether the thickness of a coal bed has any influence on selenium distribution within a coal bed, the geometric mean of selenium is plotted for coal that is greater than or less than 28 inches thick, for each coal bed where there are more than 30 samples in the thickness category (fig. 6a). The geometric mean for selenium in thick coal is greater than in thin coal for 12 of the 14 coal beds that have more than 30 samples in each of the two thickness categories (tables 4b and 4c). This suggests that selenium is not concentrated in the top and bottom surfaces of each coal bed, but rather uniformly distributed. For comparison, higher concentrations of ash yield are found in thick coal compared to thin coal in 8 of 14 cases (fig. 6b; tables 4b and 4c). In contrast to selenium and ash yield, sulfur concentrations are higher in thin coal compared to thick coal in 12 of 14 cases (fig. 6c; tables 4b and 4c).

Stratigraphic Trends in Selenium

When the selenium concentrations in coal beds are considered in a stratigraphic context, selenium concentrations appear to be generally higher in coal beds in the upper Kanawha and lowermost Allegheny Formations and equivalent strata compared to coal beds in underlying and overlying stratigraphic intervals (figs. 4a, 5a, and 6a; table 2). Eight coal beds, each with more than 30 samples, from the Cedar Grove/Whitesburg up through the Clarion have an average, median, and geometric mean selenium concentration greater than 3.9, 3.5 and 3.6 ppm respectively and a lower quartile greater than 2.7 ppm (table 4a). This stratigraphic interval will be referred to in this report as "selenium greater than background" or SGB in reference to the elevated levels of selenium in the coal beds. Thirteen coal beds from the underlying interval and ten coal beds from the overlying interval, each with more than 30 samples, have lower average, median, and geometric mean selenium concentrations that are less than 3.9, 3.5, and 3.6,

respectively, with 3, 2, and 1 exceptions, respectively. These two stratigraphic intervals will be referred to as pre-SGB and post-SGB. This stratigraphic trend of lower-higher-lower selenium concentrations in coal beds in the (1) pre-SGB interval (Pocahontas No. 3 to Williamson/Amburgy), (2) SGB interval (Cedar Grove/Whitesburg to Clarion), and (3) post-SGB interval (Lower Kittanning to Waynesburg) is also apparent in thick (≥ 28 inch) and thin (< 28 inch) coal bed samples (fig. 6a; tables 4b and 4c). In thick coal beds, with more than 30 thick samples in a coal bed, the range for geometric mean values for selenium in the pre-SGB, SGB, and post-SGB intervals is 2.0 to 3.8 ppm, 3.5 to 7.0 ppm, and 1.4 to 4.5 ppm, respectively. In thin coal beds, with more than 30 thin samples in a coal bed, the geometric mean values for selenium have a range of 1.9 to 2.9 ppm, 3.8 to 4.6 ppm, and 2.6 to 3.4 ppm in the pre-SGB, SGB, and post-SGB intervals, respectively.

On the basis of data from the COALQUAL database (Bragg and others, 1998), selenium concentrations in coal beds in the Appalachian basin coal region have a distinctive stratigraphic trend. Selenium is relatively low in coal beds contained in Lower and lower Middle Pennsylvanian strata, the pre-SGB interval (fig. 2; table 2). These strata include the Lower Pennsylvanian, Pocahontas and New River Formations, and the lower Middle Pennsylvanian, lower division and lower part of the middle division of the Kanawha Formation in West Virginia and equivalent strata in other states in the northern and central Appalachian basin. There is a relative increase in selenium in the middle of the Middle Pennsylvanian, upper part of the middle division and the upper division of the Kanawha Formation and lowermost Allegheny Formation in West Virginia (and equivalent strata), the SGB interval. The upper Kanawha Formation and lower Allegheny Formation (and equivalent strata) coal beds in the northern and central Appalachian basin that have elevated levels of selenium, comprise the coal beds that are the predominant targets of MTM (table 2). After reaching a maximum selenium concentration in the lower Allegheny Formation No. 5 Block coal bed, selenium concentrations are relatively low in the coal beds in the overlying upper Middle Pennsylvanian Allegheny Formation and the Upper Pennsylvanian Conemaugh and Monongahela Formations, the post-SGB interval.

Statistical calculations were conducted for the pre-SGB, SGB, and post-SGB stratigraphic intervals that included all coal samples, regardless of the number of coal samples in each coal bed (table 5). The average and median selenium concentrations both show a trend of lower-higher-lower values from oldest to youngest for the three stratigraphic intervals whether all coal (table 5a), thick coal (table 5b), or thin coal (table 5c) samples are considered. This trend is apparent even though elevated concentrations of selenium (> 4.5 ppm) are present in coal samples in each of the three stratigraphic intervals (figs. 1 and 5a; tables 4a, 4b, and 4c). The trend in selenium contrasts to an average, median, geometric mean, and midspread ash yield trend that is lower-higher-higher (figs. 4b, 5b, and 6b) in the pre-SGB, SGB, and post-SGB intervals, respectively (tables 5a, 5b, and 5c). The average, median, geometric mean, and midspread sulfur concentration trend is lower-lower-higher (figs. 4c, 5c, and 6c) for the pre-SGB, SGB, and post-SGB intervals, respectively (tables 5a, 5b, and 5c), which is different from both the selenium concentration and

ash yield trends. The difference in the stratigraphic trends for selenium, ash yield, and sulfur are illustrated by histograms of their concentration distribution in each of the three stratigraphic intervals for all (fig. 7a), thick (fig. 7b), and thin (fig. 7c) coal samples.

CONCLUSIONS

1. Mountaintop mining practices remove most of the coal. Therefore, coal is unlikely to be the source of slightly elevated concentrations of selenium found in streams impacted by MTM. Underground coal mining practices leave a significant portion of the coal, which may be a source of selenium in abandoned and active underground coal mine drainage.
2. The spatial (regional and stratigraphic) distribution of elevated selenium concentration coal samples (defined as > 4.5 ppm Se in this report) includes both the northern and central Appalachian basin and is not restricted to the MTM region or the MTM stratigraphic interval of southern West Virginia and eastern Kentucky.
3. There is more variability in selenium concentration stratigraphically among coal beds than geographically among states.
4. Selenium concentrations within a coal bed have a normal distribution.
5. Selenium does not appear to be concentrated in the surfaces of coal beds and has slightly higher concentrations in thick (≥ 28 inch) than thin (< 28 inch) portions of coal beds.
6. Statistical results suggest that selenium concentrations are approximately two times higher in coal beds in the "selenium greater than background" interval of the middle Middle Pennsylvanian (equivalent to the uppermost Westphalian B, Westphalian C, and lowermost Westphalian D in western Europe terminology or the upper Atokan and lowest Desmoinesian in mid-continent time series terminology) than in older or younger coal beds in the Appalachian basin.
7. The stratigraphic trend in selenium concentration is the same for all thicknesses, thick (≥ 28 inch), or thin (< 28 inch) coal bed samples.
8. The stratigraphic trend in selenium concentrations does not correspond to the stratigraphic trends in either ash yield or sulfur concentration.
9. Understanding stratigraphic trends of selenium in coal is important to coal users to predict potential total selenium in fly ash and other byproducts that may be reintroduced to the environment at disposal sites.
10. Whether stratigraphic trends in selenium concentration in coal beds indicate trends in selenium concentration in associated strata needs to be confirmed with rock analyses.

FUTURE WORK

There is a critical need to evaluate selenium concentrations in the non-coal strata of the Appalachian Plateau region, especially where the rocks are subjected to significant surface and underground disturbance and could be a source of selenium, for example in land disturbance such as MTM. Extensive data are not currently available for the selenium concentrations in the overburden and interburden rocks of the SGB interval in the Appalachian Plateau region.

Preliminary data from three cores indicate that the concentration of selenium in rocks in the SGB stratigraphic interval, the interval most commonly subjected to current intensive MTM, may be higher than in rocks above and below this interval (work in progress by Cecil, Dulong, and Renton). Further sampling and analyses of the rocks in the SGB interval is needed to assess potential rates of weathering and leaching and the produced ionic species in leachates to better understand the potential sources of selenium to the environment from coal mining practices and other major rock disturbance throughout the Appalachian Plateau region.

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Figure 1. Coal bed sample locations (N = 3223).

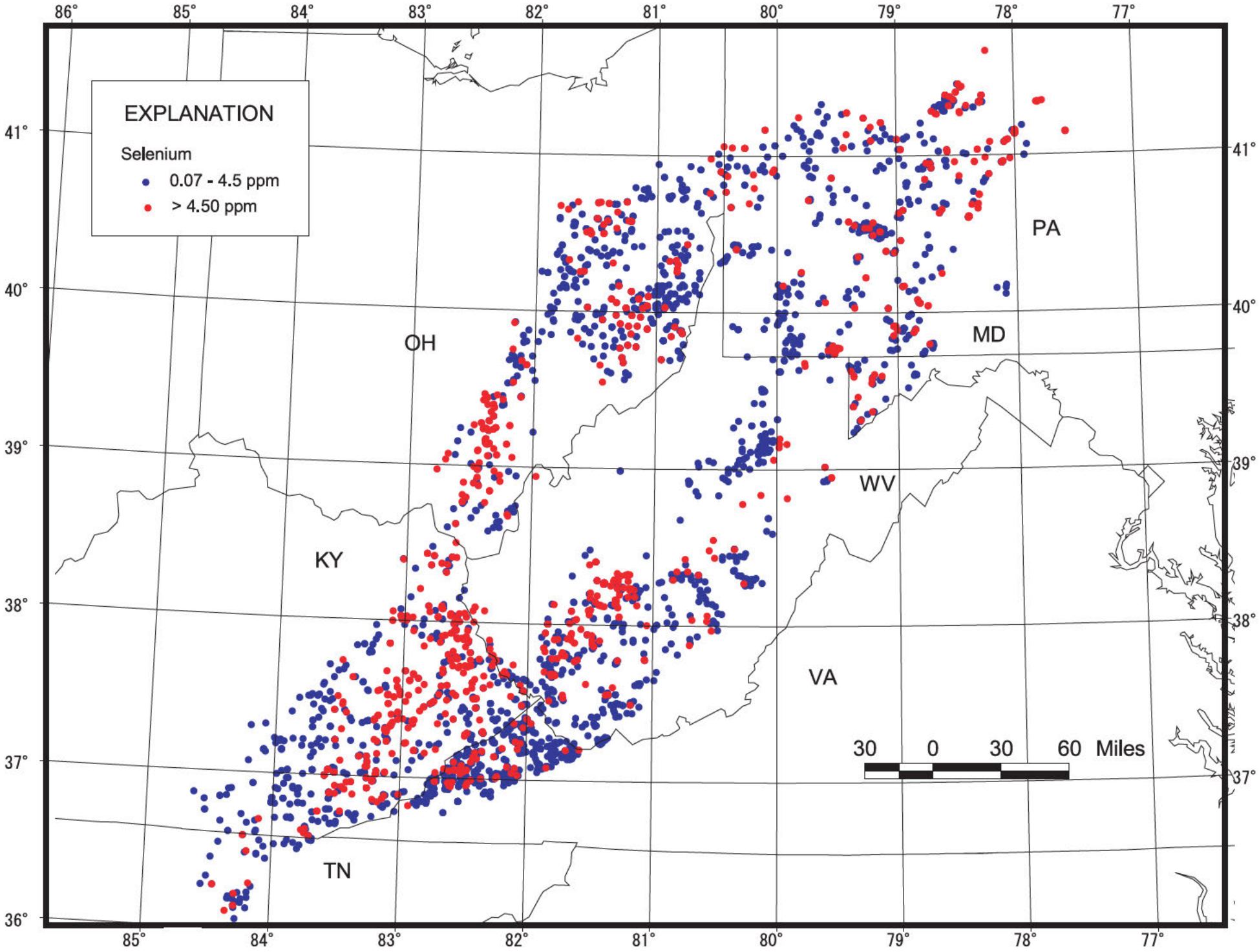
EXPLANATION
Selenium
0.07 - 4.5 ppm
> 4.50 ppm
PA
MD
OH
WV
KY
VA
TN
30 0 30 60 Miles
86°
85°
84°
83°
82°
81°
80°
79°
78°
77°
41°
40°
39°
38°
37°
36°

Figure 2. Stratigraphic correlation of coal beds and coal zones in part of the Middle Pennsylvanian Series in the northern and central Appalachian basin coal region, from the northeast to the southwest (modified from Neuzil, 2001, fig.1 http://pubs.usgs.gov/prof/p1625c/CHAPTER_I/CHAPTER_I.pdf.) Chart showing correlation of coal zones in part of the Middle Pennsylvanian Series in the northern and central Appalachian Basin coal regions, from the northeast to the southwest. Stratigraphic relationships and coal-zone correlations are indicated for southern West Virginia, eastern Kentucky, southwestern Virginia, and northern Tennessee. Beyond this explanation, the correlation chart is broken into four pages: ***Page 3*** = Upper left quadrant of chart; ***Page 4*** = Upper right quadrant of chart; ***Page 5*** = Lower left quadrant of chart; ***Page 6*** = Lower right quadrant of chart. Formal and informal unit names, stratigraphic relationships, and coal zone correlations are drawn from Rice and others (1994); also see references therein, except as noted: a, Kosanke (1988); b, Eble (1994); c, Blake (1992); d, Blake (1998); e, Donald R. Chesnut, Jr. and Cortland F. Eble (KGS, written commun., 1999); f, Blake and others (1994); g, Chesnut (1992); h. Chesnut (1997); i, Nolde (1994a); j, Nolde (1994b); k. Charles L. Rice (USGS retired, oral commun., 1999); and l, Rice (1984). This correlation chart is generalized and not all units are shown. 'Coal' indicates coal bed. Coal zones are noted. Query '?' indicates uncertain correlation of this unit. Empty formal or informal unit boxes indicate no significant unit present at this horizon. Unshaded units are coal. Shaded units are clastic and carbonate sedimentary units; many are marine in origin. Where two coal bed names appear in one block, they are both considered to be in the same coal zone in this study. 'Marine zone' indicates the presence of an unnamed marine zone. Boxes are not to scale and do not imply length of time, thickness of interval, or aerial extent of unit. 'Group (this report)' indicates stratigraphic group names used throughout the northern and central Appalachian Basin coal resource assessment reports for data entry purposes. 'Code (this report)' indicates code used in this chapter for data entry purposes. 'SGB' is selenium greater than background interval from table 2. Stratigraphic position and correlative coal beds are indicated for Pond Creek coal and Coalburg coal bed (see fig. 3). Pittsburgh coal bed (see fig. 3) is in the Upper Pennsylvanian Monongahela Formation, which is above the stratigraphic interval in this figure.

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						Pennsylvania		West Virginia				
										Kanawha Valley region	Tug Fork region	
							Bituminous coal field			Southern West Virginia coal field	Southern West Virginia coal field	Southern West Virginia coal field
										Boone, Clay, Fayette, Greenbrier, Kanawha, Nicholas, Raleigh, Wyoming Cos.	Boone, Lincoln, Logan, McDowell, Mingo, Wayne, Wyoming Cos.	
System	Series	Midcontinent Stage	Group (this report)	Code (this report)	Coal Zone Names (this report)	Formation	Formal or informal units	Formation	Divisions of Blake (1998)	Formal or informal units	Formal or informal units	Formal or informal units
		Desmoinesian (part)	Allegheny (part)			Allegheny (part)	Lower Kittanning coal	Charleston Sandstone (part)		No. 6 Block coal (a,b,c)	No. 6 Block coal (a,b,c)	No. 6 Block coal zone (a,b,c)
				13	No. 5 Block coal zone		Clarion coal (?)			No. 5 Block coal (a,b,c)	No. 5 Block coal (a,b,c)	No. 5 Block coal zone (a,b,c)
							Brookville coal (?)			Little No. 5 Block coal (c)	Little No. 5 Block coal (c)	Little No. 5 Block coal (c)
										Stockton "A" coal (c)	Stockton "A" coal (c)	Stockton "A" coal (c)
		Atokan					Homewood Sandstone Member		upper	Kanawha black flint of White (1891)	Kanawha black flint of White (1891)	Kanawha black flint of White (1891)
				14	Stockton and Coalburg coal zone		Lower Mercer coal (?)			Stockton coal	Stockton coal	Stockton coal zone (c,d)
				15						Coalburg coal	Coalburg coal	Coalburg coal zone (c,d)
										Arnett Member (d)	Arnett Member (d)	Arnett Member (d)
				16	Winifrede/Hazard coal zone					Winifrede coal (d,e)	Winifrede, Buffalo Creek coals (d,e)	Winifrede coal zone (c,d,f)
				17						Lower Winifrede coal (d,e)	Lower Winifrede, Lower Buffalo Creek coals (d,e)	
										Winifrede limestone of White (1908) (c,d,f)	Buffalo Creek limestone of Hennen and Reger (1914) (c,d,f)	Winifrede Shale Member (c,d,f)

Kentucky				Virginia			Tennessee				
			Harlan subdistrict								
		Hazard and Big Sandy reserve districts	Upper Cumberland River reserve district					Jellico area	Walnut Mountain area		
		Eastern Kentucky coal field	Eastern Kentucky coal field			Southwest Virginia coal field		west of Cumberland overthrust sheet	Cumberland overthrust sheet		
		Breathitt, Floyd, Harlan, Johnson, Knott, Leslie, Letcher, Martin, Perry, Pike Cos.	Bell, Harlan, Letcher Cos.			western Buchanan, Dickenson, Lee, Wise Cos.		Anderson, Campbell, Morgan, Scott Cos.	Campbell, Claiborne Cos.	SGB interval (from table 2)	Coal bed (from fig. 3)
Group as used by Chesnut (1992)	Formations of Chesnut (1992)	Formal or informal units	Formal or informal units	Formation	Informal division of Nolde (1994a)	Formal or informal units	Formation of Wilson and others (1956) as revised by Hardeman and others (1966)	Formal or informal units	Formal or informal units		
	Princess (part)	eroded	eroded			eroded		eroded	eroded	post-SGB interval (part) (from table 2)	
		Richardson, Skyline coal zones (g,h)								SGB interval (from table 2)	
				Harlan							
		Stoney Fork Member (?) (g)									
	Four Corners	Broas coal zone (e,g,h)	Black Mountain coal zone (h)			No. 13 coal					
		Peach Orchard coal zone (e,g,h)	High Splint coal zone (h)			High Splint coal (i)	Vowell Mountain (part)	Hazard No. 9 (?) (k)			Coalburg coal (from fig 3)
		Arnett Member (h)									
		Hazard coal zone (h)	Morris coal zone (h)			Morris, No. 11 coals (i,j)		Braden Mountain, Pewee coals (l)			
		Haddix coal zone (h)	Lower Highsplint coal (h)			Reynolds Sandstone Member (i,j)		Red Ash coal			
			Reynolds Sandstone Member (h)					Fodderstack Sandstone Member			
		Magoffin Member (g,h)	Magoffin Member (g,h)			Magoffin Member		Magoffin Member			

						Pennsylvania		West Virginia				
										Kanawha Valley region	Tug Fork region	
							Bituminous coal field			Southern West Virginia coal field	Southern West Virginia coal field	Southern West Virginia coal field
										Boone, Clay, Fayette, Greenbrier, Kanawha, Nicholas, Raleigh, Wyoming Cos.	Boone, Lincoln, Logan, McDowell, Mingo, Wayne, Wyoming Cos.	
System	Series	Midcontinent Stage	Group (this report)	Code (this report)	Coal Zone Names (this report)	Formation	Formal or informal units	Formation	Divisions of Blake (1998)	Formal or informal units	Formal or informal units	Formal or informal units
Pennsylvanian (part)	Middle (part)	Morrowan (part)	Pottsville (part)			Pottsville (part)	?	Kanawha Formation (part)	middle	Chilton coal (c,d,f)	Chilton "A" coal (c,d,f)	Chilton coal zone (c,d,f)
												marine zone (d)
										Hernshaw coal (?) (c,d,f)	Chilton coal (c,f)	Fire Clay coal zone (c,d,f)
										Seth limestone of Krebs and Teets (1915) (c,d,f)		marine zone (c,d,f)
										Cedar Grove coal (c,d,f)	Hernshaw coal (c,d,f)	Cedar Grove coal (d.f)
											Dingess limestone of Hennen and Reger (1914) (c,d,f)	Dingess Shale Member
				22	Williamson/Amburgy coal zone					Alma coal (c,d,f)	Williamson coal (c,d,f)	Williamson coal zone
										Campbell Creek limestone of White (1885) (c,d,f)	Seth limestone of Krebs and Teets (1915) (d)	Campbell Creek limestone of White (1885)
				24	Campbell Creek/Upper Elkhorn No. 3 coal zone					Peerless coal, Campbell Creek coal zone (c,d,f)	Cedar Grove coal (c,d,f)	Peerless, Campbell Creek coal zones (c,f)
										No. 2 Gas coal, Campbell Creek coal zone (c,d,f)	Lower Cedar Grove coal (c,d,f)	No. 2 Gas, Campbell Creek coal zones (c,d,f)
				25	Upper Elkhorn Nos. 1 and 2/Powellton coal zone					Powellton coal (c,d,f)	Alma coal (c,d,f)	Powellton coal zone (d)
										Cannelton limestone of White (1885) (c,d,f)	Campbell Creek limestone of White (1885) (c,d,f)	Crummies Member (d)
										Eagle coal (c,d,f)	Campbell Creek coal (c,f)	Eagle coal zone (c,d)
										Eagle limestone and shale of White (1891) (c,d,f)	Cannelton limestone of White (1885) (c,d,f)	Betsie Shale Member

modified from Neuzil (2001) U.S. Geological Survey Professional Paper 1625-C, Chapter I, Figure 1.

Kentucky				Virginia			Tennessee				
			Harlan subdistrict								
		Hazard and Big Sandy reserve districts	Upper Cumberland River reserve district					Jellico area	Walnut Mountain area		
		Eastern Kentucky coal field	Eastern Kentucky coal field			Southwest Virginia coal field		west of Cumberland overthrust sheet	Cumberland overthrust sheet		
		Breathitt, Floyd, Harlan, Johnson, Knott, Leslie, Letcher, Martin, Perry, Pike Cos.	Bell, Harlan, Letcher Cos.			western Buchanan, Dickenson, Lee, Wise Cos.		Anderson, Campbell, Morgan, Scott Cos.	Campbell, Claiborne Cos.	SGB interval (from table 2)	Coal bed (from fig. 3)
Group as used by Chesnut (1992)	Formations of Chesnut (1992)	Formal or informal units	Formal or informal units	Formation	Informal division of Nolde (1994a)	Formal or informal units	Formation of Wilson and others (1956) as revised by Hardeman and others (1966)	Formal or informal units	Formal or informal units		
Breathitt (part)	Hyden	Copland coal zone, Taylor coal	Limestone coal	Wise (part)	Wis	Pardee coal	Red	Sharp coal			
		marine zone (h)	marine zone (h)					Caryville Sandstone Member (?)			
		Fire Clay rider coal zone	Smith coal zone			Gin Creek coal		Big Mary coal			
		Fire Clay coal	Wallins Creek coal zone			Phillips coal	Graves Gap	Windrock coal	Walnut Mountain coal		
		member J (h)			unit 3			Roach Creek Sandstone Member (?)	Magoffin Member (l)		
		Whitesburg coal zone	Stray coal zone			House coal (?) (i,j)		Upper Pioneer coal			
		Kendrick Shale Member (g,h)	Kendrick Shale Member (g,h)			Kendrick Shale Member		Kendrick Shale Member		pre-SGB interval (part) (from table 2)	
	Pikeville	Williamson, Amburgy coal zones	Creech coal zone		unit 2	Low Splint coal		Lower Pioneer, Jordan coals	Windrock coal (l)		
		Elkins Fork shale of Morse (1931) (h)	Elkins Fork shale of Morse (1931) (h)			Marcum Hollow Sandstone Member	Indian Bluff	Pioneer Sandstone Member			
		Upper Elkhorn No. 3 coal zone	Taggart coal zone (h)			Taggart coal (i,j)		Elk Gap coal	Jordan coal (l)		
			Taggart Marker coal (h)			Taggart Marker coal (i,j)			Pioneer Sandstone Member (?) (l)		
		Upper Elkhorn No. 1, Upper Elkhorn No. 2 coals (h)	Harlan coal zone (h)			Wilson, Upper St. Charles coals (i,j)	Slatestone (part)	Jellico coal zone	Jellico coal zone (l)		
		Crummies Member (h)	Crummies Member (h)			marine zone (j)		Sand Gap Sandstone Member	Newcomb Sandstone Member		
		Pond Creek, Lower Elkhorn coals	Imboden coal, Path Fork coal zone (h)			Kelly coal, Imboden coal zone (i,j)		Blue Gem coal zone	Rich Mountain coal zone		Pond Creek coal (from fig 3)
		Betsie Shale Member (g,h)	Betsie Shale Member (g,h)			Betsie Shale Member (j)		Betsie Shale Member	Betsie Shale Member		

Figure 3a. Histograms of selenium concentration in three coal beds (Pond Creek, Coalburg, and Pittsburgh) that each have > 100 samples.

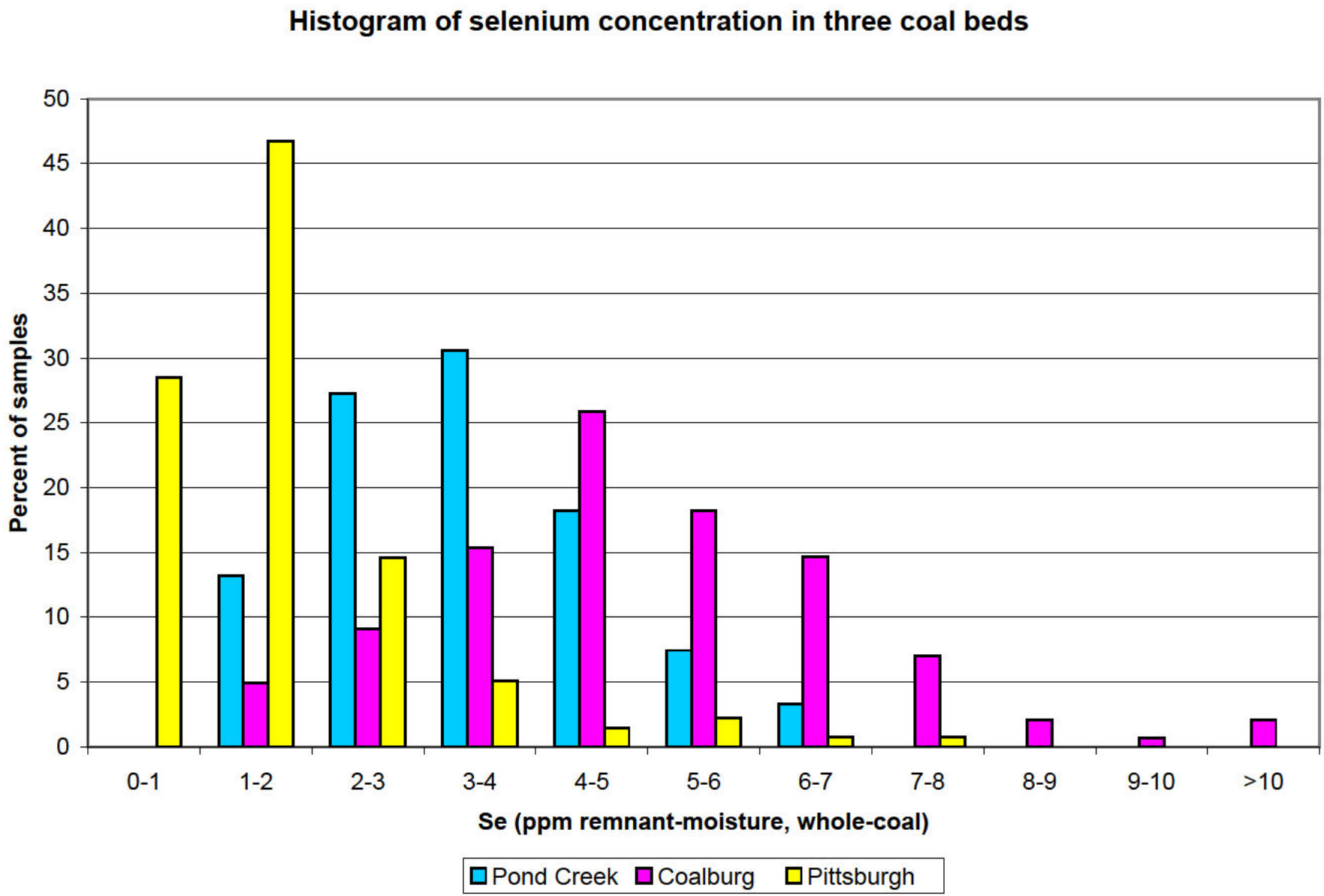

Histogram of selenium concentration in three coal beds
Percent of samples
50
45
40
35
30
25
20
15
10
5
0
0-1
1-2
2-3
3-4
4-5
5-6
6-7
7-8
8-9
9-10
>10
Se (ppm remnant-moisture, whole-coal)
Pond Creek
Coalburg
Pittsburgh

Figure3b. Histograms of ash yield concentration in three coal beds (Pond Creek, Coalburg, and Pittsburgh) that each have > 100 samples.

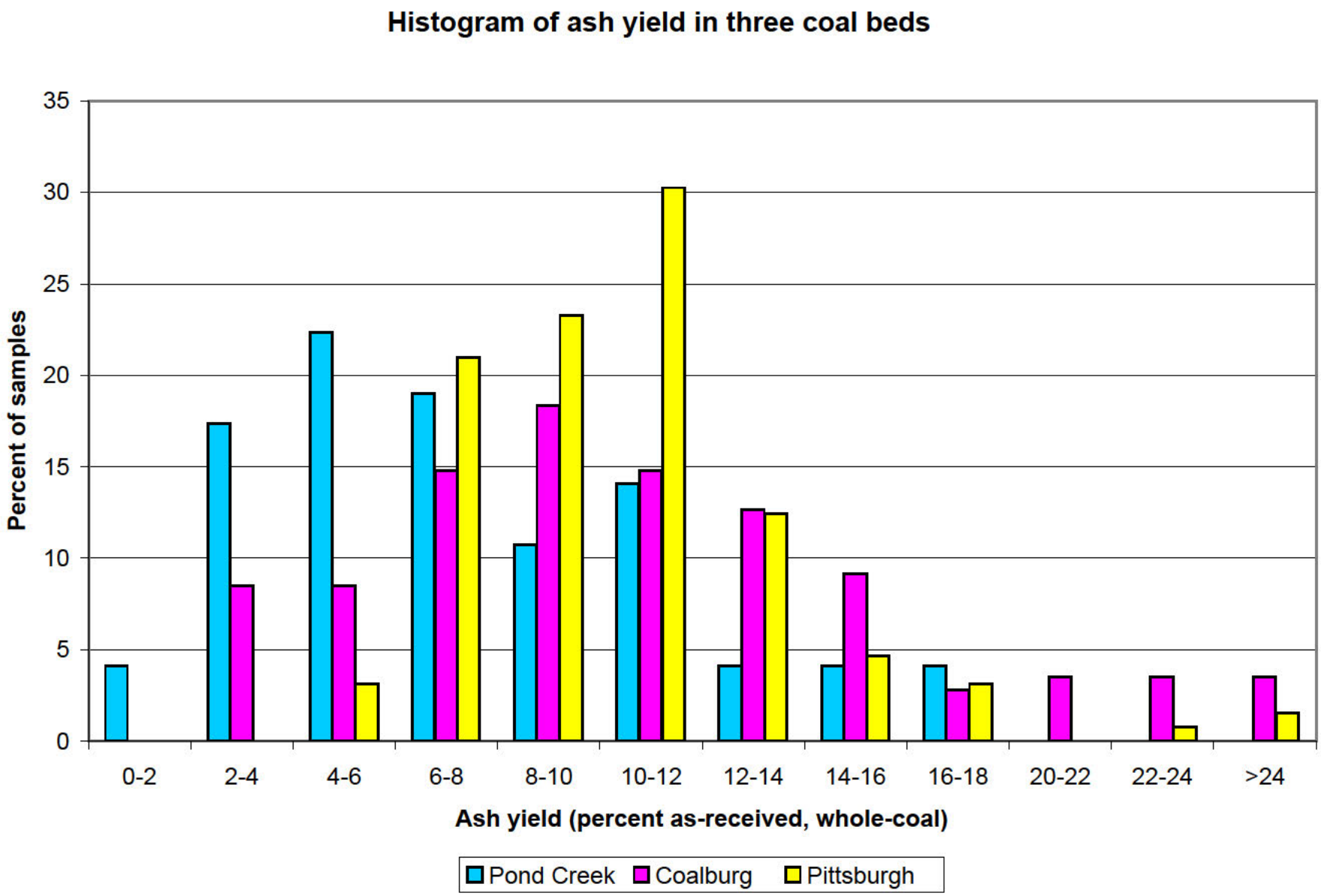

Histogram of ash yield in three coal beds
Percent of samples
35
30
25
20
15
10
5
0
0-2
2-4
4-6
6-8
8-10
10-12
12-14
14-16
16-18
20-22
22-24
>24
Ash yield (percent as-received, whole-coal)
Pond Creek
Coalburg
Pittsburgh

Figure 3c. Histograms of sulfur concentration in three coal beds (Pond Creek, Coalburg, and Pittsburgh) that each have > 100 samples.

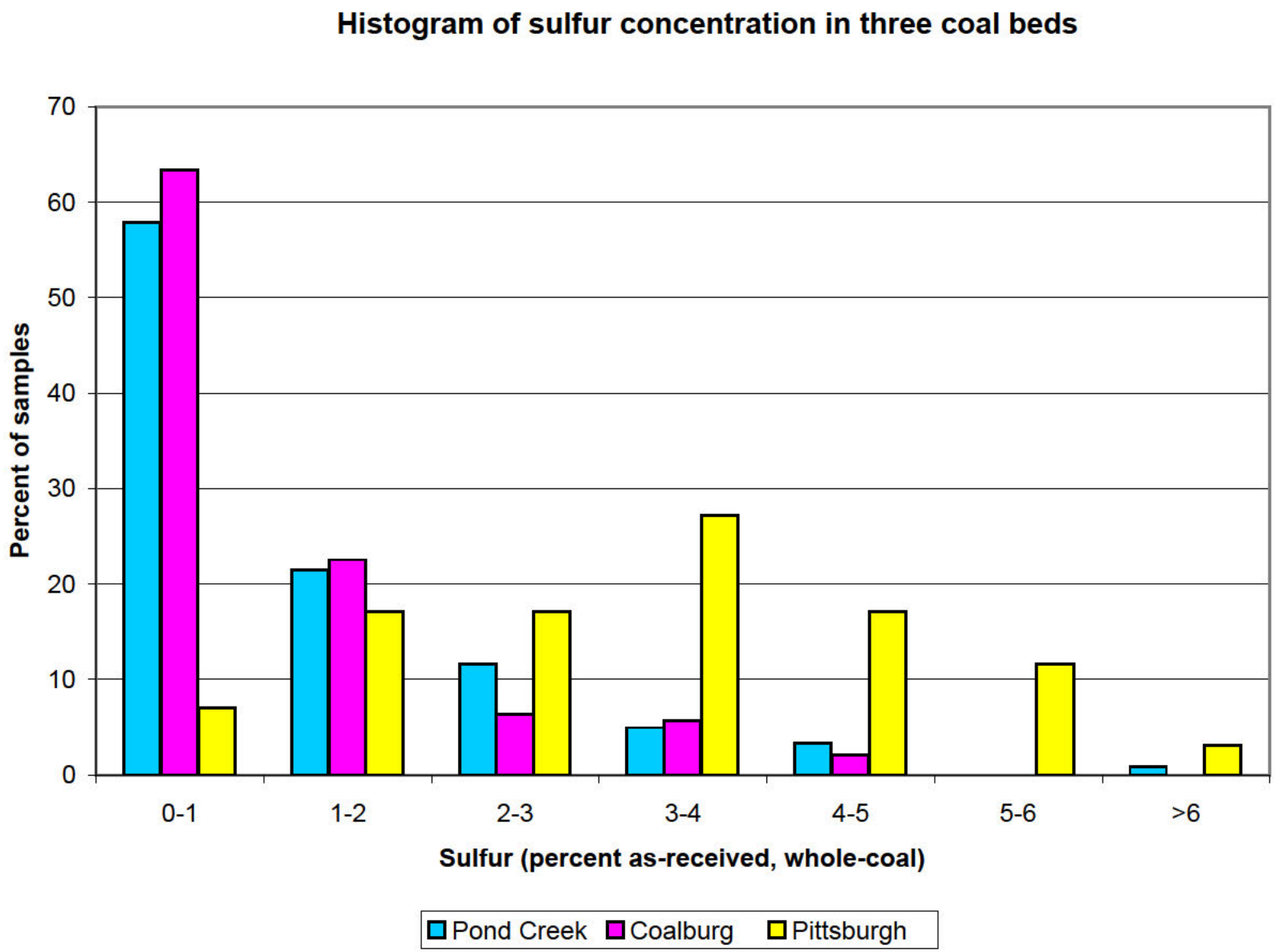

Histogram of sulfur concentration in three coal beds
Percent of samples
70
60
50
40
30
20
10
0
0-1
1-2
2-3
3-4
4-5
5-6
>6
Sulfur (percent as-received, whole-coal)
Pond Creek
Coalburg
Pittsburgh

Figure 4a. Chart of average, median, and geometric mean of selenium concentration in coal beds with $\geq$ 30 samples.

Se (ppm remnant-moisture, whole-coal)
0
1
2
3
4
5
6
7
8
Waynesburg
Sewickley
Redstone
Pittsburgh
Lower Bakerstown
Upper Freeport
Lower Freeport
Upper Kittanning
Middle Kittanning
Lower Kittanning
Clarion
Brookville
No 5 Block
Stockton
Coalburg
Winifrede/Hazard
Fire Clay
Cedar Grove/Whitesburg
Williamson/Amburgy
Campbell Creek/Upper E khorn No 3
Upper E khorn Nos. 1 and 2/Powellton
Pond Creek
Matewan/Clintwood
Little Eagle/Dorchester
Glenalum Tunnel/Splashdam
Gilbert A/Upper Banner
Douglas/Kennedy
Iaeger/Jawbone
Sewell/Lower Seaboard
Beckley/War Creek
Pocahontas No 3
coal bed (≥30 samples)
Geometric Mean
Median
Average

Figure 4b. Chart of average, median, and geometric mean of ash yield in coal beds with $\geq$ 30 samples.

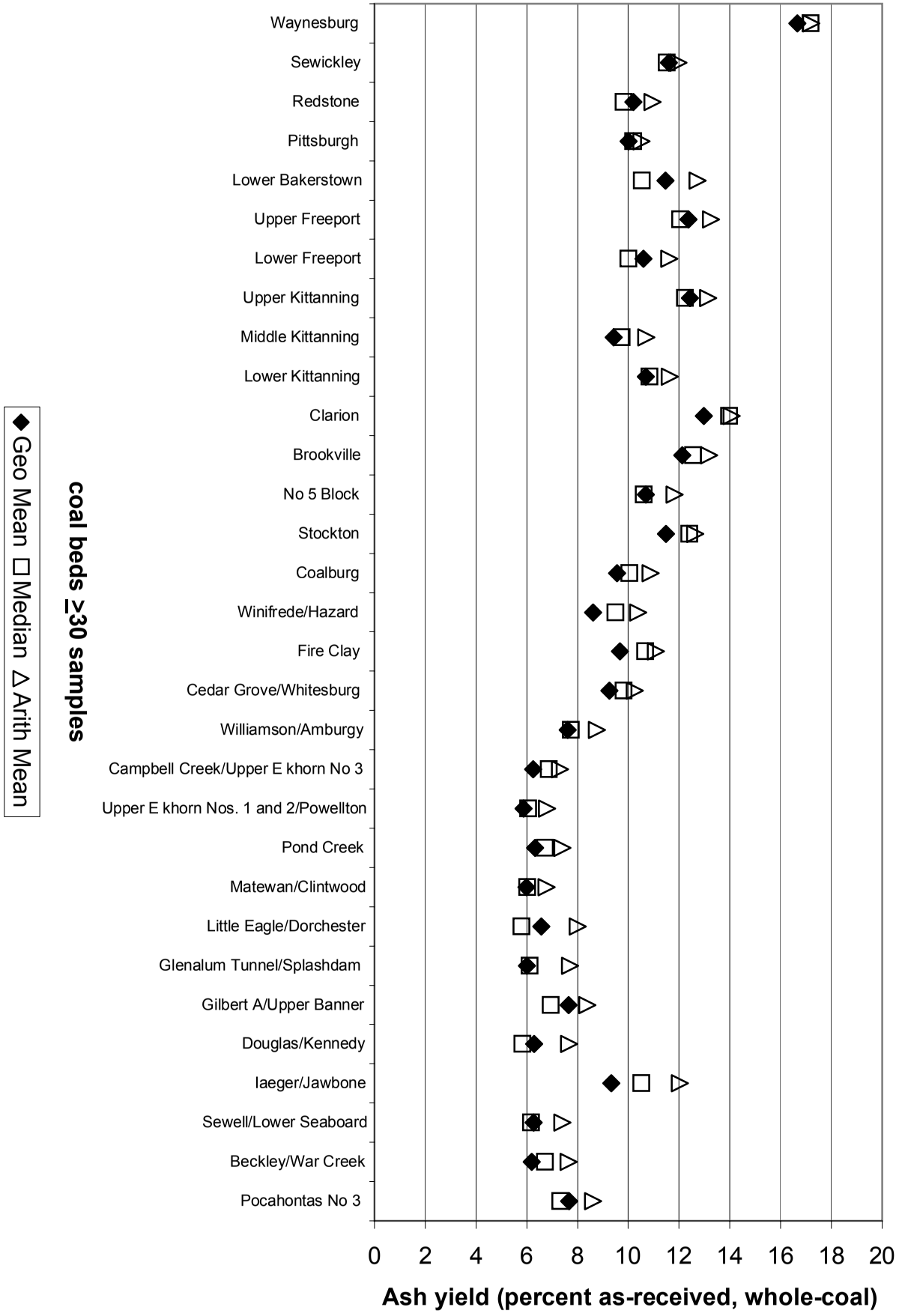

Geo Mean
Median
Arith Mean
coal beds ≥30 samples
Waynesburg
Sewickley
Redstone
Pittsburgh
Lower Bakerstown
Upper Freeport
Lower Freeport
Upper Kittanning
Middle Kittanning
Lower Kittanning
Clarion
Brookville
No 5 Block
Stockton
Coalburg
Winifrede/Hazard
Fire Clay
Cedar Grove/Whitesburg
Williamson/Amburgy
Campbell Creek/Upper E khorn No 3
Upper E khorn Nos. 1 and 2/Powellton
Pond Creek
Matewan/Clintwood
Little Eagle/Dorchester
Glenalum Tunnel/Splashdam
Gilbert A/Upper Banner
Douglas/Kennedy
Iaeger/Jawbone
Sewell/Lower Seaboard
Beckley/War Creek
Pocahontas No 3
0
2
4
6
8
10
12
14
16
18
20
Ash yield (percent as-received, whole-coal)

Figure 4c. Chart of average, median, and geometric mean of sulfur concentration in coal beds with $\geq$ 30 samples.

Sulfur (percent as-received, whole-coal)
0.0
0.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
Waynesburg
Sewickley
Redstone
Pittsburgh
Lower Bakerstown
Upper Freeport
Lower Freeport
Upper Kittanning
Middle Kittanning
Lower Kittanning
Clarion
Brookville
No 5 Block
Stockton
Coalburg
Winifrede/Hazard
Fire Clay
Cedar Grove/Whitesburg
Williamson/Amburgy
Campbell Creek/Upper E khorn No 3
Upper E khorn Nos. 1 and 2/Powellton
Pond Creek
Matewan/Clintwood
Little Eagle/Dorchester
Glenalum Tunnel/Splashdam
Gilbert A/Upper Banner
Douglas/Kennedy
Iaeger/Jawbone
Sewell/Lower Seaboard
Beckley/War Creek
Pocahontas No 3
coal beds ≥30 samples
Geo Mean
Median
Arith Mean

Figure 5a. Chart of median and midspread of selenium concentration in coal beds with $\geq$ 30 samples.

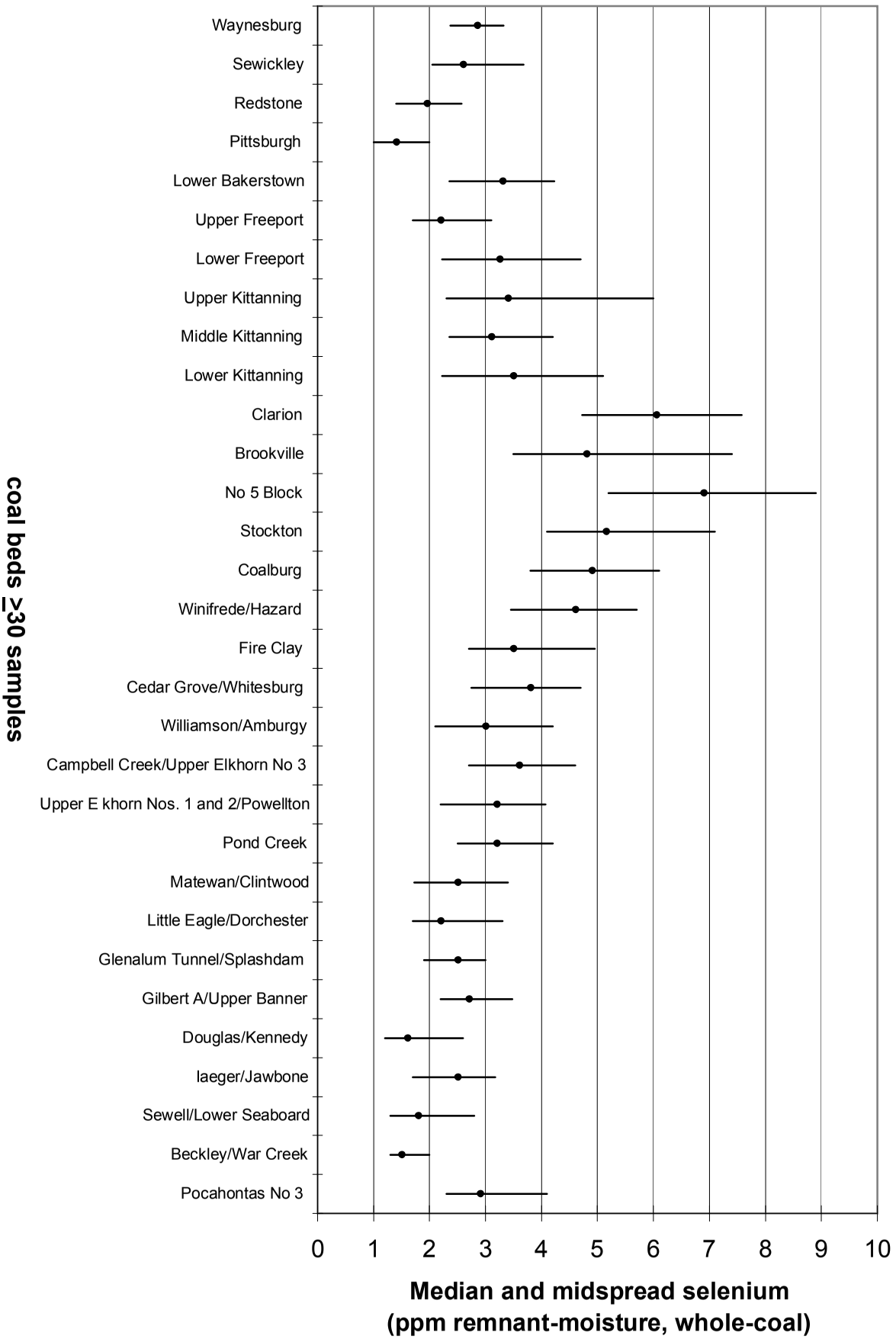

Waynesburg
Sewickley
Redstone
Pittsburgh
Lower Bakerstown
Upper Freeport
Lower Freeport
Upper Kittanning
Middle Kittanning
Lower Kittanning
Clarion
Brookville
No 5 Block
Stockton
Coalburg
Winifrede/Hazard
Fire Clay
Cedar Grove/Whitesburg
Williamson/Amburgy
Campbell Creek/Upper Elkhorn No 3
Upper E khorn Nos. 1 and 2/Powellton
Pond Creek
Matewan/Clintwood
Little Eagle/Dorchester
Glenalum Tunnel/Splashdam
Gilbert A/Upper Banner
Douglas/Kennedy
laeger/Jawbone
Sewell/Lower Seaboard
Beckley/War Creek
Pocahontas No 3
coal beds ≥30 samples
0
1
2
3
4
5
6
7
8
9
10
Median and midspread selenium
(ppm remnant-moisture, whole-coal)

Figure 5b. Chart of median and midspread of ash yield in coal beds with $\geq$ 30 samples.

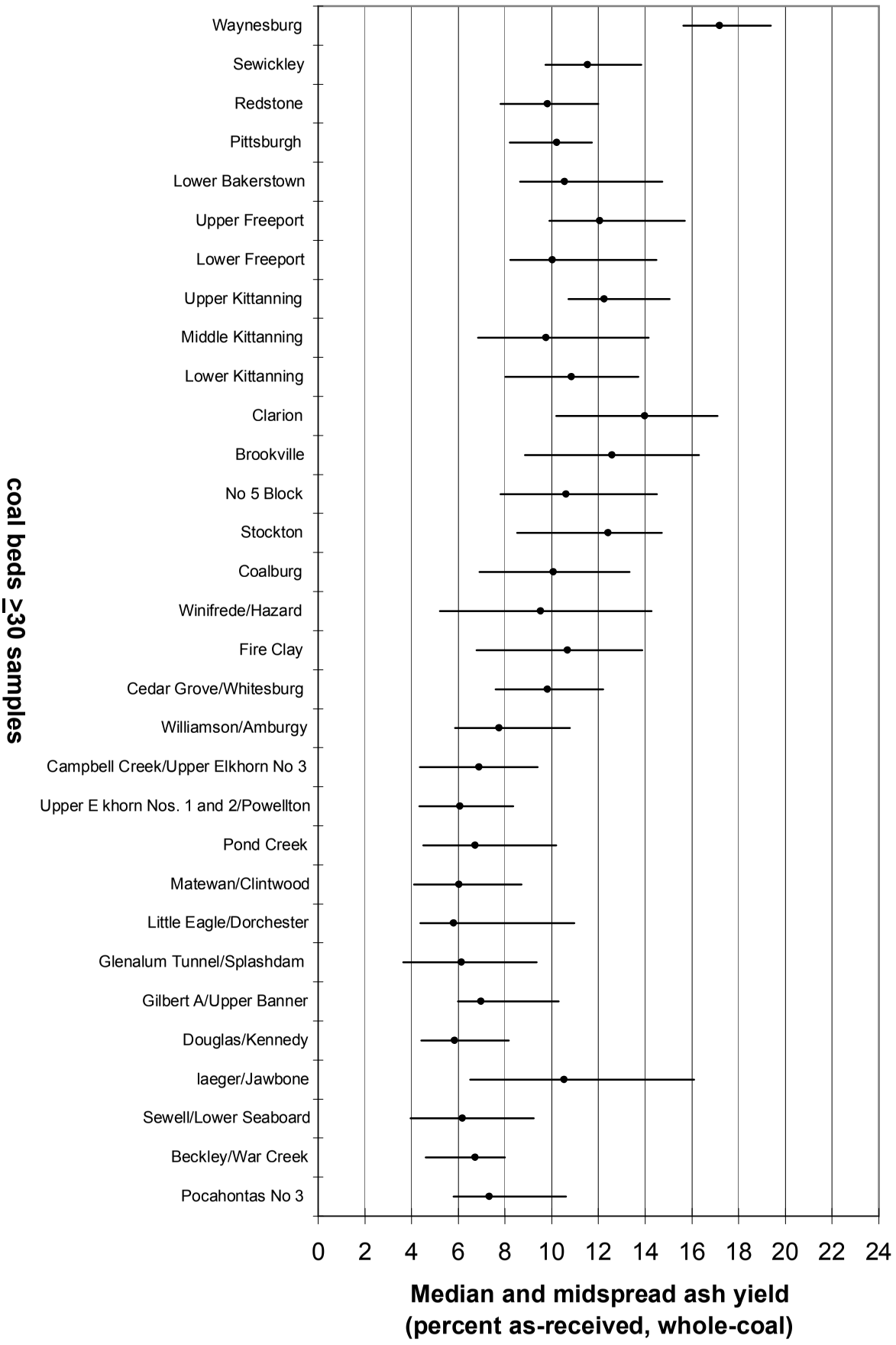

Waynesburg
Sewickley
Redstone
Pittsburgh
Lower Bakerstown
Upper Freeport
Lower Freeport
Upper Kittanning
Middle Kittanning
Lower Kittanning
Clarion
Brookville
No 5 Block
Stockton
Coalburg
Winifrede/Hazard
Fire Clay
Cedar Grove/Whitesburg
Williamson/Amburgy
Campbell Creek/Upper Elkhorn No 3
Upper E khorn Nos. 1 and 2/Powellton
Pond Creek
Matewan/Clintwood
Little Eagle/Dorchester
Glenalum Tunnel/Splashdam
Gilbert A/Upper Banner
Douglas/Kennedy
Iaeger/Jawbone
Sewell/Lower Seaboard
Beckley/War Creek
Pocahontas No 3
coal beds ≥30 samples
0
2
4
6
8
10
12
14
16
18
20
22
24
Median and midspread ash yield
(percent as-received, whole-coal)

Figure 5c. Chart of median and midspread of sulfur concentration in coal beds with $\geq$ 30 samples.

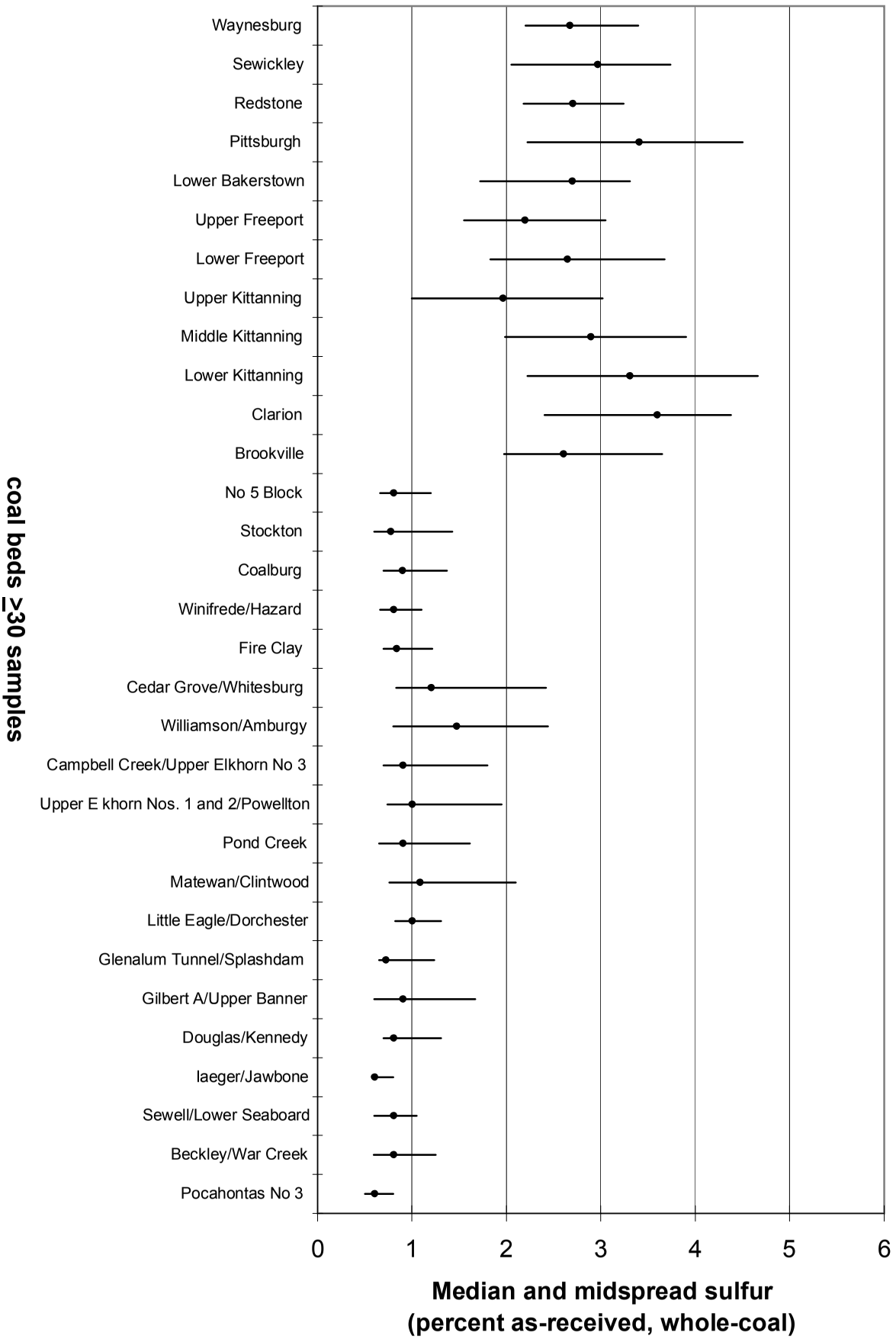

Waynesburg
Sewickley
Redstone
Pittsburgh
Lower Bakerstown
Upper Freeport
Lower Freeport
Upper Kittanning
Middle Kittanning
Lower Kittanning
Clarion
Brookville
No 5 Block
Stockton
Coalburg
Winifrede/Hazard
Fire Clay
Cedar Grove/Whitesburg
Williamson/Amburgy
Campbell Creek/Upper Elkhorn No 3
Upper E khorn Nos. 1 and 2/Powellton
Pond Creek
Matewan/Clintwood
Little Eagle/Dorchester
Glenalum Tunnel/Splashdam
Gilbert A/Upper Banner
Douglas/Kennedy
Iaeger/Jawbone
Sewell/Lower Seaboard
Beckley/War Creek
Pocahontas No 3
coal beds ≥30 samples
0
1
2
3
4
5
6
Median and midspread sulfur
(percent as-received, whole-coal)

Figure 6a. Chart of geometric mean of selenium concentration for all, thick ($\geq$ 28 inch), or thin (< 28 inch) coal samples in coal beds with $\geq$ 30 samples.

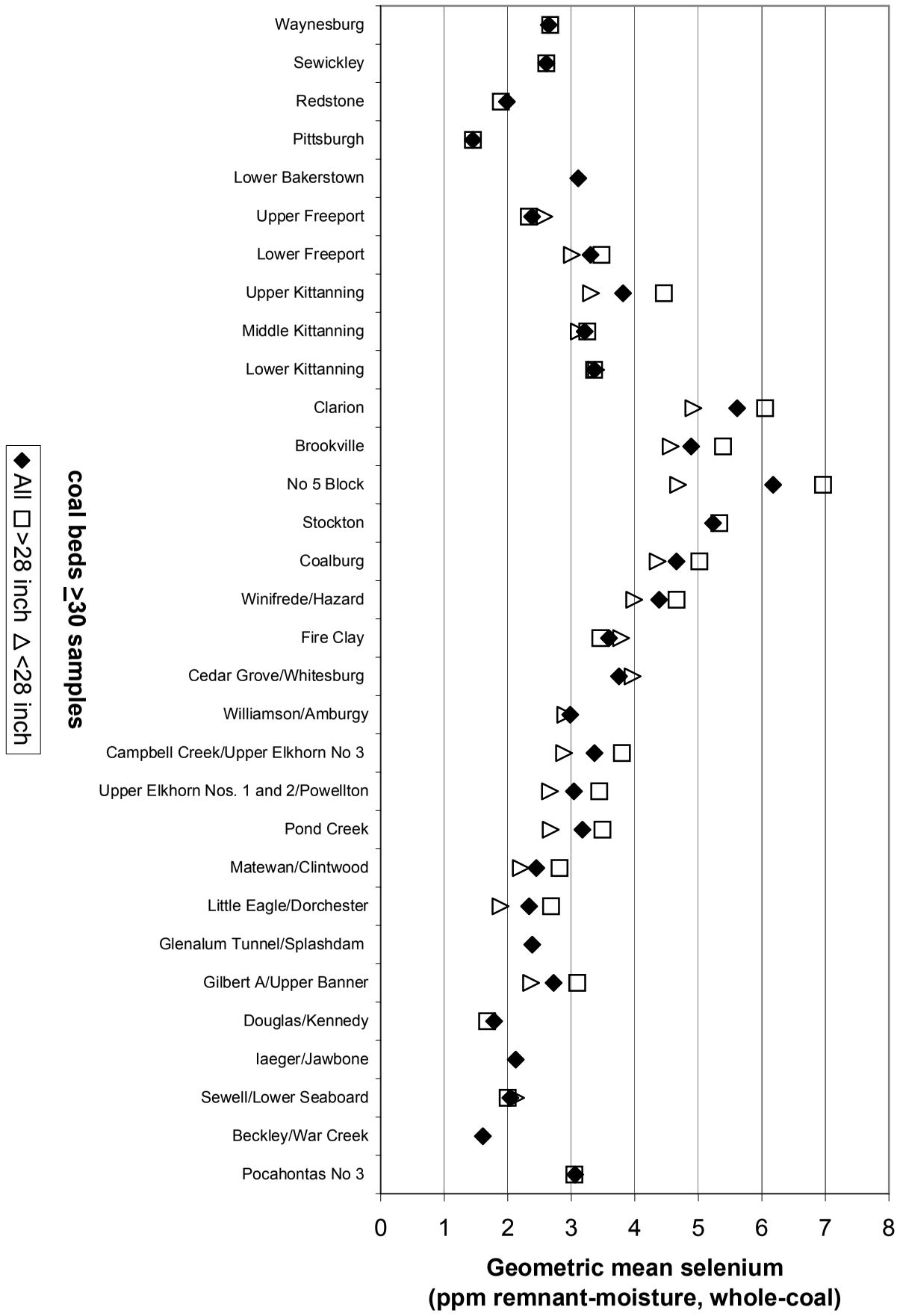

Waynesburg
Sewickley
Redstone
Pittsburgh
Lower Bakerstown
Upper Freeport
Lower Freeport
Upper Kittanning
Middle Kittanning
Lower Kittanning
Clarion
Brookville
No 5 Block
Stockton
Coalburg
Winifrede/Hazard
Fire Clay
Cedar Grove/Whitesburg
Williamson/Amburgy
Campbell Creek/Upper Elkhorn No 3
Upper Elkhorn Nos. 1 and 2/Powellton
Pond Creek
Matewan/Clintwood
Little Eagle/Dorchester
Glenalum Tunnel/Splashdam
Gilbert A/Upper Banner
Douglas/Kennedy
Iaeger/Jawbone
Sewell/Lower Seaboard
Beckley/War Creek
Pocahontas No 3
0
1
2
3
4
5
6
7
8
Geometric mean selenium
(ppm remnant-moisture, whole-coal)
coal beds ≥30 samples
◆ All □ >28 inch △ <28 inch

Figure 6b. Chart of geometric mean of ash yield for all, thick ($\geq$ 28 inch), or thin (< 28 inch) coal samples in coal beds with $\geq$ 30 samples.

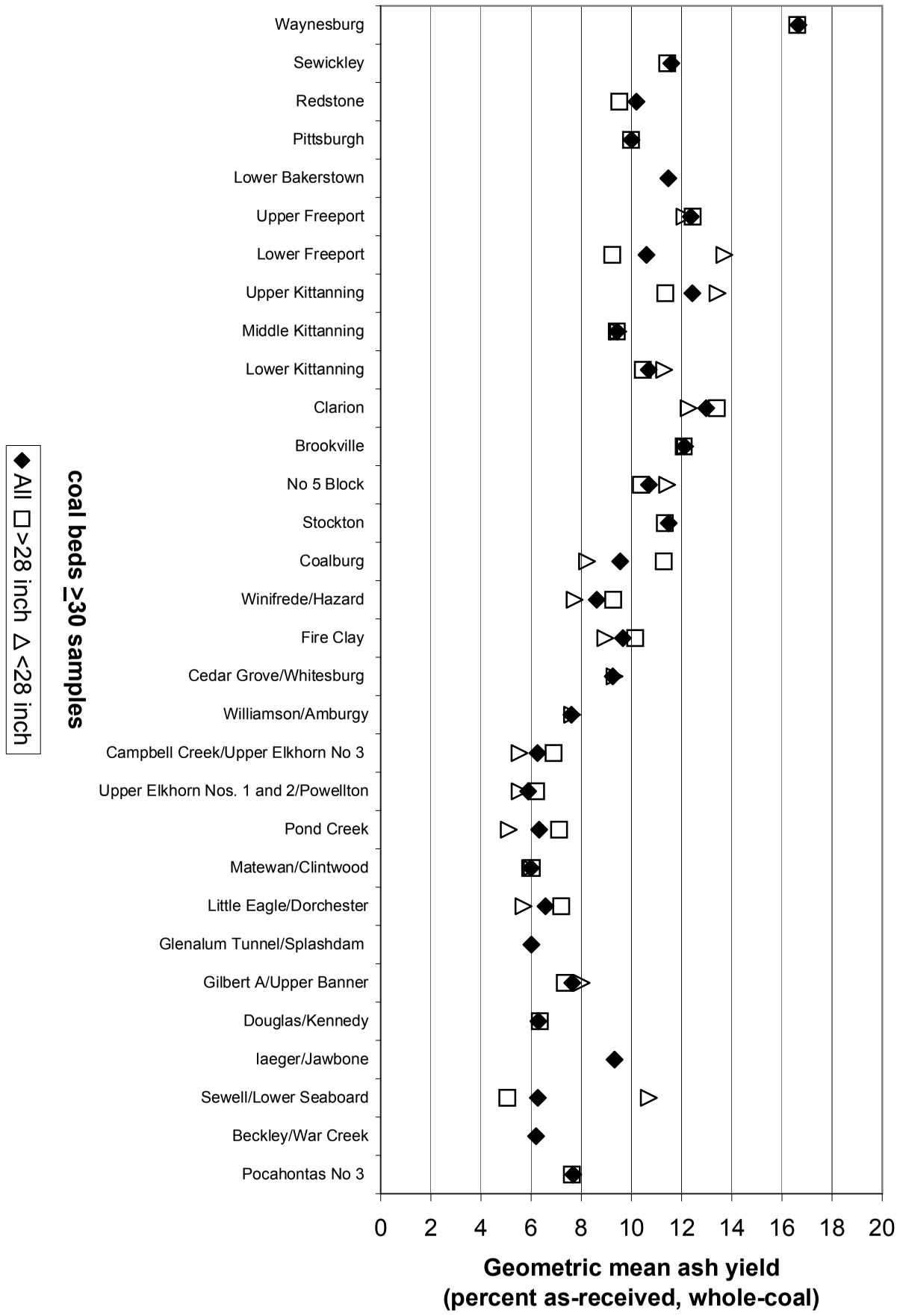

Waynesburg
Sewickley
Redstone
Pittsburgh
Lower Bakerstown
Upper Freeport
Lower Freeport
Upper Kittanning
Middle Kittanning
Lower Kittanning
Clarion
Brookville
No 5 Block
Stockton
Coalburg
Winifrede/Hazard
Fire Clay
Cedar Grove/Whitesburg
Williamson/Amburgy
Campbell Creek/Upper Elkhorn No 3
Upper Elkhorn Nos. 1 and 2/Powellton
Pond Creek
Matewan/Clintwood
Little Eagle/Dorchester
Glenalum Tunnel/Splashdam
Gilbert A/Upper Banner
Douglas/Kennedy
Iaeger/Jawbone
Sewell/Lower Seaboard
Beckley/War Creek
Pocahontas No 3
0
2
4
6
8
10
12
14
16
18
20
Geometric mean ash yield
(percent as-received, whole-coal)
coal beds ≥30 samples
◆ All □ >28 inch △ <28 inch

Figure 6c. Chart of geometric mean of sulfur concentration for all, thick ($\geq$ 28 inch), or thin (< 28 inch) coal samples in coal beds with $\geq$ 30 samples.

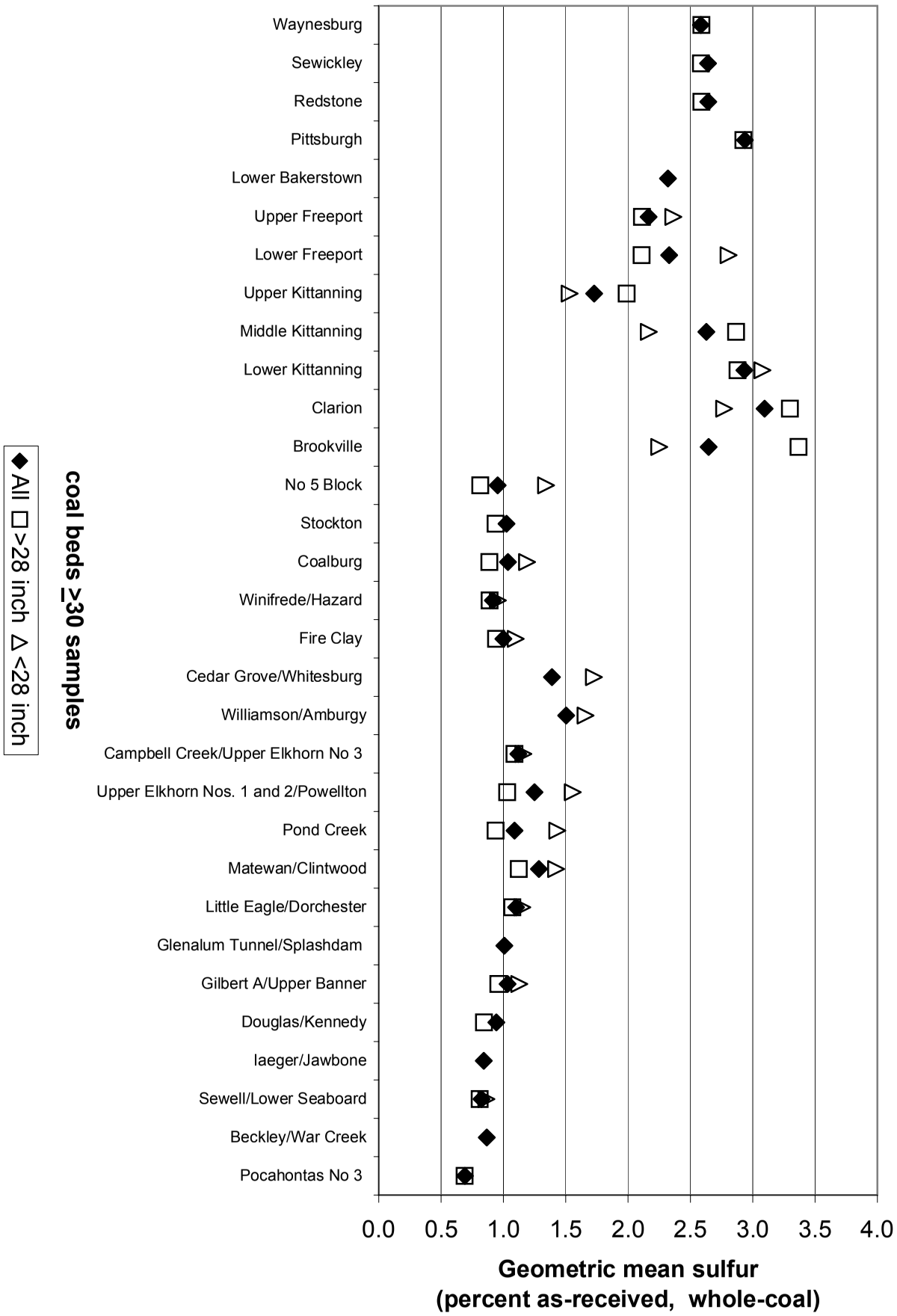
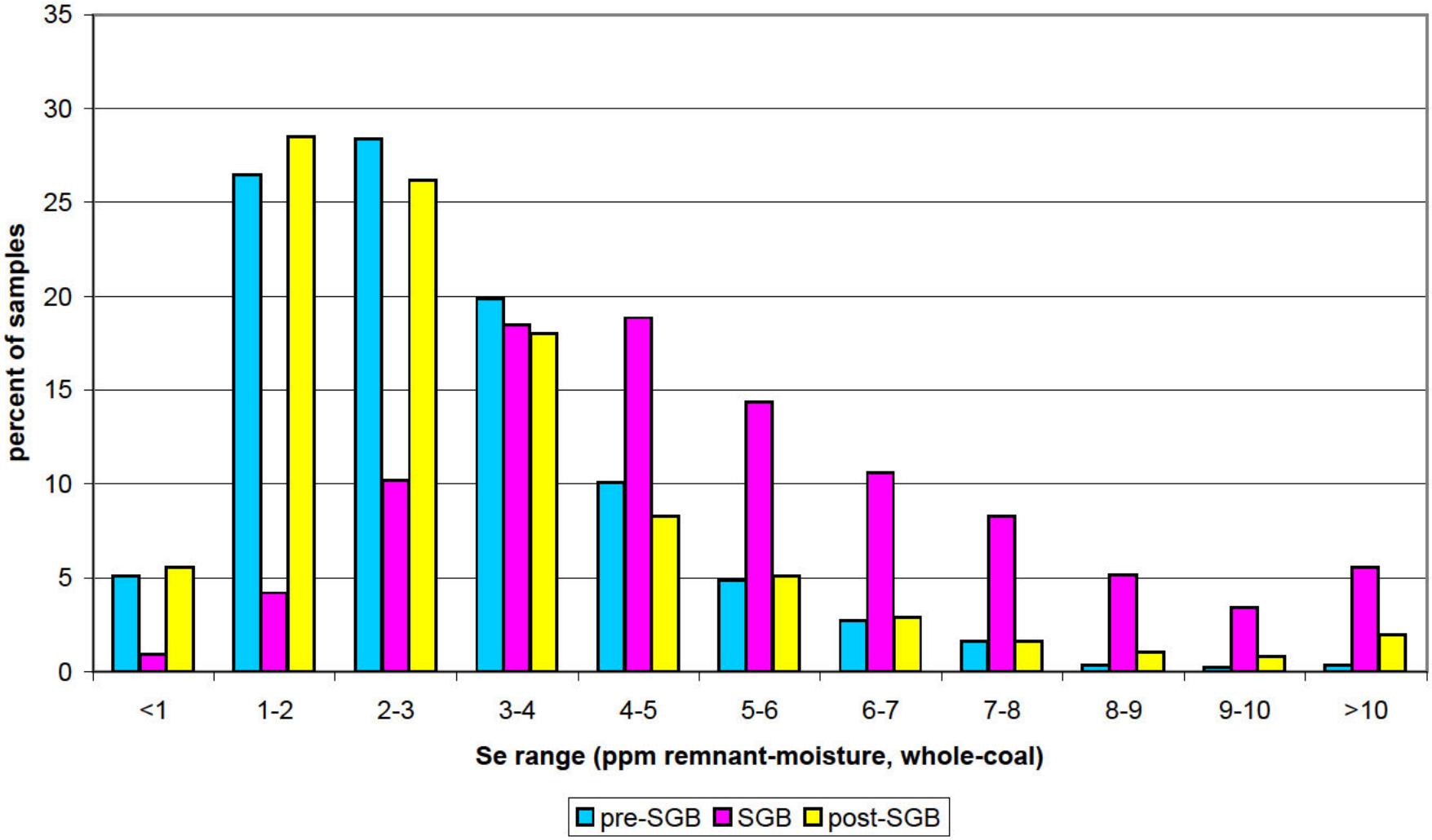
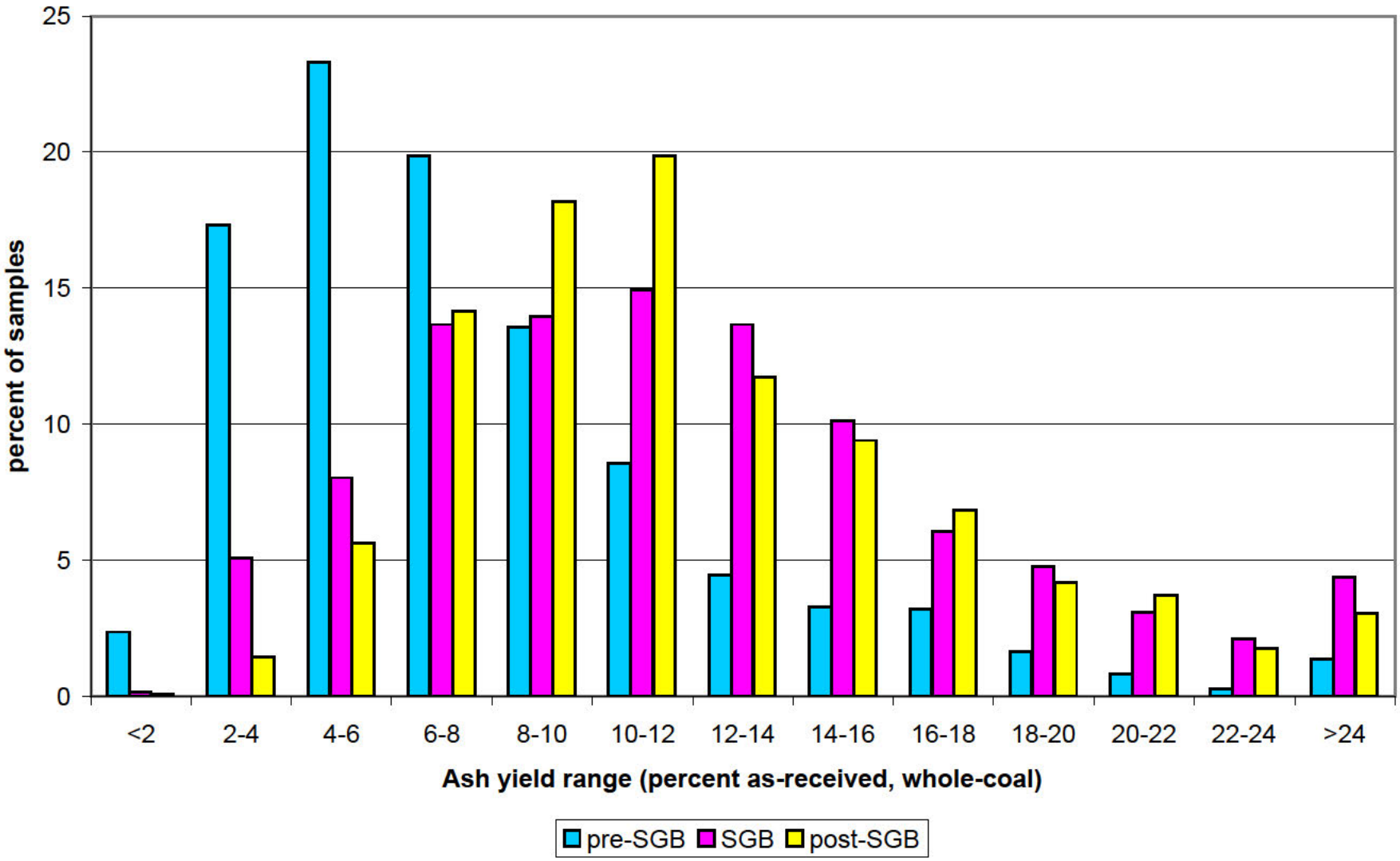

Waynesburg
Sewickley
Redstone
Pittsburgh
Lower Bakerstown
Upper Freeport
Lower Freeport
Upper Kittanning
Middle Kittanning
Lower Kittanning
Clarion
Brookville
No 5 Block
Stockton
Coalburg
Winifrede/Hazard
Fire Clay
Cedar Grove/Whitesburg
Williamson/Amburgy
Campbell Creek/Upper Elkhorn No 3
Upper Elkhorn Nos. 1 and 2/Powellton
Pond Creek
Matewan/Clintwood
Little Eagle/Dorchester
Glenalum Tunnel/Splashdam
Gilbert A/Upper Banner
Douglas/Kennedy
Iaeger/Jawbone
Sewell/Lower Seaboard
Beckley/War Creek
Pocahontas No 3
0.0
0.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
Geometric mean sulfur
(percent as-received, whole-coal)
coal beds ≥30 samples
◆ All □ >28 inch △ <28 inch

Figure 7a. Histograms of selenium, ash yield and sulfur concentrations in three stratigraphic intervals (pre-SGB, SGB, and post-SGB) for all coal bed samples. [Number of samples listed in table 5a. Coal beds in stratigraphic intervals pre-SGB, SGB, and post-SGB listed in table 2.]

Histogram of selenium concentration in three stratigraphic intervals for all coal bed samples.



Histogram of ash yield in three stratigraphic intervals for all coal bed samples.



Histogram of total sulfur concentration in three stratigraphic intervals for all coal bed samples.

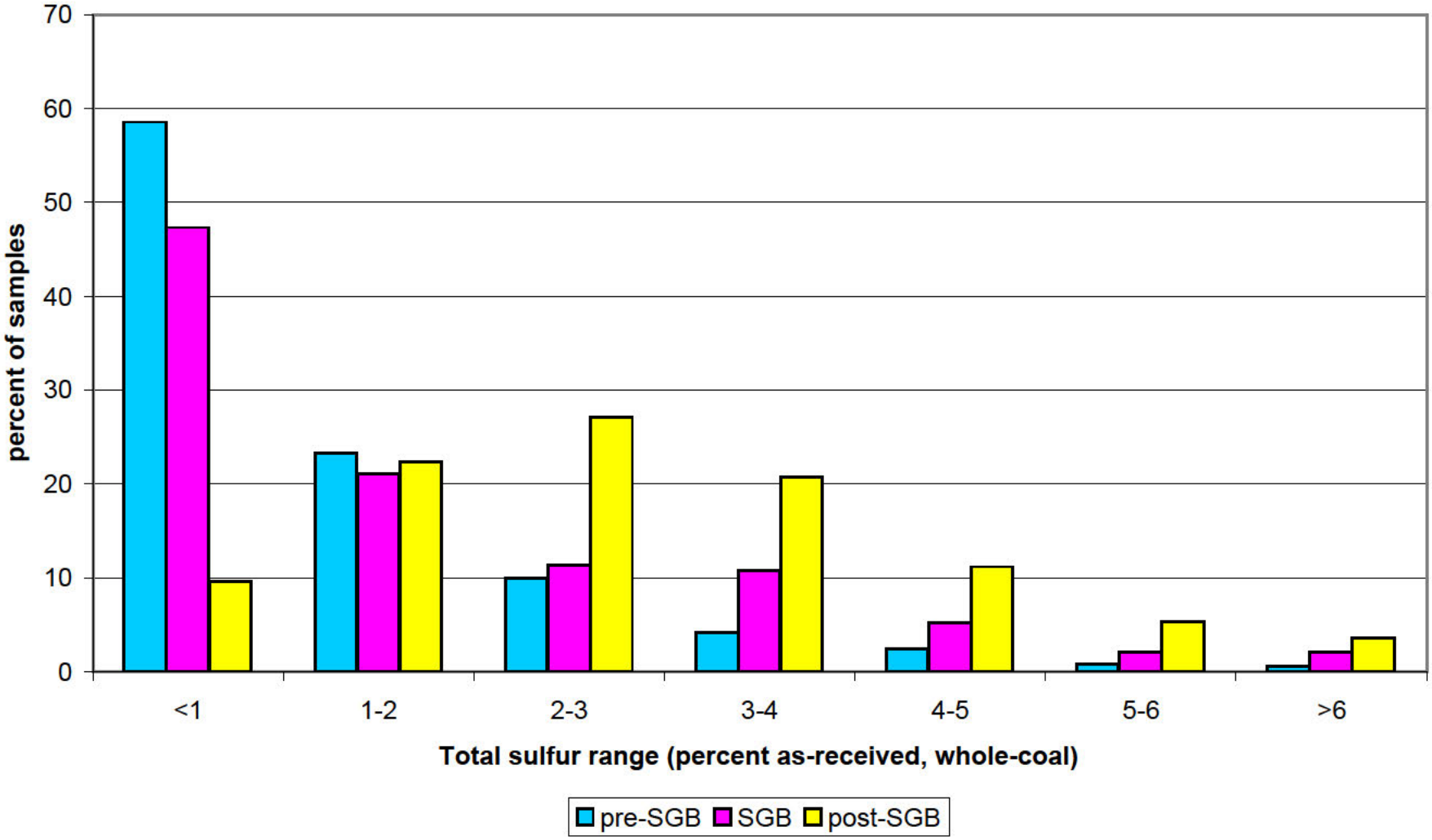
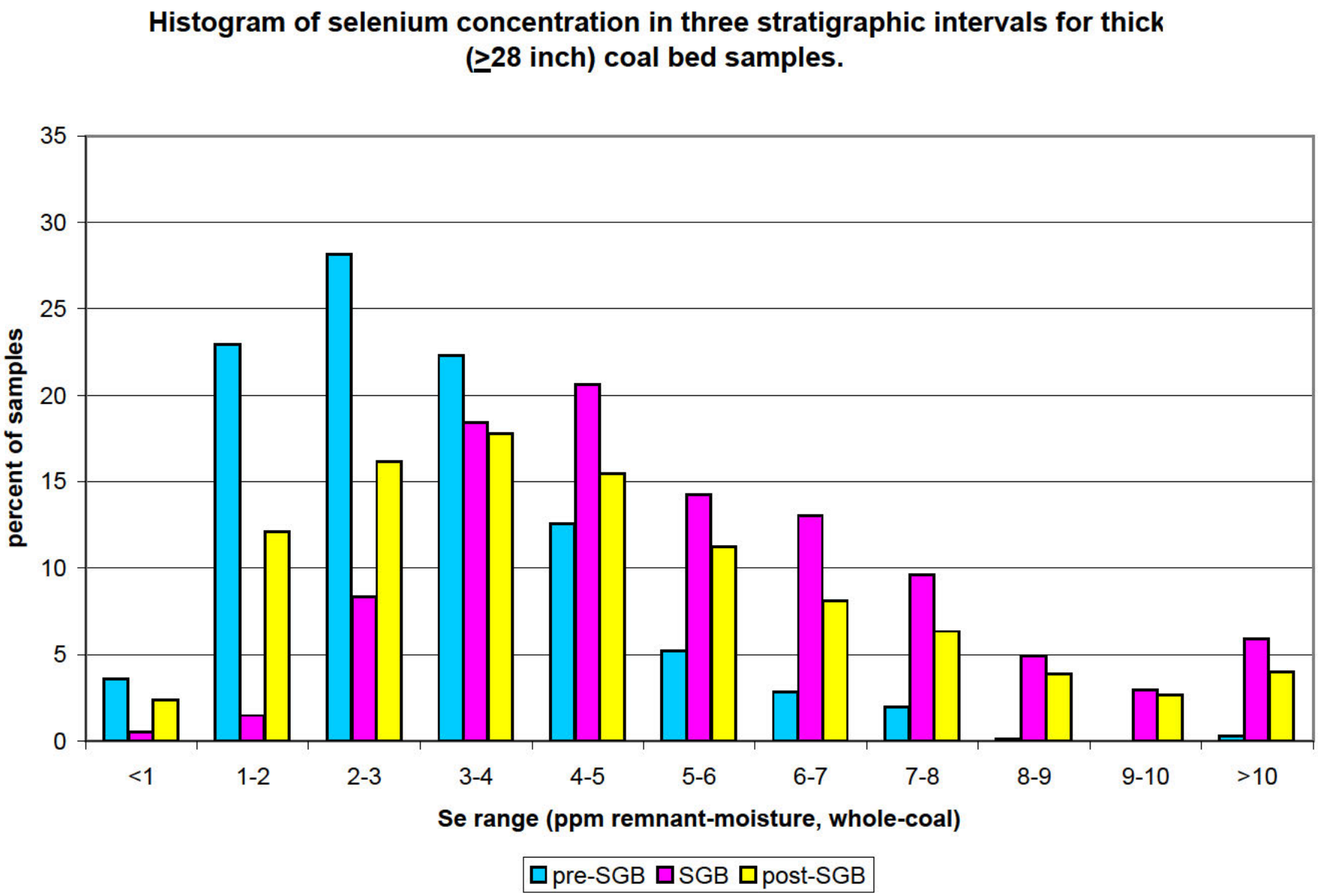
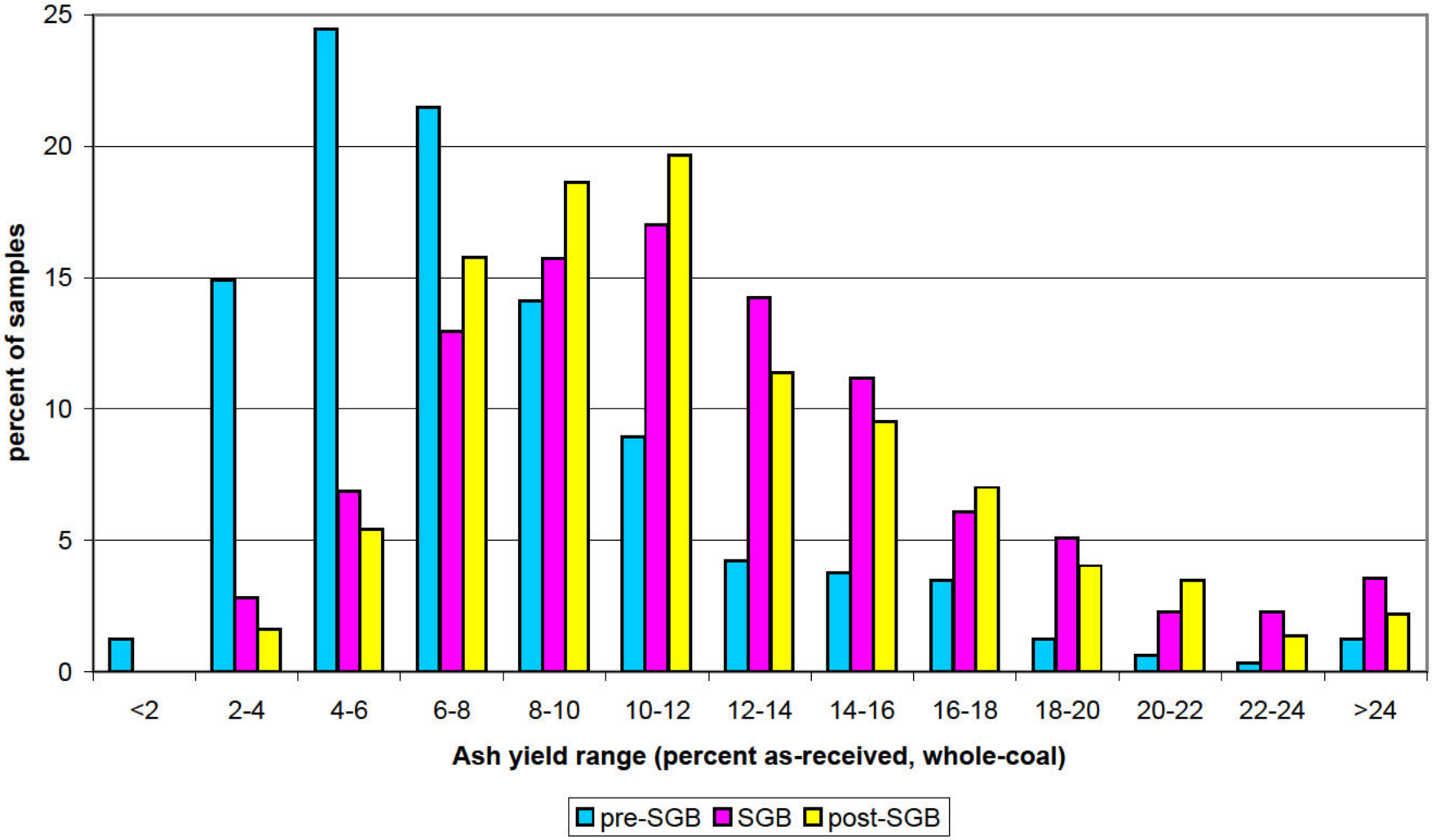


Figure 7b. Histograms of selenium, ash yield and sulfur concentrations in three stratigraphic intervals (pre-SGB, SGB, and post-SGB) for thick ($\geq$ 28 inch) coal bed samples. [Number of samples listed in table 5b. Coal beds in stratigraphic intervals pre-SGB, SGB, and post-SGB listed in table 2.]


Histogram of selenium concentration in three stratigraphic intervals for thick (≥28 inch) coal bed samples.
percent of samples
35
30
25
20
15
10
5
0
<1
1-2
2-3
3-4
4-5
5-6
6-7
7-8
8-9
9-10
>10
Se range (ppm remnant-moisture, whole-coal)
pre-SGB
SGB
post-SGB

Histogram of ash yield in three stratigraphic intervals for thick (≥28 inch) coal bed samples.



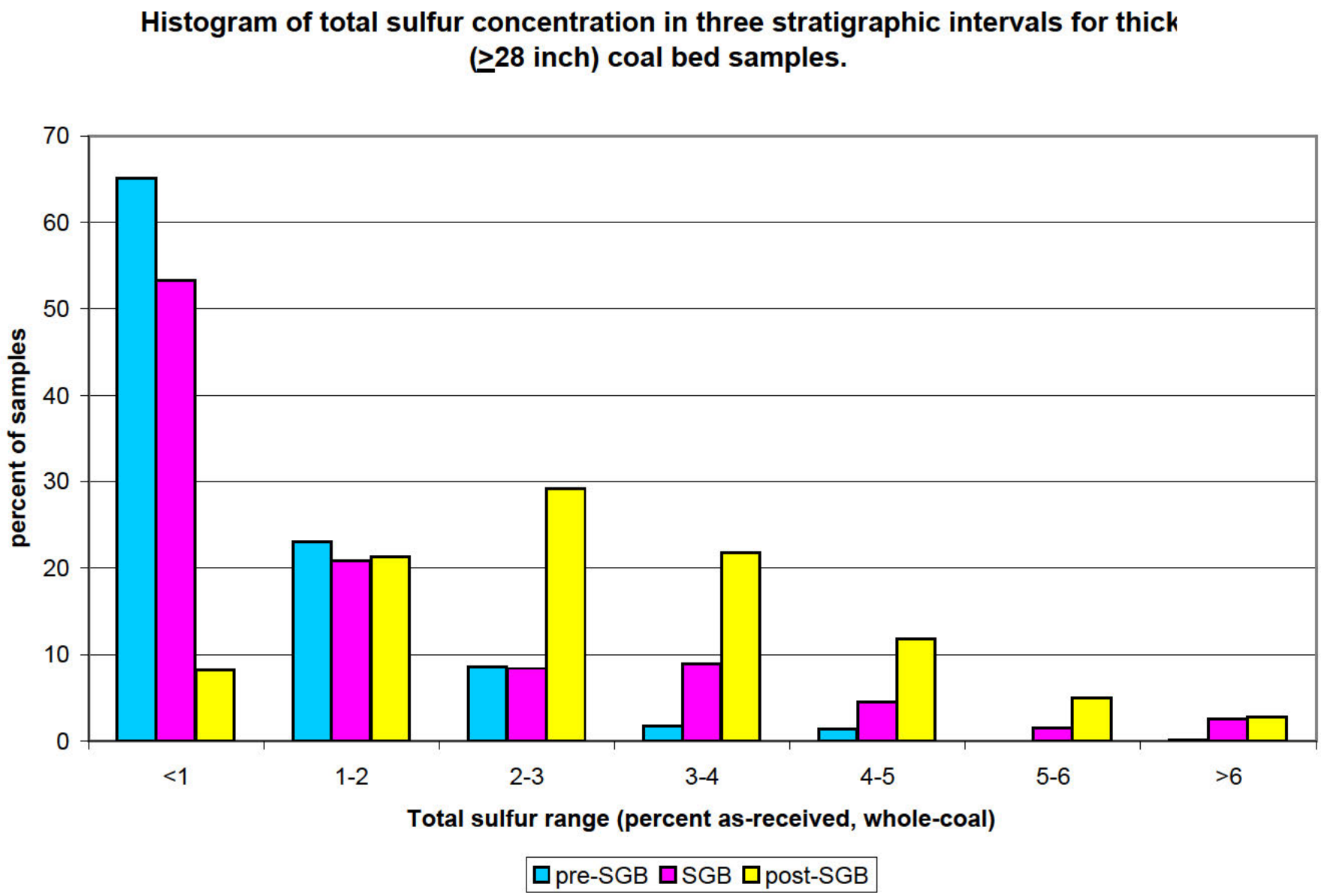
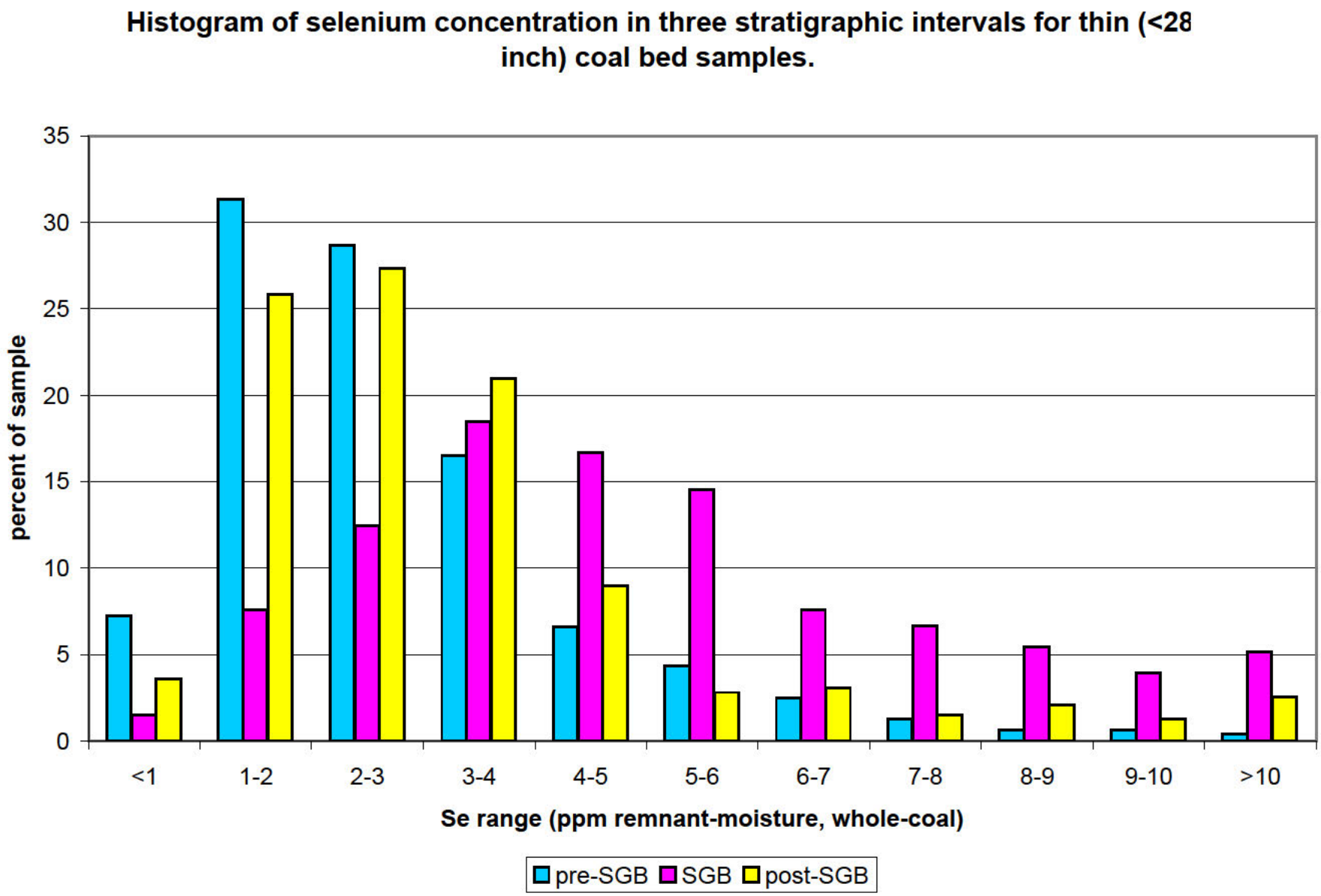
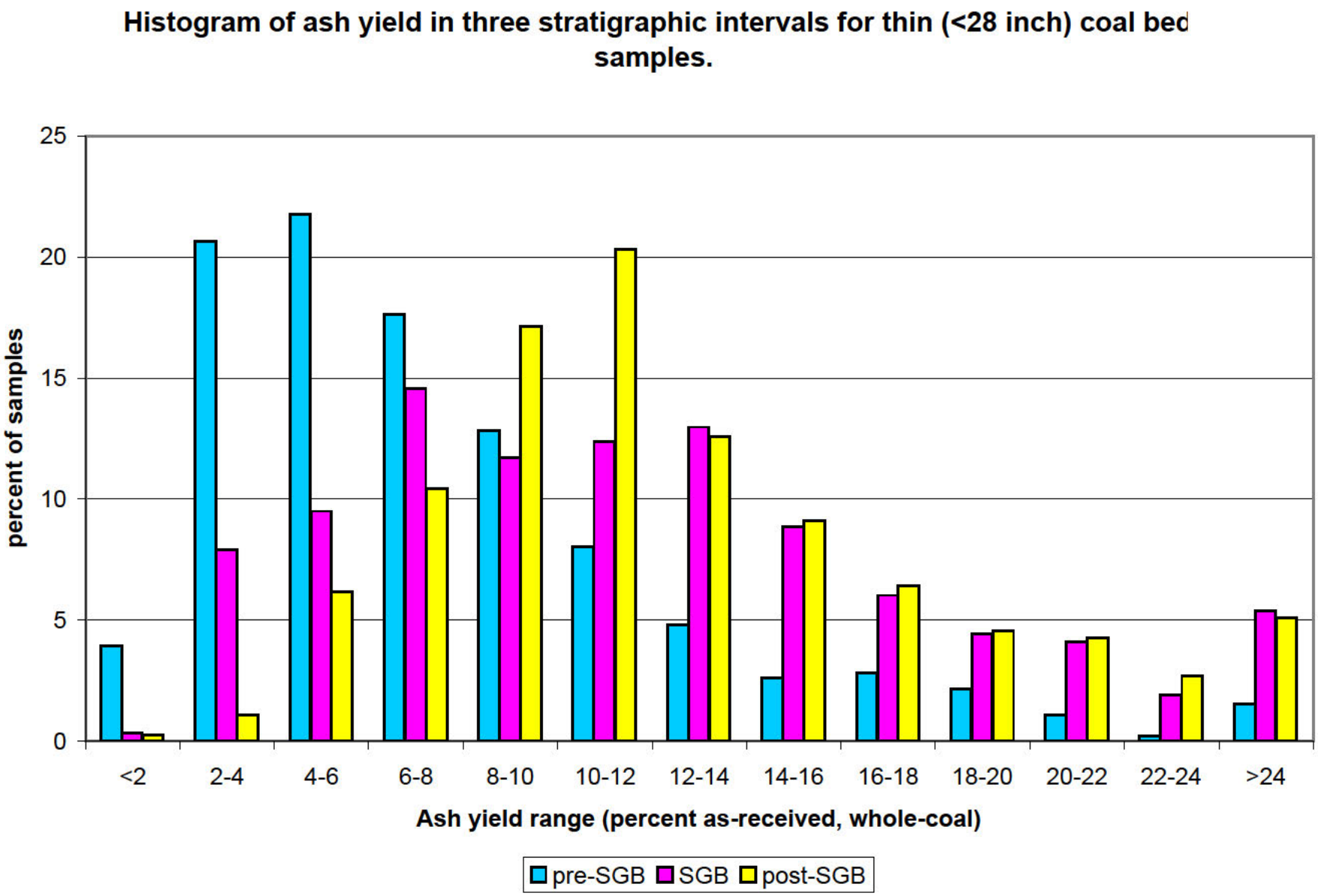

Histogram of total sulfur concentration in three stratigraphic intervals for thick
(≥28 inch) coal bed samples.
percent of samples
70
60
50
40
30
20
10
0
<1
1-2
2-3
3-4
4-5
5-6
>6
Total sulfur range (percent as-received, whole-coal)
pre-SGB
SGB
post-SGB

Figure 7c. Histograms of selenium, ash yield and sulfur concentrations in three stratigraphic intervals (pre-SGB, SGB, and post-SGB) for thin (< 28 inch) coal bed samples. [Number of samples listed in table 5c. Coal beds in stratigraphic intervals pre-SGB, SGB, and post-SGB listed in table 2.]


Histogram of selenium concentration in three stratigraphic intervals for thin (<28 inch) coal bed samples.
percent of sample
35
30
25
20
15
10
5
0
<1
1-2
2-3
3-4
4-5
5-6
6-7
7-8
8-9
9-10
>10
Se range (ppm remnant-moisture, whole-coal)
pre-SGB
SGB
post-SGB


Histogram of ash yield in three stratigraphic intervals for thin (<28 inch) coal bed samples.
percent of samples
25
20
15
10
5
0
<2
2-4
4-6
6-8
8-10
10-12
12-14
14-16
16-18
18-20
20-22
22-24
>24
Ash yield range (percent as-received, whole-coal)
pre-SGB
SGB
post-SGB

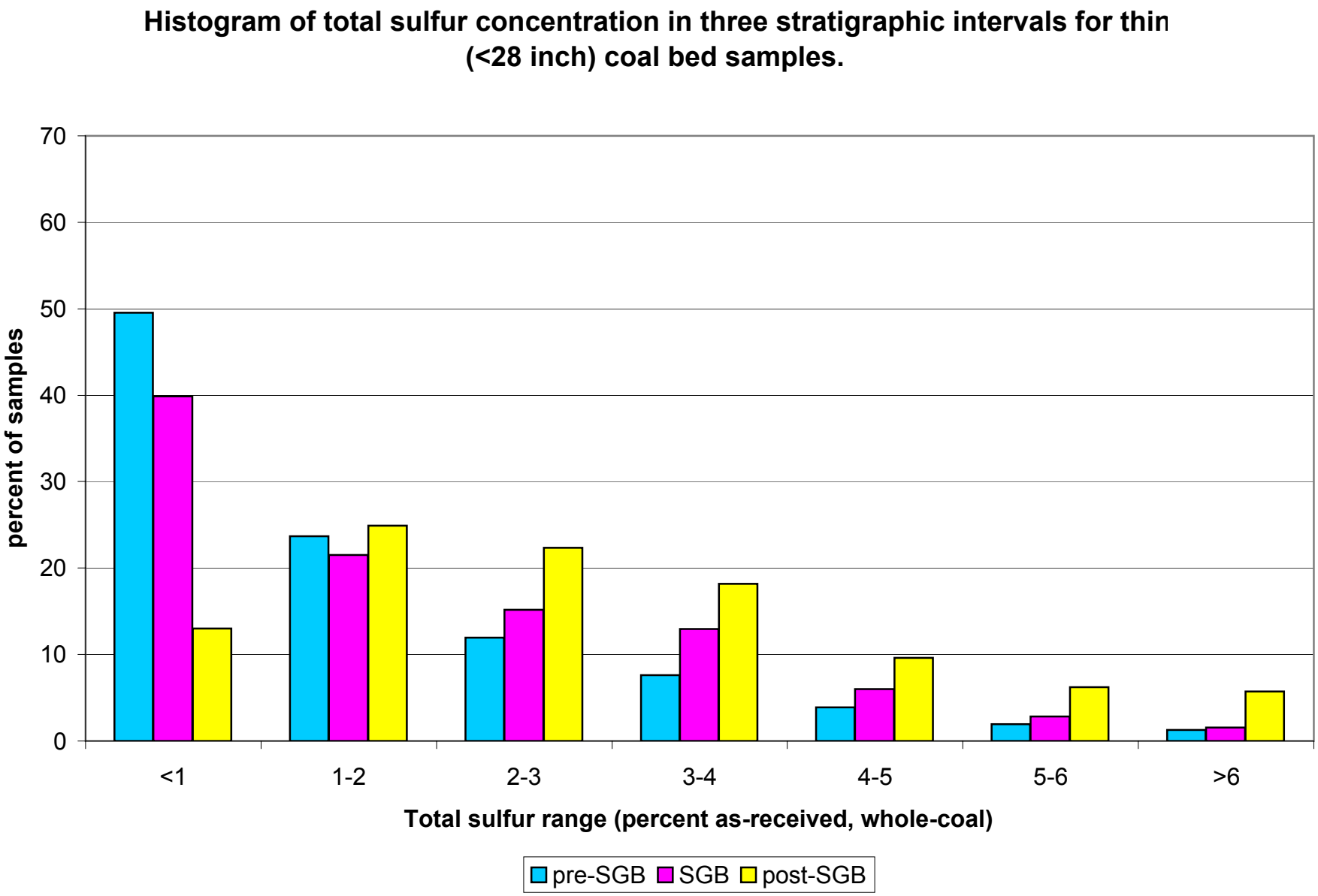

Histogram of total sulfur concentration in three stratigraphic intervals for thin
(<28 inch) coal bed samples.
percent of samples
70
60
50
40
30
20
10
0
<1
1-2
2-3
3-4
4-5
5-6
>6
Total sulfur range (percent as-received, whole-coal)
pre-SGB
SGB
post-SGB

Table 1. Coal bed names used in this report (names in bold), correlative alternate coal bed names used in COALQUAL database (see column CBED in Appendix 1), number of samples (N) from each state, and total number of samples for each coal bed (in bold) [nWV = northern West Virgina coal field sWV = southern West Virginia coal field]

COAL BED NAMES (COALQUAL database)	Number of Samples								
COAL BED NAMES (BOLD, THIS REPORT)	**PA**	**MD**	**OH**	**nWV**	**sWV**	**KY**	**TN**	**VA**	**Total**
WAYNESBURG	29	1		6					36
WAYNESBURG NO 11			24						24
WAYNESBURG	**29**	**1**	**24**	**6**					**60**
MEIGS CREEK NO 9			27						27
SEWICKLEY	11	2		2					15
SEWICKLEY	**11**	**2**	**27**	**2**					**42**
FISHPOT	**1**		**3**						**4**
REDSTONE	14	1		42					57
REDSTONE NO 8A			17						17
REDSTONE	**14**	**1**	**17**	**42**					**74**
PITTSBURGH ROOF	8								8
PITTSBURGH ROOSTER	2								2
PITTSBURGH ROOF	**10**								**10**
PITTSBURGH	29	1		40					70
PITTSBURGH NO 8			66						66
PITTSBURGH-PITTSBURGH ROOF	1								1
PITTSBURGH	**30**	**1**	**66**	**40**					**137**
ELK LICK				1					1
WELLERSBURG	2								2
ELK LICK	**2**			**1**					**3**
FEDERAL HILL	**3**								**3**
HARLEM	**1**	**3**	**5**						**9**
UPPER BAKERSTOWN	**4**								**4**
ANDERSON			11						11
BAKERSTOWN	1	3		1					5
BARTON	1								1
LOWER BAKERSTOWN	8	5							13
LOWER BAKERSTOWN	**10**	**8**	**11**	**1**					**30**
WILGUS			**4**						**4**
BRUSH CREEK	**9**	**2**							**11**
MAHON NG	7		11						18
SPEER	2								2
MAHONING	**9**		**11**						**20**
KELLY R DER	1								1
UPPER FREEPORT RIDER	5								5
UPPER FREEPORT RIDER	**6**								**6**
KELLY	1								1
PR NCESS NO 9				4		1			5
UPPER FREEPORT	192	20		3					215
UPPER FREEPORT NO 7			57						57
UPPER FREEPORT	**193**	**20**	**57**	**7**		**1**			**278**
LOWER FREEPORT	57								57
LOWER FREEPORT NO 6A			42						42
LOWER FREEPORT R DER	1								1
MOSHANNON	2								2
PR NCESS NO 8						1			1
LOWER FREEPORT	**60**		**42**			**1**			**103**
UPPER KITTANNING 2 RIDER	1								1
UPPER KITTANNING R DER	2								2
UPPER KITTANNING RIDER	**3**								**3**
UPPER KITTANNING	**64**	**2**		**1**					**67**

Table 1. Coal bed names used in this report (names in bold), correlative alternate coal bed names used in COALQUAL database (see column CBED in Appendix 1), number of samples (N) from each state, and total number of samples for each coal bed (in bold) [nWV = northern West Virgina coal field sWV = southern West Virginia coal field]

COAL BED NAMES (COALQUAL database)	Number of Samples								
COAL BED NAMES (BOLD, THIS REPORT)	**PA**	**MD**	**OH**	**nWV**	**sWV**	**KY**	**TN**	**VA**	**Total**
M DDLE KITTANNING 1 RIDER	2								2
M DDLE KITTANNING 2 RIDER	2								2
M DDLE KITTANNING R DER	4								4
MIDDLE KITTANNING RIDER	**8**								**8**
M DDLE KITTANNING	78	2		3					83
M DDLE KITTANNING A	1								1
M DDLE KITTANNING NO 6			151						151
M DDLE KITTANNING SPLIT	1								1
PR NCESS NO 7						7			7
MIDDLE KITTANNING	**80**	**2**	**151**	**3**		**7**			**243**
STRASBURG	1								1
STRASBURG NO 5A			10						10
STRASBURG	**1**		**10**						**11**
LOWER KITTANN NG 1 R DER	2								2
LOWER KITTANN NG 2 R DER	2								2
LOWER KITTANN NG 3 R DER	1								1
LOWER KITTANN NG R DER	2								2
LOWER KITTANNING RIDER	**7**								**7**
KITTANN NG		2							2
LAWRENCE			1						1
LOWER KITTANN NG	78	2		4					84
LOWER KITTANN NG NO 5			103						103
NO 6 BLOCK				5					5
PR NCESS NO 6						2			2
UPPER KITTANNING				1					1
LOWER KITTANNINGNo. 6 BLOCK	**78**	**4**	**104**	**10**		**2**			**198**
CLARION	8								8
CLARION 4A-SCRUBGRASS			1						1
CLARION COAL ZONE			6						6
CLARION NO 1	2								2
CLARION NO 2	1								1
CLARION NO 4A			40						40
CLARION-BROOKVILLE	2								2
CLARION-BROOKVILLE RIDER	1								1
LAUREL						1			1
LAUREL RIDER						1			1
SCRUBGRASS	2		4						6
UPPER CLARION	5								5
CLARION	**21**		**51**			**2**			**74**
BROOKV LLE	30								30
BROOKV LLE NO 4			30						30
BROOKV LLE-CLARION	2								2
LOWER CLARION	7								7
OGAN			1						1
WINTERS			3						3
BROOKVILLE	**39**		**34**						**73**

Table 1. Coal bed names used in this report (names in bold), correlative alternate coal bed names used in COALQUAL database (see column CBED in Appendix 1), number of samples (N) from each state, and total number of samples for each coal bed (in bold) [nWV = northern West Virgina coal field sWV = southern West Virginia coal field]

COAL BED NAMES (COALQUAL database)	Number of Samples								
COAL BED NAMES (BOLD, THIS REPORT)	**PA**	**MD**	**OH**	**nWV**	**sWV**	**KY**	**TN**	**VA**	**Total**
KNOB						1			1
KNOB SPLIT 2						1			1
KNOB ZONE						5			5
LOWER KITTANN NG					4				4
LOWER NO 5 BLOCK					6				6
LOWER RICHARDSON						1			1
NO 5 BLOCK					30				30
PR NCESS NO 5						5			5
RICHARDSON						19			19
RICHARDSON R DER						1			1
SKYLINE						8			8
SKYLINE SPLIT 1						1			1
SKYLINE SPLIT 2						1			1
SKYLINE SPLIT 3						1			1
SKYLINE SPLIT 4						1			1
SKYLINE SPLIT 5						1			1
SKYLINE SPLIT 6						1			1
UPPER NO 5 BLOCK					3				3
UPPER RICHARDSON						1			1
UPPER SPLIT NO 5 BLOCK					2				2
NO 5 BLOCK					**45**	**48**			**93**
STOCKTON A					3				3
UPPER KITTANNING					1				1
STOCKTON A/LITTLE NO 5 BLOCK					**4**				**4**
TIONESTA			**5**						**5**
UPPER MERCER	6								6
UPPER MERCER NO 3A			2						2
UPPER MERCER	**6**		**2**						**8**
LOWER MERCER	3								3
LOWER MERCER A	1								1
LOWER MERCER B	1								1
LOWER MERCER NO 3			2						2
MERCER	17								17
LOWER MERCER	**22**		**2**						**24**
QUAKERTOWN	2								2
QUAKERTOWN NO 2			7						7
QUAKERTOWN	**2**		**7**						**9**
BROAS						14			14
BROAS, UPPER RIDER						1			1
HAZARD NO 9						4			4
HINDMAN						15			15
PR NCESS NO 4						2			2
STOCKTON					17				17
STOCKTON RIDER					1				1
STOCKTON-LEWISTON					1				1
T PTOP						4			4
UPPER BROAS						3			3
STOCKTON					**19**	**43**			**62**

Table 1. Coal bed names used in this report (names in bold), correlative alternate coal bed names used in COALQUAL database (see column CBED in Appendix 1), number of samples (N) from each state, and total number of samples for each coal bed (in bold) [nWV = northern West Virgina coal field sWV = southern West Virginia coal field]

COAL BED NAMES (COALQUAL database)	Number of Samples								
COAL BED NAMES (BOLD, THIS REPORT)	**PA**	**MD**	**OH**	**nWV**	**sWV**	**KY**	**TN**	**VA**	**Total**
COALBURG					22				22
COALBURG A					1				1
FRANCIS						9			9
FRANCIS R DER						4			4
HAZARD NO 7						19			19
HAZARD NO 8						9			9
HIGH SPLINT						1		1	2
LENOX						1			1
LOWER PEACH ORCHARD						9			9
M DDLE PEACH ORCHARD						1			1
MUDSEAM						6			6
PEACH ORCHARD						33			33
PEACH ORCHARD RIDER						1			1
PR NCESS NO 3						6			6
PR NCESS NO 3 RIDER						1			1
SEBASTIAN						3			3
UPPER PEACH ORCHARD						16			16
COALBURG					**23**	**119**		**1**	**143**
HAZARD						38			38
HAZARD NO 5A						2			2
HAZARD RIDER						5			5
INDEX						1			1
MORRIS						3		3	6
PEWEE							5		5
PRATER						3			3
RED SPR NGS						1			1
WIN FREDE					17	1			18
WINIFREDE/HAZARD					**17**	**54**	**5**	**3**	**79**
LOWER WINIFREDE/HAZARD						**10**			**10**
CHILTON A					1				1
COPLAND						3			3
LIMESTONE						1			1
PARDEE								5	5
TAYLOR						5			5
CHILTON/TAYLOR					**1**	**9**		**5**	**15**
BIG MARY						2	7		9
F RE CLAY RIDER						20			20
FIRE CLAY RIDER						**22**	**7**		**29**
CHILTON					2				2
F RE CLAY						40			40
HERNSHAW					2				2
HIGNITE						2			2
LITTLE FIRE CLAY						6			6
PH LL PS								1	1
STRAY						6			6
UPPER WHITESBURG						2			2
WALLINS CREEK						1			1
WALNUT MOUNTA N							2		2
WHITESBURG						2			2
WINDROCK							4		4
FIRE CLAY					**4**	**59**	**6**	**1**	**70**

Table 1. Coal bed names used in this report (names in bold), correlative alternate coal bed names used in COALQUAL database (see column CBED in Appendix 1), number of samples (N) from each state, and total number of samples for each coal bed (in bold) [nWV = northern West Virgina coal field sWV = southern West Virginia coal field]

COAL BED NAMES (COALQUAL database)	Number of Samples								
COAL BED NAMES (BOLD, THIS REPORT)	**PA**	**MD**	**OH**	**nWV**	**sWV**	**KY**	**TN**	**VA**	**Total**
CEDAR GROVE					2				2
DINGESS					2				2
HERNSHAW					12				12
HOUSE								2	2
LOWER HIGNITE						2			2
LOWER WHITESBURG						3			3
UPPER WHITESBURG						3			3
WHITESBURG						11			11
WHITESBURG RIDER						2			2
CEDAR GROVE/WHITESBURG					**16**	**21**		**2**	**39**
ALMA					1				1
AMBURGY						7			7
CANNEL CITY						5			5
CREECH						3			3
GUN CREEK						1			1
JORDAN							1		1
LOW SPL NT						2	1	3	6
PEERLESS					1				1
PIONEER							1		1
POPLAR LICK						2	3		5
STERLING						1			1
WILLIAMSON						13			13
WILLIAMSON/AMBURGY					**2**	**34**	**6**	**3**	**45**
34 NCH								1	1
BUCKEYE SPRING						3			3
CAMPBELL CREEK					12				12
CEDAR GROVE					13				13
DARBY						3			3
KELLIOKA						4			4
LITTLE CANEY						7			7
LOWER CAMPBELL CREEK					4				4
LOWER CEDAR GROVE					6	2			8
NO 2 GAS					15				15
PEERLESS					12				12
TAGGART								9	9
TAGGART MARKER								3	3
TOM COOPER						1			1
UPPER CEDAR GROVE					7				7
UPPER ELKHORN 3 2ND RIDER						1			1
UPPER ELKHORN NO 3						29			29
UPPER ELKHORN NO 3 RIDER						1			1
UPPER ELKHORN NO 3 5						1			1
VAN LEAR						9			9
CAMPBELL CREEK/UPPER ELKHORN NO 3					**69**	**61**		**13**	**143**

Table 1. Coal bed names used in this report (names in bold), correlative alternate coal bed names used in COALQUAL database (see column CBED in Appendix 1), number of samples (N) from each state, and total number of samples for each coal bed (in bold) [nWV = northern West Virgina coal field sWV = southern West Virginia coal field]

COAL BED NAMES (COALQUAL database)	Number of Samples								
COAL BED NAMES (BOLD, THIS REPORT)	**PA**	**MD**	**OH**	**nWV**	**sWV**	**KY**	**TN**	**VA**	**Total**
ALMA					12	4			16
GRASSY						7			7
HARLAN						6			6
HUCKLEBERRY						4			4
JELLICO						26	3		29
JOYNER							1		1
M NGO						1			1
POWELLTON					10				10
POWELLTON A					1				1
RIM						2			2
UPPER ALMA						2			2
UPPER ELKHORN NO 1						8			8
UPPER ELKHORN NO 2						18			18
UPPER ELKHORN NO 2-1						2			2
UPPER ELKHORN NO 2-1 RIDER						1			1
UPPER ST CHARLES								1	1
WILSON								5	5
UPPER ELKHORN NOS. 1 AND 2/POWELLTON					**23**	**81**	**4**	**6**	**114**
KELLY								**3**	**3**
BLUE GEM						23	3		26
BLUE GEM RIDER						1			1
CAMPBELL CREEK					9			2	11
EAGLE					31				31
IMBODEN						1		9	10
IMBODEN MARKER								4	4
LITTLE BLUE GEM						1			1
LOWER CAMPBELL CREEK					1				1
LOWER ELKHORN						9			9
LOWER PATH FORK						1			1
NO 2 GAS					8				8
PATH FORK						3			3
POND CREEK						10			10
POND CREEK RIDER						2			2
STRAIGHT CREEK						2			2
V RES						1			1
POND CREEK					**49**	**54**	**3**	**15**	**121**
BLA R								17	17
BLA R MARKER								3	3
CLINTWOOD						3		55	58
CLINTWOOD MARKER								2	2
CLINTWOOD RIDER								1	1
COAL CREEK							3		3
COLONY						2			2
COLONY RIDER						1			1
HANCE						4			4
HANCE SPLIT 1						1			1
HANCE SPLIT 2						1			1
HANCE SPLIT 3						1			1
HANCE SPLIT 4						1			1
LILY						9			9
MANCHESTER						15			15
MATEWAN					2				2
RIVER GEM						1			1
RIVER GEM R DER						1			1
ZACHARIAH						3			3
MATEWAN/CLINTWOOD					**2**	**43**	**3**	**78**	**126**

Table 1. Coal bed names used in this report (names in bold), correlative alternate coal bed names used in COALQUAL database (see column CBED in Appendix 1), number of samples (N) from each state, and total number of samples for each coal bed (in bold) [nWV = northern West Virgina coal field sWV = southern West Virginia coal field]

COAL BED NAMES (COALQUAL database)	Number of Samples								
COAL BED NAMES (BOLD, THIS REPORT)	**PA**	**MD**	**OH**	**nWV**	**sWV**	**KY**	**TN**	**VA**	**Total**
EAGLE					5			1	6
LYONS								15	15
M LLARD						2			2
MIDDLE WAR EAGLE/EAGLE					**5**	**2**		**16**	**23**
BENS CREEK					5				5
GLAMORGAN						2			2
MASON						4	4		8
BENS CREEK/BLAIR					**5**	**6**	**4**		**15**
DORCHESTER								50	50
GLEN MARY							3		3
LITTLE EAGLE					3				3
LYONS								14	14
NORTON								16	16
POPLAR CREEK							1		1
POWELLTON					1				1
LITTLE EAGLE/DORCHESTER					**4**		**4**	**80**	**88**
GILBERT					2				2
HAGY						2		8	10
LOWER WAR EAGLE					1				1
LOWER WAR EAGLE/HAGY					**3**	**2**		**8**	**13**
GLENALUM TUNNEL					1				1
GRAY HAWK						7			7
REX							4		4
SPLASH DAM						1			1
SPLASHDAM								19	19
SPLITSEAM						3			3
GLENALUM TUNNEL/SPLASHDAM					**1**	**11**	**4**	**19**	**35**
BARREN FORK						5			5
BARREN FORK R DER						1			1
BEATTYVILLE						3			3
CORLEY HOLLOW						1			1
HALSEY ROUGH						3			3
LEE								5	5
UPPER BANNER								28	28
GILBERT A/UPPER BANNER						**13**		**33**	**46**
GILBERT					3				3
LOWER BANNER								20	20
GILBERT/LOWER BANNER					**3**			**20**	**23**
BIG FORK								**3**	**3**
DOUGLAS					4				4
KENNEDY								28	28
LOWER DOUGLAS					1				1
RED ASH RIDER								2	2
WIDOW KENNEDY								2	2
DOUGLAS/KENNEDY					**5**			**32**	**37**
JEWELL								11	11
RAVEN								6	6
RAVEN NO 1								3	3
STEARNS NO 2						4			4
JEWELL/RAVEN						**4**		**20**	**24**

Table 1. Coal bed names used in this report (names in bold), correlative alternate coal bed names used in COALQUAL database (see column CBED in Appendix 1), number of samples (N) from each state, and total number of samples for each coal bed (in bold) [nWV = northern West Virgina coal field sWV = southern West Virginia coal field]

COAL BED NAMES (COALQUAL database)	Number of Samples								
COAL BED NAMES (BOLD, THIS REPORT)	**PA**	**MD**	**OH**	**nWV**	**sWV**	**KY**	**TN**	**VA**	**Total**
BEAVER CREEK						1			1
IAEGER					2				2
JAWBONE								22	22
JAWBONE RIDER								3	3
JAWBONE-T LLER								5	5
STEARNS NO 1 5						1			1
IAEGER/JAWBONE					**2**	**2**		**30**	**34**
STEARNS						8			8
STEARNS ZONE						1			1
T LLER								8	8
LOWER IAEGER/TILLER						**9**		**8**	**17**
CASTLE								4	4
CASTLE RIDER								1	1
SEWELL B					1				1
SEWELL B/GREASY CREEK					**1**			**5**	**6**
M DDLE SEABOARD								1	1
SEWELL A					5			1	6
SEWELL A					**5**			**2**	**7**
DIRTY NO 6								1	1
DIRTY SIX					1			1	2
DIRTY SIX					**1**			**2**	**3**
LOWER SEABOARD								8	8
SEWELL				1	39			4	44
SEWELL RIDER					3				3
SHARON NO 1			6						6
SEWELL/LOWER SEABOARD			**6**	**1**	**42**			**12**	**61**
SMITH						3		2	5
UPPER HORSEPEN								7	7
WELCH					1			2	3
WELCH/UPPER HORSEPEN					**1**	**3**		**11**	**15**
LITTLE RALEIGH/MIDDLE HORSEPEN					**7**			**1**	**8**
BECKLEY					25			2	27
BECKLEY RIDER					1				1
WAR CREEK								2	2
BECKLEY/WAR CREEK					**26**			**4**	**30**
F RE CREEK					19				19
F RE CREEK R DER								2	2
LOWER HORSEPEN								1	1
FIRE CREEK/LOWER HORSEPEN					**19**			**3**	**22**
POCAHONTAS NO. 10/LITTLE FIRE CREEK								**3**	**3**
COVE CREEK								7	7
POCAHONTAS NO 7					1				1
POCAHONTAS NO 7					**1**			**7**	**8**
POCAHONTAS NO 6					**13**				**13**
POCAHONTAS NO 4					**12**			**1**	**13**
POCAHONTAS NO 3					37			14	51
POCAHONTAS NO 3 RDR					2				2
POCAHONTAS NO 3					**39**			**14**	**53**
POCAHONTAS NO 1								**3**	**3**
Grand Total	**723**	**46**	**639**	**114**	**469**	**723**	**46**	**467**	**3227**

Table 2. Stratigraphic list of coal bed names used in this report and number (N) of samples, thick samples (≥28 inch), and thin samples (<28 inch).

Stratigraphic system, series, stage, and formation names have been debated and revised in the literature numerous times. We cite recent references for the stratigraphic intervals used in this table and report. ***** = some and ****** = significant mountaintop mining, target coal beds. Coal bed code letters indicate coal beds with N ≥30 samples. SGB (selenium greater than background) indicates the stratigrahic interval with coal beds' average selenium concentration greater than average selenium concentration in Appalachian basin coal. Stratigraphic intervals pre-SGB, SGB, and post-SGB, this report, used in fig. 7 and table 5.

Table 2. Stratigraphic list of coal bed names used in this report and number (N) of samples, thick samples (≥28 inch), and thin samples (<28 inch).

System	Peppers (1996) western European Series and Stage	Peppers (1996) Midcon-tinent System	Peppers (1996) Midcon-tinent Series	Peppers (1996), Blake (1998) West Virginia Formation	Chesnut (1996) eastern Kentucky Group and Formation	This report central and northern Appalachian basin Coal bed names	All samples N	All samples coal bed code, N ≥30	Thick samples ≥28 inch N	Thick samples ≥28 inch coal bed code, N ≥30	Thin samples <28 inch N	Thin samples <28 inch coal bed code, N ≥30	This report Se trend Interval
	Stephanian C	Upper Pennsylvaian	Virgilian	Monongahela	Monongahela	Waynesburg	60	**A**	56	**A**	4		post-SGB
						Sewickley	42	**B**	40	**B**	2		
						Fishpot	4		1		3		
						Redstone	74	**C**	56	**C**	18		
						Pittsburgh Roof	10		2		8		
						Pittsburgh	137	**D**	132	**D**	5		
	Stephanian B		Missourian	Conemaugh	Conemaugh	Elk Lick	3		2		1		
						Federal Hill	3		1		2		
	Stephanian A					Harlem	9		1		8		
						Upper Bakerstown	4		2		2		
						Lower Bakerstown	30	**E**	12		18		
						Wilgus	4		1		3		
						Brush Creek	11		3		8		
	Westphalian D		Desmoinsian			Mahoning	20		6		14		
				Allegheny/Charleston	Breathitt / Princess	Upper Freeport Rider	6		3		3		
						Upper Freeport	278	**F**	215	**F**	63	**F**	
						Lower Freeport	103	**G**	67	**G**	36	**G**	
						Upper Kittanning Rider	3				3		
						Upper Kittanning	67	**H**	32	**H**	35	**H**	
						Middle Kittanning Rider	8				8		
						Middle Kittanning	243	**I**	168	**I**	75	**I**	
						Strasburg	11		1		10		
						Lower Kittanning Rider	7		1		6		
						Lower Kittanning / ** No 6 block	198	**J**	141	**J**	57	**J**	
						Clarion	74	**K**	47	**K**	27		
						Brookville	73	**L**	30	**L**	43	**L**	
		ylvanian				** No 5 Block	93	**M**	65	**M**	28		
						* Stockton A / Little No 5 Block	4		2		2		
						Tionesta	5		4		1		
						Upper Mercer	8		2		6		

Pennsylvanian	Westphalian C	Middle Penns	Atokan	Kanawha upper division	Breathitt / Four Corners	Lower Mercer	24		7		17		SGB
						Quakertown	9		2		7		
						** Stockton	62	**N**	51	**N**	11		
						** Coalburg	143	**O**	67	**O**	76	**O**	
						* Winifrede / Hazard	79	**P**	48	**P**	31	**P**	
						* Lower Winifrede / Hazard	10		4		6		
				Kanawha middle division	Breathitt / Hyden	Chilton/Taylor	15		9		6		
						Fire Clay Rider	29		13		16		
						* Fire Clay	70	**Q**	40	**Q**	30	**Q**	
						* Cedar Grove / * Whitesburg	39	**R**	16		23		
	Westphalian B				Breathitt / Pikeville	* Williamson / * Amburgy	45	**S**	19		26		pre-SGB
						* Campbell Creek / * Upper Elkhorn No 3	143	**T**	80	**T**	63	**T**	
						Upper Elkhorn Nos 1 and 2 / Powellton	114	**U**	59	**U**	55	**U**	
						Kelly	3		3				
						Pond Creek	121	**V**	78	**V**	43	**V**	
				Kanawha lower division	Breathitt / Grundy	Matewan / Clintwood	126	**W**	54	**W**	72	**W**	
						Middle War Eagle / Eagle	23		12		11		
						Bens Creek / Blair	15		11		4		
						Little Eagle / Dorchester	88	**X**	54	**X**	34	**X**	
	Westphalian A	Lower Pennsylvanian	Morrowan			Lower War Eagle / Hagy	13		8		5		
						Glenalum Tunnel / Splashdam	35	**Y**	17		18		
						Gilbert A / Upper Banner	46	**Z**	24		22		
						Gilbert / Lower Banner	23		17		6		
						Big Fork	3		2		1		
						Douglas / Kennedy	37	**AA**	22		15		
				New River	Breathitt / Alvy Creek	Jewell / Raven	24		19		5		
						Iaeger / Jawbone	34	**BB**	17		17		
						Lower Iaeger / Tiller	17		7		10		
					Breathitt / Bottom Creek	Sewell B / Greasy Creek	6		2		4		
						Sewell A	7		3		4		
						Dirty Six	3		3				
						Sewell / Lower Seaboard	61	**CC**	41	**CC**	20		
						Welch / Upper Horsepen	15		10		5		
						Little Raleigh / Middle Horsepen	8		5		3		
	Namurian C					Beckley / War Creek	30	**DD**	18		12		
						Fire Creek / Lower Horsepen	22		14		8		
						Pocahontas No 10 / Little Fire Creek	3		1		2		
	Namurian B			Pocahontas	Breathitt / Pocahontas	Pocahontas No 7	8		3		5		
						Pocahontas No 6	13		10		3		
						Pocahontas No 4	13		13				
						Pocahontas No 3	53	**EE**	43	**EE**	10		
						Pocahontas No 1	3				3		
						Grand Total	**3227**	**31**	**2019**	**23**	**1208**	**14**	

Table 3. Coal quality statistics by state for selenium, thickness, ash yield, sulfur, pyritic sulfur, arsenic, mercury, and manganese. [N = number of samples; nWV = northern West Virginia coal field; sWV = southern West Virginia coal field.]

Parameter	State	N	Average	Standard Deviation	Minimum	Lower Quartile	Median	Upper Quartile	Maximum
			ppm	ppm	ppm	ppm	ppm	ppm	ppm
Selenium	**PA**	723	3.6	2.6	0.41	1.9	2.8	4.2	21
Selenium	**MD**	46	3.4	2.8	0.63	1.7	2.3	4.2	14
Selenium	**OH**	638	3.7	2.4	0.60	2.1	3.1	4.7	17
Selenium	**nWV**	113	2.5	2.3	0.20	1.1	1.7	2.7	14
Selenium	**sWV**	469	3.8	2.3	0.76	2.1	3.5	4.6	16
Selenium	**KY**	723	4.2	2.3	0.07	2.6	3.8	5.5	18
Selenium	**TN**	46	3.1	1.6	0.50	1.9	2.9	4.1	8
Selenium	**VA**	465	2.7	1.4	0.07	1.7	2.5	3.4	8
			in	in	in	in	in	in	in
Thickness	**PA**	723	36	19	2	23	33	47	115
Thickness	**MD**	46	34	23	8	20	27	40	112
Thickness	**OH**	639	37	15	9	27	36	45	125
Thickness	**nWV**	114	57	21	8	42	58	72	108
Thickness	**sWV**	469	39	19	4	27	38	49	172
Thickness	**KY**	723	29	18	3	16	26	39	156
Thickness	**TN**	46	34	13	9	26	33	40	84
Thickness	**VA**	467	33	16	5	22	31	41	128
			percent	percent	percent	percent	percent	percent	percent
Ash y\ield	**PA**	665	12.87	5.24	1.70	8.98	11.82	15.90	31.20
Ash y\ield	**MD**	45	14.56	6.64	5.55	9.78	13.01	18.40	29.31
Ash y\ield	**OH**	625	11.94	5.20	2.20	8.60	10.91	14.32	32.40
Ash y\ield	**nWV**	94	9.95	3.64	5.60	7.23	9.05	11.40	20.90
Ash y\ield	**sWV**	449	8.68	5.13	0.90	5.10	7.40	10.70	31.50
Ash y\ield	**KY**	695	9.59	5.47	0.90	5.51	8.57	12.66	32.90
Ash y\ield	**TN**	46	7.48	5.59	1.60	3.20	5.10	10.80	22.00
Ash y\ield	**VA**	433	8.30	5.28	1.66	4.50	6.60	10.51	30.90
			percent	percent	percent	percent	percent	percent	percent
Sulfur	**PA**	717	2.48	1.45	0.39	1.44	2.20	3.21	9.34
Sulfur	**MD**	45	2.16	1.39	0.40	1.17	1.99	2.80	8.00
Sulfur	**OH**	625	3.53	1.53	0.50	2.50	3.40	4.50	10.60
Sulfur	**nWV**	95	2.55	1.16	0.40	1.75	2.60	3.20	6.80
Sulfur	**sWV**	449	0.97	0.62	0.40	0.60	0.80	1.10	6.30
Sulfur	**KY**	695	1.65	1.29	0.40	0.71	1.08	2.20	8.90
Sulfur	**TN**	46	1.71	1.31	0.50	0.80	1.20	2.18	5.20
Sulfur	**VA**	433	1.19	0.89	0.40	0.68	0.85	1.27	6.61

Table 3. Coal quality statistics by state for selenium, thickness, ash yield, sulfur, pyritic sulfur, arsenic, mercury, and manganese. [N = number of samples; nWV = northern West Virginia coal field; sWV = southern West Virginia coal field.]

Parameter	State	N	Average	Standard Deviation	Minimum	Lower Quartile	Median	Upper Quartile	Maximum
			percent	percent	percent	percent	percent	percent	percent
Pyritic sulfur	**PA**	688	1.61	1.25	0.01	0.71	1.38	2.17	7.31
Pyritic sulfur	**MD**	45	1.41	1.20	0.01	0.57	1.22	1.94	6.18
Pyritic sulfur	**OH**	625	2.10	1.24	0.03	1.22	1.90	2.78	8.97
Pyritic sulfur	**nWV**	22	1.31	0.85	0.13	0.74	1.22	1.69	3.18
Pyritic sulfur	**sWV**	84	0.30	0.41	0.02	0.07	0.17	0.32	2.14
Pyritic sulfur	**KY**	694	0.89	1.11	0.01	0.11	0.35	1.30	7.62
Pyritic sulfur	**TN**	46	0.79	0.98	0.03	0.10	0.39	1.01	3.65
Pyritic sulfur	**VA**	427	0.49	0.70	0.01	0.09	0.21	0.52	5.22
			ppm	ppm	ppm	ppm	ppm	ppm	ppm
Arsenic	**PA**	719	34	39	0.31	11.0	22	43	410
Arsenic	**MD**	46	25	21	0.80	9.9	18	31	79
Arsenic	**OH**	638	24	33	0.49	5.8	13	31	390
Arsenic	**nWV**	113	19	21	0.90	6.9	11	20	100
Arsenic	**sWV**	467	11	16	0.08	1.8	5	12	130
Arsenic	**KY**	718	29	52	0.50	3.8	11	34	680
Arsenic	**TN**	46	24	32	0.30	3.1	10	34	160
Arsenic	**VA**	466	20	31	0.45	3.4	8	21	330
			ppm	ppm	ppm	ppm	ppm	ppm	ppm
Mercury	**PA**	723	0.28	0.26	0.003	0.110	0.22	0.38	2.9
Mercury	**MD**	46	0.33	0.40	0.003	0.085	0.18	0.32	1.6
Mercury	**OH**	639	0.21	0.15	0.003	0.100	0.17	0.27	1.1
Mercury	**nWV**	114	0.25	0.20	0.007	0.120	0.20	0.30	1.0
Mercury	**sWV**	469	0.13	0.16	0.007	0.043	0.08	0.16	1.8
Mercury	**KY**	721	0.18	0.17	0.007	0.060	0.13	0.24	1.5
Mercury	**TN**	46	0.16	0.15	0.007	0.038	0.12	0.22	0.6
Mercury	**VA**	466	0.11	0.11	0.003	0.045	0.07	0.16	0.8
			ppm	ppm	ppm	ppm	ppm	ppm	ppm
Manganese	**PA**	720	25	40	0.9	8.5	15	25	470
Manganese	**MD**	46	18	18	1.1	6.7	12	22	90
Manganese	**OH**	639	31	47	2.5	13.0	20	33	690
Manganese	**nWV**	114	28	34	2.8	12.0	21	29	290
Manganese	**sWV**	468	20	44	0.7	4.3	8	17	540
Manganese	**KY**	721	18	43	1.2	5.4	9	17	660
Manganese	**TN**	46	15	14	2.8	5.7	11	18	70
Manganese	**VA**	466	21	27	0.8	6.2	12	23	260

Table 4. Coal quality statistics for coal beds with≥ 5 samples for selenium, thickness, ash yield, sulfur, pyritic sulfur, arsenic, mercury, and manganese: a. all, b. thcik (≥ 28 inch), and c. thin (< 28 inch) coal bed samples. [Coal bed code from table 2 if N≥ 30; * if N < 30 for a specific parameter; N = number of samples.]

Table 4a. Coal Samples, all thicknesses.

Coal bed name, this repor	Thickness range	Coal bed code N ≥ 30	Selenium N	Geometric mean ppm	Average ppm	Standard Deviation ppm	Minimum ppm	Lower Quartile ppm	Median ppm	Upper Quartile ppm	Maximum ppm
Waynesburg	all	A	60	2.6	2.8	0.90	0.64	2.4	2.9	3.3	5.5
Sewickley	all	B	42	2.6	2.9	1.3	0.70	2.1	2.6	3.7	7.2
Redstone	all	C	74	2.0	2.2	1.2	0.50	1.4	2.0	2.6	7.0
Pittsburgh Roof	all		10	1.9	2.1	1.1	0.60	1.5	1.8	2.6	4.4
Pittsburgh	all	D	137	1.4	1.7	1.2	0.20	1.0	1.4	2.0	7.5
Harlem	all		9	1.1	1.2	0.32	0.68	0.90	1.2	1.4	1.6
Lower Bakerstown	all	E	30	3.1	3.5	1.9	1.5	2.4	3.3	4.2	11
Brush Creek	all		11	2.7	3.0	1.6	1.2	2.0	2.9	3.5	6.4
Mahoning	all		20	2.0	2.2	1.1	1.2	1.5	1.9	2.5	4.7
Upper Freeport Rider	all		6	2.8	3.2	1.5	1.4	1.8	3.5	4.2	5.1
Upper Freeport	all	F	277	2.4	2.8	2.0	0.43	1.7	2.2	3.1	14
Lower Freeport	all	G	102	3.3	3.9	2.6	0.90	2.2	3.3	4.7	15
Upper Kittanning	all	H	67	3.8	4.6	2.9	1.3	2.3	3.4	6.0	13
Middle Kittanning Rider	all		8	4.5	5.2	2.3	1.0	3.6	5.9	6.6	8.1
Middle Kittanning	all	I	243	3.2	3.6	2.1	1.0	2.4	3.1	4.2	17
Strasburg	all		11	3.6	3.9	1.6	1.5	3.6	3.9	4.1	7.7
Lower Kittanning Rider	all		7	3.4	3.9	2.5	1.6	2.4	3.1	4.4	8.9
Lower Kittanning/No 6 block	all	J	198	3.4	4.0	2.6	0.60	2.2	3.5	5.1	20
Clarion	all	K	74	5.6	6.2	2.5	1.2	4.7	6.1	7.6	14
Brookville	all	L	73	4.9	5.7	3.4	1.2	3.5	4.8	7.4	21
No 5 Block	all	M	93	6.2	7.1	3.1	0.10	5.2	6.9	8.9	18
Tionesta	all		5	7.7	8.1	2.9	5.8	6.2	7.1	8.2	13
Upper Mercer	all		8	7.7	8.6	4.3	3.1	5.8	7.2	12	16
Lower Mercer	all		24	6.2	7.1	3.1	0.84	5.6	6.6	8.8	13
Quakertown	all		9	5.9	7.2	4.2	1.2	4.5	5.7	12	12
Stockton	all	N	62	5.2	5.6	1.9	2.4	4.1	5.2	7.1	11
Coalburg	all	O	143	4.7	5.0	1.9	1.2	3.8	4.9	6.1	12
Winifrede/Hazard	all	P	79	4.4	4.7	1.8	0.50	3.5	4.6	5.7	11
Lower Winifrede/Hazard	all		10	2.8	4.0	2.0	0.07	3.4	4.0	5.0	7.4
Chilton/Taylor	all		15	3.1	3.7	2.2	0.73	2.4	3.4	4.4	8.7
Fire Clay Rider	all		29	4.0	4.5	2.6	1.7	3.2	4.1	4.9	13
Fire Clay	all	Q	70	3.6	3.9	1.6	1.3	2.7	3.5	5.0	9.0
Cedar Grove/Whitesburg	all	R	39	3.8	4.1	1.8	1.2	2.8	3.8	4.7	9.4
Williamson/Amburgy	all	S	45	3.0	3.3	1.6	0.90	2.1	3.0	4.2	7.5
Campbell Creek/Upper Elkhorn No 3	all	T	143	3.4	3.8	1.6	0.07	2.7	3.6	4.6	9.3
Upper Elkhorn Nos 1 and 2/Powellton	all	U	114	3.0	3.5	2.0	0.64	2.2	3.2	4.1	16
Pond Creek	all	V	121	3.2	3.4	1.2	1.2	2.5	3.2	4.2	6.7
Matewan/Clintwood	all	W	126	2.4	2.8	1.6	0.54	1.7	2.5	3.4	8.0
Middle War Eagle/Eagle	all		23	3.1	3.5	2.1	1.1	2.2	3.1	4.3	9.3
Bens Creek/Blair	all		15	2.0	2.2	0.88	0.80	1.8	2.0	2.5	4.2
Little Eagle/Dorchester	all	X	87	2.3	2.7	1.6	0.63	1.7	2.2	3.3	7.1
Lower War Eagle/Hagy	all		13	2.9	3.1	0.76	1.3	2.7	3.2	3.6	4.0
Glenalum Tunnel/Splashdam	all	Y	35	2.4	2.5	0.82	0.76	1.9	2.5	3.0	4.4
Gilbert A/Upper Banner	all	Z	46	2.7	3.0	1.3	1.2	2.2	2.7	3.5	6.7
Gilbert/Lower Banner	all		23	2.7	2.9	1.1	1.4	2.3	2.7	3.1	6.3
Douglas/Kennedy	all	AA	37	1.8	2.2	1.8	0.40	1.2	1.6	2.6	11
Jewell/Raven	all		24	1.9	2.2	1.2	0.20	1.5	2.1	2.7	5.9
Iaeger/Jawbone	all	BB	34	2.1	2.7	1.9	0.07	1.7	2.5	3.2	11
Lower Iaeger/Tiller	all		17	2.5	2.7	1.0	1.0	2.1	2.7	2.9	5.4
Sewell B/Greasy Creek	all		6	2.0	2.3	1.3	1.2	1.3	1.7	3.4	4.0
Sewell A	all		7	1.8	1.9	0.64	0.93	1.5	1.6	2.5	2.6
Sewell/Lower Seaboard	all	CC	61	2.0	2.6	2.2	0.76	1.3	1.8	2.8	14
Welch/Upper Horsepen	all		15	1.6	1.8	0.79	0.70	1.2	1.8	2.2	3.6
Little Raleigh/Middle Horsepen	all		8	2.1	2.2	0.63	1.1	1.9	2.1	2.6	3.1
Beckley/War Creek	all	DD	30	1.6	1.8	1.2	0.78	1.3	1.5	2.0	7.0
Fire Creek/Lower Horsepen	all		22	2.1	2.4	1.2	0.67	1.6	2.1	3.1	4.9
Pocahontas No 7	all		7	1.6	1.8	1.0	1.0	1.2	1.4	1.8	4.0
Pocahontas No 6	all		13	2.5	2.8	1.3	1.1	2.0	2.3	3.3	5.9
Pocahontas No 4	all		13	2.4	2.5	1.1	1.8	2.0	2.3	2.5	5.9
Pocahontas No 3	all	EE	53	3.1	3.4	1.7	1.1	2.3	2.9	4.1	8.2

Table 4. Coal quality statistics for coal beds with≥ 5 samples for selenium, thickness, ash yield, sulfur, pyritic sulfur, arsenic, mercury, and manganese: a. all, b. thcik (≥ 28 inch), and c. thin (< 28 inch) coal bed samples. [Coal bed code from table 2 if N≥ 30; * if N < 30 for a specific parameter; N = number of samples.]

Table 4a. Coal Samples, all thicknesses.

Coal Bed Name This Study	Thickness range	Coal bed code N ≥ 30	Thickness N	Geometric mean in	Average in	Standard Deviation in	Minimum in	Lower Quartile in	Median in	Upper Quartile in	Maximum in
Waynesburg	all	A	60	45.3	48.1	17.3	20.5	35.9	43.2	57.8	95.0
Sewickley	all	B	42	44.7	46.3	12.3	19.8	38.5	46.5	54.8	87.5
Redstone	all	C	74	40.4	45.5	20.3	12.0	28.1	47.3	61.8	88.0
Pittsburgh Roof	all		10	22.7	24.2	8.6	10.2	20.1	23.5	27.3	42.0
Pittsburgh	all	D	137	57.7	61.8	21.8	9.0	47.0	59.5	75.5	125.0
Harlem	all		9	23.9	24.3	4.7	17.5	20.0	25.8	27.0	32.0
Lower Bakerstown	all	E	30	27.4	28.7	8.9	13.2	23.3	27.0	32.9	56.0
Brush Creek	all		11	18.4	20.8	10.4	7.8	14.4	20.0	26.7	38.0
Mahoning	all		20	22.0	24.7	12.2	4.8	17.6	22.0	29.3	63.0
Upper Freeport Rider	all		6	24.0	25.4	8.7	15.0	18.0	27.5	30.6	36.0
Upper Freeport	all	F	278	36.7	41.3	18.0	2.0	29.3	42.0	49.2	105.5
Lower Freeport	all	G	103	31.0	34.8	16.0	5.4	25.1	32.6	42.5	74.0
Upper Kittanning	all	H	67	26.9	30.7	16.5	6.6	19.8	26.4	37.2	94.8
Middle Kittanning Rider	all		8	12.6	15.2	8.3	3.0	11.4	15.0	19.5	27.6
Middle Kittanning	all	I	243	31.3	34.1	13.2	2.5	26.0	34.0	41.4	95.5
Strasburg	all		11	18.8	19.8	6.8	12.8	14.3	17.5	23.9	33.0
Lower Kittanning Rider	all		7	13.7	17.3	15.6	6.6	9.9	12.0	15.6	51.6
Lower Kittanning/No 6 block	all	J	198	32.2	34.1	11.7	9.8	26.4	33.3	39.2	86.4
Clarion	all	K	74	29.6	33.7	17.2	9.0	20.1	31.6	42.6	96.0
Brookville	all	L	73	24.3	27.4	13.6	6.6	17.0	23.0	36.0	61.5
No 5 Block	all	M	93	37.7	47.0	32.5	7.4	24.0	40.0	55.0	171.8
Tionesta	all		5	31.9	36.0	15.1	10.5	36.6	39.5	44.3	49.3
Upper Mercer	all		8	21.7	23.8	10.8	11.4	15.9	21.9	29.3	40.5
Lower Mercer	all		24	24.6	26.8	12.2	10.8	21.9	24.3	30.2	69.6
Quakertown	all		9	24.1	24.7	6.1	18.5	19.8	24.0	26.0	38.4
Stockton	all	N	62	37.0	43.0	19.6	5.9	30.2	45.5	54.1	93.3
Coalburg	all	O	143	26.6	32.5	20.8	4.3	17.6	26.8	45.0	112.5
Winifrede/Hazard	all	P	79	27.6	31.9	15.8	4.3	20.3	31.0	40.0	73.2
Lower Winifrede/Hazard	all		10	20.7	22.7	8.9	6.7	17.7	24.2	29.1	35.8
Chilton/Taylor	all		15	24.5	32.1	22.1	5.5	14.4	31.1	41.4	85.2
Fire Clay Rider	all		29	21.6	27.9	19.5	6.0	10.2	27.2	38.0	91.3
Fire Clay	all	Q	70	28.5	33.4	17.5	6.0	20.0	32.0	44.0	80.5
Cedar Grove/Whitesburg	all	R	39	21.6	25.9	13.6	3.1	15.3	23.5	34.7	52.0
Williamson/Amburgy	all	S	45	23.0	27.4	16.5	5.5	14.6	24.0	38.9	84.0
Campbell Creek/Upper Elkhorn No 3	all	T	143	27.5	30.6	13.8	7.0	20.8	29.7	38.2	85.5
Upper Elkhorn Nos 1 and 2/Powellton	all	U	114	24.7	28.5	14.2	7.1	16.0	28.3	39.0	69.3
Pond Creek	all	V	121	30.8	35.2	16.5	4.0	23.6	34.0	44.1	85.4
Matewan/Clintwood	all	W	126	23.6	26.4	12.7	7.7	17.7	25.0	33.5	87.2
Middle War Eagle/Eagle	all		23	27.5	30.0	13.0	12.6	20.1	28.8	37.8	64.8
Bens Creek/Blair	all		15	27.4	30.2	11.6	7.0	25.3	31.0	35.7	50.0
Little Eagle/Dorchester	all	X	88	28.9	31.2	11.8	10.2	22.0	32.4	37.2	66.0
Lower War Eagle/Hagy	all		13	26.0	28.2	9.0	6.0	22.8	28.8	33.6	39.0
Glenalum Tunnel/Splashdam	all	Y	35	27.4	30.7	14.7	11.0	17.3	27.6	40.8	69.0
Gilbert A/Upper Banner	all	Z	46	25.5	30.0	18.1	6.3	17.4	29.4	37.1	110.2
Gilbert/Lower Banner	all		23	36.6	40.1	16.0	12.8	29.3	41.0	45.7	71.0
Douglas/Kennedy	all	AA	37	30.9	32.2	9.7	18.0	26.5	30.5	36.0	62.0
Jewell/Raven	all		24	30.9	35.6	15.6	6.0	29.5	37.0	43.3	68.4
Iaeger/Jawbone	all	BB	34	29.1	33.4	17.2	8.4	24.6	28.6	41.0	77.8
Lower Iaeger/Tiller	all		17	18.4	23.9	17.7	5.4	9.0	18.0	35.9	68.4
Sewell B/Greasy Creek	all		6	21.4	23.2	10.2	13.0	16.7	18.8	32.0	36.0
Sewell A	all		7	26.7	28.8	11.3	12.0	23.3	27.8	34.5	46.0
Sewell/Lower Seaboard	all	CC	61	33.0	35.9	14.6	12.5	24.0	35.9	44.0	70.6
Welch/Upper Horsepen	all		15	33.1	40.5	30.3	11.0	24.0	31.0	43.0	128.0
Little Raleigh/Middle Horsepen	all		8	32.2	34.8	13.0	17.0	22.5	42.0	42.0	51.0
Beckley/War Creek	all	DD	30	28.8	33.2	17.6	8.0	23.3	29.0	40.1	87.0
Fire Creek/Lower Horsepen	all		22	31.5	34.7	15.9	14.0	21.3	31.9	40.5	70.0
Pocahontas No 7	all		8	21.8	24.2	11.7	10.5	16.3	20.1	34.8	42.5
Pocahontas No 6	all		13	32.5	33.2	6.6	23.0	30.1	33.3	38.0	43.5
Pocahontas No 4	all		13	64.8	65.9	12.6	49.0	60.1	62.6	76.0	91.0
Pocahontas No 3	all	EE	53	41.7	45.9	18.3	11.1	34.0	47.4	55.8	94.0

Table 4. Coal quality statistics for coal beds with≥ 5 samples for selenium, thickness, ash yield, sulfur, pyritic sulfur, arsenic, mercury, and manganese: a. all, b. thcik (≥ 28 inch), and c. thin (< 28 inch) coal bed samples. [Coal bed code from table 2 if N≥ 30; * if N < 30 for a specific parameter; N = number of samples.]

Table 4a. Coal Samples, all thicknesses.

			Ash Yield								
Coal Bed Name This Study	Thickness range	Coal bed code N ≥ 30	N	Geometric mean percent	Average percent	Standard Deviation percent	Minimum percent	Lower Quartile percent	Median percent	Upper Quartile percent	Maximum percent
Waynesburg	all	A	57	16.65	17.20	3.71	3.16	15.63	17.16	19.37	29.70
Sewickley	all	B	40	11.59	11.98	3.10	5.70	9.72	11.50	13.83	20.20
Redstone	all	C	71	10.20	10.96	4.69	5.60	7.80	9.80	12.00	27.20
Pittsburgh Roof	all		10	14.63	15.30	4.39	6.80	12.95	15.62	17.25	22.30
Pittsburgh	all	D	129	10.00	10.51	3.83	4.40	8.20	10.18	11.72	32.03
Harlem	all		9	9.83	10.05	2.23	7.30	7.79	9.80	11.60	13.02
Lower Bakerstown	all	E *	29	11.47	12.74	6.22	5.55	8.65	10.52	14.74	29.30
Brush Creek	all		11	11.80	12.49	4.92	7.17	9.90	11.28	13.92	25.50
Mahoning	all		17	11.09	11.59	3.83	7.00	9.02	10.27	13.05	20.23
Upper Freeport Rider	all		6	12.61	14.05	8.09	8.10	8.89	11.81	14.19	29.70
Upper Freeport	all	F	218	12.36	13.26	5.08	3.60	9.90	12.03	15.69	29.31
Lower Freeport	all	G	103	10.60	11.61	5.38	3.90	8.23	10.00	14.48	31.20
Upper Kittanning	all	H	65	12.43	13.14	4.48	4.54	10.71	12.21	15.05	30.21
Middle Kittanning Rider	all		8	9.03	10.13	5.68	4.50	7.50	8.80	10.65	22.70
Middle Kittanning	all	I	239	9.43	10.71	5.33	1.70	6.85	9.73	14.16	28.66
Strasburg	all		11	11.32	11.73	3.15	6.30	9.80	11.80	13.57	16.80
Lower Kittanning Rider	all		7	11.43	13.08	7.50	5.70	7.49	12.90	15.29	27.44
Lower Kittanning/No 6 block	all	J	193	10.69	11.64	5.01	2.80	8.02	10.82	13.70	31.50
Clarion	all	K	74	12.98	14.07	5.43	4.20	10.19	13.95	17.09	28.38
Brookville	all	L	72	12.12	13.19	5.60	5.30	8.86	12.55	16.30	29.45
No 5 Block	all	M	85	10.70	11.83	5.52	2.70	7.80	10.59	14.50	31.50
Tionesta	all		5	13.58	15.26	9.64	9.82	10.62	10.75	12.70	32.40
Upper Mercer	all		8	18.07	18.61	4.48	10.40	16.57	19.08	21.11	24.52
Lower Mercer	all		23	15.22	16.18	5.32	4.80	12.78	15.07	19.73	27.09
Quakertown	all		9	11.09	12.10	4.35	3.30	10.33	12.81	14.42	17.40
Stockton	all	N	60	11.48	12.64	5.61	4.22	8.53	12.39	14.72	29.60
Coalburg	all	O	142	9.55	10.87	5.56	2.70	6.91	10.04	13.33	30.70
Winifrede/Hazard	all	P	77	8.62	10.39	6.13	2.00	5.20	9.49	14.27	28.50
Lower Winifrede/Hazard	all		10	7.43	8.26	3.81	3.50	5.66	7.43	10.82	15.10
Chilton/Taylor	all		15	11.56	12.53	5.75	5.70	8.95	12.70	13.54	30.00
Fire Clay Rider	all		23	11.38	12.88	6.96	3.65	8.75	11.12	16.05	32.90
Fire Clay	all	Q	66	9.66	11.08	5.85	2.50	6.79	10.66	13.88	31.80
Cedar Grove/Whitesburg	all	R	37	9.25	10.26	4.58	2.47	7.60	9.80	12.20	23.30
Williamson/Amburgy	all	S	44	7.61	8.76	4.99	2.30	5.86	7.72	10.77	26.10
Campbell Creek/Upper Elkhorn No 3	all	T	142	6.25	7.30	3.87	0.90	4.35	6.86	9.40	21.60
Upper Elkhorn Nos 1 and 2/Powellton	all	U	111	5.88	6.81	3.91	1.60	4.33	6.04	8.35	22.37
Pond Creek	all	V	121	6.32	7.40	3.95	1.22	4.50	6.70	10.20	16.80
Matewan/Clintwood	all	W	125	5.99	6.78	3.54	1.73	4.10	6.00	8.70	21.60
Middle War Eagle/Eagle	all		21	5.16	5.88	3.17	1.66	3.79	5.50	6.70	14.01
Bens Creek/Blair	all		15	5.08	7.20	6.26	1.60	2.65	4.34	10.40	18.30
Little Eagle/Dorchester	all	X	88	6.57	8.01	5.31	1.93	4.38	5.77	10.97	28.20
Lower War Eagle/Hagy	all		12	9.63	10.70	5.16	4.30	8.14	9.99	12.30	22.80
Glenalum Tunnel/Splashdam	all	Y	35	6.01	7.70	5.87	1.74	3.65	6.10	9.35	25.30
Gilbert A/Upper Banner	all	Z	41	7.64	8.38	3.92	3.60	5.99	6.94	10.30	20.67
Gilbert/Lower Banner	all		20	9.08	10.20	4.87	3.40	6.46	10.12	12.83	19.63
Douglas/Kennedy	all	AA	32	6.29	7.67	6.07	2.75	4.41	5.82	8.15	29.55
Jewell/Raven	all		19	6.41	7.95	5.75	2.40	3.95	5.90	9.83	24.59
Iaeger/Jawbone	all	BB	33	9.33	12.03	8.06	2.00	6.50	10.50	16.10	30.90
Lower Iaeger/Tiller	all		17	8.48	9.64	4.84	2.90	6.10	8.81	12.20	19.40
Sewell B/Greasy Creek	all		5	10.02	10.88	5.12	5.90	7.46	10.31	11.64	19.09
Sewell A	all		5	5.66	6.80	5.38	3.70	3.90	4.20	5.90	16.30
Sewell/Lower Seaboard	all	CC	52	6.27	7.39	4.59	2.30	3.95	6.15	9.23	21.60
Welch/Upper Horsepen	all		9	6.83	7.42	3.09	3.40	5.20	8.00	8.30	13.19
Little Raleigh/Middle Horsepen	all		6	8.75	10.59	8.62	5.10	5.98	7.80	9.18	27.85
Beckley/War Creek	all	DD *	27	6.19	7.64	5.61	0.90	4.60	6.70	8.00	29.30
Fire Creek/Lower Horsepen	all		22	6.23	6.91	3.31	2.60	5.03	6.50	8.63	17.20
Pocahontas No 7	all		8	9.40	11.23	8.09	4.60	7.44	8.74	10.96	29.25
Pocahontas No 6	all		13	7.33	7.98	3.78	4.30	5.60	6.90	9.60	17.90
Pocahontas No 4	all		13	6.14	6.35	1.84	4.20	5.60	5.93	6.60	11.40
Pocahontas No 3	all	EE	49	7.68	8.61	4.45	2.90	5.80	7.30	10.60	26.00

Table 4. Coal quality statistics for coal beds with≥ 5 samples for selenium, thickness, ash yield, sulfur, pyritic sulfur, arsenic, mercury, and manganese: a. all, b. thcik (≥ 28 inch), and c. thin (< 28 inch) coal bed samples. [Coal bed code from table 2 if N≥ 30; * if N < 30 for a specific parameter; N = number of samples.]

Table 4a. Coal Samples, all thicknesses.

			Sulfur								
Coal Bed Name This Study	Thickness range	Coal bed code N ≥ 30	N	Geometric mean percent	Average percent	Standard Deviation percent	Minimum percent	Lower Quartile percent	Median percent	Upper Quartile percent	Maximum percent
Waynesburg	all	A	58	2.58	2.77	0.98	0.70	2.20	2.67	3.40	5.20
Sewickley	all	B	40	2.64	2.95	1.28	0.70	2.05	2.96	3.74	5.90
Redstone	all	C	71	2.64	2.84	1.05	0.80	2.18	2.70	3.24	5.90
Pittsburgh Roof	all		10	2.23	2.88	1.99	0.60	1.26	2.30	4.38	6.50
Pittsburgh	all	D	129	2.94	3.34	1.48	0.40	2.22	3.40	4.50	6.70
Harlem	all		9	1.38	1.70	1.12	0.50	0.80	1.26	2.70	3.66
Lower Bakerstown	all	E *	29	2.32	2.66	1.22	0.40	1.72	2.69	3.31	5.41
Brush Creek	all		11	2.46	3.01	1.88	0.39	2.05	2.39	3.36	7.50
Mahoning	all		17	2.08	2.41	1.27	0.63	1.43	1.93	3.22	5.10
Upper Freeport Rider	all		6	1.97	2.72	2.08	0.50	1.10	2.27	4.46	5.40
Upper Freeport	all	F	270	2.16	2.45	1.29	0.59	1.55	2.19	3.05	8.00
Lower Freeport	all	G	103	2.33	2.77	1.48	0.50	1.83	2.64	3.68	7.22
Upper Kittanning	all	H	65	1.73	2.11	1.25	0.40	1.00	1.96	3.02	5.72
Middle Kittanning Rider	all		8	1.25	1.79	1.47	0.50	0.50	1.55	2.63	4.40
Middle Kittanning	all	I	239	2.63	3.01	1.45	0.50	1.99	2.89	3.90	8.11
Strasburg	all		11	4.28	4.88	1.98	1.10	4.41	5.59	6.14	7.20
Lower Kittanning Rider	all		7	1.33	1.49	0.80	0.82	0.91	1.00	1.95	2.93
Lower Kittanning/No 6 block	all	J	193	2.93	3.47	1.81	0.40	2.22	3.30	4.66	10.40
Clarion	all	K	74	3.09	3.53	1.61	0.50	2.41	3.59	4.38	9.34
Brookville	all	L	72	2.65	3.08	1.81	0.70	1.98	2.60	3.65	10.40
No 5 Block	all	M	85	0.95	1.15	0.89	0.40	0.66	0.80	1.20	4.87
Tionesta	all		5	3.99	4.92	3.49	1.38	2.97	4.80	4.83	10.60
Upper Mercer	all		8	3.53	3.73	1.31	2.19	2.77	3.70	4.45	5.96
Lower Mercer	all		23	2.13	2.58	1.58	0.51	1.47	1.91	3.75	6.15
Quakertown	all		9	1.70	2.35	2.19	0.55	0.90	1.71	2.40	7.21
Stockton	all	N	60	1.02	1.33	1.19	0.50	0.60	0.77	1.43	5.50
Coalburg	all	O	142	1.04	1.24	0.88	0.40	0.70	0.90	1.37	4.70
Winifrede/Hazard	all	P	77	0.91	1.05	0.71	0.41	0.66	0.80	1.10	4.70
Lower Winifrede/Hazard	all		10	0.91	0.99	0.48	0.60	0.69	0.77	1.21	2.14
Chilton/Taylor	all		15	1.45	1.78	1.27	0.60	0.90	1.20	2.77	4.90
Fire Clay Rider	all		23	2.24	2.70	1.52	0.69	1.32	2.80	3.60	5.20
Fire Clay	all	Q	66	1.00	1.18	0.91	0.50	0.70	0.83	1.22	5.95
Cedar Grove/Whitesburg	all	R	37	1.39	1.73	1.22	0.60	0.83	1.20	2.42	4.53
Williamson/Amburgy	all	S	44	1.50	1.84	1.25	0.59	0.80	1.47	2.44	5.80
Campbell Creek/Upper Elkhorn No 3	all	T	142	1.12	1.35	0.95	0.46	0.70	0.90	1.80	5.10
Upper Elkhorn Nos 1 and 2/Powellton	all	U	111	1.25	1.59	1.28	0.50	0.74	1.00	1.95	6.60
Pond Creek	all	V	121	1.09	1.37	1.09	0.41	0.65	0.90	1.61	6.30
Matewan/Clintwood	all	W	125	1.28	1.62	1.28	0.50	0.76	1.08	2.10	6.61
Middle War Eagle/Eagle	all		21	1.33	1.58	0.89	0.46	0.90	1.40	2.40	3.10
Bens Creek/Blair	all		15	1.17	1.38	0.89	0.50	0.80	1.00	1.88	3.56
Little Eagle/Dorchester	all	X	88	1.10	1.24	0.79	0.50	0.82	1.00	1.31	5.00
Lower War Eagle/Hagy	all		12	1.56	1.80	0.99	0.60	1.13	1.41	2.61	3.60
Glenalum Tunnel/Splashdam	all	Y	35	1.01	1.29	1.16	0.60	0.65	0.72	1.24	5.20
Gilbert A/Upper Banner	all	Z	41	1.03	1.29	1.03	0.40	0.60	0.90	1.67	5.80
Gilbert/Lower Banner	all		20	0.92	1.01	0.50	0.56	0.60	0.80	1.13	2.19
Douglas/Kennedy	all	AA	32	0.94	1.05	0.58	0.50	0.70	0.80	1.31	2.93
Jewell/Raven	all		19	0.96	1.29	1.27	0.50	0.60	0.75	1.14	4.20
Iaeger/Jawbone	all	BB	33	0.84	1.12	1.15	0.50	0.60	0.60	0.80	4.90
Lower Iaeger/Tiller	all		17	1.67	2.77	2.63	0.50	0.60	1.59	4.20	8.90
Sewell B/Greasy Creek	all		5	1.36	1.52	0.75	0.60	1.13	1.39	1.96	2.54
Sewell A	all		5	0.65	0.66	0.13	0.50	0.60	0.60	0.80	0.80
Sewell/Lower Seaboard	all	CC	52	0.82	0.91	0.48	0.40	0.60	0.80	1.05	2.58
Welch/Upper Horsepen	all		9	0.81	0.86	0.32	0.50	0.72	0.80	1.00	1.40
Little Raleigh/Middle Horsepen	all		6	0.72	0.75	0.21	0.50	0.58	0.80	0.88	1.00
Beckley/War Creek	all	DD *	27	0.87	1.00	0.61	0.40	0.60	0.80	1.25	3.20
Fire Creek/Lower Horsepen	all		22	0.86	0.90	0.28	0.40	0.70	0.85	1.10	1.50
Pocahontas No 7	all		8	0.76	0.81	0.33	0.50	0.56	0.63	1.15	1.27
Pocahontas No 6	all		13	1.00	1.06	0.43	0.50	0.80	0.90	1.20	2.30
Pocahontas No 4	all		13	0.64	0.65	0.12	0.50	0.60	0.65	0.70	0.88
Pocahontas No 3	all	EE	49	0.69	0.74	0.33	0.40	0.50	0.60	0.80	1.80

Table 4. Coal quality statistics for coal beds with≥ 5 samples for selenium, thickness, ash yield, sulfur, pyritic sulfur, arsenic, mercury, and manganese: a. all, b. thcik (≥ 28 inch), and c. thin (< 28 inch) coal bed samples. [Coal bed code from table 2 if N≥ 30; * if N < 30 for a specific parameter; N = number of samples.]

Table 4a. Coal Samples, all thicknesses.

			Pyritic Sulfur								
Coal Bed Name This Study	Thickness range	Coal bed code N ≥ 30	N	Geometric mean percent	Average percent	Standard Deviation percent	Minimum percent	Lower Quartile percent	Median percent	Upper Quartile percent	Maximum percent
Waynesburg	all	A	50	1.49	1.83	0.95	0.05	1.11	1.77	2.33	4.00
Sewickley	all	B	38	1.09	1.45	0.78	0.02	0.96	1.35	1.94	2.87
Redstone	all	C	35	1.63	1.90	1.00	0.19	1.24	1.75	2.41	4.93
Pittsburgh Roof	all		10	1.01	1.99	1.84	0.03	0.55	1.31	3.23	5.74
Pittsburgh	all	D	99	1.66	2.09	1.07	0.05	1.39	2.02	2.89	5.16
Harlem	all		9	0.60	0.94	0.81	0.07	0.26	0.62	1.22	2.44
Lower Bakerstown	all	E *	29	1.12	1.61	0.90	0.01	0.74	1.69	2.25	3.46
Brush Creek	all		11	1.45	2.18	1.75	0.05	1.31	1.52	2.38	6.45
Mahoning	all		16	0.90	1.44	0.98	0.02	0.70	1.36	2.08	3.34
Upper Freeport Rider	all		6	0.50	1.90	1.95	0.01	0.26	1.42	3.57	4.39
Upper Freeport	all	F	264	1.22	1.58	1.10	0.05	0.81	1.35	1.89	6.18
Lower Freeport	all	G	102	1.15	1.77	1.15	0.01	0.95	1.64	2.50	5.43
Upper Kittanning	all	H	63	0.72	1.40	1.17	0.01	0.37	1.41	2.15	5.41
Middle Kittanning Rider	all		8	0.30	1.06	1.10	0.02	0.04	0.99	1.73	2.89
Middle Kittanning	all	I	234	1.33	1.78	1.18	0.01	0.99	1.63	2.39	6.85
Strasburg	all		11	2.53	3.12	1.54	0.38	2.74	3.11	3.95	5.48
Lower Kittanning Rider	all		7	0.39	0.68	0.71	0.07	0.16	0.49	1.06	1.78
Lower Kittanning/No 6 block	all	J	186	1.62	2.24	1.43	0.02	1.21	2.02	3.02	8.08
Clarion	all	K	74	1.58	2.15	1.33	0.03	1.39	1.98	2.68	7.31
Brookville	all	L	71	1.36	1.85	1.60	0.07	0.91	1.38	2.03	8.97
No 5 Block	all	M	55	0.23	0.69	0.93	0.01	0.05	0.33	0.84	3.46
Tionesta	all		5	3.00	3.77	2.92	1.13	2.02	3.39	3.65	8.67
Upper Mercer	all		8	2.63	2.89	1.28	1.31	2.20	2.59	4.00	4.66
Lower Mercer	all		22	1.00	1.64	1.30	0.02	0.80	1.01	2.58	4.75
Quakertown	all		9	0.93	1.80	2.18	0.14	0.44	1.11	1.52	6.81
Stockton	all	N	43	0.26	0.75	1.11	0.01	0.08	0.30	0.76	4.85
Coalburg	all	O	120	0.28	0.61	0.79	0.01	0.11	0.28	0.82	3.99
Winifrede/Hazard	all	P	63	0.19	0.45	0.68	0.01	0.07	0.20	0.58	3.66
Lower Winifrede/Hazard	all		10	0.16	0.30	0.38	0.04	0.07	0.15	0.33	1.16
Chilton/Taylor	all		14	0.50	1.01	1.08	0.07	0.19	0.37	2.17	2.86
Fire Clay Rider	all		23	0.92	1.58	1.27	0.03	0.57	1.30	2.31	4.21
Fire Clay	all	Q	62	0.24	0.49	0.66	0.02	0.10	0.22	0.56	3.33
Cedar Grove/Whitesburg	all	R *	22	0.76	1.39	1.11	0.02	0.38	1.08	2.37	3.54
Williamson/Amburgy	all	S	42	0.48	0.97	0.97	0.02	0.18	0.66	1.38	4.18
Campbell Creek/Upper Elkhorn No 3	all	T	80	0.30	0.76	0.94	0.03	0.09	0.24	1.22	3.50
Upper Elkhorn Nos 1 and 2/Powellton	all	U	90	0.36	0.93	1.17	0.01	0.12	0.30	1.46	5.17
Pond Creek	all	V	73	0.27	0.70	0.88	0.02	0.07	0.23	1.11	3.78
Matewan/Clintwood	all	W	123	0.36	0.85	1.06	0.01	0.14	0.32	1.23	5.22
Middle War Eagle/Eagle	all		17	0.43	0.83	0.71	0.02	0.18	0.68	1.35	2.06
Bens Creek/Blair	all		10	0.34	0.84	1.00	0.06	0.08	0.33	1.47	2.90
Little Eagle/Dorchester	all	X	85	0.28	0.47	0.56	0.01	0.15	0.31	0.51	3.27
Lower War Eagle/Hagy	all		9	0.51	0.91	0.94	0.06	0.23	0.59	1.13	2.80
Glenalum Tunnel/Splashdam	all	Y	34	0.18	0.66	1.07	0.01	0.04	0.18	0.61	4.20
Gilbert A/Upper Banner	all	Z	41	0.23	0.61	0.99	0.01	0.10	0.19	0.78	5.72
Gilbert/Lower Banner	all		17	0.18	0.29	0.34	0.03	0.09	0.17	0.30	1.36
Douglas/Kennedy	all	AA *	27	0.23	0.37	0.46	0.05	0.13	0.19	0.42	2.07
Jewell/Raven	all		19	0.20	0.56	0.98	0.03	0.07	0.18	0.37	3.61
Iaeger/Jawbone	all	BB *	29	0.17	0.55	0.94	0.02	0.07	0.10	0.29	3.23
Lower Iaeger/Tiller	all		16	0.60	2.16	2.40	0.03	0.07	1.27	3.72	7.62
Sewell B/Greasy Creek	all		4	0.78	0.86	0.46	0.48	0.55	0.74	1.06	1.49
Sewell A	all		0								
Sewell/Lower Seaboard	all	CC *	22	0.28	0.46	0.46	0.04	0.09	0.39	0.59	1.79
Welch/Upper Horsepen	all		8	0.13	0.21	0.18	0.01	0.09	0.14	0.37	0.46
Little Raleigh/Middle Horsepen	all		6	0.13	0.17	0.10	0.02	0.11	0.19	0.22	0.30
Beckley/War Creek	all	DD *	19	0.18	0.37	0.54	0.03	0.10	0.13	0.29	2.14
Fire Creek/Lower Horsepen	all		13	0.18	0.27	0.25	0.02	0.16	0.18	0.26	0.96
Pocahontas No 7	all		7	0.14	0.24	0.22	0.02	0.08	0.19	0.36	0.62
Pocahontas No 6	all		4	0.32	0.38	0.21	0.12	0.27	0.41	0.52	0.59
Pocahontas No 4	all		4	0.09	0.11	0.07	0.04	0.05	0.11	0.16	0.17
Pocahontas No 3	all	EE *	19	0.13	0.18	0.11	0.02	0.08	0.19	0.25	0.38

Table 4. Coal quality statistics for coal beds with≥ 5 samples for selenium, thickness, ash yield, sulfur, pyritic sulfur, arsenic, mercury, and manganese: a. all, b. thcik (≥ 28 inch), and c. thin (< 28 inch) coal bed samples. [Coal bed code from table 2 if N≥ 30; * if N < 30 for a specific parameter; N = number of samples.]

Table 4a. Coal Samples, all thicknesses.

			Arsenic								
Coal Bed Name This Study	Thickness range	Coal bed code N ≥ 30	N	Geometric mean ppm	Average ppm	Standard Deviation ppm	Minimum ppm	Lower Quartile ppm	Median ppm	Upper Quartile ppm	Maximum ppm
Waynesburg	all	A	60	16	19	14	0.80	10	15	25	74
Sewickley	all	B	42	5.4	6.7	4.1	0.80	3.7	6.1	8.5	19
Redstone	all	C	74	16	28	41	1.5	8.0	14	32	290
Pittsburgh Roof	all		9	11	17	12	0.85	9.3	14	25	41
Pittsburgh	all	D	136	11	17	18	0.70	5.5	11	22	87
Harlem	all		9	8.8	15	16	1.5	5.9	9.3	19	53
Lower Bakerstown	all	E	30	30	47	69	3.4	14	34	50	390
Brush Creek	all		11	21	32	23	0.76	16	30	40	77
Mahoning	all		20	71	96	87	9.3	46	73	110	410
Upper Freeport Rider	all		6	35	62	60	2.7	25	49	78	170
Upper Freeport	all	F	278	30	40	32	2.4	19	31	50	200
Lower Freeport	all	G	102	24	37	34	0.88	14	30	51	190
Upper Kittanning	all	H	67	24	41	41	1.0	12	29	53	230
Middle Kittanning Rider	all		8	22	43	39	1.4	16	38	61	120
Middle Kittanning	all	I	240	11	22	29	0.70	4.6	10	28	180
Strasburg	all		11	15	28	30	2.7	5.4	15	35	100
Lower Kittanning Rider	all		7	11	15	13	3.0	5.6	9.6	22	38
Lower Kittanning/No 6 block	all	J	197	15	27	40	0.31	8.3	15	32	320
Clarion	all	K	74	10	17	17	1.4	3.9	9.8	27	73
Brookville	all	L	73	10	20	31	0.49	4.9	10	18	180
No 5 Block	all	M	92	5.8	14	24	0.75	1.9	4.9	13	150
Tionesta	all		5	33	49	44	9.1	17	30	80	110
Upper Mercer	all		8	27	37	39	11	17	21	38	130
Lower Mercer	all		24	14	26	36	1.6	7.8	14	28	160
Quakertown	all		9	22	28	24	9.5	12	17	41	81
Stockton	all	N	62	5.2	12	16	0.60	1.7	4.3	20	79
Coalburg	all	O	142	6.8	15	25	0.40	2.6	6.2	16	170
Winifrede/Hazard	all	P	79	5.4	15	39	0.50	2.1	4.8	11	270
Lower Winifrede/Hazard	all		9	6.0	12	16	1.2	2.6	5.6	13	52
Chilton/Taylor	all		15	8.5	17	19	1.2	2.5	7.7	30	58
Fire Clay Rider	all		29	23	45	61	1.2	9.2	30	46	300
Fire Clay	all	Q	70	6.7	14	21	0.70	2.8	5.1	17	120
Cedar Grove/Whitesburg	all	R	39	10	24	46	0.75	3.6	10	34	280
Williamson/Amburgy	all	S	45	13	29	35	0.61	5.0	16	33	170
Campbell Creek/Upper Elkhorn No 3	all	T	142	7.2	17	26	0.85	2.3	7.0	19	170
Upper Elkhorn Nos 1 and 2/Powellton	all	U	114	13	42	90	0.80	4.3	11	34	680
Pond Creek	all	V	120	5.9	16	25	0.08	1.7	5.5	17	120
Matewan/Clintwood	all	W	126	10	26	37	0.50	3.4	9.9	32	180
Middle War Eagle/Eagle	all		23	17	38	37	1.1	3.8	29	66	110
Bens Creek/Blair	all		15	9.7	29	37	0.30	3.2	6.2	42	110
Little Eagle/Dorchester	all	X	88	12	23	28	1.1	3.9	14	29	130
Lower War Eagle/Hagy	all		13	23	75	110	1.0	4.2	48	59	330
Glenalum Tunnel/Splashdam	all	Y	35	7.7	21	31	0.87	2.8	5.7	22	120
Gilbert A/Upper Banner	all	Z	46	9.2	20	26	0.76	3.5	6.4	32	99
Gilbert/Lower Banner	all		23	11	23	34	1.6	4.0	8.4	22	120
Douglas/Kennedy	all	AA	37	14	23	25	1.6	7.7	11	30	100
Jewell/Raven	all		24	6.5	8.3	6.8	2.0	4.5	6.9	10	30
Iaeger/Jawbone	all	BB	34	5.9	14	20	0.45	2.4	6.0	15	80
Lower Iaeger/Tiller	all		17	15	50	81	1.6	4.7	14	56	310
Sewell B/Greasy Creek	all		6	23	39	32	1.5	20	29	66	79
Sewell A	all		7	3.8	5.3	6.1	2.0	2.4	3.1	4.3	19
Sewell/Lower Seaboard	all	CC	61	6.4	13	17	0.40	2.9	6.4	16	78
Welch/Upper Horsepen	all		15	12	22	22	1.4	4.5	11	40	64
Little Raleigh/Middle Horsepen	all		8	5.0	5.8	3.7	2.2	3.8	4.9	6.2	14
Beckley/War Creek	all	DD	30	8.8	18	22	0.25	4.2	12	19	89
Fire Creek/Lower Horsepen	all		22	7.9	12	11	1.3	3.1	12	16	40
Pocahontas No 7	all		7	12	26	31	2.7	4.6	7.6	44	75
Pocahontas No 6	all		12	11	18	22	1.4	6.4	11	19	85
Pocahontas No 4	all		13	6.6	12	13	1.2	3.5	5.0	16	39
Pocahontas No 3	all	EE	53	5.3	12	16	0.30	1.7	5.1	12	73

Table 4. Coal quality statistics for coal beds with≥ 5 samples for selenium, thickness, ash yield, sulfur, pyritic sulfur, arsenic, mercury, and manganese: a. all, b. thcik (≥ 28 inch), and c. thin (< 28 inch) coal bed samples. [Coal bed code from table 2 if N≥ 30; * if N < 30 for a specific parameter; N = number of samples.]

Table 4a. Coal Samples, all thicknesses.

			Mercury								
Coal Bed Name This Study	Thickness range	Coal bed code N ≥ 30	N	Geometric mean ppm	Average ppm	Standard Deviation ppm	Minimum ppm	Lower Quartile ppm	Median ppm	Upper Quartile ppm	Maximum ppm
Waynesburg	all	A	60	0.15	0.17	0.082	0.010	0.13	0.15	0.20	0.53
Sewickley	all	B	42	0.10	0.12	0.066	0.021	0.080	0.10	0.14	0.29
Redstone	all	C	74	0.15	0.22	0.17	0.007	0.10	0.17	0.29	0.93
Pittsburgh Roof	all		10	0.24	0.31	0.21	0.068	0.15	0.28	0.43	0.69
Pittsburgh	all	D	137	0.13	0.17	0.15	0.003	0.081	0.13	0.21	1.0
Harlem	all		9	0.076	0.14	0.11	0.007	0.030	0.18	0.23	0.31
Lower Bakerstown	all	E	30	0.16	0.23	0.24	0.003	0.12	0.18	0.25	1.3
Brush Creek	all		11	0.17	0.27	0.22	0.010	0.11	0.20	0.35	0.70
Mahoning	all		20	0.32	0.40	0.27	0.068	0.26	0.30	0.45	1.0
Upper Freeport Rider	all		6	0.76	0.84	0.44	0.490	0.57	0.73	0.83	1.7
Upper Freeport	all	F	278	0.25	0.33	0.25	0.003	0.20	0.29	0.38	2.9
Lower Freeport	all	G	103	0.20	0.30	0.24	0.003	0.14	0.27	0.41	1.6
Upper Kittanning	all	H	67	0.18	0.31	0.29	0.003	0.080	0.27	0.48	1.4
Middle Kittanning Rider	all		8	0.42	0.53	0.37	0.140	0.25	0.48	0.65	1.3
Middle Kittanning	all	I	243	0.15	0.23	0.21	0.003	0.11	0.17	0.28	1.6
Strasburg	all		11	0.23	0.27	0.13	0.076	0.17	0.27	0.38	0.45
Lower Kittanning Rider	all		7	0.048	0.12	0.12	0.003	0.037	0.090	0.18	0.33
Lower Kittanning/No 6 block	all	J	198	0.15	0.24	0.21	0.003	0.10	0.19	0.33	1.6
Clarion	all	K	74	0.14	0.18	0.14	0.010	0.086	0.13	0.24	0.76
Brookville	all	L	73	0.16	0.22	0.21	0.018	0.10	0.20	0.27	1.5
No 5 Block	all	M	93	0.13	0.18	0.18	0.023	0.082	0.14	0.23	1.5
Tionesta	all		5	0.11	0.16	0.16	0.054	0.055	0.057	0.18	0.43
Upper Mercer	all		8	0.16	0.21	0.14	0.040	0.11	0.20	0.29	0.42
Lower Mercer	all		24	0.13	0.23	0.17	0.003	0.088	0.20	0.39	0.51
Quakertown	all		9	0.12	0.16	0.13	0.033	0.073	0.12	0.26	0.42
Stockton	all	N	62	0.11	0.16	0.15	0.007	0.061	0.12	0.20	0.67
Coalburg	all	O	143	0.10	0.15	0.12	0.007	0.060	0.10	0.21	0.59
Winifrede/Hazard	all	P	79	0.090	0.16	0.17	0.007	0.042	0.084	0.22	1.0
Lower Winifrede/Hazard	all		9	0.044	0.079	0.093	0.007	0.020	0.049	0.055	0.26
Chilton/Taylor	all		15	0.15	0.20	0.17	0.043	0.090	0.16	0.26	0.74
Fire Clay Rider	all		29	0.19	0.23	0.16	0.055	0.12	0.18	0.26	0.72
Fire Clay	all	Q	70	0.082	0.12	0.099	0.007	0.050	0.080	0.22	0.43
Cedar Grove/Whitesburg	all	R	39	0.099	0.18	0.22	0.003	0.038	0.12	0.25	1.1
Williamson/Amburgy	all	S	45	0.092	0.14	0.11	0.010	0.045	0.091	0.22	0.49
Campbell Creek/Upper Elkhorn No 3	all	T	142	0.085	0.13	0.12	0.007	0.051	0.091	0.17	0.72
Upper Elkhorn Nos 1 and 2/Powellton	all	U	114	0.11	0.16	0.14	0.007	0.059	0.12	0.24	0.81
Pond Creek	all	V	121	0.078	0.12	0.12	0.003	0.049	0.080	0.16	0.57
Matewan/Clintwood	all	W	126	0.077	0.14	0.12	0.003	0.035	0.11	0.21	0.56
Middle War Eagle/Eagle	all		23	0.080	0.12	0.11	0.007	0.040	0.10	0.17	0.45
Bens Creek/Blair	all		15	0.052	0.10	0.11	0.007	0.025	0.039	0.18	0.29
Little Eagle/Dorchester	all	X	88	0.076	0.12	0.11	0.003	0.050	0.070	0.16	0.51
Lower War Eagle/Hagy	all		13	0.11	0.18	0.15	0.003	0.10	0.16	0.27	0.55
Glenalum Tunnel/Splashdam	all	Y	35	0.13	0.19	0.15	0.003	0.068	0.13	0.28	0.55
Gilbert A/Upper Banner	all	Z	46	0.058	0.099	0.11	0.003	0.050	0.070	0.12	0.51
Gilbert/Lower Banner	all		23	0.061	0.11	0.11	0.003	0.045	0.070	0.15	0.37
Douglas/Kennedy	all	AA	37	0.080	0.14	0.15	0.007	0.050	0.080	0.19	0.62
Jewell/Raven	all		24	0.080	0.10	0.083	0.015	0.050	0.075	0.13	0.37
Iaeger/Jawbone	all	BB	34	0.086	0.13	0.11	0.007	0.051	0.090	0.19	0.42
Lower Iaeger/Tiller	all		17	0.096	0.27	0.30	0.007	0.034	0.13	0.52	1.0
Sewell B/Greasy Creek	all		6	0.12	0.23	0.29	0.014	0.080	0.16	0.20	0.80
Sewell A	all		7	0.11	0.20	0.21	0.020	0.055	0.070	0.36	0.51
Sewell/Lower Seaboard	all	CC	61	0.13	0.20	0.21	0.017	0.060	0.14	0.26	0.97
Welch/Upper Horsepen	all		15	0.10	0.17	0.21	0.030	0.060	0.077	0.20	0.81
Little Raleigh/Middle Horsepen	all		8	0.083	0.11	0.080	0.014	0.064	0.091	0.13	0.27
Beckley/War Creek	all	DD	30	0.074	0.15	0.32	0.007	0.050	0.075	0.11	1.8
Fire Creek/Lower Horsepen	all		22	0.076	0.092	0.058	0.025	0.050	0.071	0.13	0.23
Pocahontas No 7	all		7	0.026	0.044	0.030	0.003	0.024	0.060	0.065	0.070
Pocahontas No 6	all		13	0.089	0.20	0.24	0.015	0.030	0.080	0.32	0.66
Pocahontas No 4	all		13	0.042	0.054	0.031	0.007	0.039	0.050	0.080	0.095
Pocahontas No 3	all	EE	53	0.068	0.11	0.12	0.007	0.050	0.072	0.11	0.66

Table 4. Coal quality statistics for coal beds with≥ 5 samples for selenium, thickness, ash yield, sulfur, pyritic sulfur, arsenic, mercury, and manganese: a. all, b. thcik (≥ 28 inch), and c. thin (< 28 inch) coal bed samples. [Coal bed code from table 2 if N≥ 30; * if N < 30 for a specific parameter; N = number of samples.]

Table 4a. Coal Samples, all thicknesses.

Coal Bed Name This Study	Thickness range	Coal bed code N ≥ 30	Manganese N	Geometric mean ppm	Average ppm	Standard Deviation ppm	Minimum ppm	Lower Quartile ppm	Median ppm	Upper Quartile ppm	Maximum ppm
Waynesburg	all	A	60	26	32	27	10	20	25	35	180
Sewickley	all	B	42	20	33	53	6.4	11	16	24	260
Redstone	all	C	74	28	45	65	5	17	25	39	460
Pittsburgh Roof	all		10	14	15	5.9	6.1	13	14	17	27
Pittsburgh	all	D	137	21	29	33	1.4	14	20	35	300
Harlem	all		9	16	25	27	6.2	7.3	15	28	90
Lower Bakerstown	all	E	30	24	43	71	6.5	12	16	52	390
Brush Creek	all		11	13	27	46	3.4	5.6	8.6	25	160
Mahoning	all		20	12	16	13	3.3	6.4	13	25	59
Upper Freeport Rider	all		6	15	20	16	5.8	8.7	15	28	47
Upper Freeport	all	F	276	16	22	21	1.1	9.3	16	27	140
Lower Freeport	all	G	103	17	34	75	0.92	9.2	16	30	690
Upper Kittanning	all	H	67	13	18	22	3.3	8.2	12	21	170
Middle Kittanning Rider	all		8	24	26	12	14	16	24	32	46
Middle Kittanning	all	I	242	18	25	29	1.7	10	17	28	310
Strasburg	all		11	25	35	32	6.3	17	28	42	120
Lower Kittanning Rider	all		7	8.5	9.6	6.4	5.8	6.4	7.9	8.5	24
Lower Kittanning/No 6 block	all	J	198	16	26	47	1.6	9.7	15	26	430
Clarion	all	K	74	20	27	29	3.6	12	22	33	220
Brookville	all	L	73	17	29	57	2.1	10	17	26	470
No 5 Block	all	M	93	7.8	13	24	1.4	4.4	6.8	12	200
Tionesta	all		5	35	99	180	13	21	21	21	420
Upper Mercer	all		8	32	52	63	8.8	15	32	55	200
Lower Mercer	all		24	15	26	39	4.1	6.9	15	25	190
Quakertown	all		9	11	22	34	2.6	5.1	11	15	110
Stockton	all	N	62	7.6	11	18	1.2	5.3	7.1	12	140
Coalburg	all	O	143	9.4	13	13	1.1	5.9	9.0	16	120
Winifrede/Hazard	all	P	79	9.4	14	14	1.2	5.8	8.0	16	83
Lower Winifrede/Hazard	all		9	6.2	8.0	6.3	1.6	4.6	4.8	12	21
Chilton/Taylor	all		15	12	21	28	3	7.0	9.6	22	89
Fire Clay Rider	all		29	22	44	71	3.6	11	17	48	350
Fire Clay	all	Q	70	9.4	15	17	1.9	5.0	7.7	20	86
Cedar Grove/Whitesburg	all	R	39	11	41	130	0.73	5.1	9.4	15	660
Williamson/Amburgy	all	S	45	11	21	44	2.2	5.8	9.9	17	250
Campbell Creek/Upper Elkhorn No 3	all	T	142	7.8	11	11	1.2	3.9	7.4	15	63
Upper Elkhorn Nos 1 and 2/Powellton	all	U	114	7.7	12	15	0.96	4.2	7.1	12	110
Pond Creek	all	V	121	13	27	59	2.1	6.6	12	22	540
Matewan/Clintwood	all	W	126	8.0	15	38	1.1	4.4	7.1	14	390
Middle War Eagle/Eagle	all		23	9.6	21	28	0.75	4.7	8.0	19	100
Bens Creek/Blair	all		15	8.1	15	21	3	4.1	4.9	16	68
Little Eagle/Dorchester	all	X	88	9.0	17	28	1.1	3.8	8.3	15	170
Lower War Eagle/Hagy	all		13	13	22	31	2.4	6.3	12	24	120
Glenalum Tunnel/Splashdam	all	Y	35	7.8	14	18	1.2	4.0	6.0	18	84
Gilbert A/Upper Banner	all	Z	46	12	16	13	1.5	7.3	12	21	70
Gilbert/Lower Banner	all		23	20	25	17	4.5	14	17	29	60
Douglas/Kennedy	all	AA	37	18	32	39	2.8	9.0	20	33	190
Jewell/Raven	all		24	23	27	17	7.8	16	21	35	74
Iaeger/Jawbone	all	BB	34	15	26	32	1.1	7.5	16	31	160
Lower Iaeger/Tiller	all		17	24	29	18	7.3	15	29	37	74
Sewell B/Greasy Creek	all		6	14	22	29	5.4	7.9	12	16	81
Sewell A	all		7	16	27	30	2.4	11	17	28	91
Sewell/Lower Seaboard	all	CC	61	12	27	49	1.5	4.9	9.3	29	320
Welch/Upper Horsepen	all		15	9.4	11	6.7	3.8	6.1	9.4	15	27
Little Raleigh/Middle Horsepen	all		7	32	65	97	8.3	14	22	60	280
Beckley/War Creek	all	DD	30	11	36	77	1.4	4.8	7.2	27	320
Fire Creek/Lower Horsepen	all		22	6.7	11	15	1.0	3.1	7.5	13	75
Pocahontas No 7	all		7	15	27	29	1.3	8.8	18	37	79
Pocahontas No 6	all		13	8.3	19	37	1.5	2.9	8.0	15	140
Pocahontas No 4	all		13	18	37	68	3.4	8.5	21	30	260
Pocahontas No 3	all	EE	53	16	24	28	1.7	10	19	27	200

Table 4. Coal quality statistics for coal beds with ≥ 5 samples for selenium, thickness, ash yield, sulfur, pyritic sulfur, arsenic, mercury, and manganese: a. all, b. thcik (≥ 28 inch), and c. thin (< 28 inch) coal bed samples. [Coal bed code from table 2 if N ≥ 30; * if N < 30 for a specific parameter; N = number of samples.]

Table 4b. Thick Coal Samples, ≥28 inch thick.

			Selenium								
Coal bed name, this study	Thickness range	Coal bed code N≥30	N	Geometric mean ppm	Average ppm	Standard Deviation ppm	Minimum ppm	Lower Quartile ppm	Median ppm	Upper Quartile ppm	Maximum ppm
Waynesburg	≥ 28 in	A	56	2.7	2.8	0.89	0.64	2.4	2.9	3.3	5.5
Sewickley	≥ 28 in	B	40	2.6	2.9	1.3	0.70	2.2	2.6	3.6	7.2
Redstone	≥ 28 in	C	56	1.9	2.1	1.1	0.50	1.4	1.9	2.4	6.9
Pittsburgh	≥ 28 in	D	132	1.4	1.7	1.2	0.20	1.0	1.4	2.0	7.5
Lower Bakerstown	≥ 28 in		12	3.5	3.7	1.5	1.6	2.8	3.4	4.8	6.6
Mahoning	≥ 28 in		6	2.5	2.8	1.2	1.5	1.9	2.3	3.7	4.5
Upper Freeport	≥ 28 in	F	215	2.3	2.7	1.8	0.72	1.7	2.2	3.0	14
Lower Freeport	≥ 28 in	G	66	3.5	4.2	2.9	1.1	2.3	3.2	4.9	15
Upper Kittanning	≥ 28 in	H	32	4.5	5.2	3.1	1.4	2.8	4.1	6.4	13
Middle Kittanning	≥ 28 in	I	168	3.3	3.6	2.0	0.99	2.3	3.2	4.5	17
Lower Kittanning/No 6 block	≥ 28 in	J	141	3.4	4.0	2.6	0.60	2.2	3.7	5.4	20
Clarion	≥ 28 in	K	47	6.0	6.5	2.5	2.3	5.0	6.2	7.5	14
Brookville	≥ 28 in	L	30	5.4	6.1	3.0	1.8	3.9	5.3	7.7	14
No 5 Block	≥ 28 in	M	65	7.0	7.4	2.6	3.1	5.7	7.0	8.9	17
Lower Mercer	≥ 28 in		7	7.7	8.3	3.3	4.0	5.9	8.3	10	13
Stockton	≥ 28 in	N	51	5.3	5.6	1.9	2.7	4.1	5.5	7.1	11
Coalburg	≥ 28 in	O	67	5.0	5.2	1.5	1.8	4.3	4.9	6.3	8.7
Winifrede/Hazard	≥ 28 in	P	48	4.7	4.9	1.7	2.4	3.8	4.8	5.6	11
Chilton/Taylor	≥ 28 in		9	2.5	3.0	1.7	0.73	2.0	3.0	3.8	5.8
Fire Clay Rider	≥ 28 in		13	4.0	4.1	1.3	2.4	3.5	3.6	4.4	7.8
Fire Clay	≥ 28 in	Q	40	3.5	3.7	1.2	1.3	2.8	3.4	4.5	6.3
Cedar Grove/Whitesburg	≥ 28 in		16	3.5	3.6	1.1	2.2	2.5	3.7	4.5	5.5
Williamson/Amburgy	≥ 28 in		19	3.1	3.5	1.7	0.90	2.5	3.5	4.1	7.5
Campbell Creek/Upper Elkhorn No 3	≥ 28 in	T	80	3.8	4.0	1.3	1.7	3.0	3.9	4.7	7.8
Upper Elkhorn Nos 1 and 2/Powellton	≥ 28 in	U	59	3.4	3.7	1.5	0.93	2.9	3.6	4.4	7.7
Pond Creek	≥ 28 in	V	78	3.5	3.7	1.2	1.6	2.7	3.7	4.5	6.7
Matewan/Clintwood	≥ 28 in	W	54	2.8	3.2	1.6	0.54	2.1	2.9	3.8	7.4
Middle War Eagle/Eagle	≥ 28 in		12	3.4	3.7	1.4	1.7	3.0	3.4	4.3	6.0
Bens Creek/Blair	≥ 28 in		11	2.1	2.1	0.55	1.1	1.9	2.0	2.4	3.3
Lit le Eagle/Dorchester	≥ 28 in	X	53	2.7	3.0	1.6	1.2	1.8	2.5	3.5	7.1
Lower War Eagle/Hagy	≥ 28 in		8	2.9	3.0	0.86	1.3	2.7	3.1	3.7	4.0
Glenalum Tunnel/Splashdam	≥ 28 in		17	2.6	2.8	0.93	0.76	2.2	2.8	3.2	4.4
Gilbert A/Upper Banner	≥ 28 in		24	3.1	3.3	1.1	1.2	2.5	3.0	3.6	5.6
Gilbert/Lower Banner	≥ 28 in		17	2.7	2.9	1.1	1.7	2.2	2.7	3.0	6.3
Douglas/Kennedy	≥ 28 in		22	1.7	2.2	2.2	0.40	1.1	1.3	2.3	11
Jewell/Raven	≥ 28 in		19	1.7	2.0	0.88	0.20	1.5	2.0	2.7	3.8
Iaeger/Jawbone	≥ 28 in		17	1.9	2.5	1.3	0.07	1.7	2.7	3.1	4.8
Lower Iaeger/Tiller	≥ 28 in		7	2.6	2.8	0.97	1.0	2.8	2.9	3.0	4.3
Sewell/Lower Seaboard	≥ 28 in	CC	41	2.0	2.5	2.3	0.76	1.3	1.8	2.5	14
Welch/Upper Horsepen	≥ 28 in		10	1.6	1.8	0.91	0.70	1.1	1.7	2.2	3.6
Lit le Raleigh/Middle Horsepen	≥ 28 in		5	2.2	2.2	0.44	1.7	1.9	2.1	2.6	2.7
Beckley/War Creek	≥ 28 in		18	1.5	1.6	0.44	0.78	1.3	1.5	1.8	2.4
Fire Creek/Lower Horsepen	≥ 28 in		14	2.5	2.7	1.1	1.1	1.8	2.8	3.3	4.9
Pocahontas No 6	≥ 28 in		10	2.7	2.9	1.4	1.4	2.1	2.5	3.8	5.9
Pocahontas No 4	≥ 28 in		13	2.4	2.5	1.1	1.8	2.0	2.3	2.5	5.9
Pocahontas No 3	≥ 28 in	EE	43	3.0	3.4	1.7	1.1	2.3	3.0	4.1	8.2

Table 4. Coal quality statistics for coal beds with ≥ 5 samples for selenium, thickness, ash yield, sulfur, pyritic sulfur, arsenic, mercury, and manganese: a. all, b. thcik (≥ 28 inch), and c. thin (< 28 inch) coal bed samples. [Coal bed code from table 2 if N ≥ 30; * if N < 30 for a specific parameter; N = number of samples.]

Table 4b. Thick Coal Samples, ≥28 inch thick.

			Thickness								
Coal Bed Name This Study	Thickness range	Coal bed code N≥30	N	Geometric mean in	Average in	Standard Deviation in	Minimum in	Lower Quartile in	Median in	Upper Quartile in	Maximum in
Waynesburg	≥ 28 in	A	56	47.3	49.8	16.7	28.3	37.3	46.1	58.4	95.0
Sewickley	≥ 28 in	B	40	46.4	47.5	11.2	32.0	39.0	47.8	55.1	87.5
Redstone	≥ 28 in	C	56	51.6	54.0	15.7	28.0	38.1	55.1	67.2	88.0
Pittsburgh	≥ 28 in	D	132	60.0	63.3	20.7	28.0	49.9	60.5	75.5	125 0
Lower Bakerstown	≥ 28 in		12	36.1	36.8	8.0	28.0	32.1	35.9	36.9	56.0
Mahoning	≥ 28 in		6	37.2	38.5	12.4	28.0	33.2	34.8	37.1	63.0
Upper Freeport	≥ 28 in	F	215	46.2	48.1	14.4	28.0	39.0	46.5	50.5	105 5
Lower Freeport	≥ 28 in	G	67	41.3	43.0	13.2	28.5	33.6	38.0	50.2	74.0
Upper Kittanning	≥ 28 in	H	32	41.0	43.2	15.5	28.4	31.4	37.2	51.8	94.8
Middle Kittanning	≥ 28 in	I	168	39.4	40.4	10.3	28.0	33.5	38.7	45.0	95.5
Lower Kittanning/No 6 block	≥ 28 in	J	141	37.9	38.9	10.2	28.0	32.4	36.0	41.5	86.4
Clarion	≥ 28 in	K	47	41.1	43.0	14.5	28.8	31.9	39.3	48.8	96.0
Brookville	≥ 28 in	L	30	39.7	40.9	10.4	28.4	32.3	37.8	49.4	61.5
No 5 Block	≥ 28 in	M	65	53.8	59.7	30.9	28.0	40.0	49.6	70.5	171 8
Lower Mercer	≥ 28 in		7	38.9	40.5	13.8	29.4	33.6	35.1	41.1	69.6
Stockton	≥ 28 in	N	51	47.7	49.7	14.5	28.5	40.0	48.0	58.7	93.3
Coalburg	≥ 28 in	O	67	47.0	49.7	18.1	28.0	37.0	45.5	55.6	112 5
Winifrede/Hazard	≥ 28 in	P	48	40.0	41.5	12.1	28.0	32.8	37.9	45.9	73.2
Chilton/Taylor	≥ 28 in		9	43.1	45.6	17.8	29.6	35.0	40.9	46.1	85.2
Fire Clay Rider	≥ 28 in		13	42.6	44.6	16.3	33.0	35.0	38.0	46.0	91.3
Fire Clay	≥ 28 in	Q	40	43.7	45.3	13.0	28.0	34.7	43.0	51.3	80.5
Cedar Grove/Whitesburg	≥ 28 in		16	38.6	39.4	8.1	28.3	31.8	40.4	45.3	52.0
Williamson/Amburgy	≥ 28 in		19	41.3	42.9	13.4	28.8	35.2	39.4	46.6	84.0
Campbell Creek/Upper Elkhorn No 3	≥ 28 in	T	80	38.4	39.7	11.2	28.0	31.3	37.6	44.8	85.5
Upper Elkhorn Nos 1 and 2/Powellton	≥ 28 in	U	59	39.0	40.0	9.2	28.0	32.6	39.0	43.9	69.3
Pond Creek	≥ 28 in	V	78	42.7	44.3	12.8	28.0	35.1	42.1	47.4	85.4
Matewan/Clintwood	≥ 28 in	W	54	36.9	37.9	10.2	28.0	31.2	35.5	43.2	87.2
Middle War Eagle/Eagle	≥ 28 in		12	38.6	39.7	10.3	28.8	34.2	37.8	39.0	64.8
Bens Creek/Blair	≥ 28 in		11	35.2	35.8	7.1	28.5	30.9	32.0	39.4	50.0
Lit le Eagle/Dorchester	≥ 28 in	X	54	37.7	38.5	8.6	28.7	33.1	36.5	41.9	66.0
Lower War Eagle/Hagy	≥ 28 in		8	33.4	33.6	3.7	28.4	32.0	33.5	36.1	39.0
Glenalum Tunnel/Splashdam	≥ 28 in		17	41.5	42.8	11.1	28.8	32.0	41.4	49.6	69.0
Gilbert A/Upper Banner	≥ 28 in		24	39.5	41.7	17.4	29.4	32.1	36.8	42.5	110 2
Gilbert/Lower Banner	≥ 28 in		17	46.3	47.4	11.2	32.8	39.6	44.4	56.4	71.0
Douglas/Kennedy	≥ 28 in		22	36.8	37.7	8.8	28.0	32.3	35.0	40.4	62.0
Jewell/Raven	≥ 28 in		19	40.5	41.7	10.8	28.0	32.8	41.0	47.2	68.4
Iaeger/Jawbone	≥ 28 in		17	44.2	46.2	14.5	29.5	35.0	41.2	59.9	77.8
Lower Iaeger/Tiller	≥ 28 in		7	40.0	41.5	13.6	29.8	34.3	36.0	44.0	68.4
Sewell/Lower Seaboard	≥ 28 in	CC	41	42.4	43.7	11.2	28.6	35.9	42.8	52.0	70.6
Welch/Upper Horsepen	≥ 28 in		10	45.1	51.4	31.8	28.0	31.3	38.0	57.8	128 0
Lit le Raleigh/Middle Horsepen	≥ 28 in		5	43.7	43.8	4.0	42.0	42.0	42.0	42.0	51.0
Beckley/War Creek	≥ 28 in		18	40.5	42.8	16.0	28.0	30.5	39.3	51.0	87.0
Fire Creek/Lower Horsepen	≥ 28 in		14	41.4	43.2	13.6	29.5	32.3	36.8	56.3	70.0
Pocahontas No 6	≥ 28 in		10	35.5	35.8	4.8	30.1	31.1	35.8	39.9	43.5
Pocahontas No 4	≥ 28 in		13	64.8	65.9	12.6	49.0	60.1	62.6	76.0	91.0
Pocahontas No 3	≥ 28 in	EE	43	50.5	52.1	14.0	31.0	43.3	51.8	57.6	94.0

Table 4. Coal quality statistics for coal beds with ≥ 5 samples for selenium, thickness, ash yield, sulfur, pyritic sulfur, arsenic, mercury, and manganese: a. all, b. thcik (≥ 28 inch), and c. thin (< 28 inch) coal bed samples. [Coal bed code from table 2 if N ≥ 30; * if N < 30 for a specific parameter; N = number of samples.]

Table 4b. Thick Coal Samples, ≥28 inch thick.

			Ash Yield								
Coal Bed Name This Study	Thickness range	Coal bed code N≥30	N	Geometric mean percent	Average percent	Standard Deviation percent	Minimum percent	Lower Quartile percent	Median percent	Upper Quartile percent	Maximum percent
Waynesburg	≥ 28 in	A	53	16.61	17.12	3.34	3.16	15.66	17.16	19.37	22.96
Sewickley	≥ 28 in	B	38	11.42	11.81	3.06	5.70	9.71	11.31	13.23	20.20
Redstone	≥ 28 in	C	53	9.51	10.20	4.39	5.60	7.60	9.02	11.10	25.70
Pittsburgh	≥ 28 in	D	124	9.98	10.51	3.88	4.40	8.03	10.10	11.74	32.03
Lower Bakerstown	≥ 28 in		11	11.84	13.25	6.49	5.55	8.07	11.83	17.37	24.90
Mahoning	≥ 28 in		4	11.31	11.45	2.09	9.51	10.08	11.02	12.39	14.25
Upper Freeport	≥ 28 in	F	169	12.44	13.22	4.79	3.60	10.30	12.00	15.60	29.10
Lower Freeport	≥ 28 in	G	67	9.23	9.94	4.12	3.90	7.67	8.46	11.41	26.43
Upper Kittanning	≥ 28 in	H	30	11.35	11.82	3.56	5.69	10.22	11.20	12.98	24.00
Middle Kittanning	≥ 28 in	I	165	9.41	10.59	5.07	2.20	6.80	9.20	14.32	23.80
Lower Kittanning/No 6 block	≥ 28 in	J	138	10.45	11.44	5.13	2.80	7.70	10.55	13.49	31.50
Clarion	≥ 28 in	K	47	13.40	14.37	5.40	4.80	10.81	13.58	17.25	28.38
Brookville	≥ 28 in	L *	29	12.08	13.10	5.83	6.22	8.90	11.33	14.62	29.45
No 5 Block	≥ 28 in	M	58	10.37	11.31	4.70	2.70	7.90	10.36	14.09	27.50
Lower Mercer	≥ 28 in		7	15.02	15.68	5.49	10.82	12.78	13.42	16.43	27.09
Stockton	≥ 28 in	N	49	11.33	12.57	5.62	4.22	8.00	12.65	15.43	28.20
Coalburg	≥ 28 in	O	67	11.28	12.35	5.36	3.42	8.70	11.40	14.32	30.70
Winifrede/Hazard	≥ 28 in	P	46	9.27	10.72	5.65	2.44	6.91	9.75	14.35	28.50
Chilton/Taylor	≥ 28 in		9	11.19	11.49	2.59	6.80	9.20	12.70	13.28	14.00
Fire Clay Rider	≥ 28 in		13	11.58	12.24	4.35	6.51	9.00	11.12	15.90	22.00
Fire Clay	≥ 28 in	Q	40	10.15	11.45	5.83	3.34	7.06	10.50	14.62	31.80
Cedar Grove/Whitesburg	≥ 28 in		15	9.15	10.50	5.60	2.47	7.45	9.80	11.90	23.30
Williamson/Amburgy	≥ 28 in		19	7.57	8.92	5.43	2.30	6.26	7.63	11.09	26.10
Campbell Creek/Upper Elkhorn No 3	≥ 28 in	T	79	6.89	7.60	3.43	2.30	4.88	7.17	9.30	21.60
Upper Elkhorn Nos 1 and 2/Powellton	≥ 28 in	U	59	6.20	6.97	3.55	1.65	4.56	6.24	8.89	19.10
Pond Creek	≥ 28 in	V	78	7.11	8.00	3.73	1.66	5.48	7.24	10.27	16.80
Matewan/Clintwood	≥ 28 in	W	54	6.02	6.68	3.46	2.57	4.51	6.05	7.45	21.60
Middle War Eagle/Eagle	≥ 28 in		10	4.85	5.55	3.23	2.10	3.67	3.80	7.25	12.54
Bens Creek/Blair	≥ 28 in		11	4.23	6.07	6.13	1.60	2.65	3.22	5.90	18.30
Lit le Eagle/Dorchester	≥ 28 in	X	54	7.19	8.75	5.82	1.93	4.75	6.53	12.05	28.20
Lower War Eagle/Hagy	≥ 28 in		8	9.68	11.03	6.01	4.30	8.52	9.99	11.89	22.80
Glenalum Tunnel/Splashdam	≥ 28 in		17	8.98	10.50	6.29	3.40	6.10	9.10	13.90	25.30
Gilbert A/Upper Banner	≥ 28 in		22	7.34	7.94	3.50	3.60	5.99	6.72	9.38	18.19
Gilbert/Lower Banner	≥ 28 in		14	10.95	11.86	4.68	4.68	7.75	11.85	14.70	19.63
Douglas/Kennedy	≥ 28 in		18	6.34	7.40	4.95	3.08	4.57	6.25	8.25	22.57
Jewell/Raven	≥ 28 in		16	6.20	7.81	5.95	2.40	3.75	5.86	9.35	24.59
Iaeger/Jawbone	≥ 28 in		16	11.51	13.83	8.38	2.44	7.88	12.80	16.46	30.90
Lower Iaeger/Tiller	≥ 28 in		7	7.77	8.63	4.34	3.68	6.05	7.20	10.51	16.40
Sewell/Lower Seaboard	≥ 28 in	CC	37	5.05	5.57	2.62	2.30	3.60	4.44	7 00	12.36
Welch/Upper Horsepen	≥ 28 in		7	6.71	7.45	3.54	3.40	4.55	8.00	9.22	13.19
Lit le Raleigh/Middle Horsepen	≥ 28 in		5	6.94	7.14	1.90	5.10	5.80	6.50	9.10	9.20
Beckley/War Creek	≥ 28 in		16	5.78	6.62	3.01	0.90	5.05	6.30	7.53	12.00
Fire Creek/Lower Horsepen	≥ 28 in		14	6.92	7.54	3.53	3.60	5.43	6.50	8.90	17.20
Pocahontas No 6	≥ 28 in		10	7.71	8.46	4.14	4.60	5.60	6.95	10.58	17.90
Pocahontas No 4	≥ 28 in		13	6.14	6.35	1.84	4.20	5.60	5.93	6.60	11.40
Pocahontas No 3	≥ 28 in	EE	41	7.62	8.44	3.85	2.90	5.80	7.30	10.60	16.09

Table 4. Coal quality statistics for coal beds with ≥ 5 samples for selenium, thickness, ash yield, sulfur, pyritic sulfur, arsenic, mercury, and manganese: a. all, b. thcik (≥ 28 inch), and c. thin (< 28 inch) coal bed samples. [Coal bed code from table 2 if N ≥ 30; * if N < 30 for a specific parameter; N = number of samples.]

Table 4b. Thick Coal Samples, ≥28 inch thick.

			Sulfur								
Coal Bed Name This Study	Thickness range	Coal bed code N≥30	N	Geometric mean percent	Average percent	Standard Deviation percent	Minimum percent	Lower Quartile percent	Median percent	Upper Quartile percent	Maximum percent
Waynesburg	≥ 28 in	A	54	2.59	2.75	0.93	0.70	2.20	2.65	3 34	5.20
Sewickley	≥ 28 in	B	38	2.58	2.89	1.29	0.70	1.95	2.92	3 58	5.90
Redstone	≥ 28 in	C	53	2.59	2.76	0.99	0.90	2.10	2.60	3.20	5.66
Pittsburgh	≥ 28 in	D	124	2.92	3.34	1.50	0.40	2.08	3.35	4.50	6.70
Lower Bakerstown	≥ 28 in		11	1.91	2.23	1.11	0.40	1.55	2.40	2.91	4.39
Mahoning	≥ 28 in		4	2.22	2.73	1.50	0.63	2.26	3.06	3.53	4.15
Upper Freeport	≥ 28 in	F	210	2.11	2.35	1.12	0.59	1.60	2.13	2.80	6.30
Lower Freeport	≥ 28 in	G	67	2.11	2.49	1.25	0.50	1.68	2.56	3.23	5.75
Upper Kittanning	≥ 28 in	H	30	1.99	2.35	1.22	0.40	1.36	2.25	3.30	5.60
Middle Kittanning	≥ 28 in	I	165	2.87	3.18	1.32	0.50	2.30	3.05	3.91	7.50
Lower Kittanning/No 6 block	≥ 28 in	J	138	2.88	3.42	1.78	0.40	2.11	3.30	4.55	8.43
Clarion	≥ 28 in	K	47	3.30	3.71	1.66	0.66	2.70	3.70	4.46	9.34
Brookville	≥ 28 in	L *	29	3.37	3.76	1.96	1.31	2.30	3.12	4.56	10.40
No 5 Block	≥ 28 in	M	58	0.81	0.92	0.66	0.40	0.60	0.73	0 97	4.87
Lower Mercer	≥ 28 in		7	2.37	2.89	2.07	1.36	1.47	1.60	4.08	6.15
Stockton	≥ 28 in	N	49	0.94	1.17	1.01	0.50	0.60	0.70	1.30	5.40
Coalburg	≥ 28 in	O	67	0.89	0.99	0.54	0.40	0.67	0.80	1.10	3.12
Winifrede/Hazard	≥ 28 in	P	46	0.89	0.99	0.55	0.50	0.65	0.80	1 08	3.50
Chilton/Taylor	≥ 28 in		9	1.15	1.28	0.72	0.60	0.90	1.11	1.32	3.10
Fire Clay Rider	≥ 28 in		13	2.19	2.63	1.45	0.69	1.44	2.80	3.50	5.20
Fire Clay	≥ 28 in	Q	40	0.94	1.02	0.48	0.50	0.74	0.86	1.11	2.57
Cedar Grove/Whitesburg	≥ 28 in		15	1.01	1.19	0.97	0.60	0.77	0.90	1.15	4.53
Williamson/Amburgy	≥ 28 in		19	1.32	1.61	1.05	0.59	0.78	1.16	2.45	4.00
Campbell Creek/Upper Elkhorn No 3	≥ 28 in	T	79	1.09	1.28	0.82	0.46	0.70	0.90	1.65	4.00
Upper Elkhorn Nos 1 and 2/Powellton	≥ 28 in	U	59	1.03	1.21	0.86	0.51	0.70	0.80	1.39	4.50
Pond Creek	≥ 28 in	V	78	0.94	1.11	0.78	0.41	0.60	0.80	1 32	4.50
Matewan/Clintwood	≥ 28 in	W	54	1.12	1.33	0.90	0.50	0.71	0.92	1.72	4.40
Middle War Eagle/Eagle	≥ 28 in		10	1.13	1.38	0.88	0.46	0.62	1.20	2.13	2.80
Bens Creek/Blair	≥ 28 in		11	1.15	1.31	0.73	0.50	0.80	1.00	1.88	2.60
Lit le Eagle/Dorchester	≥ 28 in	X	54	1.07	1.16	0.55	0.60	0.81	1.00	1 28	3.38
Lower War Eagle/Hagy	≥ 28 in		8	1.38	1.58	0.86	0.60	0.87	1.41	2.17	3.00
Glenalum Tunnel/Splashdam	≥ 28 in		17	1.01	1.28	1.16	0.60	0.66	0.75	1.16	4.40
Gilbert A/Upper Banner	≥ 28 in		22	0.96	1.17	0.81	0.40	0.60	0.82	1.79	3.17
Gilbert/Lower Banner	≥ 28 in		14	0.85	0.93	0.45	0.56	0.60	0.80	1.04	2.10
Douglas/Kennedy	≥ 28 in		18	0.84	0.91	0.40	0.50	0.60	0.77	0.93	1.70
Jewell/Raven	≥ 28 in		16	0.87	1.16	1.20	0.50	0.58	0.72	0.95	4.20
Iaeger/Jawbone	≥ 28 in		16	0.61	0.62	0.11	0.50	0.54	0.60	0.64	0.90
Lower Iaeger/Tiller	≥ 28 in		7	1.03	1.82	2.36	0.50	0.53	0.60	1.93	6.70
Sewell/Lower Seaboard	≥ 28 in	CC	37	0.81	0.87	0.36	0.40	0.60	0.80	1 00	2.20
Welch/Upper Horsepen	≥ 28 in		7	0.77	0.82	0.31	0.50	0.61	0.80	0.90	1.40
Lit le Raleigh/Middle Horsepen	≥ 28 in		5	0.78	0.80	0.19	0.50	0.80	0.80	0.90	1.00
Beckley/War Creek	≥ 28 in		16	0.95	1.06	0.49	0.40	0.60	1.15	1.43	1.90
Fire Creek/Lower Horsepen	≥ 28 in		14	0.89	0.94	0.31	0.40	0.73	0.85	1.18	1.50
Pocahontas No 6	≥ 28 in		10	0.97	0.99	0.19	0.80	0.82	0.90	1.18	1.30
Pocahontas No 4	≥ 28 in		13	0.64	0.65	0.12	0.50	0.60	0.65	0.70	0.88
Pocahontas No 3	≥ 28 in	EE	41	0.69	0.73	0.28	0.40	0.52	0.65	0.80	1.80

Table 4. Coal quality statistics for coal beds with ≥ 5 samples for selenium, thickness, ash yield, sulfur, pyritic sulfur, arsenic, mercury, and manganese: a. all, b. thcik (≥ 28 inch), and c. thin (< 28 inch) coal bed samples. [Coal bed code from table 2 if N ≥ 30; * if N < 30 for a specific parameter; N = number of samples.]

Table 4b. Thick Coal Samples, ≥28 inch thick.

			Pyritic Sulfur								
Coal Bed Name This Study	Thickness range	Coal bed code N≥30	N	Geometric mean percent	Average percent	Standard Deviation percent	Minimum percent	Lower Quartile percent	Median percent	Upper Quartile percent	Maximum percent
Waynesburg	≥ 28 in	A	47	1.57	1.83	0.89	0.14	1.12	1.78	2 33	4.00
Sewickley	≥ 28 in	B	36	1.05	1.40	0.76	0.02	0.91	1.30	1 93	2.87
Redstone	≥ 28 in	C *	19	1.76	1.97	1.03	0.67	1.30	1.75	2.31	4.93
Pittsburgh	≥ 28 in	D	94	1.64	2.08	1.09	0.05	1.33	2.00	2.89	5.16
Lower Bakerstown	≥ 28 in		11	0.84	1.37	0.84	0.01	0.65	1.65	1.76	2.73
Mahoning	≥ 28 in		4	0.64	1.58	1.14	0.02	1.18	1.79	2.18	2.72
Upper Freeport	≥ 28 in	F	208	1.19	1.52	1.00	0.05	0.86	1.33	1.81	5.57
Lower Freeport	≥ 28 in	G	66	0.97	1.58	1.04	0.01	0.73	1.59	2.31	3.92
Upper Kittanning	≥ 28 in	H *	29	0.94	1.57	1.20	0.02	0.66	1.43	2.15	5.41
Middle Kittanning	≥ 28 in	I	161	1.46	1.80	1.03	0.04	1.07	1.69	2.27	6.49
Lower Kittanning/No 6 block	≥ 28 in	J	134	1.54	2.19	1.42	0.02	1.16	2.01	3.00	6.07
Clarion	≥ 28 in	K	47	1.76	2.19	1.38	0.18	1.34	1.99	2.66	7.31
Brookville	≥ 28 in	L *	29	1.99	2.44	1.82	0.63	1.32	1.75	3.10	8.97
No 5 Block	≥ 28 in	M	31	0.13	0.38	0.66	0.02	0.03	0.10	0 39	3.07
Lower Mercer	≥ 28 in		6	1.18	1.59	1.59	0.58	0.75	0.92	1.47	4.75
Stockton	≥ 28 in	N	35	0.23	0.60	0.88	0.01	0.09	0.30	0.68	4.02
Coalburg	≥ 28 in	O	51	0.24	0.42	0.45	0.03	0.11	0.27	0.53	1.79
Winifrede/Hazard	≥ 28 in	P	34	0.20	0.41	0.56	0.01	0.07	0.24	0 54	2.95
Chilton/Taylor	≥ 28 in		9	0.31	0.46	0.58	0.13	0.18	0.33	0.38	1.97
Fire Clay Rider	≥ 28 in		13	0.81	1.35	1.00	0.03	0.62	1.19	1.96	3.41
Fire Clay	≥ 28 in	Q	36	0.23	0.39	0.44	0.03	0.12	0.21	0.47	1.85
Cedar Grove/Whitesburg	≥ 28 in		6	0.24	0.77	1.15	0.02	0.07	0.34	0.79	3.02
Williamson/Amburgy	≥ 28 in		19	0.39	0.85	0.93	0.04	0.12	0.35	1.27	3.34
Campbell Creek/Upper Elkhorn No 3	≥ 28 in	T	43	0.29	0.68	0.84	0.03	0.10	0.22	1.14	2.92
Upper Elkhorn Nos 1 and 2/Powellton	≥ 28 in	U	42	0.23	0.52	0.74	0.02	0.09	0.19	0.76	3.65
Pond Creek	≥ 28 in	V	40	0.19	0.36	0.40	0.02	0.06	0.17	0 56	1.39
Matewan/Clintwood	≥ 28 in	W	53	0.29	0.59	0.72	0.03	0.12	0.26	0.84	3.30
Middle War Eagle/Eagle	≥ 28 in		7	0.23	0.61	0.69	0.02	0.08	0.18	1.13	1.65
Bens Creek/Blair	≥ 28 in		7	0.32	0.73	0.79	0.06	0.07	0.42	1.30	1.93
Lit le Eagle/Dorchester	≥ 28 in	X	51	0.25	0.40	0.38	0.01	0.14	0.33	0 50	2.12
Lower War Eagle/Hagy	≥ 28 in		5	0.31	0.50	0.43	0.06	0.12	0.59	0.60	1.13
Glenalum Tunnel/Splashdam	≥ 28 in		16	0.16	0.66	1.17	0.01	0.03	0.20	0.59	4.20
Gilbert A/Upper Banner	≥ 28 in		22	0.21	0.47	0.60	0.02	0.09	0.15	0.76	1.91
Gilbert/Lower Banner	≥ 28 in		12	0.14	0.18	0.16	0.03	0.09	0.14	0.21	0.65
Douglas/Kennedy	≥ 28 in		15	0.19	0.26	0.26	0.06	0.12	0.19	0.27	1.08
Jewell/Raven	≥ 28 in		16	0.17	0.42	0.70	0.03	0.06	0.14	0.36	2.20
Iaeger/Jawbone	≥ 28 in		14	0.10	0.13	0.10	0.02	0.06	0.10	0.14	0.36
Lower Iaeger/Tiller	≥ 28 in		6	0.17	1.21	2.17	0.03	0.04	0.05	1.27	5.43
Sewell/Lower Seaboard	≥ 28 in	CC *	10	0.19	0.30	0.30	0.04	0.08	0.18	0.46	1.00
Welch/Upper Horsepen	≥ 28 in		6	0.16	0.21	0.16	0.08	0.09	0.14	0.30	0.45
Lit le Raleigh/Middle Horsepen	≥ 28 in		5	0.18	0.20	0.08	0.08	0.19	0.19	0.23	0.30
Beckley/War Creek	≥ 28 in		10	0.20	0.39	0.43	0.04	0.09	0.18	0.72	1.12
Fire Creek/Lower Horsepen	≥ 28 in		7	0.22	0.32	0.31	0.04	0.18	0.19	0.35	0.96
Pocahontas No 6	≥ 28 in		2	0.40	0.41	0.12	0.32	na	na	na	0.49
Pocahontas No 4	≥ 28 in		4	0.09	0.11	0.07	0.04	0.05	0.11	0.16	0.17
Pocahontas No 3	≥ 28 in	EE *	18	0.13	0.17	0.11	0.02	0.08	0.18	0.26	0.38

Table 4. Coal quality statistics for coal beds with ≥ 5 samples for selenium, thickness, ash yield, sulfur, pyritic sulfur, arsenic, mercury, and manganese: a. all, b. thcik (≥ 28 inch), and c. thin (< 28 inch) coal bed samples. [Coal bed code from table 2 if N ≥ 30; * if N < 30 for a specific parameter; N = number of samples.]

Table 4b. Thick Coal Samples, ≥28 inch thick.

			Arsenic								
Coal Bed Name This Study	Thickness range	Coal bed code N≥30	N	Geometric mean ppm	Average ppm	Standard Deviation ppm	Minimum ppm	Lower Quartile ppm	Median ppm	Upper Quartile ppm	Maximum ppm
Waynesburg	≥ 28 in	A	56	16	19	12	5.8	11	15	23	74
Sewickley	≥ 28 in	B	40	5.2	6.4	4.0	0.80	3.6	5.6	7.6	19
Redstone	≥ 28 in	C	56	14	23	25	2.7	7.9	12	26	120
Pittsburgh	≥ 28 in	D	131	11	17	17	0.70	5.3	11	22	87
Lower Bakerstown	≥ 28 in		12	20	28	23	3.4	13	17	43	73
Mahoning	≥ 28 in		6	55	76	53	9.3	44	75	95	160
Upper Freeport	≥ 28 in	F	215	28	36	29	2.4	18	29	44	200
Lower Freeport	≥ 28 in	G	67	22	33	33	0.88	12	28	38	190
Upper Kittanning	≥ 28 in	H	32	23	34	29	2.4	14	27	44	130
Middle Kittanning	≥ 28 in	I	168	9.3	17	23	0.90	4.3	8.3	20	180
Lower Kittanning/No 6 block	≥ 28 in	J	140	13	21	32	0.31	7.8	14	26	320
Clarion	≥ 28 in	K	47	8.9	15	17	2.1	3.9	6.3	21	61
Brookville	≥ 28 in	L	30	10	19	33	2.3	6.7	8.1	18	180
No 5 Block	≥ 28 in	M	65	4.5	8.6	11	0.75	1.8	4.3	10	49
Lower Mercer	≥ 28 in		7	18	25	27	5.7	13	14	23	84
Stockton	≥ 28 in	N	51	4.6	10	14	0.60	1.7	3.7	14	79
Coalburg	≥ 28 in	O	67	5.7	11	20	0.60	2.2	5.8	14	150
Winifrede/Hazard	≥ 28 in	P	48	5.6	11	18	0.70	2.5	4.7	12	100
Chilton/Taylor	≥ 28 in		9	7.2	12	12	1.5	2.6	7.7	15	31
Fire Clay Rider	≥ 28 in		13	14	20	15	1.2	9.1	18	30	47
Fire Clay	≥ 28 in	Q	40	6.3	12	20	0.70	3.0	5.1	15	120
Cedar Grove/Whitesburg	≥ 28 in		16	5.9	11	14	0.75	1.7	7.8	9.8	42
Williamson/Amburgy	≥ 28 in		19	9.3	24	35	0.80	3.6	10	23	120
Campbell Creek/Upper Elkhorn No 3	≥ 28 in	T	80	6.7	13	18	0.85	2.3	7.1	14	85
Upper Elkhorn Nos 1 and 2/Powellton	≥ 28 in	U	59	7.4	16	26	0.80	3.5	7.7	16	160
Pond Creek	≥ 28 in	V	77	3.6	7.7	11	0.08	1.4	3.2	8.5	48
Matewan/Clintwood	≥ 28 in	W	54	8.3	19	32	0.90	3.4	7.2	24	160
Middle War Eagle/Eagle	≥ 28 in		12	10	28	35	1.1	2.8	9.4	49	110
Bens Creek/Blair	≥ 28 in		11	8.0	24	33	0.30	3.2	6.2	31	97
Lit le Eagle/Dorchester	≥ 28 in	X	54	12	22	25	1.1	4.1	15	29	120
Lower War Eagle/Hagy	≥ 28 in		8	19	66	98	1.0	3.5	51	59	300
Glenalum Tunnel/Splashdam	≥ 28 in		17	7.1	20	35	1.3	2.8	5.7	12	120
Gilbert A/Upper Banner	≥ 28 in		24	6.6	12	15	1.6	3.1	4.8	14	59
Gilbert/Lower Banner	≥ 28 in		17	7.8	14	17	1.6	3.8	5.0	16	57
Douglas/Kennedy	≥ 28 in		22	10	15	16	1.6	7.0	10	16	70
Jewell/Raven	≥ 28 in		19	5.8	7.5	6.5	2.0	3.7	5.0	9.2	30
Iaeger/Jawbone	≥ 28 in		17	4.7	7.8	8.0	0.45	2.4	4.0	11	30
Lower Iaeger/Tiller	≥ 28 in		7	6.0	13	20	1.7	2.3	4.7	12	56
Sewell/Lower Seaboard	≥ 28 in	CC	41	5.1	11	15	0.40	2.6	4.2	9.9	56
Welch/Upper Horsepen	≥ 28 in		10	9.1	16	20	2.0	4.2	9.4	16	64
Lit le Raleigh/Middle Horsepen	≥ 28 in		5	6.1	7.0	4.2	2.9	5.0	5.8	7.3	14
Beckley/War Creek	≥ 28 in		18	9.3	19	22	0.25	4.3	13	25	89
Fire Creek/Lower Horsepen	≥ 28 in		14	9.8	14	12	2.2	5.3	12	16	40
Pocahontas No 6	≥ 28 in		9	9.3	13	8.1	1.4	6.3	12	19	25
Pocahontas No 4	≥ 28 in		13	6.6	12	13	1.2	3.5	5.0	16	39
Pocahontas No 3	≥ 28 in	EE	43	5.4	10	14	0.30	2.3	5.2	12	73

Table 4. Coal quality statistics for coal beds with ≥ 5 samples for selenium, thickness, ash yield, sulfur, pyritic sulfur, arsenic, mercury, and manganese: a. all, b. thcik (≥ 28 inch), and c. thin (< 28 inch) coal bed samples. [Coal bed code from table 2 if N ≥ 30; * if N < 30 for a specific parameter; N = number of samples.]

Table 4b. Thick Coal Samples, ≥28 inch thick.

			Mercury								
Coal Bed Name This Study	Thickness range	Coal bed code N≥30	N	Geometric mean ppm	Average ppm	Standard Deviation ppm	Minimum ppm	Lower Quartile ppm	Median ppm	Upper Quartile ppm	Maximum ppm
Waynesburg	≥ 28 in	A	56	0.15	0.16	0.074	0.060	0.13	0.15	0.19	0.53
Sewickley	≥ 28 in	B	40	0.099	0.12	0.067	0.021	0.079	0.098	0.15	0.29
Redstone	≥ 28 in	C	56	0.17	0.23	0.18	0.007	0.10	0.18	0 31	0.93
Pittsburgh	≥ 28 in	D	132	0.13	0.17	0.15	0.003	0.082	0.14	0 21	1.0
Lower Bakerstown	≥ 28 in		12	0.18	0.21	0.16	0.080	0.12	0.15	0 23	0.57
Mahoning	≥ 28 in		6	0.30	0.31	0.065	0.26	0.27	0.28	0.31	0.43
Upper Freeport	≥ 28 in	F	215	0.24	0.31	0.20	0.003	0.20	0.28	0 37	1.7
Lower Freeport	≥ 28 in	G	67	0.23	0.33	0.26	0.003	0.20	0.30	0.43	1.6
Upper Kittanning	≥ 28 in	H	32	0.25	0.37	0.30	0.030	0.11	0.35	0 52	1.4
Middle Kittanning	≥ 28 in	I	168	0.16	0.22	0.19	0.003	0.12	0.18	0 27	1.6
Lower Kittanning/No 6 block	≥ 28 in	J	141	0.14	0.23	0.22	0.003	0.10	0.18	0.32	1.6
Clarion	≥ 28 in	K	47	0.14	0.18	0.15	0.022	0.079	0.13	0 24	0.76
Brookville	≥ 28 in	L	30	0.19	0.25	0.26	0.048	0.12	0.21	0 29	1.5
No 5 Block	≥ 28 in	M	65	0.13	0.17	0.12	0.024	0.083	0.14	0 25	0.52
Lower Mercer	≥ 28 in		7	0.24	0.29	0.15	0.040	0.23	0.26	0.40	0.48
Stockton	≥ 28 in	N	51	0.10	0.15	0.14	0.007	0.059	0.11	0.19	0.62
Coalburg	≥ 28 in	O	67	0.089	0.12	0.11	0.007	0.060	0.082	0.16	0.52
Winifrede/Hazard	≥ 28 in	P	48	0.084	0.14	0.18	0.007	0.042	0.078	0.17	1.0
Chilton/Taylor	≥ 28 in		9	0.14	0.17	0.085	0.043	0.12	0.16	0.18	0.30
Fire Clay Rider	≥ 28 in		13	0.16	0.18	0.13	0.083	0.12	0.12	0.18	0.58
Fire Clay	≥ 28 in	Q	40	0.085	0.13	0.10	0.007	0.050	0.087	0.19	0.43
Cedar Grove/Whitesburg	≥ 28 in		16	0.051	0.089	0.086	0.003	0.030	0.050	0.13	0.26
Williamson/Amburgy	≥ 28 in		19	0.081	0.13	0.10	0.010	0.039	0.085	0.22	0.35
Campbell Creek/Upper Elkhorn No 3	≥ 28 in	T	80	0.085	0.12	0.096	0.007	0.055	0.091	0.15	0.52
Upper Elkhorn Nos 1 and 2/Powellton	≥ 28 in	U	59	0.10	0.14	0.13	0.014	0.060	0.095	0.18	0.81
Pond Creek	≥ 28 in	V	78	0.068	0.097	0.090	0.003	0.044	0.070	0.12	0.46
Matewan/Clintwood	≥ 28 in	W	54	0.058	0.10	0.088	0.003	0.035	0.083	0.14	0.36
Middle War Eagle/Eagle	≥ 28 in		12	0.082	0.13	0.12	0.007	0.035	0.14	0.18	0.45
Bens Creek/Blair	≥ 28 in		11	0.045	0.088	0.10	0.007	0.025	0.039	0.11	0.28
Lit le Eagle/Dorchester	≥ 28 in	X	54	0.095	0.13	0.10	0.010	0.055	0.087	0 20	0.40
Lower War Eagle/Hagy	≥ 28 in		8	0.11	0.18	0.11	0.003	0.090	0.20	0.28	0.29
Glenalum Tunnel/Splashdam	≥ 28 in		17	0.12	0.17	0.14	0.045	0.065	0.12	0 25	0.55
Gilbert A/Upper Banner	≥ 28 in		24	0.071	0.11	0.12	0.003	0.050	0.075	0.13	0.51
Gilbert/Lower Banner	≥ 28 in		17	0.046	0.092	0.10	0.003	0.021	0.050	0.082	0.35
Douglas/Kennedy	≥ 28 in		22	0.067	0.11	0.11	0.007	0.050	0.068	0.14	0.50
Jewell/Raven	≥ 28 in		19	0.074	0.10	0.091	0.015	0.050	0.060	0.13	0.37
Iaeger/Jawbone	≥ 28 in		17	0.077	0.12	0.10	0.007	0.050	0.10	0.17	0.41
Lower Iaeger/Tiller	≥ 28 in		7	0.051	0.19	0.36	0.007	0.021	0.052	0.11	1.0
Sewell/Lower Seaboard	≥ 28 in	CC	41	0.12	0.21	0.24	0.017	0.059	0.13	0 25	0.97
Welch/Upper Horsepen	≥ 28 in		10	0.073	0.093	0.075	0.030	0.053	0.069	0.082	0.25
Lit le Raleigh/Middle Horsepen	≥ 28 in		5	0.13	0.14	0.082	0.068	0.082	0.12	0.17	0.27
Beckley/War Creek	≥ 28 in		18	0.067	0.18	0.41	0.007	0.046	0.078	0.11	1.8
Fire Creek/Lower Horsepen	≥ 28 in		14	0.074	0.090	0.058	0.025	0.042	0.070	0.13	0.19
Pocahontas No 6	≥ 28 in		10	0.084	0.21	0.26	0.015	0.022	0.074	0.36	0.66
Pocahontas No 4	≥ 28 in		13	0.042	0.054	0.031	0.007	0.039	0.050	0.080	0.095
Pocahontas No 3	≥ 28 in	EE	43	0.056	0.081	0.079	0.007	0.046	0.065	0.10	0.47

Table 4. Coal quality statistics for coal beds with ≥ 5 samples for selenium, thickness, ash yield, sulfur, pyritic sulfur, arsenic, mercury, and manganese: a. all, b. thcik (≥ 28 inch), and c. thin (< 28 inch) coal bed samples. [Coal bed code from table 2 if N ≥ 30; * if N < 30 for a specific parameter; N = number of samples.]

Table 4b. Thick Coal Samples, ≥28 inch thick.

			Manganese								
Coal Bed Name This Study	Thickness range	Coal bed code N≥30	N	Geometric mean ppm	Average ppm	Standard Deviation ppm	Minimum ppm	Lower Quartile ppm	Median ppm	Upper Quartile ppm	Maximum ppm
Waynesburg	≥ 28 in	A	56	27	32	28	11	20	25	37	180
Sewickley	≥ 28 in	B	40	18	27	42	6.4	11	15	23	260
Redstone	≥ 28 in	C	56	25	35	31	5.0	17	24	36	140
Pittsburgh	≥ 28 in	D	132	21	29	33	1.4	14	20	36	300
Lower Bakerstown	≥ 28 in		12	18	26	25	6.6	12	15	25	75
Mahoning	≥ 28 in		6	13	16	10	4.9	9.1	14	23	30
Upper Freeport	≥ 28 in	F	215	16	22	20	2.5	10	16	27	140
Lower Freeport	≥ 28 in	G	67	14	31	87	0.92	8.2	13	21	690
Upper Kittanning	≥ 28 in	H	32	14	22	31	3.3	8.3	12	24	170
Middle Kittanning	≥ 28 in	I	167	20	27	32	3.7	12	19	32	310
Lower Kittanning/No 6 block	≥ 28 in	J	141	16	26	48	1.6	9.8	14	26	430
Clarion	≥ 28 in	K	47	20	27	32	3.6	13	21	28	220
Brookville	≥ 28 in	L	30	15	19	12	2.3	10	14	25	52
No 5 Block	≥ 28 in	M	65	8.1	15	27	1.4	4.1	7.5	12	200
Lower Mercer	≥ 28 in		7	11	14	11	4.1	5.6	12	19	35
Stockton	≥ 28 in	N	51	6.8	8.7	5.9	1.2	5.3	6.9	11	25
Coalburg	≥ 28 in	O	67	8.7	11	8.2	1.1	5.7	9.1	13	54
Winifrede/Hazard	≥ 28 in	P	48	11	15	17	1.9	6.2	9.5	16	83
Chilton/Taylor	≥ 28 in		9	12	20	27	3.0	8.8	9.6	13	89
Fire Clay Rider	≥ 28 in		13	16	20	15	3.6	11	15	24	56
Fire Clay	≥ 28 in	Q	40	9.2	14	18	1.9	5.0	8.2	16	86
Cedar Grove/Whitesburg	≥ 28 in		16	13	46	130	2.6	6.0	9.1	19	530
Williamson/Amburgy	≥ 28 in		19	13	27	55	2.8	7.5	11	19	250
Campbell Creek/Upper Elkhorn No 3	≥ 28 in	T	80	9.4	13	12	1.2	5.5	8.8	16	63
Upper Elkhorn Nos 1 and 2/Powellton	≥ 28 in	U	59	8.9	14	17	0.96	4.6	9.2	17	110
Pond Creek	≥ 28 in	V	78	13	29	67	2.2	6.6	12	23	540
Matewan/Clintwood	≥ 28 in	W	54	7.9	14	23	1.1	3.9	7.3	14	150
Middle War Eagle/Eagle	≥ 28 in		12	9.0	21	32	1.7	3.7	7.7	16	100
Bens Creek/Blair	≥ 28 in		11	7.0	15	24	3.0	3.8	4.9	5.7	68
Lit le Eagle/Dorchester	≥ 28 in	X	54	10	21	35	1.1	4.7	8.9	16	170
Lower War Eagle/Hagy	≥ 28 in		8	13	27	39	2.4	5.6	17	25	120
Glenalum Tunnel/Splashdam	≥ 28 in		17	12	20	23	2.1	4.6	11	29	84
Gilbert A/Upper Banner	≥ 28 in		24	13	17	12	3.9	7.3	15	22	53
Gilbert/Lower Banner	≥ 28 in		17	23	29	18	4.5	16	23	50	60
Douglas/Kennedy	≥ 28 in		22	20	35	45	2.9	11	24	32	190
Jewell/Raven	≥ 28 in		19	24	29	18	7.8	16	23	36	74
Iaeger/Jawbone	≥ 28 in		17	18	35	43	1.2	8.7	15	37	160
Lower Iaeger/Tiller	≥ 28 in		7	21	24	13	10	16	17	33	45
Sewell/Lower Seaboard	≥ 28 in	CC	41	9.3	17	21	1.5	4.4	8.2	21	100
Welch/Upper Horsepen	≥ 28 in		10	10	12	7.3	5.2	6.4	9.7	16	27
Lit le Raleigh/Middle Horsepen	≥ 28 in		4	39	91	130	8.3	16	38	110	280
Beckley/War Creek	≥ 28 in		18	9.6	30	70	1.4	4.8	6.3	22	300
Fire Creek/Lower Horsepen	≥ 28 in		14	6.6	8.1	5.1	2.7	3.5	7.5	12	19
Pocahontas No 6	≥ 28 in		10	8.4	22	42	1.5	2.8	11	15	140
Pocahontas No 4	≥ 28 in		13	18	37	68	3.4	8.5	21	30	260
Pocahontas No 3	≥ 28 in	EE	43	17	25	31	1.7	9.4	20	27	200

Table 4. Coal quality statistics for coal beds with ≥ 5 samples for selenium, thickness, ash yield, sulfur, pyritic sulfur, arsenic, mercury, and manganese: a. all, b. hcik (≥ 28 inch), and c. thin (< 28 inch) coal bed samples. [Coal bed code from table 2 if N ≥ 30; * if N < 30 for a specific parameter; N = number of samples.]

Table 4c. Thin Coal Smples, <28 inch thick.

			Selenium								
Coal bed name, this study	Thickness range	Coal bed code N≥30	N	Geometric mean ppm	Average ppm	Standard Deviation ppm	Minimum ppm	Lower Quartile ppm	Median ppm	Upper Quar ile ppm	Maximum ppm
Redstone	< 28 in		18	2.3	2.6	1.5	1.1	1.7	2.3	3.0	7.0
Pittsburgh Roof	< 28 in		8	2.1	2.3	1.1	1.4	1.5	1.8	2.7	4.4
Pittsburgh	< 28 in		5	1.5	1.7	1.0	0.70	1.3	1.4	1.5	3.4
Harlem	< 28 in		8	1.1	1.2	0.32	0.68	0.95	1.3	1.4	1.6
Lower Bakerstown	< 28 in		18	2.9	3.3	2.2	1.5	2.1	2.8	3.8	11
Brush Creek	< 28 in		8	2.7	3.1	1.7	1.2	2.0	2.6	3.6	6.4
Mahoning	< 28 in		14	1.8	2.0	0.91	1.2	1.4	1.6	2.3	4.7
Upper Freeport	< 28 in	F	62	2.6	3.2	2.6	0.43	1.8	2.3	3.7	14
Lower Freeport	< 28 in	G	36	3.0	3.4	1.8	0.90	2.2	3.3	4.3	9.1
Upper Kittanning	< 28 in	H	35	3.3	3.9	2.6	1.3	2.3	2.9	4.7	11
Middle Kittanning Rider	< 28 in		8	4.5	5.2	2.3	1.0	3.6	5.9	6.6	8.1
Middle Kittanning	< 28 in	I	75	3.1	3.6	2.3	0.99	2.4	3.0	3.9	14
Strasburg	< 28 in		10	3.8	4.1	1.5	1.5	3.7	4.0	4.1	7.7
Lower Kittanning Rider	< 28 in		6	2.9	3.1	1.2	1.6	2.3	2.9	3.8	4.8
Lower Kittanning/No 6 block	< 28 in	J	57	3.4	4.1	2.7	0.98	2.3	3.2	4.5	14
Clarion	< 28 in		27	4.9	5.6	2.5	1.2	3.3	5.4	8.0	9.5
Brookville	< 28 in	L	43	4.6	5.4	3.6	1.2	3.3	4.4	6.4	21
No 5 Block	< 28 in		28	4.7	6.4	4.0	0.10	3.6	5.9	8.5	18
Upper Mercer	< 28 in		6	6.3	6.8	3.0	3.1	5.5	6.6	7.2	12
Lower Mercer	< 28 in		17	5.6	6.6	3.0	0.84	5.6	6.5	8.2	13
Quakertown	< 28 in		7	5.5	6.9	4.2	1.2	4.1	5.7	11	12
Stockton	< 28 in		11	4.8	5.2	2.2	2.4	3.9	4.6	6.3	8.7
Coalburg	< 28 in	O	76	4.4	4.9	2.2	1.2	3.3	4.7	5.7	12
Winifrede/Hazard	< 28 in	P	31	4.0	4.5	2.0	0.50	3.2	3.9	5.8	9.2
Lower Winifrede/Hazard	< 28 in		6	2.2	3.7	1.9	0.07	3.8	4.0	4.3	5.9
Chilton/Taylor	< 28 in		6	4.2	4.8	2.7	2.0	3.2	3.6	6.6	8.7
Fire Clay Rider	< 28 in		16	4.1	4.9	3.3	1.7	2.7	4.1	4.9	13
Fire Clay	< 28 in	Q	30	3.8	4.2	2.0	1.7	2.6	3.8	5.5	9.0
Cedar Grove/Whitesburg	< 28 in		23	4.0	4.4	2.1	1.2	2.8	4.3	5.1	9.4
Williamson/Amburgy	< 28 in		26	2.9	3.2	1.6	1.0	2.1	2.8	4.3	7.4
Campbell Creek/Upper Elkhorn No 3	< 28 in	T	63	2.9	3.5	2.0	0.07	2.0	2.9	4.3	9.3
Upper Elkhorn Nos 1 and 2/Powellton	< 28 in	U	55	2.7	3.2	2.5	0.64	1.9	2.6	3.4	16
Pond Creek	< 28 in	V	43	2.7	2.9	1.2	1.2	2.1	3.0	3.4	6.6
Matewan/Clintwood	< 28 in	W	72	2.2	2.6	1.6	0.62	1.5	2.2	3.0	8.0
Middle War Eagle/Eagle	< 28 in		11	2.7	3.4	2.7	1.1	2.0	2.4	3.5	9.3
Lit le Eagle/Dorchester	< 28 in	X	34	1.9	2.2	1.3	0.63	1.4	1.8	2.7	7.0
Lower War Eagle/Hagy	< 28 in		5	3.1	3.1	0.65	2.0	3.2	3.3	3.5	3.6
Glenalum Tunnel/Splashdam	< 28 in		18	2.2	2.3	0.66	1.4	1.7	2.3	2.8	3.8
Gilbert A/Upper Banner	< 28 in		22	2.4	2.7	1.4	1.2	1.6	2.3	3.3	6.7
Gilbert/Lower Banner	< 28 in		6	2.8	3.0	1.2	1.4	2.3	2.8	3.9	4.7
Douglas/Kennedy	< 28 in		15	2.0	2.2	1.1	0.90	1.5	1.8	2.7	4.6
Jewell/Raven	< 28 in		5	2.4	2.9	2.0	0.88	1.7	2.4	3.7	5.9
Iaeger/Jawbone	< 28 in		17	2.3	2.9	2.4	0.70	1.7	2.5	3.2	11
Lower Iaeger/Tiller	< 28 in		10	2.4	2.6	1.1	1.5	2.0	2.4	2.8	5.4
Sewell/Lower Seaboard	< 28 in		20	2.1	2.7	2.1	0.79	1.1	1.9	4.1	7.0
Welch/Upper Horsepen	< 28 in		5	1.8	1.9	0.56	1.0	1.8	1.8	2.2	2.5
Beckley/War Creek	< 28 in		12	1.8	2.2	1.8	0.80	1.2	1.6	2.3	7.0
Fire Creek/Lower Horsepen	< 28 in		8	1.5	1.8	1.1	0.67	0.96	1.9	2.0	4.0
Pocahontas No 7	< 28 in		4	1.7	2.0	1.4	1.0	1.2	1.6	2.4	4.0
Pocahontas No 3	< 28 in		10	3.1	3.5	1.7	1.9	2.1	2.6	5.2	6.0

Table 4. Coal quality statistics for coal beds with ≥ 5 samples for selenium, thickness, ash yield, sulfur, pyritic sulfur, arsenic, mercury, and manganese: a. all, b. hcik (≥ 28 inch), and c. thin (< 28 inch) coal bed samples. [Coal bed code from table 2 if N ≥ 30; * if N < 30 for a specific parameter; N = number of samples.]

Table 4c. Thin Coal Smples, <28 inch thick.

			Thickness								
Coal Bed Name This Study	Thickness range	Coal bed code N≥30	N	Geometric mean in	Average in	Standard Deviation in	Minimum in	Lower Quartile in	Median in	Upper Quar ile in	Maximum in
Redstone	< 28 in		18	19.0	19.3	3.5	12.0	17.0	18.0	21.6	25.3
Pittsburgh Roof	< 28 in		8	20.3	21.1	5.8	10.2	18.4	23.2	24.2	27.6
Pittsburgh	< 28 in		5	20.6	22.1	7.5	9.0	23.8	24.5	25.8	27.5
Harlem	< 28 in		8	23.0	23.3	4.0	17.5	19.6	25.4	26.3	27.0
Lower Bakerstown	< 28 in		18	22.8	23.2	4.1	13.2	20.9	24.3	26.4	27.6
Brush Creek	< 28 in		8	14.5	15.6	5.8	7.8	12.9	14.7	20.0	24.6
Mahoning	< 28 in		14	17.6	18.8	5.7	4.8	16.1	19.1	22.4	27.0
Upper Freeport	< 28 in	F	63	16.6	18.3	6.6	2.0	13.0	19.0	24.0	27.0
Lower Freeport	< 28 in	G	36	18.1	19.3	6.3	5.4	14.9	19.5	25.6	27.6
Upper Kittanning	< 28 in	H	35	18.3	19.3	5.6	6.6	15.3	20.4	23.7	27.6
Middle Kittanning Rider	< 28 in		8	12.6	15.2	8.3	3.0	11.4	15.0	19.5	27.6
Middle Kittanning	< 28 in	I	75	18.7	20.1	6.1	2.5	16.7	21.3	25.2	27.8
Strasburg	< 28 in		10	17.8	18.5	5.5	12.8	14.1	16.3	22.2	27.9
Lower Kittanning Rider	< 28 in		6	11.0	11.6	4.2	6.6	9.8	11.1	12.0	19.2
Lower Kittanning/No 6 block	< 28 in	J	57	21.6	22.1	4.3	9.8	20.4	23.0	25.2	27.8
Clarion	< 28 in		27	16.7	17.6	5.4	9.0	13.8	18.0	20.6	26.4
Brookville	< 28 in	L	43	17.3	18.0	4.9	6.6	15.6	18.3	21.2	27.6
No 5 Block	< 28 in		28	16.4	17.5	5.9	7.4	12.8	17.8	21.7	27.6
Upper Mercer	< 28 in		6	17.8	18.6	5.9	11.4	14.1	18.3	23.0	26.4
Lower Mercer	< 28 in		17	20.4	21.1	5.2	10.8	18.0	24.0	24.6	27.0
Quakertown	< 28 in		7	22.0	22.2	2.8	18.5	19.8	22.8	24.3	26.0
Stockton	< 28 in		11	11.3	12.3	5.3	5.9	7.9	12.5	15.2	23.6
Coalburg	< 28 in	O	76	16.1	17.3	5.9	4.3	13.3	18.0	21.1	27.8
Winifrede/Hazard	< 28 in	P	31	15.6	17.0	6.4	4.3	11.4	19.0	22.0	26.8
Lower Winifrede/Hazard	< 28 in		6	15.9	17.3	6.8	6.7	14.2	17.8	21.3	26.0
Chilton/Taylor	< 28 in		6	10.5	12.0	6.9	5.5	6.6	10.9	15.0	23.5
Fire Clay Rider	< 28 in		16	12.4	14.4	7.8	6.0	7.6	13.2	18.8	27.2
Fire Clay	< 28 in	Q	30	16.1	17.5	6.6	6.0	12.2	18.5	22.6	27.6
Cedar Grove/Whitesburg	< 28 in		23	14.5	16.5	7.2	3.1	11.7	16.1	22.6	26.8
Williamson/Amburgy	< 28 in		26	15.0	16.1	6.0	5.5	11.2	15.4	21.1	27.2
Campbell Creek/Upper Elkhorn No 3	< 28 in	T	63	18.0	19.0	5.8	7.0	15.2	20.0	23.2	27.6
Upper Elkhorn Nos 1 and 2/Powellton	< 28 in	U	55	15.1	16.2	5.7	7.1	12.3	15.4	20.7	27.2
Pond Creek	< 28 in	V	43	17.1	18.8	6.7	4.0	13.9	20.0	24.2	27.8
Matewan/Clintwood	< 28 in	W	72	16.9	17.8	5.6	7.7	13.2	18.0	22.8	27.6
Middle War Eagle/Eagle	< 28 in		11	19.0	19.5	4.8	12.6	16.7	18.5	22.6	28.0
Lit le Eagle/Dorchester	< 28 in	X	34	18.9	19.7	5.2	10.2	17.0	20.8	23.9	27.0
Lower War Eagle/Hagy	< 28 in		5	17.4	19.6	8.2	6.0	19.2	22.2	22.8	27.6
Glenalum Tunnel/Splashdam	< 28 in		18	18.6	19.4	5.8	11.0	14.9	17.3	25.4	27.6
Gilbert A/Upper Banner	< 28 in		22	15.8	17.2	6.6	6.3	12.3	17.0	23.5	27.0
Gilbert/Lower Banner	< 28 in		6	18.7	19.3	4.9	12.8	15.6	19.9	22.4	25.8
Douglas/Kennedy	< 28 in		15	23.9	24.1	3.1	18.0	22.0	24.0	27.0	27.6
Jewell/Raven	< 28 in		5	11.2	12.5	6.4	6.0	7.5	10.8	17.0	21.0
Iaeger/Jawbone	< 28 in		17	19.1	20.6	7.1	8.4	15.1	24.5	26.6	27.6
Lower Iaeger/Tiller	< 28 in		10	10.7	11.6	5.1	5.4	8.3	10.5	13.2	21.6
Sewell/Lower Seaboard	< 28 in		20	19.7	20.1	4.0	12.5	18.0	20.5	23.5	25.5
Welch/Upper Horsepen	< 28 in		5	17.8	18.6	5.7	11.0	16.0	18.0	22.0	26.0
Beckley/War Creek	< 28 in		12	17.3	18.7	7.0	8.0	12.8	19.0	24.5	27.8
Fire Creek/Lower Horsepen	< 28 in		8	19.5	19.9	4.3	14.0	17.8	19.0	21.3	26.9
Pocahontas No 7	< 28 in		5	15.8	16.3	4.6	10.5	14.0	17.0	17.2	23.0
Pocahontas No 3	< 28 in		10	18.3	19.2	6.0	11.1	13.3	20.8	24.3	27.0

Table 4. Coal quality statistics for coal beds with ≥ 5 samples for selenium, thickness, ash yield, sulfur, pyritic sulfur, arsenic, mercury, and manganese: a. all, b. hcik (≥ 28 inch), and c. thin (< 28 inch) coal bed samples. [Coal bed code from table 2 if N ≥ 30; * if N < 30 for a specific parameter; N = number of samples.]

Table 4c. Thin Coal Smples, <28 inch thick.

			Ash Yield								
Coal Bed Name This Study	Thickness range	Coal bed code N≥30	N	Geometric mean percent	Average percent	Standard Deviation percent	Minimum percent	Lower Quartile percent	Median percent	Upper Quar ile percent	Maximum percent
Redstone	< 28 in		18	12.50	13.18	4.97	9.10	10.08	10.95	14.09	27.20
Pittsburgh Roof	< 28 in		8	15.94	16.29	3.65	11.90	13.25	16.22	18.04	22.30
Pittsburgh	< 28 in		5	10.55	10.72	2.24	8.30	10.20	10.20	10.49	14.40
Harlem	< 28 in		8	10.12	10.34	2.20	7.30	9.19	10.25	11.95	13.02
Lower Bakerstown	< 28 in		18	11.25	12.42	6.22	5.66	8.98	10.39	14.04	29.30
Brush Creek	< 28 in		8	11.64	12.55	5.78	7.17	8.78	11.28	13.76	25.50
Mahoning	< 28 in		13	11.02	11.63	4.30	7.00	8.90	9.77	13.05	20.23
Upper Freeport	< 28 in	F	49	12.11	13.37	6.03	5.50	8.20	12.10	16.36	29.31
Lower Freeport	< 28 in	G	36	13.71	14.72	6.09	8.43	9.71	12.02	17.79	31.20
Upper Kittanning	< 28 in	H	35	13.43	14.27	4.92	4.54	11.72	13.44	17.18	30.21
Middle Kittanning Rider	< 28 in		8	9.03	10.13	5.68	4.50	7.50	8.80	10.65	22.70
Middle Kittanning	< 28 in	I	74	9.47	10.98	5.91	1.70	7.04	10.21	13.58	28.66
Strasburg	< 28 in		10	11.33	11.78	3.31	6.30	9.35	11.90	13.65	16.80
Lower Kittanning Rider	< 28 in		6	11.20	13.12	8.22	5.70	6.80	11.78	15.59	27.44
Lower Kittanning/No 6 block	< 28 in	J	55	11.30	12.14	4.70	5.00	8.79	11.07	14.15	23.70
Clarion	< 28 in		27	12.28	13.55	5.55	4.20	8.80	14.70	17.04	25.57
Brookville	< 28 in	L	43	12.14	13.24	5.51	5.30	8.75	13.30	16.75	27.75
No 5 Block	< 28 in		27	11.42	12.94	6.94	4.20	7.65	11.58	15.39	31.50
Upper Mercer	< 28 in		6	18.82	18.99	2.72	15.22	17.47	19.08	20.18	23.07
Lower Mercer	< 28 in		16	15.31	16.40	5.41	4.80	13.54	16.76	20.85	24.34
Quakertown	< 28 in		7	10.50	11.60	4.44	3.30	10.11	12.81	13.81	17.23
Stockton	< 28 in		11	12.19	12.97	5.79	8.11	10.72	11.80	12.99	29.60
Coalburg	< 28 in	O	75	8.23	9.56	5.43	2.70	5.79	8.78	12.35	29.10
Winifrede/Hazard	< 28 in	P	31	7.74	9.90	6.85	2.00	3.61	9.30	13.30	26.40
Lower Winifrede/Hazard	< 28 in		6	7.98	8.99	4.43	3.50	5.70	9.06	11.73	15.10
Chilton/Taylor	< 28 in		6	12.13	14.09	8.76	5.70	8.32	12.58	15.75	30.00
Fire Clay Rider	< 28 in		10	11.13	13.72	9.57	3.65	7.99	10.42	16.31	32.90
Fire Clay	< 28 in	Q *	26	8.96	10.52	5.94	2.50	6.21	10.75	12.88	24.80
Cedar Grove/Whitesburg	< 28 in		22	9.33	10.09	3.86	3.32	7.63	9.83	12.83	18.09
Williamson/Amburgy	< 28 in		25	7.63	8.64	4.73	2.76	5.94	7.80	10.64	24.40
Campbell Creek/Upper Elkhorn No 3	< 28 in	T	63	5.54	6.92	4.36	0.90	3.41	5.40	9.44	19.10
Upper Elkhorn Nos 1 and 2/Powellton	< 28 in	U	52	5.54	6.62	4.32	1.60	4.24	5.85	8.09	22.37
Pond Creek	< 28 in	V	43	5.11	6.31	4.14	1.22	3.29	5.00	8.80	16.40
Matewan/Clintwood	< 28 in	W	71	5.96	6.85	3.63	1.73	3.85	6.00	9.01	19.70
Middle War Eagle/Eagle	< 28 in		11	5.46	6.18	3.23	1.66	4.19	6.30	6.55	14.01
Lit le Eagle/Dorchester	< 28 in	X	34	5.69	6.84	4.20	2.20	3.73	5.60	10.19	17.00
Lower War Eagle/Hagy	< 28 in		4	9.53	10.05	3.53	5.66	8.14	10.39	12.30	13.78
Glenalum Tunnel/Splashdam	< 28 in		18	4.11	5.05	4.07	1.74	2.53	4.11	6.05	19.10
Gilbert A/Upper Banner	< 28 in		19	8.01	8.90	4.41	3.65	6.10	7.05	11.46	20.67
Gilbert/Lower Banner	< 28 in		6	5.88	6.35	2.79	3.40	4.57	6.28	6.69	11.30
Douglas/Kennedy	< 28 in		14	6.22	8.03	7.46	2.75	4.38	4.69	7.80	29.55
Jewell/Raven	< 28 in		3	7.70	8.71	5.55	5.13	na	5.90	na	15.10
Iaeger/Jawbone	< 28 in		17	7.65	10.34	7.61	2.00	3.80	9.80	15.40	29.30
Lower Iaeger/Tiller	< 28 in		10	9.02	10.35	5.27	2.90	7.40	9.70	12.88	19.40
Sewell/Lower Seaboard	< 28 in		15	10.69	11.90	5.34	3.10	9.00	11.49	13.40	21.60
Welch/Upper Horsepen	< 28 in		2	7.28	7.32	0.97	6.63	na	na	na	8.00
Beckley/War Creek	< 28 in		11	6.85	9.13	8.00	2.00	4.25	7.30	10.15	29.30
Fire Creek/Lower Horsepen	< 28 in		8	5.19	5.82	2.74	2.60	3.07	6.34	7.65	10.00
Pocahontas No 7	< 28 in		5	11.09	13.48	9.72	4.81	8.32	8.92	16.10	29.25
Pocahontas No 3	< 28 in		8	7.97	9.49	7.07	3.80	6.23	7.15	10.08	26.00

Table 4. Coal quality statistics for coal beds with ≥ 5 samples for selenium, thickness, ash yield, sulfur, pyritic sulfur, arsenic, mercury, and manganese: a. all, b. hcik (≥ 28 inch), and c. thin (< 28 inch) coal bed samples. [Coal bed code from table 2 if N ≥ 30; * if N < 30 for a specific parameter; N = number of samples.]

Table 4c. Thin Coal Smples, <28 inch thick.

			Sulfur								
Coal Bed Name This Study	Thickness range	Coal bed code N≥30	N	Geometric mean percent	Average percent	Standard Deviation percent	Minimum percent	Lower Quartile percent	Median percent	Upper Quar ile percent	Maximum percent
Redstone	< 28 in		18	2.81	3.08	1.22	0.80	2.24	3.19	3.55	5.90
Pittsburgh Roof	< 28 in		8	2.52	3.22	2.08	0.60	1.58	3.10	4.71	6.50
Pittsburgh	< 28 in		5	3.26	3.35	0.91	2.56	2.60	3.40	3.40	4.80
Harlem	< 28 in		8	1.40	1.75	1.18	0.50	0.78	1.38	2.75	3.66
Lower Bakerstown	< 28 in		18	2.61	2.92	1.23	0.77	2.39	3.00	3.63	5.41
Brush Creek	< 28 in		8	2.59	2.73	1.04	1.84	2.08	2.32	3.01	5.00
Mahoning	< 28 in		13	2.04	2.31	1.25	0.90	1.43	1.84	3.22	5.10
Upper Freeport	< 28 in	F	60	2.36	2.80	1.73	0.80	1.44	2.44	3.56	8.00
Lower Freeport	< 28 in	G	36	2.81	3.30	1.73	0.60	1.97	3.03	4.53	7.22
Upper Kittanning	< 28 in	H	35	1.53	1.90	1.25	0.47	0.87	1.59	2.78	5.72
Middle Kittanning Rider	< 28 in		8	1.25	1.79	1.47	0.50	0.50	1.55	2.63	4.40
Middle Kittanning	< 28 in	I	74	2.17	2.62	1.65	0.50	1.42	2.06	3.49	8.11
Strasburg	< 28 in		10	4.17	4.81	2.07	1.10	4.25	5.31	6.22	7.20
Lower Kittanning Rider	< 28 in		6	1.25	1.41	0.85	0.82	0.90	0.96	1.68	2.93
Lower Kittanning/No 6 block	< 28 in	J	55	3.08	3.59	1.91	0.43	2.39	3.30	4.79	10.40
Clarion	< 28 in		27	2.77	3.24	1.52	0.50	2.30	3.30	3.95	6.40
Brookville	< 28 in	L	43	2.25	2.62	1.57	0.70	1.67	2.40	2.92	7.85
No 5 Block	< 28 in		27	1.34	1.65	1.11	0.50	0.80	1.02	2.15	4.30
Upper Mercer	< 28 in		6	3.82	4.02	1.35	2.19	3.18	4.07	4.72	5.96
Lower Mercer	< 28 in		16	2.03	2.45	1.37	0.51	1.49	1.99	3.74	4.69
Quakertown	< 28 in		7	1.99	2.70	2.37	0.80	1.09	1.71	3.49	7.21
Stockton	< 28 in		11	1.53	2.06	1.64	0.50	0.75	1.60	3.26	5.50
Coalburg	< 28 in	O	75	1.19	1.46	1.05	0.50	0.73	1.00	1.90	4.70
Winifrede/Hazard	< 28 in	P	31	0.96	1.15	0.89	0.41	0.67	0.80	1.27	4.70
Lower Winifrede/Hazard	< 28 in		6	0.77	0.80	0.26	0.60	0.68	0.70	0.81	1.30
Chilton/Taylor	< 28 in		6	2.03	2.54	1.60	0.70	1.25	2.77	3.21	4.90
Fire Clay Rider	< 28 in		10	2.29	2.79	1.68	0.80	1.30	2.70	3.93	5.20
Fire Clay	< 28 in	Q *	26	1.10	1.43	1.31	0.56	0.68	0.81	1.36	5.95
Cedar Grove/Whitesburg	< 28 in		22	1.73	2.09	1.25	0.70	0.93	1.88	3.06	4.30
Williamson/Amburgy	< 28 in		25	1.66	2.02	1.38	0.60	0.90	1.71	2.40	5.80
Campbell Creek/Upper Elkhorn No 3	< 28 in	T	63	1.16	1.44	1.09	0.50	0.70	0.90	1.87	5.10
Upper Elkhorn Nos 1 and 2/Powellton	< 28 in	U	52	1.56	2.02	1.53	0.50	0.82	1.31	2.78	6.60
Pond Creek	< 28 in	V	43	1.43	1.84	1.38	0.50	0.80	1.20	2.59	6.30
Matewan/Clintwood	< 28 in	W	71	1.42	1.85	1.47	0.54	0.80	1.12	2.60	6.61
Middle War Eagle/Eagle	< 28 in		11	1.55	1.76	0.90	0.60	1.08	1.50	2.62	3.10
Lit le Eagle/Dorchester	< 28 in	X	34	1.15	1.37	1.05	0.50	0.88	1.00	1.35	5.00
Lower War Eagle/Hagy	< 28 in		4	1.99	2.25	1.21	1.20	1.23	2.09	3.11	3.60
Glenalum Tunnel/Splashdam	< 28 in		18	1.01	1.30	1.19	0.60	0.64	0.70	1.49	5.20
Gilbert A/Upper Banner	< 28 in		19	1.13	1.43	1.24	0.50	0.66	1.08	1.60	5.80
Gilbert/Lower Banner	< 28 in		6	1.10	1.22	0.60	0.60	0.78	1.11	1.50	2.19
Douglas/Kennedy	< 28 in		14	1.09	1.24	0.74	0.68	0.80	0.85	1.42	2.93
Jewell/Raven	< 28 in		3	1.54	1.96	1.69	0.80	na	1.17	na	3.90
Iaeger/Jawbone	< 28 in		17	1.14	1.60	1.46	0.50	0.60	0.80	2.00	4.90
Lower Iaeger/Tiller	< 28 in		10	2.33	3.44	2.71	0.60	0.85	3.65	4.43	8.90
Sewell/Lower Seaboard	< 28 in		15	0.86	1.03	0.69	0.40	0.55	0.80	1.21	2.58
Welch/Upper Horsepen	< 28 in		2	0.97	1.02	0.42	0.72	na	na	na	1.31
Beckley/War Creek	< 28 in		11	0.76	0.91	0.78	0.40	0.55	0.70	0.80	3.20
Fire Creek/Lower Horsepen	< 28 in		8	0.81	0.84	0.23	0.57	0.68	0.83	0.95	1.20
Pocahontas No 7	< 28 in		5	0.89	0.95	0.36	0.56	0.56	1.12	1.23	1.27
Pocahontas No 3	< 28 in		8	0.71	0.83	0.55	0.40	0.50	0.60	0.85	1.80

Table 4. Coal quality statistics for coal beds with ≥ 5 samples for selenium, thickness, ash yield, sulfur, pyritic sulfur, arsenic, mercury, and manganese: a. all, b. hcik (≥ 28 inch), and c. thin (< 28 inch) coal bed samples. [Coal bed code from table 2 if N ≥ 30; * if N < 30 for a specific parameter; N = number of samples.]

Table 4c. Thin Coal Smples, <28 inch thick.

			Pyritic Sulfur								
Coal Bed Name This Study	Thickness range	Coal bed code N≥30	N	Geometric mean percent	Average percent	Standard Deviation percent	Minimum percent	Lower Quartile percent	Median percent	Upper Quar ile percent	Maximum percent
Redstone	< 28 in		16	1.49	1.82	0.99	0.19	1.12	1.79	2.37	3.51
Pittsburgh Roof	< 28 in		8	1.09	2.26	1.96	0.03	0.82	2.09	3.38	5.74
Pittsburgh	< 28 in		5	2.15	2.24	0.73	1.45	1.84	2.02	2.55	3.33
Harlem	< 28 in		8	0.60	0.98	0.85	0.07	0.25	0.89	1.38	2.44
Lower Bakerstown	< 28 in		18	1.33	1.76	0.92	0.09	1.24	1.86	2.39	3.46
Brush Creek	< 28 in		8	1.70	1.86	0.99	1.12	1.38	1.49	1.94	4.17
Mahoning	< 28 in		12	1.01	1.40	0.98	0.08	0.70	1.24	2.08	3.34
Upper Freeport	< 28 in	F	56	1.36	1.80	1.37	0.14	0.76	1.47	2.43	6.18
Lower Freeport	< 28 in	G	36	1.58	2.12	1.26	0.05	1.15	1.88	3.03	5.43
Upper Kittanning	< 28 in	H	34	0.58	1.25	1.13	0.01	0.28	1.00	2.12	4.21
Middle Kittanning Rider	< 28 in		8	0.30	1.06	1.10	0.02	0.04	0.99	1.73	2.89
Middle Kittanning	< 28 in	I	73	1.07	1.75	1.47	0.01	0.94	1.28	2.52	6.85
Strasburg	< 28 in		10	2.48	3.13	1.63	0.38	2.71	3.29	4.18	5.48
Lower Kittanning Rider	< 28 in		6	0.31	0.53	0.64	0.07	0.16	0.33	0.51	1.78
Lower Kittanning/No 6 block	< 28 in	J	52	1.83	2.38	1.46	0.02	1.40	2.08	3.13	8.08
Clarion	< 28 in		27	1.31	2.08	1.26	0.03	1.58	1.97	2.89	4.73
Brookville	< 28 in	L	42	1.04	1.45	1.30	0.07	0.60	1.14	1.78	7.10
No 5 Block	< 28 in		24	0.51	1.10	1.08	0.01	0.26	0.72	1.63	3.46
Upper Mercer	< 28 in		6	2.96	3.22	1.28	1.31	2.53	3.29	4.19	4.66
Lower Mercer	< 28 in		16	0.94	1.66	1.23	0.02	0.83	1.26	2.62	3.69
Quakertown	< 28 in		7	1.19	2.14	2.37	0.15	0.76	1.19	2.66	6.81
Stockton	< 28 in		8	0.43	1.43	1.71	0.04	0.08	1.02	2.18	4.85
Coalburg	< 28 in	O	69	0.32	0.76	0.95	0.01	0.10	0.29	1.05	3.99
Winifrede/Hazard	< 28 in	P *	29	0.18	0.50	0.80	0.01	0.08	0.15	0.74	3.66
Lower Winifrede/Hazard	< 28 in		6	0.13	0.22	0.29	0.04	0.07	0.12	0.15	0.80
Chilton/Taylor	< 28 in		5	1.21	1.99	1.11	0.07	2.24	2.25	2.55	2.86
Fire Clay Rider	< 28 in		10	1.07	1.87	1.56	0.06	0.61	1.49	2.94	4.21
Fire Clay	< 28 in	Q *	26	0.25	0.63	0.88	0.02	0.09	0.26	0.62	3.33
Cedar Grove/Whitesburg	< 28 in		16	1.17	1.62	1.03	0.09	0.91	1.54	2.41	3.54
Williamson/Amburgy	< 28 in		23	0.57	1.07	1.01	0.02	0.34	0.70	1.54	4.18
Campbell Creek/Upper Elkhorn No 3	< 28 in	T	37	0.31	0.85	1.05	0.03	0.09	0.25	1.41	3.50
Upper Elkhorn Nos 1 and 2/Powellton	< 28 in	U	48	0.52	1.28	1.36	0.01	0.19	0.88	1.86	5.17
Pond Creek	< 28 in	V	33	0.41	1.10	1.12	0.02	0.10	0.62	1.88	3.78
Matewan/Clintwood	< 28 in	W	70	0.42	1.04	1.22	0.01	0.15	0.42	1.85	5.22
Middle War Eagle/Eagle	< 28 in		10	0.68	0.98	0.72	0.06	0.54	0.74	1.62	2.06
Lit le Eagle/Dorchester	< 28 in	X	34	0.33	0.59	0.74	0.03	0.19	0.31	0.55	3.27
Lower War Eagle/Hagy	< 28 in		4	0.94	1.42	1.22	0.23	0.49	1.33	2.25	2.80
Glenalum Tunnel/Splashdam	< 28 in		18	0.19	0.66	1.01	0.01	0.06	0.17	0.82	3.65
Gilbert A/Upper Banner	< 28 in		19	0.27	0.77	1.31	0.01	0.10	0.43	0.71	5.72
Gilbert/Lower Banner	< 28 in		5	0.37	0.57	0.50	0.06	0.30	0.40	0.71	1.36
Douglas/Kennedy	< 28 in		12	0.29	0.52	0.62	0.05	0.15	0.27	0.54	2.07
Jewell/Raven	< 28 in		3	0.52	1.34	1.97	0.18	na	0.22	na	3.61
Iaeger/Jawbone	< 28 in		15	0.28	0.94	1.18	0.03	0.07	0.17	1.71	3.23
Lower Iaeger/Tiller	< 28 in		10	1.30	2.74	2.45	0.08	0.55	2.83	4.10	7.62
Sewell/Lower Seaboard	< 28 in		12	0.38	0.60	0.53	0.05	0.27	0.42	0.80	1.79
Welch/Upper Horsepen	< 28 in		2	0.07	0.24	0.32	0.01	na	na	na	0.46
Beckley/War Creek	< 28 in		9	0.15	0.36	0.67	0.03	0.10	0.13	0.22	2.14
Fire Creek/Lower Horsepen	< 28 in		6	0.14	0.21	0.17	0.02	0.15	0.17	0.21	0.52
Pocahontas No 7	< 28 in		5	0.14	0.28	0.25	0.02	0.03	0.32	0.39	0.62
Pocahontas No 3	< 28 in		1	na	na	na	na	na	0.22	na	na

Table 4. Coal quality statistics for coal beds with ≥ 5 samples for selenium, thickness, ash yield, sulfur, pyritic sulfur, arsenic, mercury, and manganese: a. all, b. hcik (≥ 28 inch), and c. thin (< 28 inch) coal bed samples. [Coal bed code from table 2 if N ≥ 30; * if N < 30 for a specific parameter; N = number of samples.]

Table 4c. Thin Coal Smples, <28 inch thick.

			Arsenic								
Coal Bed Name This Study	Thickness range	Coal bed code N≥30	N	Geometric mean ppm	Average ppm	Standard Deviation ppm	Minimum ppm	Lower Quartile ppm	Median ppm	Upper Quar ile ppm	Maximum ppm
Redstone	< 28 in		18	21	44	68	1.5	9.5	20	45	290
Pittsburgh Roof	< 28 in		7	12	17	13	0.85	12	14	22	41
Pittsburgh	< 28 in		5	24	34	27	5.8	13	32	44	75
Harlem	< 28 in		8	7.8	14	17	1.5	4.8	9.3	14	53
Lower Bakerstown	< 28 in		18	39	60	86	9.9	23	43	53	390
Brush Creek	< 28 in		8	28	36	24	10	18	30	50	77
Mahoning	< 28 in		14	79	100	99	28	49	73	120	410
Upper Freeport	< 28 in	F	63	38	51	41	4.3	24	42	66	200
Lower Freeport	< 28 in	G	35	30	45	34	2.3	21	35	75	120
Upper Kittanning	< 28 in	H	35	26	47	49	1.0	10	35	67	230
Middle Kittanning Rider	< 28 in		8	22	43	39	1.4	16	38	61	120
Middle Kittanning	< 28 in	I	72	17	34	38	0.70	7.2	21	43	160
Strasburg	< 28 in		10	18	31	31	2.9	8.1	24	35	100
Lower Kittanning Rider	< 28 in		6	9.5	14	13	3.0	5.5	7.8	18	38
Lower Kittanning/No 6 block	< 28 in	J	57	24	42	52	2.0	11	21	48	270
Clarion	< 28 in		27	12	20	18	1.4	4.2	18	27	73
Brookville	< 28 in	L	43	11	21	29	0.49	4.7	12	20	150
No 5 Block	< 28 in		27	11	28	39	0.90	3.7	12	38	150
Upper Mercer	< 28 in		6	33	44	43	16	20	30	40	130
Lower Mercer	< 28 in		17	13	26	40	1.6	6.4	12	29	160
Quakertown	< 28 in		7	20	28	27	9.5	12	13	36	81
Stockton	< 28 in		11	9.2	20	22	0.70	3.6	7.3	29	61
Coalburg	< 28 in	O	75	8.0	18	28	0.40	3.0	6.6	19	170
Winifrede/Hazard	< 28 in	P	31	5.1	22	59	0.50	1.6	5.0	9.8	270
Lower Winifrede/Hazard	< 28 in		5	6.0	8.1	6.5	2.5	2.6	5.6	13	17
Chilton/Taylor	< 28 in		6	11	25	26	1.2	3.4	17	47	58
Fire Clay Rider	< 28 in		16	35	65	77	1.7	22	38	75	300
Fire Clay	< 28 in	Q	30	7.2	17	23	0.90	2.3	6.2	27	100
Cedar Grove/Whitesburg	< 28 in		23	15	33	57	1.8	5.8	17	38	280
Williamson/Amburgy	< 28 in		26	16	32	36	0.61	8.6	27	36	170
Campbell Creek/Upper Elkhorn No 3	< 28 in	T	62	7.7	21	33	0.90	2.3	5.7	30	170
Upper Elkhorn Nos 1 and 2/Powellton	< 28 in	U	55	23	70	120	1.1	9.5	23	53	680
Pond Creek	< 28 in	V	43	14	32	34	0.40	5.4	15	53	120
Matewan/Clintwood	< 28 in	W	72	11	30	40	0.50	3.6	12	40	180
Middle War Eagle/Eagle	< 28 in		11	28	48	39	1.9	14	34	84	100
Lit le Eagle/Dorchester	< 28 in	X	34	11	24	32	1.1	3.9	13	32	130
Lower War Eagle/Hagy	< 28 in		5	32	89	140	3.5	13	48	50	330
Glenalum Tunnel/Splashdam	< 28 in		18	8.2	22	28	0.87	3.2	6.1	44	79
Gilbert A/Upper Banner	< 28 in		22	13	29	33	0.76	5.2	12	46	99
Gilbert/Lower Banner	< 28 in		6	25	49	55	5.3	10	20	96	120
Douglas/Kennedy	< 28 in		15	23	35	32	2.8	11	24	54	100
Jewell/Raven	< 28 in		5	9.9	12	7.9	5.0	7.0	10	11	25
Iaeger/Jawbone	< 28 in		17	7.5	21	26	0.51	1.5	10	23	80
Lower Iaeger/Tiller	< 28 in		10	29	76	99	1.6	9.7	35	100	310
Sewell/Lower Seaboard	< 28 in		20	10	17	19	1.2	5.5	10	20	78
Welch/Upper Horsepen	< 28 in		5	19	32	23	1.4	18	39	45	59
Beckley/War Creek	< 28 in		12	8.1	15	23	1.5	4.1	11	15	87
Fire Creek/Lower Horsepen	< 28 in		8	5.5	9.1	8.3	1.3	2.1	7.1	15	21
Pocahontas No 7	< 28 in		4	23	41	35	2.7	16	44	69	75
Pocahontas No 3	< 28 in		10	5.2	17	25	0.90	1.6	2.6	32	70

Table 4. Coal quality statistics for coal beds with ≥ 5 samples for selenium, thickness, ash yield, sulfur, pyritic sulfur, arsenic, mercury, and manganese: a. all, b. hcik (≥ 28 inch), and c. thin (< 28 inch) coal bed samples. [Coal bed code from table 2 if N ≥ 30; * if N < 30 for a specific parameter; N = number of samples.]

Table 4c. Thin Coal Smples, <28 inch thick.

			Mercury								
Coal Bed Name This Study	Thickness range	Coal bed code N≥30	N	Geometric mean ppm	Average ppm	Standard Deviation ppm	Minimum ppm	Lower Quartile ppm	Median ppm	Upper Quar ile ppm	Maximum ppm
Redstone	< 28 in		18	0.11	0.16	0.12	0.007	0 084	0.15	0.18	0.52
Pittsburgh Roof	< 28 in		8	0.26	0.32	0.21	0.085	0.17	0.28	0.43	0.69
Pittsburgh	< 28 in		5	0.14	0.21	0.21	0.058	0 077	0.10	0.22	0.57
Harlem	< 28 in		8	0.066	0.12	0.12	0.007	0 028	0.11	0.19	0.31
Lower Bakerstown	< 28 in		18	0.14	0.24	0.29	0.003	0 093	0.19	0.25	1.3
Brush Creek	< 28 in		8	0.13	0.19	0.13	0.010	0.12	0.19	0.27	0.40
Mahoning	< 28 in		14	0.33	0.44	0.32	0.068	0.21	0.35	0.63	1.0
Upper Freeport	< 28 in	F	63	0.29	0.38	0.37	0.030	0.20	0.32	0.46	2.9
Lower Freeport	< 28 in	G	36	0.15	0.25	0.20	0.003	0.10	0.17	0.35	0.87
Upper Kittanning	< 28 in	H	35	0.14	0.27	0.27	0.003	0 060	0.24	0.38	1.3
Middle Kittanning Rider	< 28 in		8	0.42	0.53	0.37	0.14	0.25	0.48	0.65	1.3
Middle Kittanning	< 28 in	I	75	0.12	0.24	0.26	0.003	0 060	0.14	0.32	1.0
Strasburg	< 28 in		10	0.24	0.27	0.14	0.076	0.15	0.29	0.39	0.45
Lower Kittanning Rider	< 28 in		6	0.035	0.088	0.080	0.003	0 020	0.080	0.16	0.18
Lower Kittanning/No 6 block	< 28 in	J	57	0.18	0.27	0.20	0.003	0.14	0.22	0.36	0.87
Clarion	< 28 in		27	0.14	0.18	0.12	0.010	0.10	0.13	0.26	0.45
Brookville	< 28 in	L	43	0.14	0.20	0.16	0.018	0 086	0.19	0.26	0.87
No 5 Block	< 28 in		28	0.13	0.21	0.28	0.023	0 056	0.14	0.23	1.5
Upper Mercer	< 28 in		6	0.15	0.19	0.14	0.040	0 090	0.20	0.24	0.41
Lower Mercer	< 28 in		17	0.11	0.20	0.17	0.003	0 080	0.17	0.38	0.51
Quakertown	< 28 in		7	0.13	0.18	0.14	0.033	0 062	0.18	0.26	0.42
Stockton	< 28 in		11	0.15	0.21	0.18	0.020	0.11	0.18	0.21	0.67
Coalburg	< 28 in	O	76	0.12	0.17	0.12	0.010	0 074	0.15	0.23	0.59
Winifrede/Hazard	< 28 in	P	31	0.099	0.17	0.16	0.007	0 045	0.10	0.29	0.55
Lower Winifrede/Hazard	< 28 in		5	0.052	0.075	0.082	0.020	0 030	0.050	0.055	0.22
Chilton/Taylor	< 28 in		6	0.17	0.25	0.26	0.060	0 090	0.17	0.28	0.74
Fire Clay Rider	< 28 in		16	0.22	0.26	0.17	0.055	0.15	0.21	0.35	0.72
Fire Clay	< 28 in	Q	30	0.079	0.11	0.096	0.007	0 050	0.070	0.22	0.32
Cedar Grove/Whitesburg	< 28 in		23	0.16	0.25	0.26	0.020	0.12	0.21	0.27	1.1
Williamson/Amburgy	< 28 in		26	0.10	0.14	0.12	0.020	0 050	0.11	0.22	0.49
Campbell Creek/Upper Elkhorn No 3	< 28 in	T	62	0.086	0.14	0.14	0.007	0 048	0.088	0.21	0.72
Upper Elkhorn Nos 1 and 2/Powellton	< 28 in	U	55	0.12	0.19	0.15	0.007	0 055	0.17	0.26	0.65
Pond Creek	< 28 in	V	43	0.10	0.17	0.15	0.007	0 062	0.11	0.24	0.57
Matewan/Clintwood	< 28 in	W	72	0.095	0.16	0.13	0.003	0 058	0.13	0.24	0.56
Middle War Eagle/Eagle	< 28 in		11	0.077	0.11	0.090	0.010	0 048	0.093	0.16	0.29
Lit le Eagle/Dorchester	< 28 in	X	34	0.053	0.094	0.11	0.003	0 032	0.062	0.11	0.51
Lower War Eagle/Hagy	< 28 in		5	0.11	0.20	0.21	0.010	0.13	0.13	0.16	0.55
Glenalum Tunnel/Splashdam	< 28 in		18	0.13	0.21	0.16	0.003	0 073	0.21	0.36	0.48
Gilbert A/Upper Banner	< 28 in		22	0.046	0.082	0.090	0.003	0 030	0.060	0.11	0.40
Gilbert/Lower Banner	< 28 in		6	0.14	0.17	0.12	0.070	0 080	0.12	0.22	0.37
Douglas/Kennedy	< 28 in		15	0.10	0.18	0.19	0.007	0 055	0.10	0.23	0.62
Jewell/Raven	< 28 in		5	0.11	0.11	0.044	0.070	0 080	0.11	0.13	0.18
Iaeger/Jawbone	< 28 in		17	0.096	0.14	0.11	0.010	0 060	0.080	0.19	0.42
Lower Iaeger/Tiller	< 28 in		10	0.15	0.32	0.25	0.007	0 085	0.39	0.54	0.60
Sewell/Lower Seaboard	< 28 in		20	0.15	0.20	0.16	0.045	0 067	0.16	0.26	0.58
Welch/Upper Horsepen	< 28 in		5	0.20	0.32	0.32	0.070	0 070	0.19	0.45	0.81
Beckley/War Creek	< 28 in		12	0.086	0.11	0.10	0.030	0 058	0.073	0.10	0.38
Fire Creek/Lower Horsepen	< 28 in		8	0.081	0.094	0.062	0.050	0 050	0.071	0.11	0.23
Pocahontas No 7	< 28 in		4	0.065	0.065	0.006	0.060	0 060	0.065	0.070	0.070
Pocahontas No 3	< 28 in		10	0.16	0.21	0.19	0.050	0 095	0.14	0.28	0.66

Table 4. Coal quality statistics for coal beds with ≥ 5 samples for selenium, thickness, ash yield, sulfur, pyritic sulfur, arsenic, mercury, and manganese: a. all, b. hcik (≥ 28 inch), and c. thin (< 28 inch) coal bed samples. [Coal bed code from table 2 if N ≥ 30; * if N < 30 for a specific parameter; N = number of samples.]

Table 4c. Thin Coal Smples, <28 inch thick.

			Manganese								
Coal Bed Name This Study	Thickness range	Coal bed code N≥30	N	Geometric mean ppm	Average ppm	Standard Deviation ppm	Minimum ppm	Lower Quartile ppm	Median ppm	Upper Quar ile ppm	Maximum ppm
Redstone	< 28 in		18	41	75	120	15	20	33	59	460
Pittsburgh Roof	< 28 in		8	15	16	6.0	6.1	14	16	18	27
Pittsburgh	< 28 in		5	12	14	6.4	3.8	11	17	18	19
Harlem	< 28 in		8	18	27	28	6.2	7.7	21	29	90
Lower Bakerstown	< 28 in		18	29	55	89	6.5	13	23	65	390
Brush Creek	< 28 in		8	15	33	53	5.2	6.3	9.3	30	160
Mahoning	< 28 in		14	12	16	15	3.3	5.7	13	24	59
Upper Freeport	< 28 in	F	61	14	21	24	1.1	7.4	12	26	140
Lower Freeport	< 28 in	G	36	24	39	42	1.2	15	23	42	170
Upper Kittanning	< 28 in	H	35	12	14	7.8	3.4	8.0	12	19	33
Middle Kittanning Rider	< 28 in		8	24	26	12	14	16	24	32	46
Middle Kittanning	< 28 in	I	75	14	20	22	1.7	8.5	15	24	140
Strasburg	< 28 in		10	27	37	32	6.3	20	31	45	120
Lower Kittanning Rider	< 28 in		6	8.5	9.9	7.0	5.8	6.4	7.2	8.4	24
Lower Kittanning/No 6 block	< 28 in	J	57	15	25	44	1.6	8.4	15	23	280
Clarion	< 28 in		27	21	28	23	5.0	12	24	41	110
Brookville	< 28 in	L	43	18	36	74	2.1	9.8	18	27	470
No 5 Block	< 28 in		28	7.1	9.6	13	3.1	4.6	6.4	9.7	71
Upper Mercer	< 28 in		6	40	63	70	11	21	44	62	200
Lower Mercer	< 28 in		17	17	30	46	4.6	8.1	15	26	190
Quakertown	< 28 in		7	12	24	38	2.6	7.4	11	15	110
Stockton	< 28 in		11	12	24	40	4.3	6.8	8.1	20	140
Coalburg	< 28 in	O	76	10	14	16	1.6	6.0	9.0	16	120
Winifrede/Hazard	< 28 in	P	31	7.7	11	9.0	1.2	3.9	6.8	17	33
Lower Winifrede/Hazard	< 28 in		5	9.2	11	7.1	3.9	4.7	12	14	21
Chilton/Taylor	< 28 in		6	13	24	31	3.3	5.9	11	24	85
Fire Clay Rider	< 28 in		16	30	64	91	4.3	10	32	68	350
Fire Clay	< 28 in	Q	30	9.7	15	17	1.9	5.0	7.1	23	83
Cedar Grove/Whitesburg	< 28 in		23	9.4	39	140	0.73	4.6	11	14	660
Williamson/Amburgy	< 28 in		26	9.8	17	34	2.2	5.6	8.4	14	180
Campbell Creek/Upper Elkhorn No 3	< 28 in	T	62	6.2	8.7	8.0	1.2	3.5	4.6	13	32
Upper Elkhorn Nos 1 and 2/Powellton	< 28 in	U	55	6.6	9.5	12	1.1	4.1	6.2	8.4	75
Pond Creek	< 28 in	V	43	13	24	40	2.1	6.6	12	21	210
Matewan/Clintwood	< 28 in	W	72	8.1	16	46	1.4	4.7	6.8	13	390
Middle War Eagle/Eagle	< 28 in		11	10	20	24	0.75	6.2	11	20	78
Lit le Eagle/Dorchester	< 28 in	X	34	7.7	11	9.8	2.0	3.6	6.7	14	42
Lower War Eagle/Hagy	< 28 in		5	11	13	8.0	4.1	11	12	14	26
Glenalum Tunnel/Splashdam	< 28 in		18	5.4	7.4	6.6	1.2	3.5	4.9	6.7	22
Gilbert A/Upper Banner	< 28 in		22	11	15	15	1.5	7.5	12	17	70
Gilbert/Lower Banner	< 28 in		6	14	14	2.7	11	13	14	16	18
Douglas/Kennedy	< 28 in		15	16	27	30	2.8	8.5	16	31	110
Jewell/Raven	< 28 in		5	19	19	4.3	12	20	21	21	23
Iaeger/Jawbone	< 28 in		17	12	18	13	1.1	7.4	16	24	48
Lower Iaeger/Tiller	< 28 in		10	25	32	21	7.3	15	34	43	74
Sewell/Lower Seaboard	< 28 in		20	20	47	78	2.1	8.0	20	36	320
Welch/Upper Horsepen	< 28 in		5	7.5	8.8	5.3	3.8	4.9	6.2	14	15
Beckley/War Creek	< 28 in		12	14	44	89	2.0	5.1	14	32	320
Fire Creek/Lower Horsepen	< 28 in		8	6.8	16	25	1.0	2.6	8.1	17	75
Pocahontas No 7	< 28 in		4	6.4	9.2	7.1	1.3	5.2	8.8	13	18
Pocahontas No 3	< 28 in		10	15	16	5.8	6.3	13	16	18	28

Table 5. Coal quality statistics for coal samples in three stratigraphic intervals (pre-SGB, SGB, post-SGB) for selenium, thickness, ash yield, sulfur, pyritic sulfur, arsenic, mercury, and manganese; a. all, b. thick (≥ 28 inch), and c. thin (<28 inch) coal bed samples. [N = number of samples. Coal beds in stratigraphic intervals pre-SGB, SGB, and post-SGB are listed in table 2.]

Table 5a. Coal Samples, all thicknesses.

Stratigraphic interval	Parameter	Units	N	Average	Standard Deviation	Minimum	Lower Quartile	Median	Upper Quartile	Maximum
post-SGB	Selenium	ppm	1,333	3.2	2.2	0.20	1.8	2.6	3.8	20
SGB	Selenium	ppm	737	5.4	2.7	0.07	3.6	5.0	6.7	21
pre-SGB	Selenium	ppm	1,153	3.0	1.6	0.07	1.8	2.7	3.7	16
post-SGB	Thickness	inch	1,335	39	19	2.0	26	36	49	125
SGB	Thickness	inch	737	34	21	3.1	19	30	45	172
pre-SGB	Thickness	inch	1,155	32	16	4.0	20	31	41	128
post-SGB	Ash Yield	percent	1,244	12.06	5.15	1.70	8.44	11.00	14.70	32.03
SGB	Ash Yield	percent	710	12.01	5.83	2.00	7.70	11.13	14.80	32.90
pre-SGB	Ash Yield	percent	1,098	7.82	4.78	0.90	4.43	6.70	9.62	30.90
post-SGB	Sulfur	percent	1,297	2.88	1.51	0.39	1.80	2.69	3.73	10.40
SGB	Sulfur	percent	710	1.83	1.54	0.40	0.70	1.10	2.57	10.60
pre-SGB	Sulfur	percent	1,098	1.34	1.08	0.40	0.70	0.90	1.54	8.90
post-SGB	Pyritic Sulfur	percent	1,198	1.79	1.21	0.01	0.94	1.61	2.48	8.08
SGB	Pyritic Sulfur	percent	602	1.12	1.31	0.01	0.14	0.60	1.73	8.97
pre-SGB	Pyritic Sulfur	percent	831	0.70	0.97	0.01	0.10	0.25	0.94	7.62
post-SGB	Arsenic	ppm	1,328	30	37	0.3	8.5	19	36	410
SGB	Arsenic	ppm	734	18	30	0.4	2.9	7.5	20	300
pre-SGB	Arsenic	ppm	1,151	23	43	0.1	3.1	8.3	25	680
post-SGB	Mercury	ppm	1,335	0.26	0.23	0.003	0.11	0.20	0.33	2.9
SGB	Mercury	ppm	736	0.17	0.16	0.003	0.060	0.12	0.24	1.5
pre-SGB	Mercury	ppm	1,153	0.14	0.15	0.003	0.050	0.085	0.18	1.8
post-SGB	Manganese	ppm	1,332	27	41	0.92	10	17	29	690
SGB	Manganese	ppm	736	20	46	0.73	5.9	11	21	660
pre-SGB	Manganese	ppm	1,152	20	37	0.75	5.2	10	20	540

Table 5. Coal quality statistics for coal samples in three stratigraphic intervals (pre-SGB, SGB, post-SGB) for selenium, thickness, ash yield, sulfur, pyritic sulfur, arsenic, mercury, and manganese; a. all, b. thick (≥ 28 inch), and c. thin (<28 inch) coal bed samples. [N = number of samples. Coal beds in stratigraphic intervals pre-SGB, SGB, and post-SGB are listed in table 2.]

Table 5b. Thick Coal Samples, ≥28 inch thick.

Stratigraphic interval	Parameter	Units	N	Average	Standard Deviation	Minimum	Lower Quartile	Median	Upper Quartile	Maximum
post-SGB	Selenium	ppm	942	3.1	2.1	0.20	1.8	2.6	3.7	20
SGB	Selenium	ppm	407	5.6	2.5	0.73	3.9	5.1	6.9	17
pre-SGB	Selenium	ppm	668	3.1	1.6	0.07	2.0	2.9	4.0	14
post-SGB	Thickness	inch	943	47	16	28	35	43	53	125
SGB	Thickness	inch	407	47	19	28	35	43	53	172
pre-SGB	Thickness	inch	669	42	13	28	33	39	47	128
post-SGB	Ash Yield	percent	870	11.77	4.92	2.20	8.25	10.80	14.50	32.03
SGB	Ash Yield	percent	394	12.14	5.43	2.44	8.42	11.20	14.50	31.80
pre-SGB	Ash Yield	percent	638	7.93	4.55	0.90	4.80	6.80	9.62	30.90
post-SGB	Sulfur	percent	912	2.88	1.41	0.39	1.90	2.70	3.71	8.43
SGB	Sulfur	percent	394	1.67	1.52	0.40	0.70	0.98	2.13	10.40
pre-SGB	Sulfur	percent	638	1.12	0.78	0.40	0.66	0.80	1.27	6.70
post-SGB	Pyritic Sulfur	percent	826	1.78	1.13	0.01	1.00	1.62	2.43	6.49
SGB	Pyritic Sulfur	percent	309	1.00	1.27	0.01	0.14	0.46	1.48	8.97
pre-SGB	Pyritic Sulfur	percent	440	0.47	0.67	0.01	0.09	0.19	0.55	5.43
post-SGB	Arsenic	ppm	941	24	27	0.3	7.8	15	32	320
SGB	Arsenic	ppm	407	13	19	0.6	2.5	6.2	15	180
pre-SGB	Arsenic	ppm	667	15	24	0.1	2.7	6.6	16	300
post-SGB	Mercury	ppm	943	0.25	0.21	0.003	0.11	0.20	0.32	1.7
SGB	Mercury	ppm	407	0.16	0.15	0.003	0.060	0.12	0.22	1.5
pre-SGB	Mercury	ppm	669	0.12	0.14	0.003	0.047	0.080	0.16	1.8
post-SGB	Manganese	ppm	942	27	40	0.92	11	18	29	690
SGB	Manganese	ppm	407	16	32	1.1	5.8	10	18	530
pre-SGB	Manganese	ppm	668	22	38	0.96	5.6	11	23	540

Table 5. Coal quality statistics for coal samples in three stratigraphic intervals (pre-SGB, SGB, post-SGB) for selenium, thickness, ash yield, sulfur, pyritic sulfur, arsenic, mercury, and manganese; a. all, b. thick (≥ 28 inch), and c. thin (<28 inch) coal bed samples. [N = number of samples. Coal beds in stratigraphic intervals pre-SGB, SGB, and post-SGB are listed in table 2.]

Table 5c. Thin Coal Smples, <28 inch thick.

Stratigraphic interval	Parameter	Units	N	Average	Standard Deviation	Minimum	Lower Quartile	Median	Upper Quartile	Maximum
post-SGB	Selenium	ppm	391	3.3	2.3	0.43	1.9	2.8	3.9	14
SGB	Selenium	ppm	330	5.2	2.8	0.07	3.2	4.6	6.4	21
pre-SGB	Selenium	ppm	485	2.8	1.7	0.07	1.7	2.4	3.4	16
post-SGB	Thickness	inch	392	20	5.9	2.0	16	21	25	28
SGB	Thickness	inch	330	17	6.1	3.1	12	18	22	28
pre-SGB	Thickness	inch	486	18	6.0	4.0	13	19	24	28
post-SGB	Ash Yield	percent	374	12.74	5.59	1.70	9.01	11.44	15.68	31.20
SGB	Ash Yield	percent	316	11.85	6.29	2.00	7.11	11.00	15.23	32.90
pre-SGB	Ash Yield	percent	460	7.66	5.09	0.90	4.12	6.40	9.61	29.55
post-SGB	Sulfur	percent	385	2.86	1.72	0.40	1.50	2.60	3.79	10.40
SGB	Sulfur	percent	316	2.02	1.55	0.41	0.80	1.50	2.91	10.60
pre-SGB	Sulfur	percent	460	1.64	1.34	0.40	0.71	1.03	2.18	8.90
post-SGB	Pyritic Sulfur	percent	372	1.81	1.37	0.01	0.76	1.58	2.58	8.08
SGB	Pyritic Sulfur	percent	293	1.24	1.35	0.01	0.15	0.82	2.00	8.67
pre-SGB	Pyritic Sulfur	percent	391	0.95	1.18	0.01	0.12	0.41	1.53	7.62
post-SGB	Arsenic	ppm	387	44	50	0.7	12	30	55	410
SGB	Arsenic	ppm	327	24	39	0.4	3.6	11	28	300
pre-SGB	Arsenic	ppm	484	34	57	0.4	4.0	13	42	680
post-SGB	Mercury	ppm	392	0.28	0.28	0.003	0.095	0.21	0.37	2.9
SGB	Mercury	ppm	329	0.19	0.17	0.003	0.070	0.15	0.26	1.5
pre-SGB	Mercury	ppm	484	0.16	0.15	0.003	0.050	0.10	0.23	0.81
post-SGB	Manganese	ppm	390	29	46	1.1	8.5	16	28	460
SGB	Manganese	ppm	329	25	58	0.73	6.1	11	22	660
pre-SGB	Manganese	ppm	484	17	34	0.75	4.7	8.7	18	390

Selenium Concentrations in Middle Pennsylvanian Coal-Bearing Strata in the Central Appalachian Basin

By Sandra G. Neuzil, Frank T. Dulong, C. Blaine Cecil, Nick Fedorko, John J. Renton, and D. K. Bhumbla

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Conversion Factors

SI to Inch/Pound

Multiply	By	To obtain
Volume		
Liter (L)	33.82	ounce, fluid (fl. oz)
Liter (L)	2.113	pint (pt)
Liter (L)	1.057	quart (qt)
Liter (L)	0.2642	gallon (gal)
Liter (L)	61.02	cubic inch (in^3)
Mass		
Gram (g)	0.03527	ounce, avoirdupois (oz)
Kilogram (kg)	2.205	pound avoirdupois (lb)

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Executive Summary

This report provides the results of a reconnaissance-level investigation of selenium (Se) concentrations in Middle Pennsylvanian coal-bearing strata in the central Appalachian basin. Bryant and others (2002) reported enrichments of Se concentrations in streams draining areas disturbed by surface mining relative to Se concentrations in streams that drain undisturbed areas; the study was conducted without the benefit of data on Se concentrations in coal-bearing strata prior to anthropogenic disturbance. Thus, the present study was conducted to provide data on Se concentrations in coal-bearing strata prior to land disturbance. The principal objectives of this work are: 1) determine the stratigraphic and regional distribution of Se concentrations in coal-bearing strata, 2) provide reconnaissance-level information on relations, if any, between Se concentrations and lithology (rock-type), and 3) develop a cursory evaluation of the leachability of Se from disturbed strata. The results reported herein are derived from analyses of samples obtained from three widely-spaced cores that were collected from undisturbed rock within a region that has been subjected to extensive land disturbance principally by either coal mining or, to a lesser extent, highway construction. The focus was on low-organic-content lithologies, not coal, within the coal-bearing interval, as these lithologies most commonly make up the fill materials after coal mining or in road construction.

The results and interpretations of the present study are summarized as follows:

- The precision of the analytical method used in this study to determine Se concentrations in rock samples is consistent with the precision as reported by ASTM (The American Society for Testing and Materials, ASTM 3052, standard method for the determination of Se in rock samples, 95 percent confidence interval (CI 95%) = 0.9 μg/g at the 1 μg/g (1 part per million, ppm) level of concentration). The precision of ASTM 3052 is likely to decrease as the concentration of Se decreases below 1 μg/g.
- The average Se concentrations in coal-bearing strata in the central Appalachian basin are similar to the average Se concentrations reported for equivalent lithologies (Horn and Adams, 1966 and references therein). Therefore, the average Se concentrations in the various

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lithologies investigated in the present study are not anomalous when compared to values reported in the literature.

- The mean Se concentrations in the higher stratigraphic interval (Stockton A coal bed, lower Allegheny Formation, down to the Chilton A coal bed, middle Kanawha Formation) are consistently higher than the mean Se concentrations in the lower stratigraphic interval (Chilton A coal bed down to the Fire Clay coal bed in the middle Kanawha Formation) in each of the three cores that were evaluated. The apparent stratigraphic trend in Se concentrations appears to mimic the stratigraphic trend of Se concentrations in coal beds reported by Neuzil and others (2005).
- There is no demonstrable regional variation (trend) in Se concentrations.
- With the possible exception of higher Se concentration in siltstone, the mean and range of selenium concentrations is similar among four dominant lithologies (claystone, shale, siltstone, and sandstone).
- Se concentrations are not consistently correlated with a specific mineral or major element.
- Se concentrations were determined in selected coal-bed roof, parting, and floor samples from one core. The mean values of Se concentrations for each of these three types of samples are statistically equal.
- Se concentrations in the selected roof, parting and floor samples are not statistically correlated with total sulfur concentrations (a proxy for the mineral pyrite, FeS_2). Therefore, it is unlikely that a majority of the Se is associated with pyrite in these samples.
- Se concentrations in the selected roof, parting, and floor samples correlate with the loss on ignition analyses (a proxy for organic matter concentrations). The loss on ignition correlation suggests that most of the Se in roof, parting, and floor samples analyzed is organically bonded. Rates of organically bonded Se dissolution are likely to be slow and are probably controlled by relatively slow rates of chemical oxidation of the host organic matter.
- Cursory leaching studies indicate that Se concentrations in rock samples are not correlated with Se concentrations in water leachates derived from splits of the same rock samples. Therefore, total Se, as determined in whole-rock samples, may not be a reliable indicator of water soluble Se. Consequently, leach testing, rather than total Se concentrations in rock, may be a more useful predictor of potential stream contamination following land disturbance.
- Although the readily soluble fraction of the total Se in coal-bearing strata is unknown, the cursory study of sequential water leaching conducted in the present investigation indicates that readily soluble Se may be rapidly removed from rock debris following disturbance of strata.

On the basis of the present study, the average concentrations of Se in Middle Pennsylvanian coal-bearing strata in the central Appalachian basin are not anomalous when compared to published values for similar rock types. In addition, the average concentrations of Se indicate that if regional trends exist, such trends are below the detection limits of the methods used in this study. Also, there is no apparent association of Se with a specific mineral or a specific rock type (claystone, shale, siltstone, or sandstone) with the possible exception of Se enrichment in certain siltstone and coal-bed roof, parting, and floor samples. Leach testing methods, rather than analyses of total Se content of rocks, may provide the most accurate assessment of the potential for Se mobilization and stream contamination as a result of land disturbance.

Introduction

The upper limit of total Se concentration in streams recommended by EPA in order to protect aquatic life is 5 micrograms per liter (μg/L, parts per billion, or ppb). Bryant and others (2002) reported that concentrations of Se in streams draining areas disturbed by surface mining of coal in the central Appalachian basin were higher (median 12 μg/L) in comparison to streams draining undisturbed areas (median 1.5 μg/L). However, a general lack of data on Se concentrations in coal-bearing strata precluded the attribution of Se concentrations in streams to specific rock types, stratigraphic intervals, or specific areas subjected to land disturbance. To address any potential correlations between bed rock geology, dissolution of Se following land disturbance, and subsequent increases in Se concentrations in streams, the U.S. Geological Survey (USGS), in cooperation with the West Virginia Geological and Economic Survey (WVGES) and West Virginia University (WVU), initiated a study to evaluate Se concentrations in coal-bearing strata (not including the coal beds) in the central Appalachian region.

In a companion study, Neuzil and others (2005) used data from the USGS National Coal Resources Data System to evaluate Se concentrations in Pennsylvanian-age coal beds in the Appalachian region. Their study indicates that Se concentrations in Middle Pennsylvanian age coal beds (the principal stratigraphic interval of mountain-top-mining at the time of their report) are somewhat enriched in Se (median 5 ppm Se, for 737 samples) relative to older and younger coal beds (median 3 ppm Se, for 1486 samples). The overall conclusions of the study by Neuzil and others (2005) are consistent with earlier observations by Gluskoter and others (1977) that Se is enriched in coal beds relative to host strata and relative to the average abundance of Se in the earth's crust. The average Se concentration of upper continental crust is poorly constrained. However, Rudnick and Gao (2003) suggest a value of 0.09 ppm Se based on few data.

Although Se concentrations in coal beds world wide (Yudovich and Ketris, 2006), in the United States (Coleman and others, 1993), in eastern Kentucky (Eble and Hower, 1997), and in West Virginia (WVGES, 2002) are relatively well known, systematic studies of Se in strata associated with coal beds have been minimal. Therefore, the present study was designed to develop a preliminary understanding of Se concentrations in coal-bearing strata in the central Appalachian basin. This report focuses on Middle Pennsylvanian strata where anthropogenic activities such as surface mining and highway construction have either disturbed or may disturb large volumes of rock.

The present study was undertaken to begin developing a data base that can be used in the assessment of the effects of land disturbance on Se concentrations in surface streams, as suggested by Bryant and others (2002). The current study is a first-stage in the possible development of a comprehensive data base, and as such this report is preliminary in nature. Far more data will be required in order to conduct a comprehensive assessment of Se concentrations in Pennsylvanian age coal-bearing strata, comparable to the report by Neuzil and others (2005) on Se in coal beds. The objectives of the present study were to: 1) evaluate the spatial variation of Se, in coal-bearing strata in the central Appalachian basin, 2) make a preliminary comparison of Se concentrations in coal-bearing strata of the region relative to average concentrations of Se in sedimentary strata, as reported in the literature, and 3) investigate the mobilization of Se by water from disturbed coal-bearing strata. For the purposes of this report, spatial variation refers to both stratigraphic variation and regional variation of Se concentrations in coal-bearing strata. Stratigraphic trends refer to any vertical trends in Se concentrations over hundreds of feet of coal-bearing strata. Regional variation

relates to regional trends in Se concentrations over tens to hundreds of square miles. Three widely spaced cores that were designated as USGS 9, USGS 11, and USGS 12 were collected, sampled, and the samples analyzed, as part of this regional study (fig. 1). The principal coal-bed stratigraphic intervals identified in each of the three cores are shown in Appendices A1, A2, and A3. The second objective is intended to discern if Se in the coal-bearing strata of the central Appalachian region is in any way anomalous when compared to similar sedimentary rocks. The third objective is to investigate whether there is any simple analysis that can be used to help predict any potential for elevation of Se in streams as a result of land disturbance.

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Methods and Analyses

Coring

The cores discussed in this report were part of a coring program that was developed to evaluate geologic controls on mine-drainage water quality, principally acid drainage. The total coring program consisted of eleven cores collected from both the northern- and southern-coal fields of West Virginia (fig. 1). One additional core was collected from Pennsylvanian strata in the Illinois basin. The cores were designated as USGS cores and they were numbered consecutively from one (1) through twelve (12) in the order that they were drilled. Preliminary results of the larger acid drainage study can be found in Dulong and others (2002). Cores included in this report are limited to those analyzed for Se (USGS 9, USGS 11, and USGS 12). The locations of the three cores were selected to provide a cursory evaluation of spatial variations (stratigraphic and regional) of Se in Middle Pennsylvanian coal-bearing strata in the central Appalachian basin (fig. 1). All three cores intercepted a stratigraphic interval in the Middle Pennsylvanian from the base of the Stockton A coal bed in the lower Allegheny Formation to the top of the Fire Clay coal bed in the middle Kanawha Formation. All coal beds intercepted in each core are listed in Appendices A1, A2, and A3.

Cores were obtained using standard coal exploratory wireline coring methods, producing a nominal 2 inch diameter core. Professional geologists from the WVGES logged all cores in the field as they were collected. Lithology terminology and abbreviations, as used by the WVGES for lithologic descriptions, are contained in Appendix A4. Core descriptions of USGS 9, USGS 11, and USGS 12 are contained in Appendices A5, A6, and A7. In addition, the three core holes were logged using standard coal-field geophysical logging that included density and natural gamma ray logs for USGS 9 (Appendix A8), USGS 11 (Appendix A9), and USGS 12 (Appendix A10). Comparison of geophysical logs with geological logs assured the accuracy of both core recovery and depth assignments to specific stratigraphic units such as coal beds.

Each core of coal-bearing strata was boxed by the geologist on site, and then sent to the WVGES core warehouse where they were sampled for Se analyses. Cores of coal beds, including partings within the coal beds, as well as six inches of strata above and below the coal (roof-rock and floor-rock respectively) were removed from the core at the coring site, placed in core boxes, and sent to the WVGES coal laboratory for standard coal analyses. Standard coal analyses by the WVGES generally include petrography, elemental analyses, forms of sulfur, and ash content. Coal

analyses are not considered in this report because coal is removed as part of the mining process and should not, therefore, represent a significant source of Se in disturbed areas. Occasionally isolated blocks of coal in sandstone channel complexes and strata between coal beds may be encountered and included in fill material. In the present study the roof, parting, and floor samples from USGS 9 were analyzed for total sulfur, ash content, and Se content.

Core Sampling

Costs prohibited analysis of entire cores. Therefore, sets of samples were selected from the cores to assure the following: 1) representative samples of all lithologies were analyzed, 2) samples of lithologies were random, and 3) roof, parting, and floor lithologies were adequately sampled. Four different sampling protocols were used: 1) selection of one-foot increment samples on the basis of lithology (USGS 9), 2) collection of one-foot samples every ten feet (USGS 9, USGS 11, and USGS 12), 3) collection of samples of roof, parting, and floor associated with coal-beds (USGS 9), and 4) selection of one-foot and partial-foot thick samples close to coal beds (USGS 9). The four sampling protocols were used to collect samples from core USGS 9 whereas only the second sampling protocol was used to collect samples from cores USGS 11 and USGS 12. Samples for analyses were obtained by splitting the core lengthwise with a diamond rock saw and taking the appropriate depth increment.

The first sampling method, used exclusively on core USGS 9, was based on lithologies. One hundred (100) one-foot increment samples representing the four principal lithologies of the core (9 claystone and mudstone, 20 shale, 23 siltstone, and 48 sandstone) were selected. The lithologic description of USGS 9 (Appendix A5) indicates a total thickness of 105 ft claystone and mudstone, 235 ft shale, 235 ft siltstone, and 1069 ft sandstone, or a distribution of the four lithologies of approximately 6, 14, 14, and 65 percent respectively. The samples selected for lithology are referred to as lithology samples, indicated as USGS 9-LITH. This sampling method assured that representative samples of the various lithologies, in proportion similar to their abundance in the entire core, were analyzed.

The second core sampling method, which was used on all three cores, consisted of collecting a one-foot increment within each ten-foot interval of the core. These samples are referred to as increment samples, indicated as USGS 9-10-ft, USGS 11-10-ft, and USGS 12-10-ft for the three cores. This method assured randomness of sampling of each core without bias toward any parameter except depth from surface.

The third sampling method involved selection of roof samples (generally six-inch increments of strata above coal beds), parting samples (variable thicknesses of rock within coal beds), and floor samples (generally six-inch increments of strata below coal beds) from core USGS 9. These samples, collectively referred to as RPF and indicated as USGS 9-RPF, were intentionally biased toward the strata that immediately overlie, are contained within, and underlie coal beds. The RPF samples were analyzed in order to evaluate the common perception that coal bed roof, parting, and floor strata tend to be relatively enriched in Se.

The fourth sampling method selected additional samples close to coal beds in core USGS 9. Some of these samples were one foot thick (indicated as 1-ft) and some were less than one foot thick (indicated as p-ft, for 'partial-foot'). Throughout this report the 1-ft samples selected close to coal beds, as well as the interval samples (one-foot thick sample collected in each ten-foot interval

of the core) are included in USGS 9-10-ft. Occasionally in this report the p-ft samples are also included in USGS 9-10-ft data analyses.

Selenium Analyses of Core Samples

Each one-foot increment of core was cut longitudinally with a saw so that about one quarter of the core was removed. These quarter-core splits were reduced in size to ¼ to ½ inch pieces with a jaw crusher. The resulting material was quartered and three parts archived in plastic sample bags. The remaining quarter was further reduced to about 1/8 inch pieces with a mortar and pestle and then ground in a shatterbox pulverizer for no more than 5 minutes to a size that passed through a 60 mesh screen.

The prepared samples were submitted to the analytical laboratory in the West Virginia University, College of Agriculture, Division of Plant and Soil Sciences, where they were analyzed for Se using the graphite furnace-atomic absorption (GFAA) method, modified ASTM 3052 [D1] (ASTM Method 3052). One quarter gram (0.25 g) of sample was weighed and placed in a fluorocarbon reaction vessel with a pressure relief valve fitted with a fluorocarbon membrane. The reaction vessel could withstand a pressure of 500 PSI. The sample was then digested in 3 milliliters (ml) of hydrofluoric acid (HF) and 9 ml of nitric acid (HNO_3) for 10 minutes in a microwave until all material appeared to be in solution. Subsequently, the digestion liquors were treated with 25 ml of saturated boric acid solution and then brought to 50 ml total volume by adding distilled water. The resultant solution was then filtered through Whatman #42 filter paper and analyzed for Se using the graphite furnace-atomic absorption spectrometer equipped with a Zeeman background correction system.

Results of the Se analyses of rock samples from all three cores are shown for USGS 9-LITH (Appendix B1), USGS 9-10-ft (Appendix B2), USGS 11-10-ft (Appendix B3), and USGS 12-10-ft (Appendix B4). Selenium determinations that were below the limits of detection (10 µg/kg) were reported as ND (not detected). It is a common statistical practice to assign a value equal to half the detection limit to samples with analyses below the detection limit. In this report, however, for statistical analyses of data sets and graphical illustration, ND data were assigned a value of zero (0). A third of the samples have a Se concentration greater than 1,000 µg/kg, which is two orders of magnitude greater than the lower detection limit. Thus, whether a value of zero or a value equal to half the detection limit (5 µg/kg) is assigned to samples with Se concentration below the detection limit will make little difference in statistical calculations and comparisons. The difference is discussed further under the heading "Results – Frequency Distribution of Selenium Concentrations in All Cores."

Analyses of Core Samples for Mineralogy and Major Element Oxides

A semi-quantitative estimate of the major-phase mineralogy was determined by X-ray diffraction (XRD) on all one-foot increment samples at WVU laboratories. The XRD method is semi-quantitative. Low values, less than approximately 5 percent, should be used with caution. The major mineralogical phases include chlorite, kaolinite, quartz, orthoclase (feldspar), calcite, pyrite, siderite, dolomite, illite, and albite (feldspar). In addition to mineralogy, the major element oxides were determined by X-ray fluorescence (XRF) at WVU laboratories. XRF is a semi-quantitative method. The major oxides include MnO, K2O, SiO2, Al2O3, SO2, Fe2O3, Na2O, MgO, TiO2, CaO, and P2O5. Results for XRD mineralogy and XRF major element oxides are

reported for USGS 9-LITH (Appendix B5), USGS 9-10-ft (Appendix B6), USGS 11-10-ft (Appendix B7), and USGS 12-10-ft (Appendix B8).

Analyses of Total Sulfur and Loss on Ignition in Coal-Bed Roof, Parting, and Floor Samples

In addition to standard coal analyses, which include total sulfur (dry basis) and ash (750º C, dry basis), the roof, parting, and floor samples from USGS 9 were analyzed for Se content. Loss on ignition (LOI) was calculated from percent ash, LOI = (100 – percent ash). Results of the analyses of roof, parting and floor samples from USGS 9 are shown in Appendix B9. Coal analyses are not considered in this report because coal is removed as part of the mining process, and should not represent a significant source of Se in disturbed areas.

Leach Tests: Saturated Paste Extract (SPE) and Sequential Water Extraction (SWE)

In addition to the analysis of total Se in selected core samples, some of the ground rock samples were analyzed for soluble Se by an adaptation of a method used in analyses of soluble salts in soils, a method known as saturated paste extract (SPE) (Rhoades, 1982). The SPE analyses were used to estimate the amount of Se that might be available for relatively rapid dissolution following land disturbance and reclamation.

The SPE Se determinations were conducted as follows on samples from USGS 9-10-ft, USGS 11-10-ft, and USGS 12-10-ft. A saturation paste of the sample was prepared by adding 11 ml deionized water to a 50-ml fluorocarbon centrifuge tube and then adding 30 g of sample. The mixture was allowed to set overnight, and then shaken for two (2) hours on a wrist-action shaker at a speed of 10. After shaking, the mixture was centrifuged at 5000 rpm for 25 minutes in an IES-Centram p4r centrifuge. The liquid obtained after centrifugation was filtered through a 0.45 µm cellulose nitrate membrane filter. The filtrate was analyzed for Se using the standard GFAA method on a Perkin-Elmer 4000 atomic absorption spectrophotometer. Results for the SPE leach tests are presented for USGS 9-10-ft (Appendix B10), USGS 11-10-ft (Appendix B11), and USGS 12-10-ft (Appendix B12).

A second SPE extraction was conducted on 7 of the 87 samples from USGS 11-10-ft. Following the initial saturated paste extract, the residual material was extracted a second time. The first extract (SPE) was labeled "A" (SPE-A) and the second extract was labeled "B" (SPE-B) (Appendix B11).

Selected samples from USGS 11-10-ft were subjected to sequential water extraction (SWE) of Se. Sequential water extractions were run on 44 fresh samples, designated A, some of which were splits derived from samples that were subjected to SPE. For the SWE samples, 10 ml of deionized water was added to 5 g of sample. The mixture was allowed to set overnight, and then shaken for two hours at a speed of 10 on a wrist-action shaker. The mixture was centrifuged at 5000 rpm for 25 minutes in an IES-Centram p4r centrifuge, and then filtered through a 0.45 µm cellulose nitrate membrane filter. The filtrate was then analyzed. Subsequent sequential extractions were conducted by adding an additional 10 ml of water to the solid residue, followed by repetition of all other steps, for up to six sequential extractions (2nd through 7th extracts). For 15 of the 44 samples, a second split was leached, resulting in analyses of duplicate samples, labeled “B.” Results for all SWE analyses for USGS 11-10-ft are presented in Appendix B13.

Results

Estimates of Analytical Precision

The American Society for Testing and Materials (ASTM) standard method for the determination of Se in rock samples (ASTM 3052 D1) was used in this study. ASTM evaluated the 95 percent confidence interval (CI 95%) for the method by conducting replicate analyses of National Institute of Standards and Testing (NIST) standard reference material (SRM) 2704, Buffalo River Sediment. NIST reports a Se concentration of 1.1 µg/g (ppm) in SRM 2704 but does not certify this value, possibly because only one analytical method was used to determine Se. ASTM analyzed SRM 2704 a number of times for 13 elements, including Se (n = 4), and reported a mean Se concentration of 1.13 µg/g (ppm) with a CI 95% of 0.9 µg/g (table 1). Thus, the determination of Se by the ASTM 3052 standard method may be relatively imprecise at the 1 µg/g (ppm) concentration level and below.

In the present study, the precision of the ASTM 3052 method for the determination of Se was estimated on the basis of analyses of replicate samples from USGS 9. Each of 12 one-foot increment samples from USGS 9 was analyzed twice, once as part of the lithology sampling, USGS 9-LITH (Appendix B1), and once as part of the 10-foot increment sampling, USGS 9-10-ft (Appendix B2). Inspection of the two sets of analyses indicate that the Se values from USGS 9-LITH samples are, in general, lower than the Se values for the USGS 9-10-ft samples (table 2).

As a result of the apparent differences in the duplicate analyses for Se in the twelve coincident samples from USGS 9, the twelve coincident samples were used to estimate the precision of the analytical method. In order to develop a data set that could be evaluated statistically, each of the twelve USGS 9-10-ft samples that was a duplicate of a USGS 9-LITH sample was sub-sampled two additional times. These sub-samples were then digested, and each digestion was analyzed three times. Thus, each of the twelve USGS 9-10-ft samples was sub-sampled a total of three times, designated as A, B, and C. The sub-samples were digested and each of the digestion liquors was analyzed in triplicate (identified as 1, 2, and 3). The data are shown in Appendix B14.

An estimate of the precision of the ASTM 3052 analytical method was based on statistical evaluation of the Se concentration data from three sub-samples and 3 replicate analyses of each sub-sample for 12 USGS 9-10-ft samples, which are coincident with 12 samples from USGS 9-LITH. The mean, standard deviation, number of analyses (N=9), and the 95 percent confidence interval (CI 95%) for the mean are shown in table 3 for the 12 coincident samples. A normalized metric was calculated in order to compare the 95 percent confidence intervals for mean Se concentrations among the 12 coincident samples in USGS 9, where replicate analyses may vary by two orders of magnitude (Appendix B14) and mean Se concentrations (table 3) are less than 1000 µg/kg (1 ppm), with the 95 percent confidence interval reported by ASTM, where the mean Se concentration (table 1) is greater than 1 µg/kg (1 ppm). The normalized metric, used here to indicate precision of results, is the CI 95% divided by the mean Se concentration, for each sample. The CI 95% reported by ASTM was divided by the mean reported by ASTM yielding a value of 0.80 (table 1). In the present study, for each sample, the CI 95% was divided by the mean and the 12 resultant values were averaged giving the lab's precision of the ASTM 3052 method as 0.80 (table 3). Thus, the precision of analyses by the ASTM 3052 method, estimated by the metric CI

95% / mean in the present study is similar to the precision reported by ASTM, even though the Se concentrations are lower in the present study (table 3) compared to the ASTM study (table 1).

Core Comparisons: a Test for Spatial Variation in Selenium Concentrations in Middle Pennsylvanian Coal-Bearing Strata

A principal objective of the present study was to evaluate spatial variation of Se concentrations in coal-bearing strata in the central Appalachian basin. Spatial variation in Se concentrations, as used in this report, refers to both stratigraphic variation (vertical trends) and regional variation (lateral trends).

Stratigraphic Variation

An analysis of stratigraphic variation of Se in Middle Pennsylvanian strata included the lower part of the Allegheny Formation down through the middle of the Kanawha Formation (Appendices A1, A2, A3). A stratigraphic comparison of Se concentration data was made within each of the three cores that were evaluated in the present study. The stratigraphic comparisons were based on the mean and 95% confidence interval of two specific stratigraphic intervals in each of the three cores. The two stratigraphic intervals were selected on the basis of a visual inspection of the data derived from analyses of samples from the first core that was analyzed, USGS 9-LITH (fig. 2). Visual inspection of the Se concentration values in USGS 9-LITH indicated that Se concentrations were commonly above the limits of detection from the Stockton A coal bed down to the Chilton A coal bed, whereas Se concentrations were commonly below the limits of detection from the Chilton A coal bed down to the Fire Clay coal bed. Thus, the two stratigraphic intervals consist of an upper interval from the base of the Stockton A coal bed down to the top of the Chilton A coal bed, and a lower interval from the base of the Chilton A coal bed down to the top of the Fire Clay coal bed. The plots of Se concentrations versus depth for the other core data sets are presented for USGS 9-10-ft (fig. 3), USGS 11-10-ft (fig. 4), and USGS 12-10-ft (fig. 5).

The univariate statistics for the two stratigraphic intervals for each core are presented in table 4. Comparisons of mean Se concentrations and their respective CI 95% for each stratigraphic interval are shown in figure 6 for each core. The rank order of the means of Se concentrations is always greater in the upper stratigraphic interval relative to the lower stratigraphic interval (table 4). However, only in USGS 9 is the mean value for Se concentration in the upper stratigraphic interval (from the bottom of the Stockton A coal bed down to the top of the Chilton A coal bed) statistically greater than that for the lower stratigraphic interval (from the bottom of the Chilton A coal bed down to the top of the Fire Clay coal bed). Statistical analyses of both samplings of USGS 9 (-LITH and -10-ft) indicate that the mean Se values in strata overlying the Chilton A Coal bed (553 and 666 μg/kg Se, respectively) are greater than the mean Se values in strata that underlie the Chilton A coal bed (64 and 329 μg/kg Se, respectively) (table 4). In contrast, based on t-tests, there are no statistical differences between the means of Se concentrations in the two stratigraphic intervals in either USGS 11-10-ft or USGS 12-10-ft (table 4). The apparent stratigraphic trend in Se concentrations in coal-bearing strata, exclusive of coal, in USGS 9 is consistent with stratigraphic trends in Se in coal beds as reported by WVGES (2002) for West Virginia and Neuzil and others (2005) for the Appalachian Plateau region. Although the rank-order of Se values in the upper and lower stratigraphic interval is consistent among the three cores, stratigraphic trends in Se concentrations cannot be verified statistically in either USGS 11 or USGS 12 for the stratigraphic intervals considered. Thus, a stratigraphic trend in Se concentrations in rock in the Middle Pennsylvanian coal-bearing strata cannot be stated with certainty on the basis of the present study.

Regional Variation

Regional variation was tested on the basis of three cores, USGS 9, USGS 11, and USGS 12 spaced approximately 50 km apart (fig.1). Regional variation among cores was evaluated by a statistical t-test comparison of mean Se concentrations (µg/kg) for each of the two stratigraphic intervals. The results are summarized in table 5. The rank order of the mean Se concentrations in the upper stratigraphic interval is USGS 9-10-ft > USGS 9-LITH > USGS 12-10-ft > USGS 11-10-ft. Statistical t-tests show that USGS 9-10-ft is greater than both USGS 12-10 ft and USGS 11-10 ft and that USGS 9-LITH is greater than USGS 11-10-ft. Otherwise, mean Se concentrations are statistically equal. For the lower stratigraphic interval, the rank order of the mean Se concentrations is USGS 9-10-ft > USGS 12-10-ft > USGS 11-10-ft > USGS 9-LITH. Statistical t-tests show that mean Se concentration in USGS 9-10-ft samples is greater than mean Se concentration in USGS 9-LITH samples. All other mean Se concentrations are equal for the lower stratigraphic interval. There are no differences in mean Se concentration between any two cores that hold for both the upper and lower stratigraphic interval. On the basis of data derived from analyses of samples obtained from the three cores that were tested in this study, there are no apparent regional variations (trends) in Se concentrations.

Frequency Distribution of Selenium Concentrations in Three Cores

The univariate statistics and frequency distribution information for Se concentrations in all 1-foot increment samples collected at 10-foot intervals (USGS 9-10-ft, USGS 11-10-ft, and USGS 12-10-ft), are shown in table 6. The Se values for USGS 9-LITH were not used for this analysis because of the different sampling method. The two highest Se values, 6820 and 3300 µg/kg, are considered high outlier values because they are each approximately twice the value of the next highest Se concentration (table 6). These samples were dropped in order to examine the frequency distribution of Se concentrations in the remaining 234 samples collected at 10-foot intervals (fig. 7). Concentrations below the limit of detection (ND) account for 33 percent of all Se concentration values. Sixty eight percent of the values are less than 500 µg/kg, and eighty nine percent of the values are below 1000 µg/kg. Therefore, the Se data appear to have a log normal distribution, which is typical for trace element geochemical data. Whether Se concentrations below the detection limit are assigned a value of zero or 5 µg/kg (half the limit of detection), the mean and standard deviation change by 2 µg/kg, which is less than 1 percent of the value of the mean and standard deviation (table 6). In this study a value of zero was assigned to samples below the detection limit, which made little overall difference to the statistics.

Selenium Concentrations and Dominant Lithologies (Rock Types)

Four dominant rock types in USGS 9 were sampled for USGS 9-LITH in proportions similar to their total thickness in the entire USGS 9 core (Appendix A5). The proportions of the four dominant rock types in core USGS 9 and the two sample sets taken from the core are as follows: claystone and mudstone, shale, siltstone, and sandstone each represent 6, 14, 14, and 65 percent of core USGS 9; 9, 20, 23, and 48 percent of samples in USGS 9-LITH; and 14, 5, 10, and 71 percent of samples in USGS 9-10-ft. The mean Se concentrations and 95 percent confidence intervals (µg/kg) within each of the four lithologies were used to evaluate the relation, if any, between rock-type and Se concentrations. Univariate statistics and comparisons among dominant lithologies were conducted on the two data sets from USGS 9, USGS 9-LITH samples selected by lithology and USGS 9-10-ft samples collected every ten feet, and are summarized in table 7.

The mean Se concentration ± the 95 percent confidence interval for the four dominant lithologies from USGS 9-LITH and USGS 9-10-ft are shown in figure 8 and figure 9. Among the four dominant rock types in the two samplings of USGS 9, the rank order of the mean Se concentrations are higher in siltstone than in claystone, shale, or sandstone. However, t-test statistical analyses show that only mean Se concentrations in siltstone are higher than in claystone for both samplings (table 7).

Selenium Concentrations in Roof, Parting, and Floor samples

T-test analyses of the Se concentration data derived from roof (rock immediately above coal beds), parting (rock within coal beds), and floor (rock immediately below coal beds) samples from USGS 9 indicate that the mean Se concentrations in coal-bed roof, parting, and floor samples are statistically equal (table 8). Because the mean Se concentrations in roof, parting, and floor samples are equal, the three data sets can be combined and referred to as RPF. The univariate statistics for USGS 9-RPF samples are shown in table 9. The mean Se concentration for all USGS 9-RPF samples was compared to the mean Se concentrations of the four dominant lithologies data sets derived from each of two samplings of USGS 9 (figs. 10 and 11). The statistical t-test comparisons of RPF samples with samples of four dominant lithologies in USGS 9-LITH and USGS 9-10-ft are summarized in table 10.

Results show that RPF samples are likely to have Se concentrations that are similar to siltstones, but greater than claystones, shales, and sandstones. The statistical similarity between RPF samples and shale samples from USGS 9-10-ft is due to the large dispersion of the mean, indicated by the large 95 percent confidence interval, for the few (N = 4) shale samples (table 7).

The statistical t-test evaluation comparing mean Se concentrations separately in each of the roof, parting and floor sample data sets with each of the four dominant rock types (lithologies) from USGS 9-LITH samples (fig. 8) and USGS 9-10-ft (fig. 9) are summarized in table 10. The results are similar to those comparing RPF samples to the four dominant lithologies. Roof and floor samples have Se concentrations similar to siltstone samples whereas roof, parting, and floor samples have Se concentrations greater than claystone, shale, and sandstone samples for USGS 9-LITH (fig. 8; table 10). The rank-order of the means for roof, parting, and floor samples and the four dominant lithology types of samples from USGS 9-LITH is as follows: parting > floor > roof > siltstone > sandstone > shale > claystone (tables 7 and 8). For USGS 9-10-ft, differences in the mean Se concentration are not discernible between roof samples and the four dominant lithologies, whereas parting and floor samples tend to have Se concentrations greater than claystone and sandstone samples and similar to shale and siltstone samples (fig. 9; table 10). The rank order of the means for roof, parting, and floor samples and the four dominant lithologies in USGS 9-10-ft is as follows: parting > siltstone > floor > roof > sandstone > claystone > shale (tables 7 and 8).

Relation Between Selenium, Mineralogy, and Major Element Oxides Concentrations

Pearson's product moment correlation coefficients were calculated between Se and each mineral and major element oxide concentration in each core sampling. Few significant correlations (at the 5 percent level of significance) were found. There are no significant correlations of Se with pyrite or Fe_2O_3 in any of the four core samplings. More than half of the samples in each of the four core sample sets have zero values (below detection limit) for calcite, pyrite, and sulfur (Appendices B5, B6, B7, B8).

Selenium concentration is significantly correlated with siderite in samples from USGS 9-LITH (fig. 12). Selenium concentrations for samples from USGS 9-10-ft are not significantly correlated with any mineral or major element.

Se concentrations in samples from USGS 11-10-ft include one point with high Se, calcite, and CaO concentrations (Appendices B3 and B7; fig.13). When this high value sample is included in the data set, the correlations between Se and calcite and between Se and CaO appear to be significant (fig. 13). Upon removal of the data point with high Se, calcite, and CaO, and given that most of the samples have calcite concentrations that are below the limit of detection, there is no significant correlation between Se and calcite or CaO in USGS 11-10-ft (fig. 13).

For samples from USGS 12-10-ft, Se is significantly correlated with clay minerals (chlorite, kaolinite, and illite), calcite, and K_2O (fig. 14). The correlation between Se and chlorite is weak as there are many points without detectable Se or measurable amounts of chlorite, and the remainder of the points are distributed above and below the trend line. The correlations between Se and kaolinite, illite, calcite, and K_2O are also weak and thus the concentration of these minerals or K_2O is not a good predictor of the Se concentration.

Sulfur, Loss on Ignition, and Selenium in Roof, Parting, and Floor Samples

The data for coal-bed roof, parting, and floor samples from USGS 9 (Appendix B9) were analyzed to determine if there is a significant correlation between Se and total sulfur. The Se concentration has a range from below detection to 3340 µg/kg and total sulfur has a range of 0.01 – 2.22 percent for 26 samples. The results indicate that Se concentrations in the selected roof, parting and floor samples do not statistically correlate with total sulfur concentrations (a proxy for the mineral pyrite, FeS_2) (fig. 15). Therefore, it is unlikely that a significant portion of Se is associated with pyrite in these samples.

The data for coal-bed roof, parting, and floor samples from USGS 9 were also analyzed to determine if there is a significant correlation between Se and organic matter. The loss on ignition data, calculated from ash analyses, were used as a proxy for the amount of organic matter. The range of loss on ignition is 6 – 48 percent (Appendix B9). Statistical evaluation of the data indicate that the Se concentrations in the roof, parting, and floor samples are correlated with the loss on ignition at the 5 percent level of significance ($R = 0.480$, which exceeds the critical value for $R_{(0.05)} = 0.388$) (fig. 16). The positive correlation between Se and loss on ignition suggests that Se may occur as organically bound Se.

The statistical comparisons conducted in the present study do not provide an unequivocal indication of any relation between Se concentrations and sample mineralogy or sample chemistry. The positive correlations that were noted between Se concentrations and sample mineralogy cannot be applied with certainty on the basis of the data derived in the present study. Therefore, further investigation is needed to determine the mode of occurrence of Se in coal-bearing strata and its association with both inorganic and organic material.

Aqueous Extraction of Soluble Selenium

There is no generally accepted standard method for the determination of soluble Se in rock samples. Therefore, in order to estimate soluble Se in the present study, both the saturated paste

extract (SPE) and sequential water extraction (SWE) methods described above were used to evaluate the amount of Se extracted by water.

The concentration of Se extracted into water from rock, was compared to the total amount of Se in the rock. The Se concentration (µg/L or ppb) extracted from rock samples by the SPE method was compared to the total Se concentration (µg/kg or ppb) in rock samples from USGS 9-10-ft (fig. 17), USGS 11-10-ft (fig. 18), and USGS 12-10-ft (fig. 19). The Se concentration (µg/L) extracted from rock samples by the SWE method also was compared to the total Se concentration (µg/kg) in rock samples from USGS 11-10-ft (fig. 20). In several rock samples, the Se concentration is below the detection limit of the GFAA method, yet detectable concentrations of Se are leached by SPE or SWE methods. In other cases, high concentrations of Se are measured in rock samples yet low concentrations of Se are leached from the rock (figs. 17, 18, 19, 20). Se concentrations in SPE leachates from rock do not correlate with Se concentration in the rock in any of the three cores (figs. 17, 18, and 19). Furthermore, the Se concentration in leachates from either the SPE or the SWE leaching method do not correlate with the Se concentration in the rock in core USGS 11 (figs. 18 and 20).

The reproducibility of water extraction of soluble Se from freshly ground rock samples was examined in core USGS 11. Comparison of Se concentration in leachates of duplicate sub-samples, SWE-A and SWE-B, give consistent results (fig. 21). It is not clear why Se concentrations are higher in SWE-B than in SWE-A in 13 of 15 samples leached in duplicate (Appendix B13). In the SWE extractions, two times as much mass of water (10 ml) as rock (5 g) was used and each sub-sample was processed in the same way. The correlation coefficient is high with an R = 0.9709 for 15 samples (fig. 21). Although SWE leaching is not a standard method to determine soluble Se, it appears to give reliable results, and the scatter of data points suggests that soluble Se concentrations appear to be reproducible within a factor of two.

The two methods of extracting soluble Se from rock were compared to determine whether the water to rock mass ratio used in the extraction influences either the concentration of Se in the water-extract leachate or the amount of Se extracted from the rock. The SPE method used 0.011 L water / 0.030 kg rock whereas the SWE method used 0.010 L water / 0.005 kg rock. Thus the SWE leach method used 5.4 times more water per kg of rock than the SPE method. The SPE-A and the SWE-A extractions, both first extraction leachates, were conducted on 44 duplicate rock samples from USGS 11-10-ft. Two observations were made. First, the concentration of Se is higher in SPE-A leachates than in SWE-A leachates in 38 of 44 samples (fig. 22) with a high correlation coefficient R = 0.8340 that suggests each method gives internally consistent results. The lower Se concentrations in SWE-A leachates compared to SPE-A leachates may be a result of dilution by more water used per mass of rock leached in the SWE method compared to the SPE method.

Second, in order to compare the amount of Se leached from rock by the two methods, the Se concentrations in SPE-A and SWE-A were normalized to account for the mass of water and rock used and is hereafter referred to as "absolute Se" with units of µg Se in solution / kg of rock leached. For SPE, the absolute Se is calculated by multiplying the Se concentration in leachate (µg Se / kg leachate) by 0.011 kg leachate / 0.030 kg rock and for SWE the absolute Se is calculated by multiplying the Se concentration in leachate (µg Se / kg leachate) by 0.010 kg leachate / 0.005 kg rock. Comparison of the absolute Se determined for the SWE and SPE methods for USGS 11 shows that the absolute Se extracted by SWE method is greater than the absolute Se extracted by the SPE method in 33 of 44 samples (fig. 23). The slope of the line in figure 23 indicates that the

SWE method extracts twice as much Se from rock as the SPE method. This suggests that the more water that comes in contact with rock, the more Se may be leached from the rock.

Sequential water extractions of Se by the SWE method were conducted in this study to determine whether the concentration of Se in leachates changes over time as successive amounts of water come into contact with the rock (Appendix B13; fig. 24). The results show that in cases where the initial leachate Se concentrations are high, approximately 30 µg/L or higher, there is a generally rapid decrease in Se concentrations in successive leachates. After several leaches, approximately four, the concentration of Se is lower, generally less than 15 µg/L, and fairly constant (fig. 24).

Discussion

Selenium Concentration, Lithology, and Mineralogy

The average Se concentrations in dominant rock types (lithologies) in this study were compared with the average Se concentrations in upper continental crust (Wedepohl, 1995; Rudnick and Gao, 2003) and sedimentary rocks (Horn and Adams, 1966; Baedecker and others, 1998). The average Se concentration in upper continental crust is estimated as 0.083 ppm by Wedepohl (1995) and 0.09 ppm by Rudnick and Gao (2003). However, sedimentary rocks only represent a small portion, approximately 14 percent, of the upper continental crust (Wedepohl, 1995). Horn and Adams (1966) estimated Se concentrations in six sedimentary and marine domains, including shale and sandstone, based on iterative geochemical mass balance calculations, starting with a range of Se concentrations reported in the literature. Se could not be brought into an internally consistent mass balance in the model, probably as a result of significant volcanic input, and should be considered as an order of magnitude estimate (Horn and Adams, 1966). The range and calculated average Se concentrations for shale and sandstone reported by Horn and Adams (1966) are similar to those for the central Appalachian basin shale and sandstone samples analyzed in this study (table 11). Se concentrations in shale, siltstone, and sandstone samples from the western U.S. are reported in the PLUTO data base (Baedecker and others, 1998). Average Se concentrations calculated for these western U.S. samples are approximately 5 to 7 times the average Se concentrations in shale, siltstone, and sandstone in the central Appalachian basin samples in this study (table 11). These comparisons suggest that the Se concentrations in central Appalachian sedimentary rocks associated with coal beds are not anomalously high when compared to upper continental crust, global estimated average sedimentary rocks, or western U.S sedimentary rocks.

Several recent studies have examined Se concentrations in various lithologies collected from cores drilled in coal-bearing strata in southern West Virginia (Jenkins and Schaer, 2005; Mullennex, 2005; Roy, 2005; Vesper and Roy, 2006). Samples in those studies were collected from different stratigraphic intervals, selected using different criteria, and categorized into different lithologic groups compared to this report. Also, data were presented with different emphases than in this report, for example, contrasting samples that were located close to or far from coal beds using either 5 ft (Mullennex, 2005) or 2 ft (Vesper and Roy, 2006) as the operational cutoff distance. Nevertheless, some general comparisons can be made to data presented in this report. Mullennex (2005) sampled 5 cores in one mine in southwestern West Virginia in the stratigraphic interval from the No. 6 Block coal, lower Allegheny Formation, down to the Coalburg coal, upper Kamawha Formation. This interval partially overlaps the upper part of the “upper stratigraphic interval” in this report. Mullennex (2005) presents mean Se concentrations for all shale and all

sandstone, regardless of proximity to coal beds. The mean Se concentrations for all shale and all sandstone in USGS 9-10-ft, USGS 11-10-ft, and USGS 12-10-ft core samples (table 11) are within a factor of three of those found by Mullennex (2005). Given the differences in sampling protocol and stratigraphic interval of Mullennex (2005) and this report, these results are fairly similar.

The present study evaluated Se concentrations in four rock types (claystone, shale, siltstone, and sandstone) in one core, USGS 9, to determine relations, if any, among rock-type and Se concentrations. For both USGS 9-LITH and USGS 9-10-ft samples, mean Se concentrations were equal in shale and claystone whereas mean Se concentrations in siltstone were greater than claystone (table 7). Other comparisons of mean Se concentrations among the lithologies were inconsistent from USGS 9-LITH samples to USGS 9-10-ft samples (table 7).

Mineralogy was determined by X-ray diffraction on all samples in four core sample sets. In one core, a correlation was found between siderite and Se whereas in another core, clay minerals (chlorite, kaolinite, and illite) correlated with Se. Calcite is below detection in most of the samples. In the few samples where calcite is present at high concentrations, the data suggest it may be associated with high Se content. There is no correlation between Se and any mineral that holds for all cores. Thus, if statistically significant correlations between Se concentrations and mineralogy exist, they are below the level of detection by the combined sampling, analytical, and statistical methods used in the present study.

Comparison of Se Concentration in Roof, Parting, Floor, and Four Dominant Lithologies

Coal-bed roof, parting, and floor samples from core USGS 9 were evaluated to determine the relation, if any, between these organic-rich samples that are adjacent to coal beds and their Se concentrations. The equality of the mean values and variances for each type of sample were used in the comparison. The variances and means are statistically equal among Se concentration for roof, parting, and floor samples as shown in table 8.

Collectively RPF (roof, parting, and floor) samples have mean Se concentrations equal to siltstone and greater than claystone and sandstone in core USGS 9 (figs. 10, 11; table 10). Another way of stating this is that organic-rich RPF samples located adjacent to coal beds have higher Se concentrations than sandstone samples with a distance from coal beds unspecified, for one core analysed. Jenkins and Schaer (2005) sampled 7 cores from 3 areas in southern West Virginia in the stratigraphic interval from the No. 5 Block coal, lower Allegheny Formation, to the Winifrede coal, upper Kanawha Formation. They found higher concentrations of Se in dark organic-rich rock close to coal beds compared to sandstone farther from coal beds. Roy (2005) and Vesper and Roy (2006) examined one core in the Coalburg through the Winifrede interval in the upper Kanawha Formation. Vesper and Roy (2006) and Mullennex (2005) found a trend of more Se in organic-rich rock ('carbolith' or 'coal and shale') than shale than sandstone. The rank order for mean Se concentration for USGS 9-LITH was RPF (organic-rich rock close to coal) > sandstone > shale and for USGS 9-10-ft RPF > sandstone = shale (tables 7, 10). The difference in the rank order of the mean Se concentration of various lithologies (organic-rich rock, shale, and sandstone) compared between results found in this report and those published in the literature may be a result of different sampling protocols and different stratigraphic intervals examined.

In this report, the Se concentrations in RPF samples do not correlate with sulfur (a proxy for pyrite) but do correlate with loss on ignition (a proxy for organic matter). Similarly, Mullennex

(2005) found no correlation between Se and total, pyritic, or organic sulfur in samples from the No. 6 Block coal bed through the Coalburg coal bed stratigraphic interval. Roy (2005) and Vesper and Roy (2006) did not find any strong correlation between Se and sulfur content or organic matter in rock samples.

Mobilization of Soluble Selenium

The results of the saturated paste extract (SPE) and sequential water extraction (SWE) studies reported herein should be used with caution because standard leaching methods have not been developed, nor have definitive Se laboratory leaching studies been conducted. The SPE results of this study suggest that total Se in rock is not a predictor for soluble Se. Roy (2005) and Vesper and Roy (2006) also noted that soluble Se was not correlated to total Se in rock. SPE or some other leaching procedure, rather than total Se values determined on whole-rock samples, may provide a more accurate indication of the potential for Se mobilization to streams following land disturbance.

The sequential water extraction (SWE) leaching method used in this study gives results that appear to be reproducible within a factor of approximately two (Appendix B13; fig. 21). Given the potential for differences in particle sizes, mineralogy, and modes of occurrence of Se in the duplicate sub-samples, this reproducibility is fairly good.

Comparison of the two leaching methods (SPE and SWE) used in this study suggest that the more water that comes into contact with rock, such as groundwater flow through rock, (1) the lower the concentration of resultant dissolved Se and (2) the more Se will be leached from the rock. In disturbed strata, the surface area of rock exposed per mass of rock is almost certainly less than in the < 60 mesh rock samples used for SPE and SWE leaching in this study. Therefore, one would expect less efficient leaching of Se in disturbed rock strata than in these laboratory studies.

The sequential leaching studies presented here suggest that Se concentrations of water passing through disturbed rock strata may have an initial increase in Se followed by a decrease in Se concentrations. Thus, soluble Se may be removed rapidly from disturbed rock strata with freshly exposed surfaces. Bonta and Dick (2003) observed an increase in Se concentration in streams below coal mining, at three of three mines studied during mining in the northern Appalachian basin in Ohio. They found that at one of two coal mines with data after mining, Se concentrations decreased to pre-mining levels within 6 years. The sequential leaching studies presented here indicate that the “half life” of dissolution of Se from coal-bearing lithologies may be relatively short; suggesting that the relative enrichment of Se in streams draining disturbed areas may decrease to baseline levels within a relatively few years.

Summary and Conclusions

The results and conclusions of the present study are summarized as follows:

- The precision of the analytical results for total Se in rock samples presented herein are consistent with the precision of the analytical method, ASTM 3052, that was used.
- The average Se concentrations in the four dominant lithologies in coal-bearing strata in the central Appalachian basin, as determined in the present study, are similar to the global average

Se concentrations reported for equivalent lithologies (Horn and Adams, 1966) and therefore are not anomalous.

- Rank order of the mean Se concentrations in all coal-bearing lithologies shows that mean Se concentrations are higher in upper strata (Stockton A coal bed to Chilton A coal bed) than in lower strata (Chilton A coal bed to Fire Clay coal bed) in three widely spaced cores in the central Appalachian basin in southern West Virginia. This stratigraphic trend is similar to the stratigraphic trend in Se concentrations in coal beds in the central Appalachian basin reported by Neuzil and others (2005).
- On the basis of data derived from analyses of samples obtained from three cores in this study, there is no demonstrable regional variation (trend) in Se concentrations.
- The present study evaluated Se concentrations in a variety of lithologies, rock types, to determine relations, if any, among rock-type and Se concentrations. The results indicate that average Se concentrations tend to be higher in siltstone compared to claystone, shale, and sandstone. When the means and variances of Se concentration are compared in claystone, shale, and sandstone, there are no statistically demonstrable differences. If differences exist, they are below the limits of verification by the methods used in the present study.
- Although Se concentrations correlate with some minerals (siderite, chlorite, kaolinite, and illite as determined by XRD) in some cores, Se does not consistently correlate with any mineral in all cores.
- Se concentrations were determined in selected coal-bed roof, parting, and floor samples from one core. When the data are evaluated statistically, taking into account the mean and variances, there are no demonstrable differences in mean Se concentrations among roof, parting, and floor samples.
- Se concentrations do not statistically correlate with total sulfur concentrations suggesting that there is not a correlation with pyrite in the selected coal-bed roof, parting, and floor samples. However, Se concentrations in the selected coal-bed roof, parting, and floor samples do correlate with the loss on ignition, which suggests an association of Se with organic matter. If so, rates of mobilization of Se from these organic-rich materials are expected to be controlled by relatively slow rates of chemical oxidation of the host organic matter. General principles of chemistry suggest that oxidation and dissolution of refractory organic compounds are typically quite slow at ambient conditions.
- The uncertainties associated with the analyses of low concentrations of Se in whole-rock samples and the lack of correlation between total Se in rock and susceptibility of Se to dissolution suggest that leaching tests, rather than whole-rock analyses, may provide a more useful estimation of the potential for Se dissolution and mobilization from coal-bearing strata and the potential for increased Se concentrations in surface streams as a result of land disturbances.
- The readily soluble fraction of total Se in coal-bearing strata is not known. However, the cursory study of sequential leaching conducted in the present investigation indicates that readily soluble Se may be rapidly removed from rock debris following disturbance of strata. It appears that the “half life” of dissolution is relatively short, suggesting that any relative enrichment of Se in streams draining disturbed areas may decrease to baseline levels within a relatively few years after disturbance. Substantiation of the conclusion that Se leaching from disturbed strata will have a short half life will require further testing at reclaimed sites.

On the basis of the present study, the average concentrations of Se in Middle Pennsylvanian coal-bearing strata in the central Appalachian basin are not anomalous when compared to published values of similar rock types. In addition, the average and spread (mean and dispersion) of Se concentrations indicate that if either stratigraphic or regional trends exist, such trends can not be verified statistically by the methods used herein. Also, there is no apparent association of Se with a specific rock type (claystone, shale, siltstone, or sandstone) with the possible exception of Se enrichment in certain siltstones. Leaching test methods, rather than total Se content of rocks, may more accurately represent the potential for Se mobilization by land disturbance.

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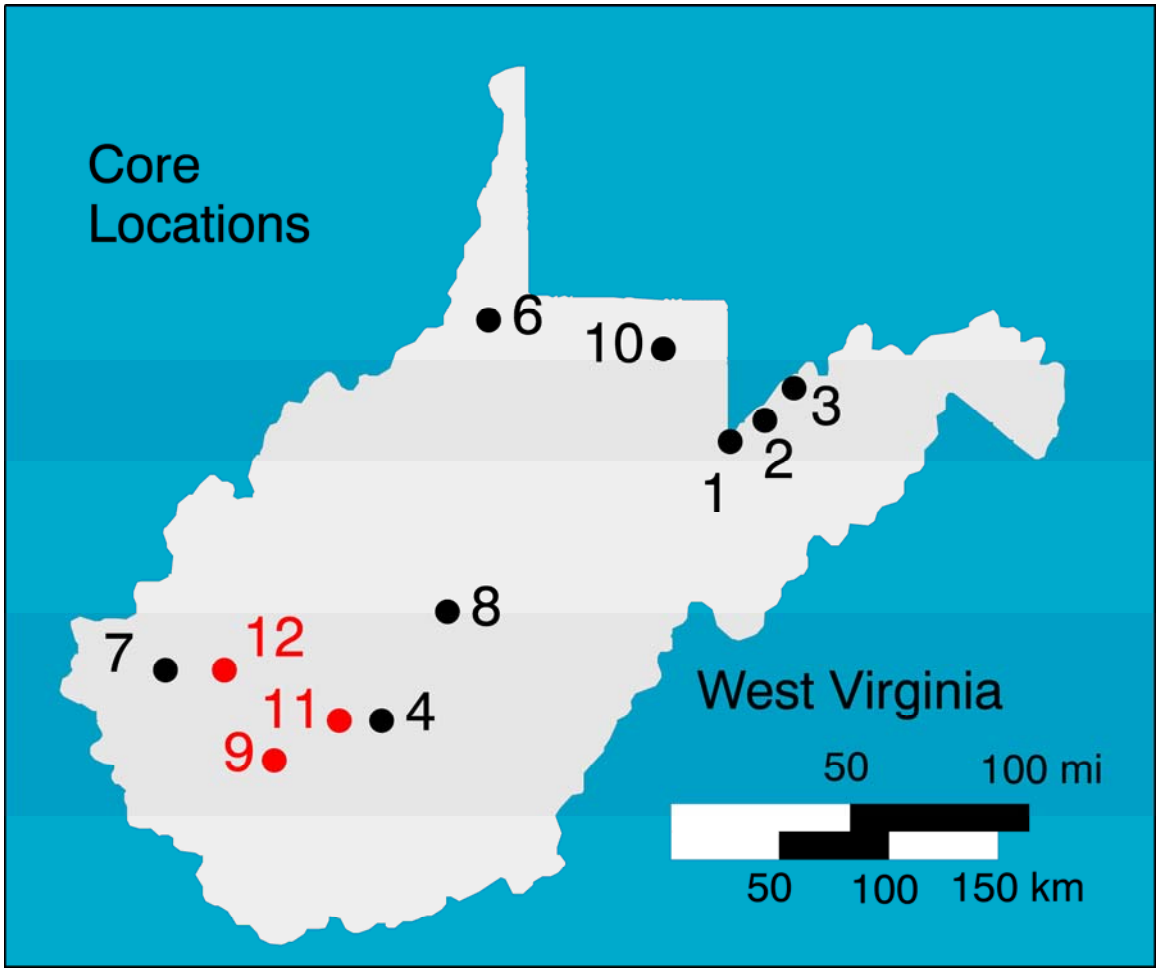


Figure 1. Map showing the location of three widely spaced cores (USGS 9, USGS 11, and USGS 12, indicated by red dots) in West Virginia, used in this study as part of a regional study of geochemical variation in the central Appalachian basin.

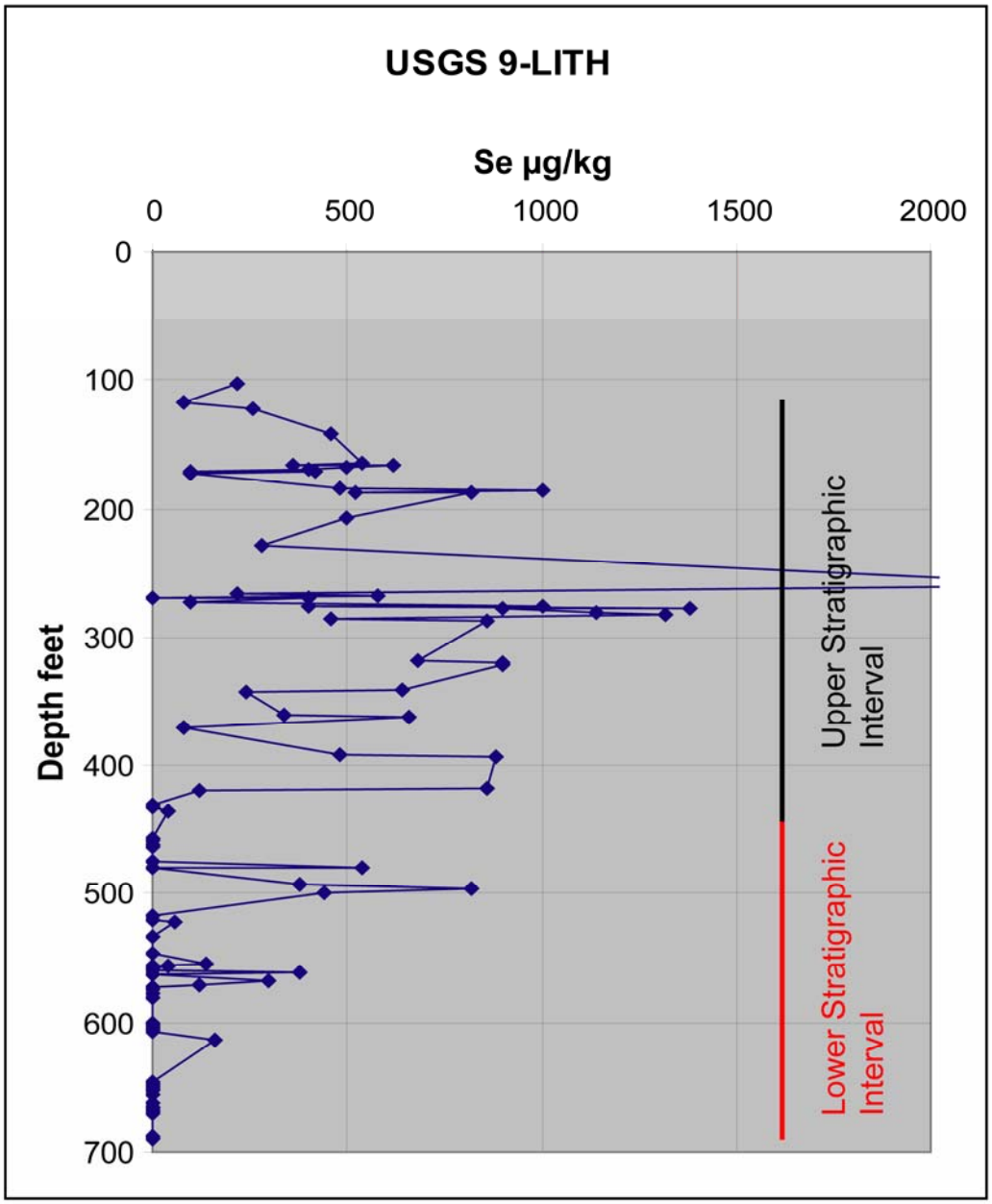


Figure 2. Se concentration (µg/kg) versus depth (ft) in core USGS 9-LITH samples, 1-foot increment samples selected by lithology.

The interval from the base of the Stockton A coal bed (114 feet) down to the top of the Chilton A coal bed (446 feet) is referred to as the upper stratigraphic interval. The interval from the base of the Chilton A coal bed (448 feet) down to the top of the Fire Clay coal bed (690 feet) is referred to as the lower stratigraphic interval. One Se value of 2440 µg/kg at 258-259 feet is larger than the maximum x-scale of 2000 µg/kg Se.

Data are from Appendix B1. [symbols indicate depth in core and Se concentration of rock samples analyzed; lines connecting symbols are for illustration purposes only and do not indicate Se concentrations of rock]

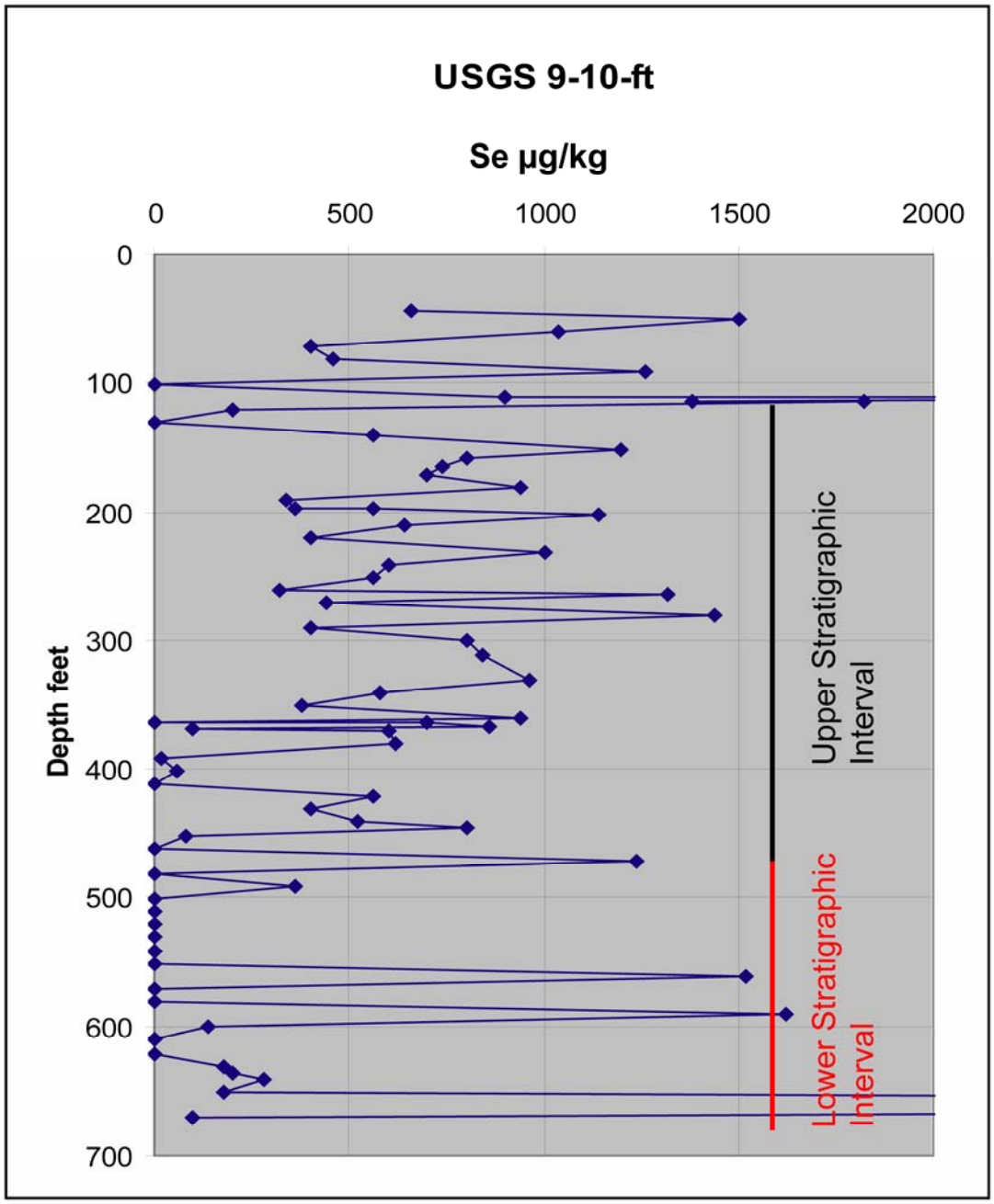


Figure 3. Se concentration (µg/kg) versus depth (ft) in core USGS 9-10-ft samples, 1-foot increment samples collected at 10-foot intervals.

The interval from the base of the Stockton A coal bed (114 feet) down to the top of the Chilton A coal bed (446 feet) is referred to as the upper stratigraphic interval. The interval from the base of the Chilton A coal bed (448 feet) down to the top of the Fire Clay coal bed (690 feet) is referred to as the lower stratigraphic interval. Two Se values of 3300 µg/kg at 110.42-110.90 feet, and 6820 µg/kg at 660-661 feet are larger than the maximum x-scale of 2000 µg/kg.

Data are from Appendix B2. [symbols indicate depth in core and Se concentration of rock samples analyzed; lines connecting symbols are for illustration purposes only and do not indicate Se concentrations of rock]

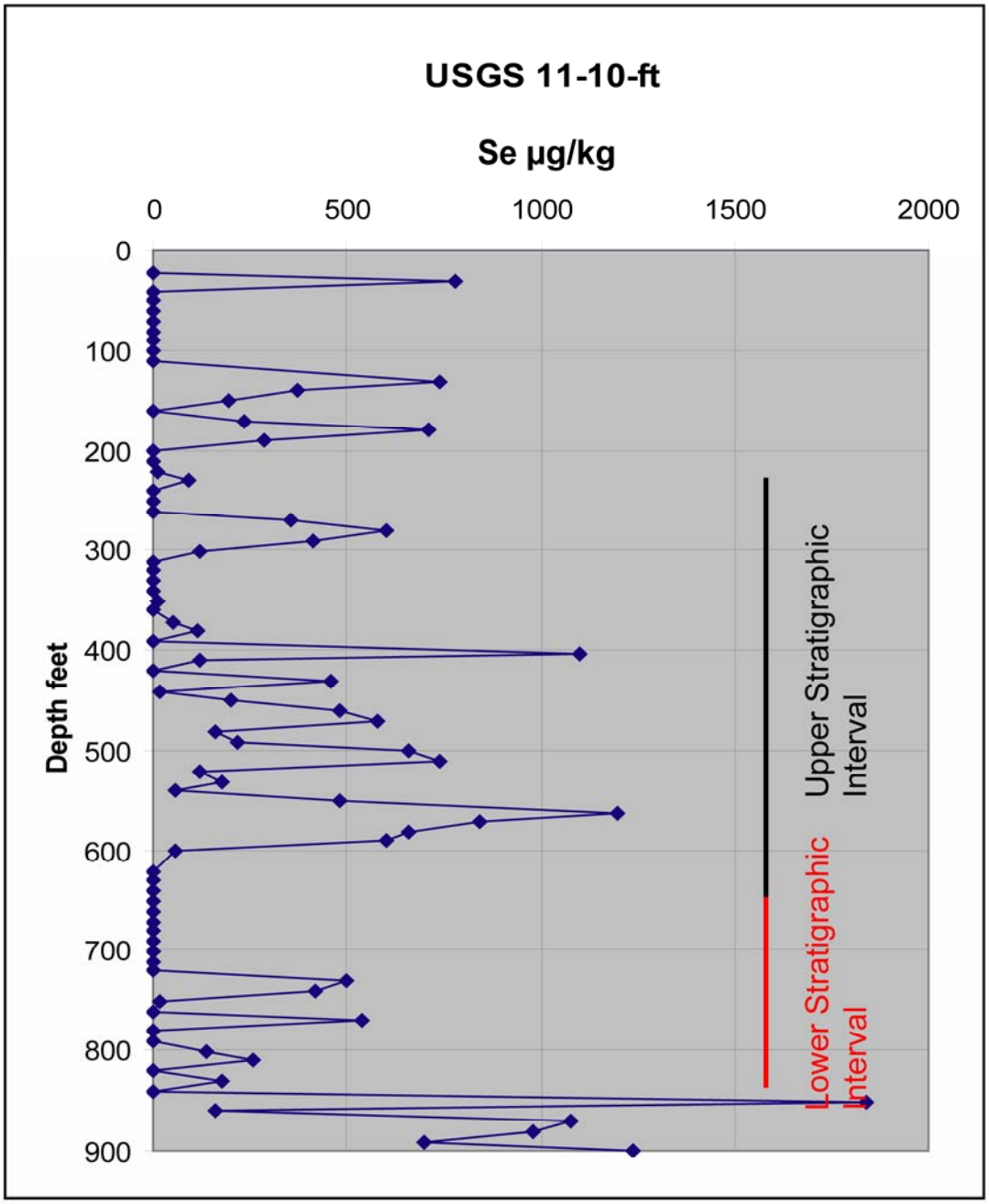


Figure 4. Se concentration (µg/kg) versus depth (ft) in core USGS 11-10-ft samples, 1-foot increment samples collected at 10-foot intervals.

The interval from the base of the Stockton A coal bed (239 feet) down to the top of the Chilton A coal bed (652 feet) is referred to as the upper stratigraphic interval. The interval from the base of the Chilton A coal bed (653 feet) down to the top of the Fire Clay coal bed (828 feet) is referred to as the lower stratigraphic interval.

Data are from Appendix B3. [symbols indicate depth in core and Se concentration of rock samples analyzed; lines connecting symbols are for illustration purposes only and do not indicate Se concentrations of rock]

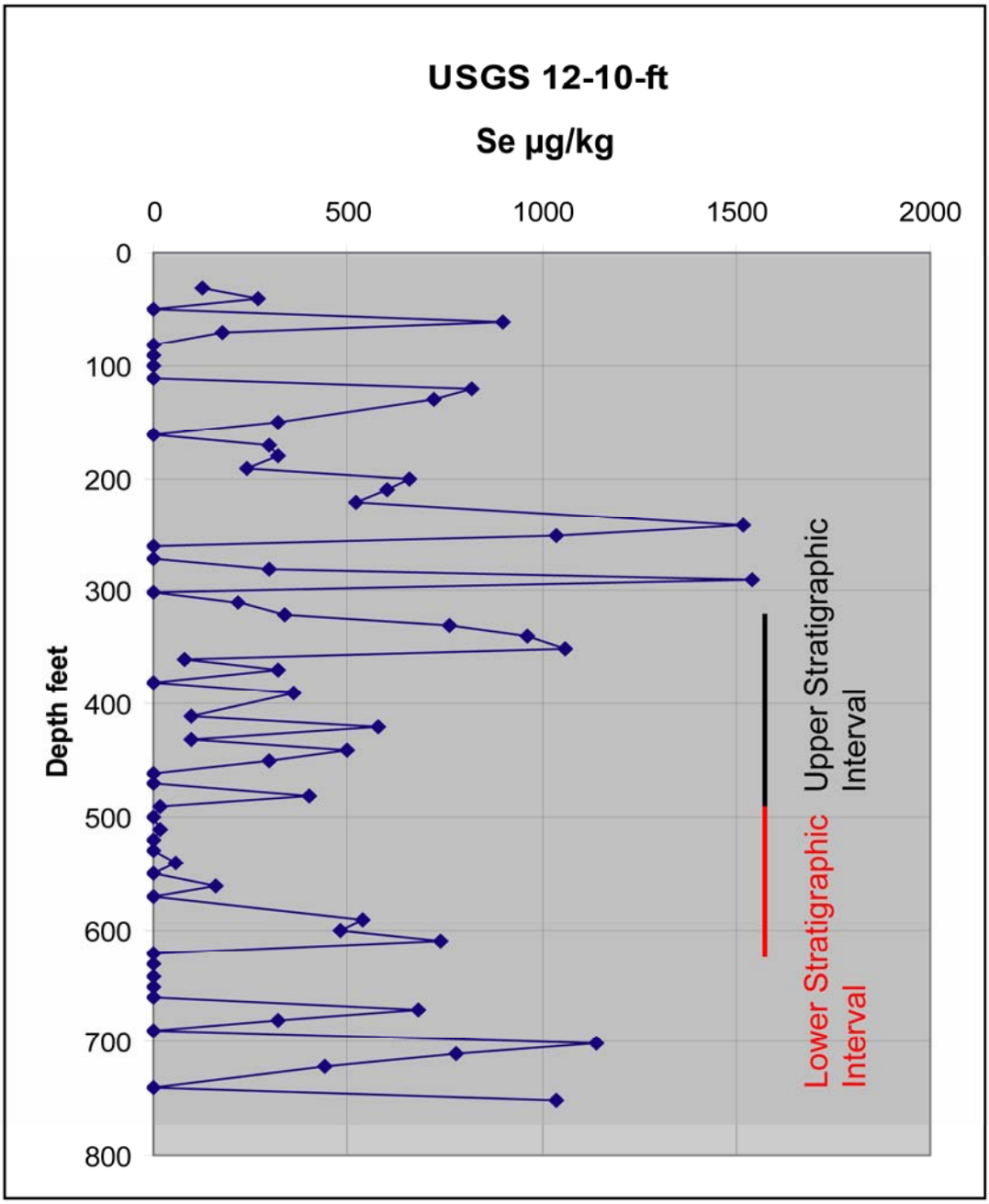


Figure 5. Se concentration (µg/kg) versus depth (ft) in core USGS 12-10-ft samples, 1-foot increment samples collected at 10-foot intervals.

The interval from the base of the Stockton A coal bed (316 feet) down to the top of the Chilton A coal bed (492 feet) is referred to as the upper stratigraphic interval. The interval from the base of the Chilton A coal bed (493 feet) down to the top of the Fire Clay coal bed (625 feet) is referred to as the lower stratigraphic interval.

Data are from Appendix B4. [symbols indicate depth in core and Se concentration of rock samples analyzed; lines connecting symbols are for illustration purposes only and do not indicate Se concentrations of rock]

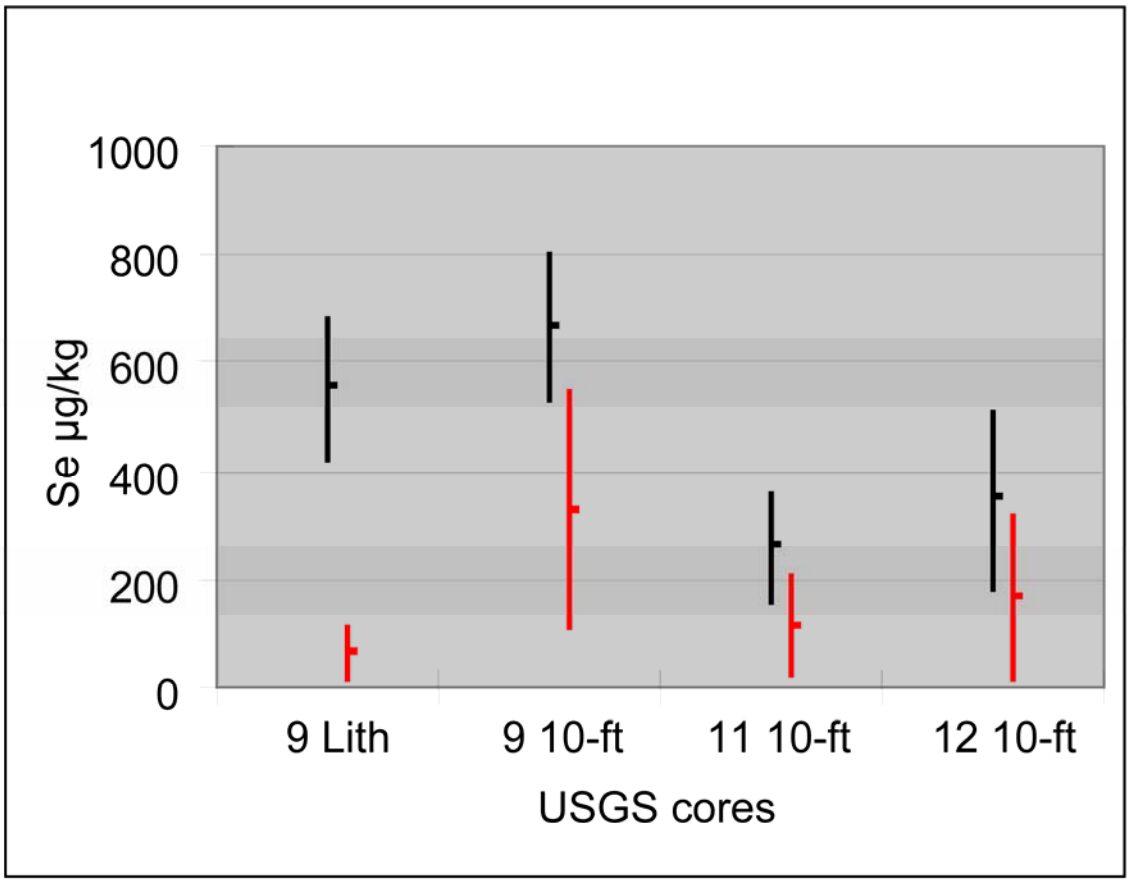


Figure 6. Mean Se concentration (µg/kg) ± 95 percent confidence interval (CI 95%) for upper and lower stratigraphic intervals in each core.

Data are from table 4. [upper stratigraphic interval (black), lower stratigraphic interval (red)]

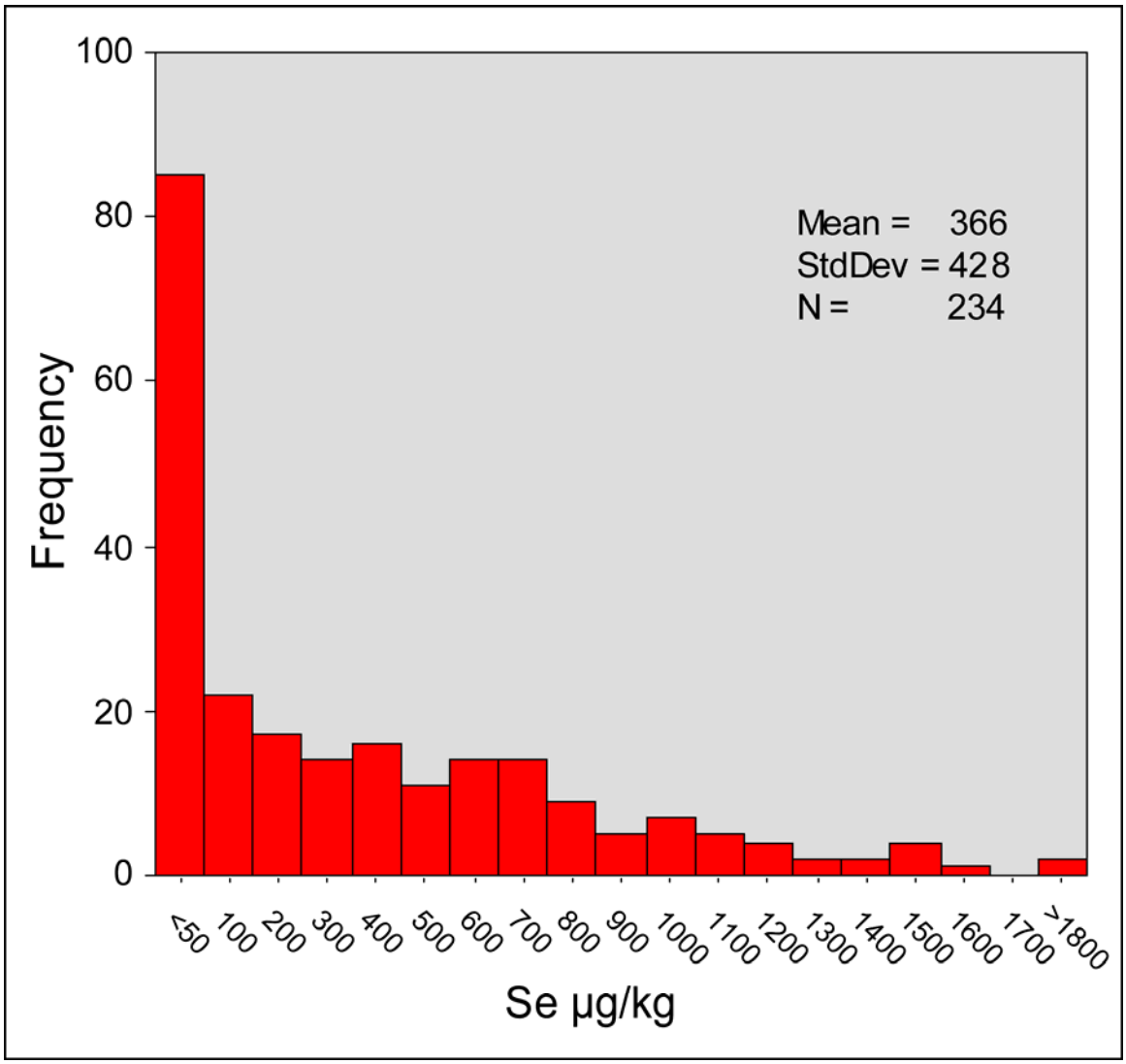


Figure 7. Frequency distribution of Se concentration (µg/kg) for all rock samples collected at 10-foot intervals from USGS 9-10-ft, USGS 11-10-ft, and USGS 12-10-ft.

Two high values for Se concentration (3300 and 6820 µg/kg in USGS 9-10-ft) are not included in mean and standard deviation calculations or shown on this figure. Bins are labeled by mid-point value, except for first bin (values <50) and last bin (values >1800).

Data are from Appendices B2, B3, and B4 and are summarized in table 6. [StdDev = standard deviation; N = number of samples]

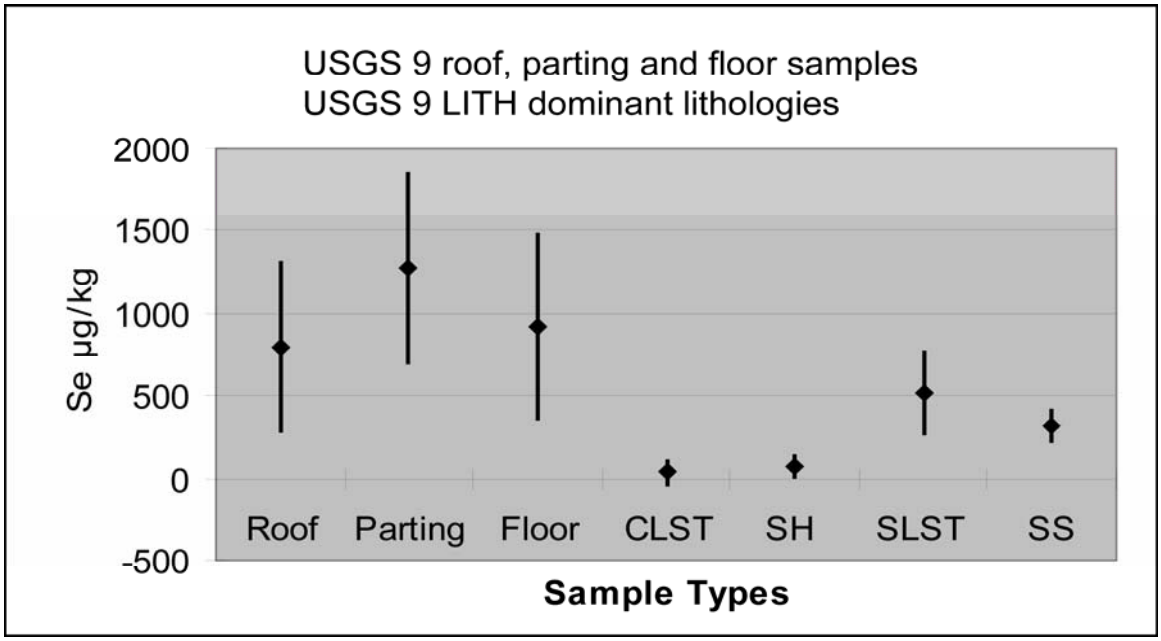


Figure 8. Mean Se concentration (µg/kg) ± 95 percent confidence interval (CI 95%) for four dominant lithologies from USGS 9-LITH and roof, parting, and floor samples from core USGS 9.

The rank-order of the mean Se concentrations for the seven sample types is: parting > floor > roof > siltstone > sandstone > shale > claystone.

Data are from tables 7 and 8. [CLST = claystone, SH = shale, SLST = siltstone, SS = sandstone]

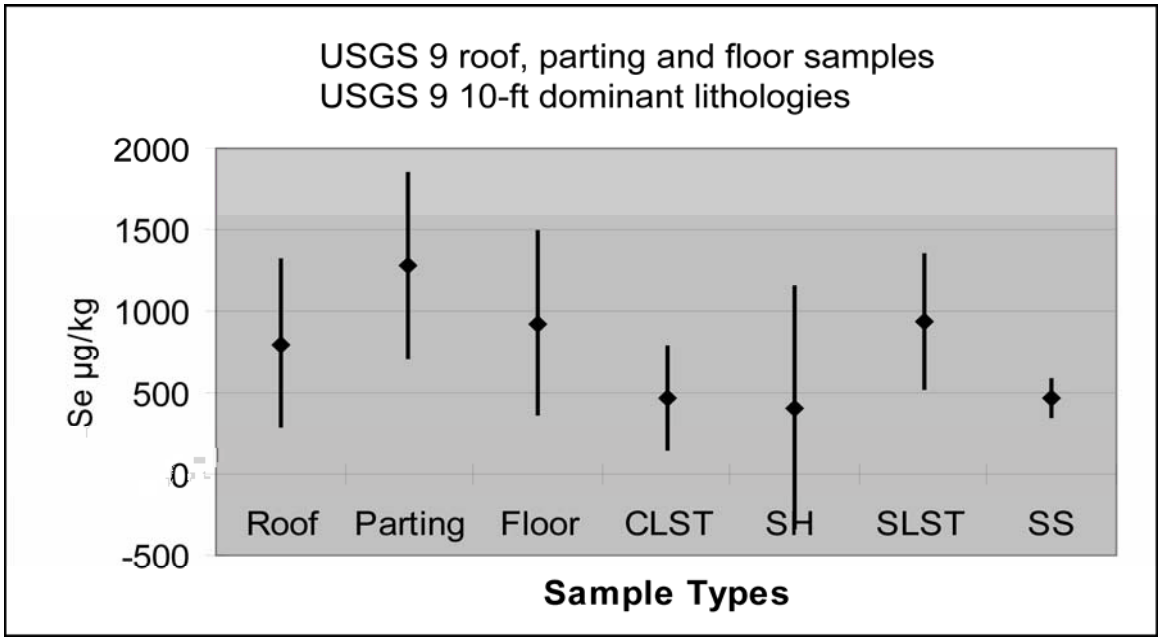


Figure 9. Mean Se concentration (µg/kg) ± 95 percent confidence interval (CI 95%) for four dominant lithologies from USGS 9-10-ft and roof, parting, and floor samples from core USGS 9.

The rank-order of the mean Se concentrations for the seven sample types is: parting > siltstone > floor > roof > sandstone > claystone > shale.

Data are from tables 7 and 8. [CLST = claystone, SH = shale, SLST = siltstone, SS = sandstone]

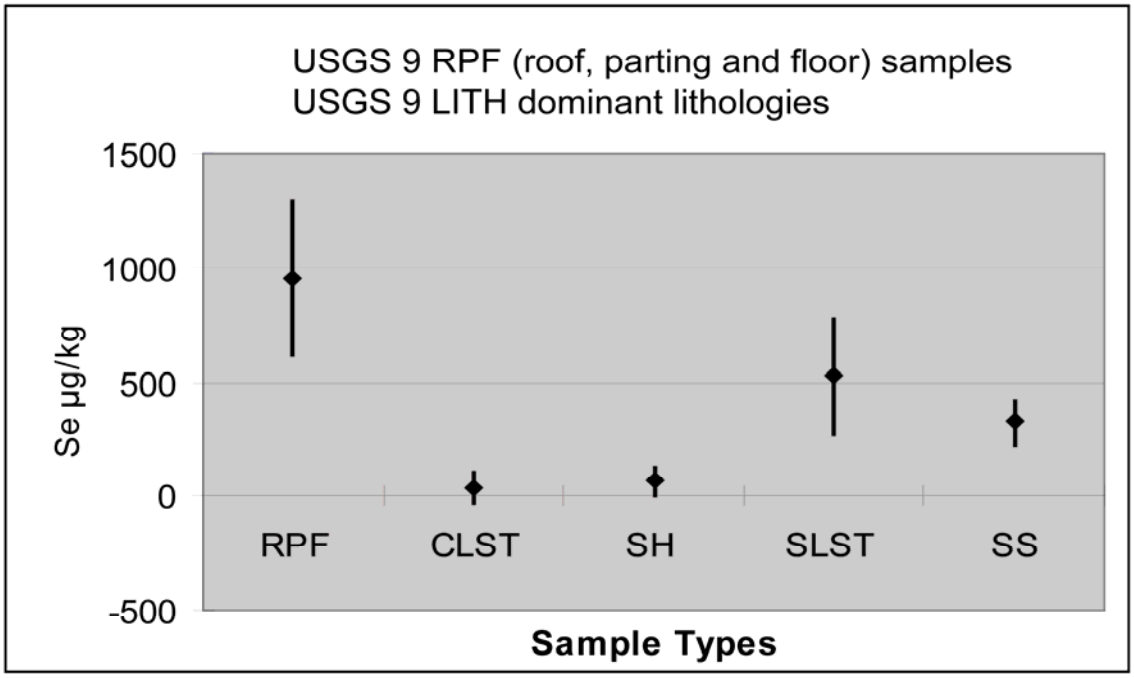


Figure 10. Mean Se concentration (µg/kg) ± 95 percent confidence interval (CI 95%) for four dominant lithologies from USGS 9-LITH and USGS 9-RPF (combined roof, parting, and floor samples from core USGS 9).

Statistical t-rests show that the mean Se concentration of RPF (952) is equal to the mean for siltstone (523) and greater than the means for claystone (33), shale (65), and sandstone (322).

Data are from tables 7, 9, and 10. [CLST = claystone, SH = shale, SLST = siltstone, SS = sandstone]

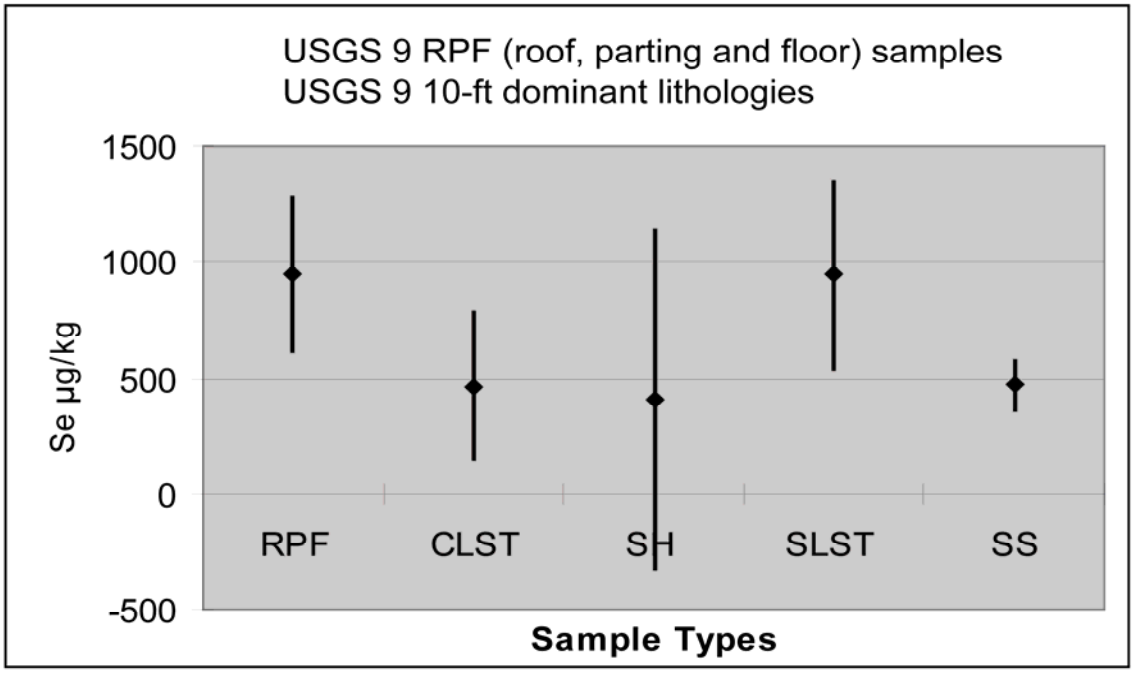


Figure 11. Mean Se concentration (µg/kg) ± 95 percent confidence interval (CI 95%) for four dominant lithologies from USGS 9-10-ft and USGS 9-RPF (combined roof, parting, and floor samples from core USGS 9).

Statistical t-tests show that the mean Se concentration of RPF (952) is equal to the means for shale (405) and siltstone (943) and greater than the means for claystone (464) and sandstone (467).

Data are from tables 7, 9, and 10. [CLST = claystone, SH = shale, SLST = siltstone, SS = sandstone]

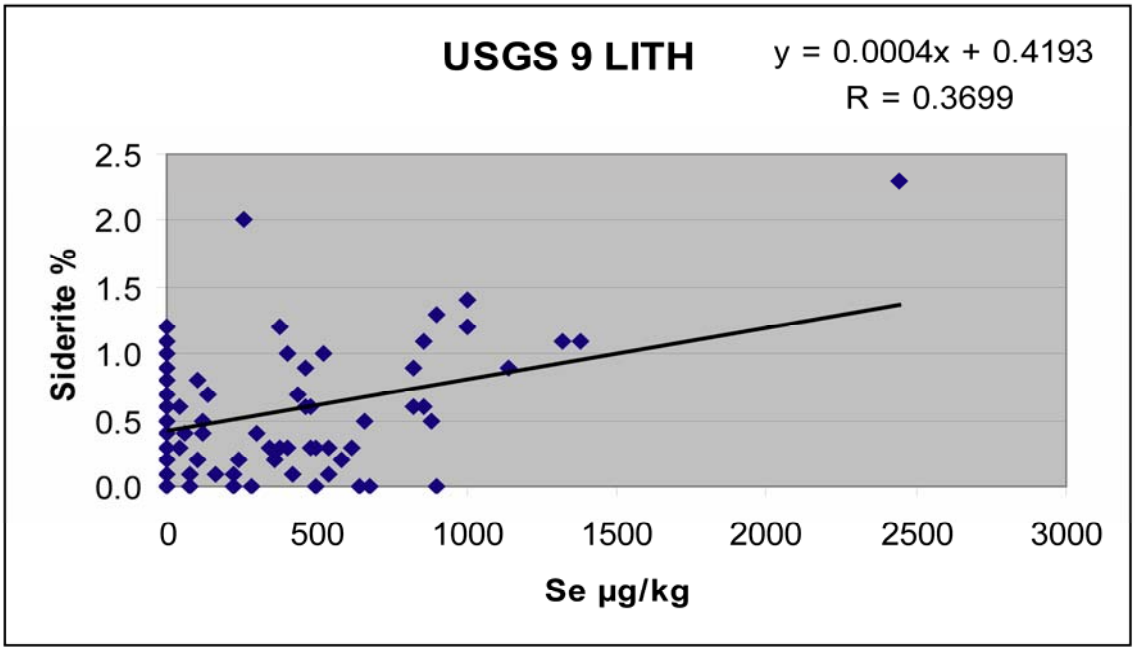
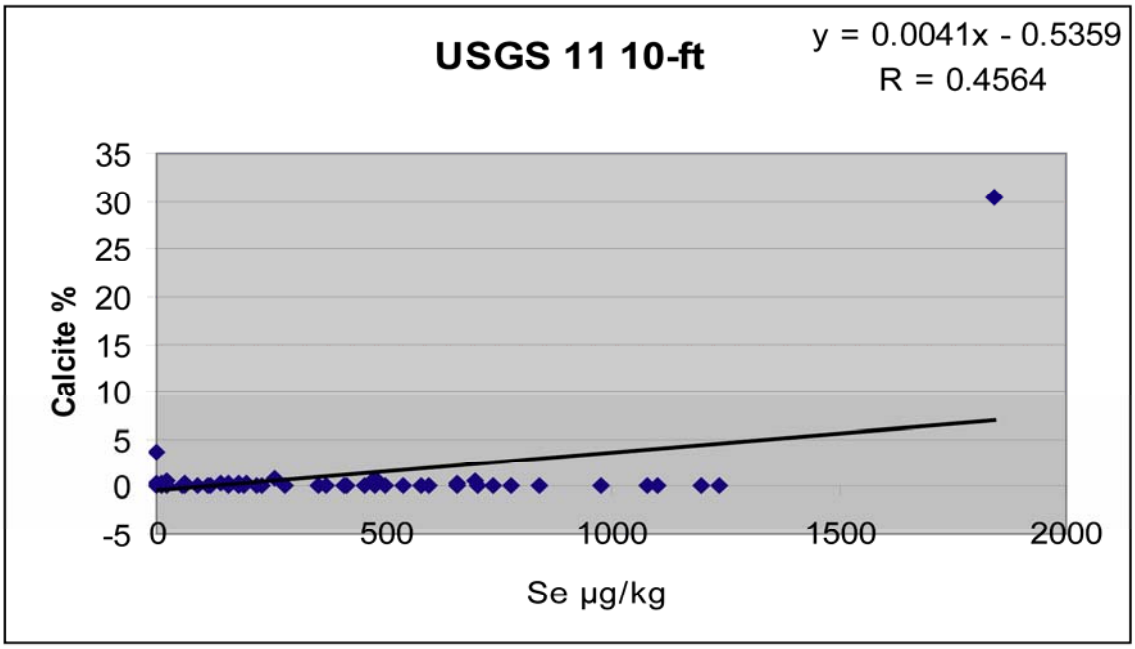


Figure 12. Se concentration (µg/kg) versus siderite (percent) in USGS 9-LITH.

Data are from Appendices B1 and B5.



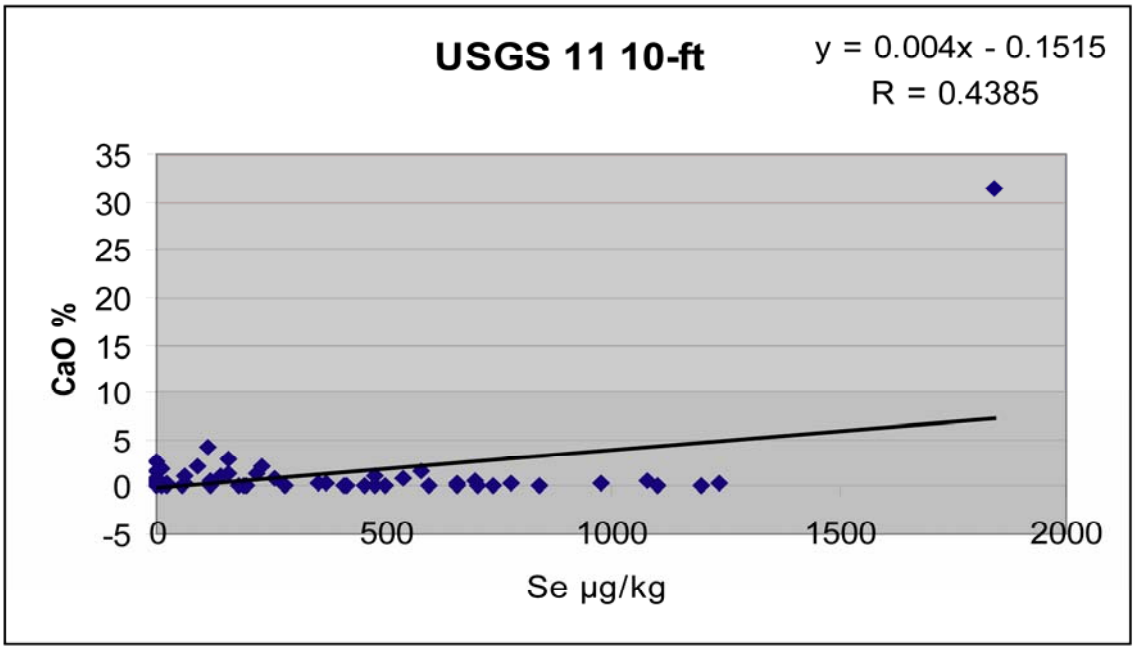


Figure 13. Se concentration (µg/kg) versus calcite and CaO (percent) in USGS 11-10-ft.

Upon removal of the point with high Se and high calcite the R value becomes 0.0762 and the correlation is no longer significant. Upon removal of the point with high Se and high CaO the R value becomes 0.10 and the correlation is no longer significant.

Data are from Appendices B3 and B7.

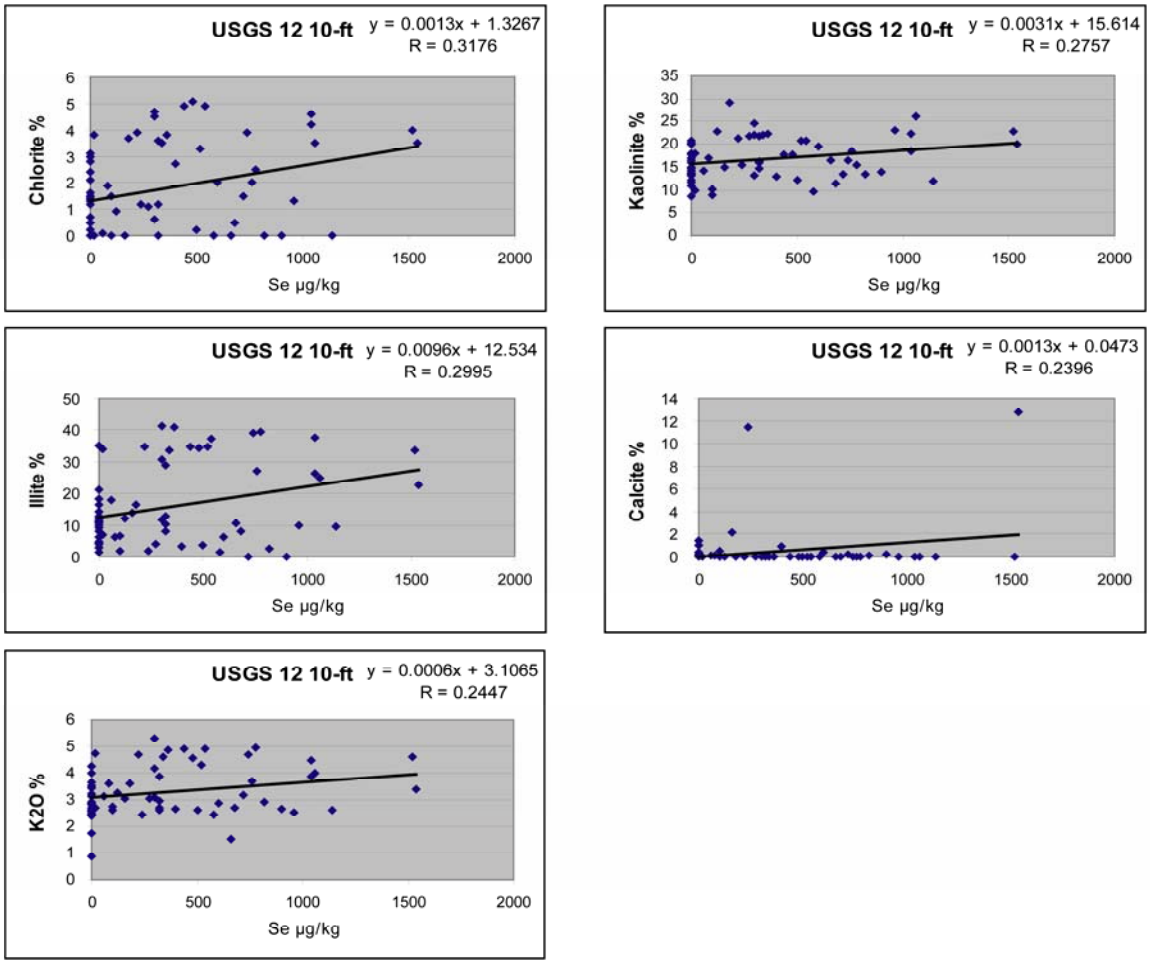


Figure 14. Se concentration (µg/kg) versus chlorite, kaolinite, illite, calcite, and K_2O (percent) in USGS 12-10-ft.

Data are from Appendices B4 and B8.

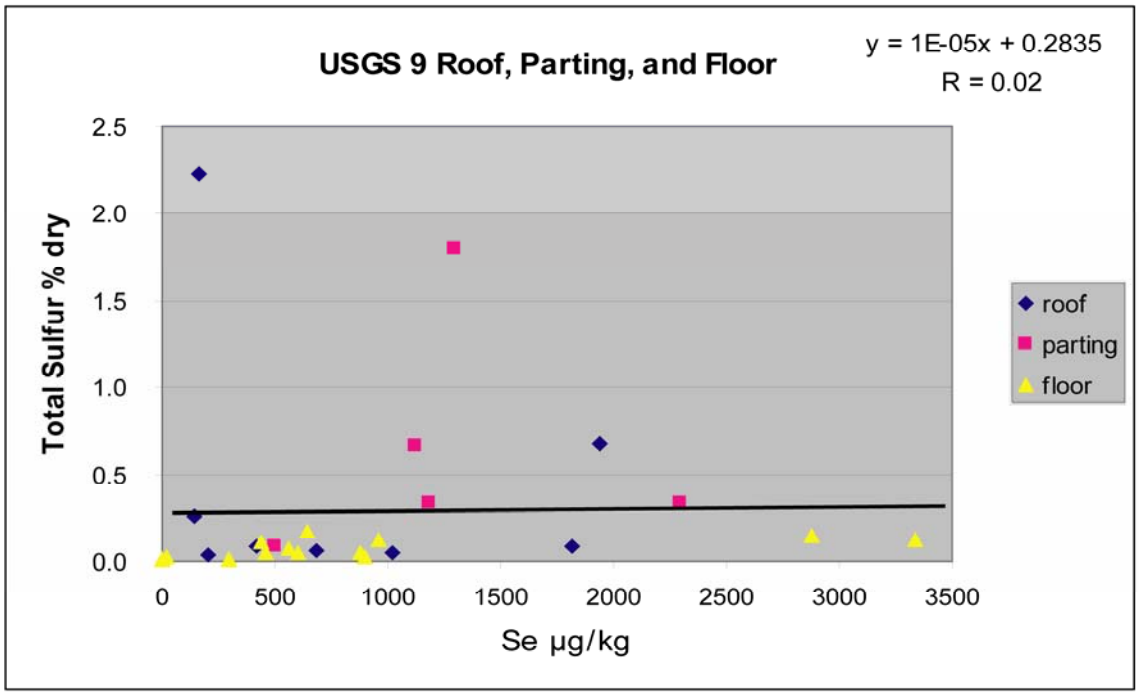


Figure 15. Se concentration (µg/kg) versus total sulfur (percent, dry basis) in roof, parting, and floor samples from USGS 9.

Data are from Appendix B9.

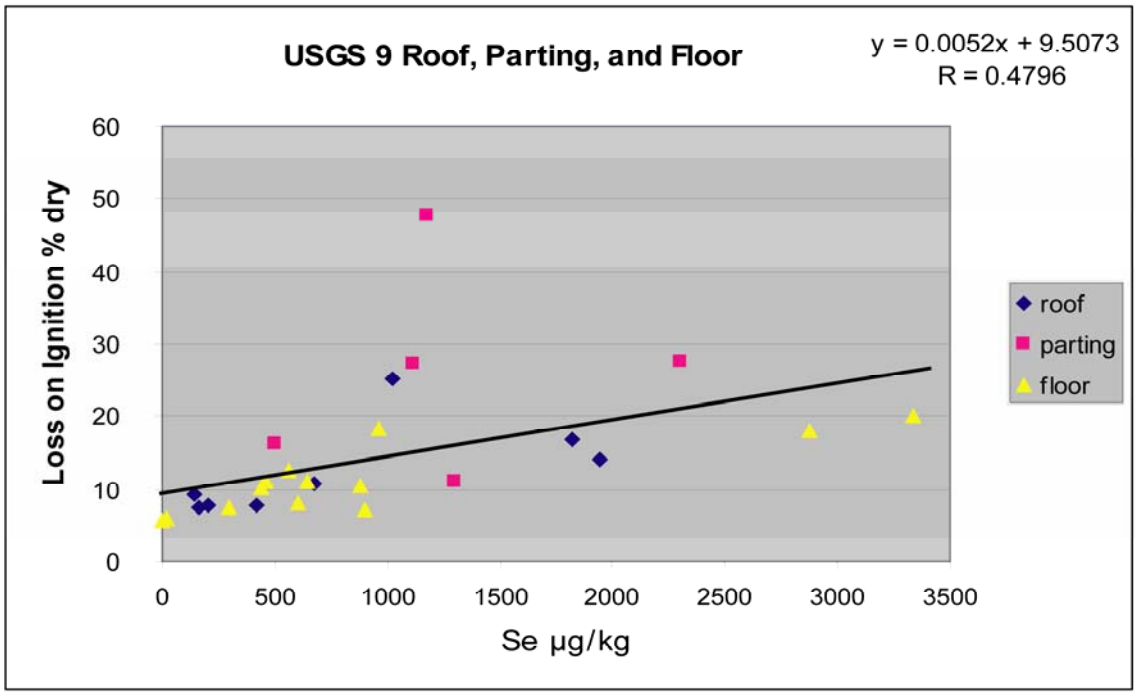


Figure 16. Se concentration (µg/kg) versus loss on ignition (percent, dry basis) in roof, parting, and floor samples from USGS 9.

Data are from Appendix B9.

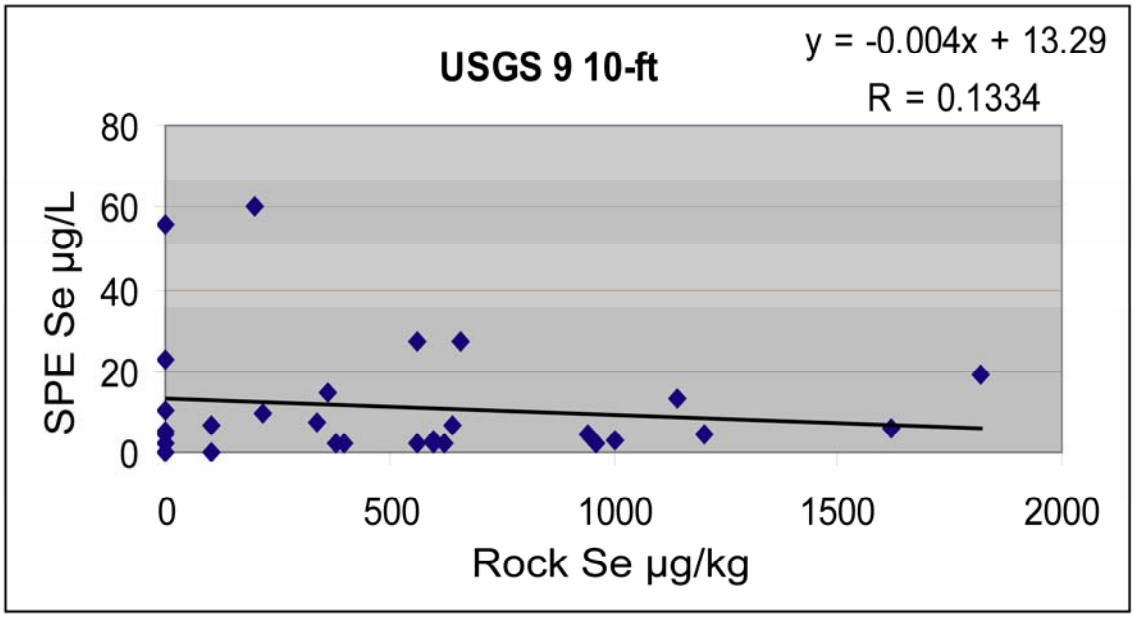


Figure 17. Se concentration (µg/L) in saturated paste extract (SPE) versus Se concentration (µg/kg) in rock samples from USGS 9-10-ft.

Two high Se values in rock (3300 and 6820 µg/kg) are not plotted and the correlation coefficient (R=0.1334) is not significant. If the two high Se values are included, the correlation coefficient is not significant either.

Data are from Appendices B2 and B10.

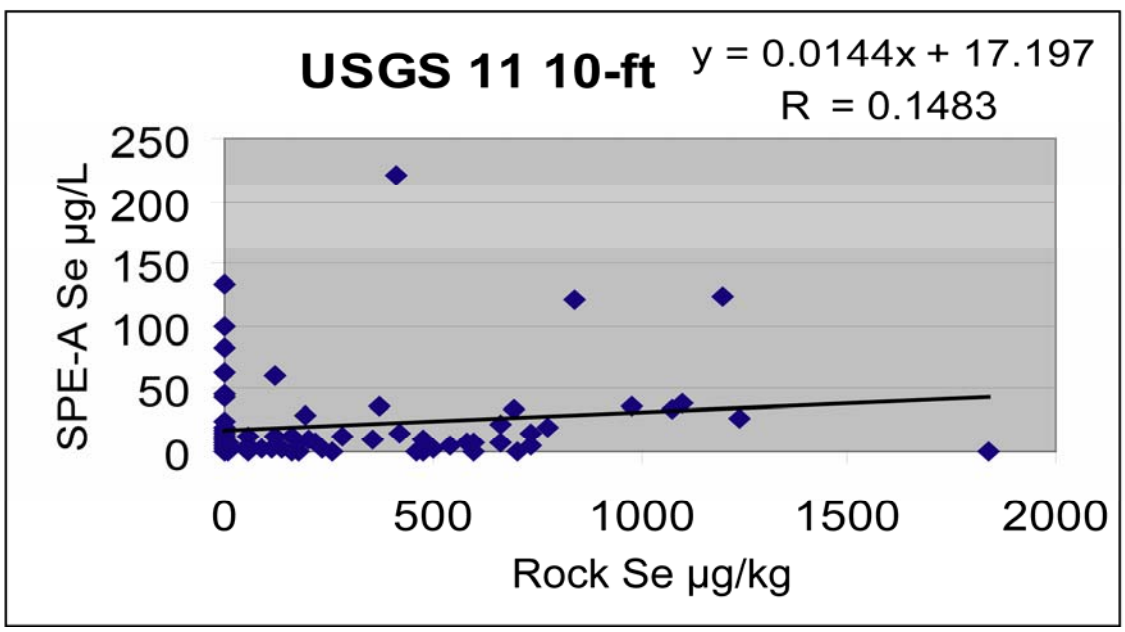


Figure 18. Se concentration (µg/L) in saturated paste extract (SPE-A) versus Se concentration (µg/kg) in rock samples from USGS 11-10-ft.

Data are from Appendices B3 and B11.

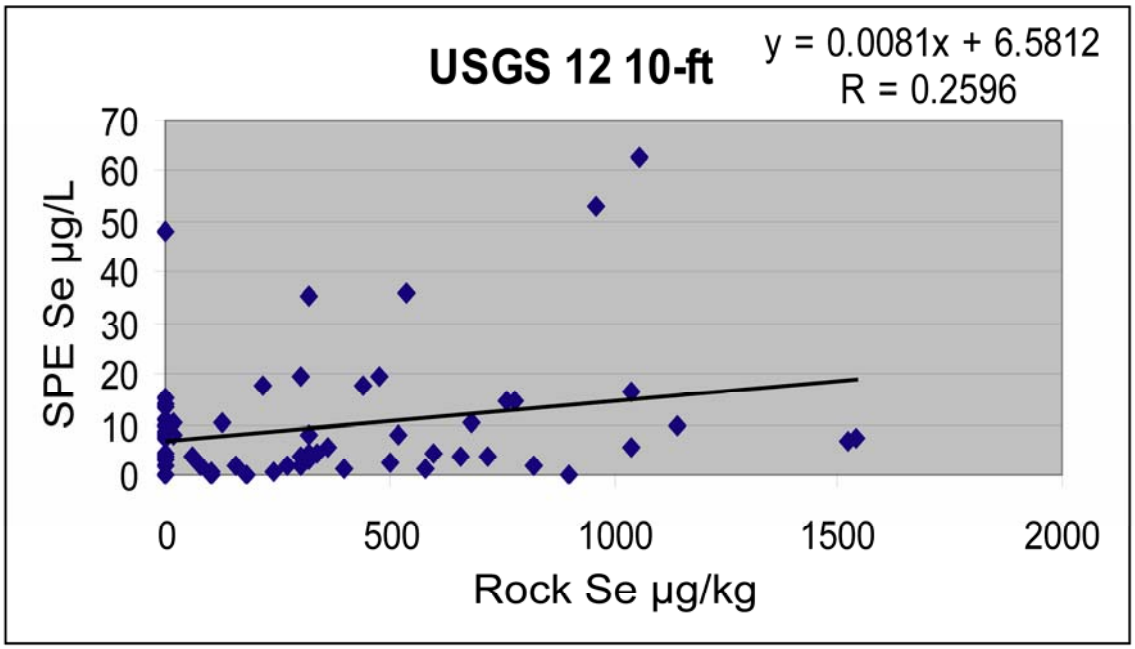


Figure 19. Se concentration (µg/L) in saturated paste extract (SPE) versus Se concentration (µg/kg) in rock samples from USGS 12-10-ft.

Data are from Appendices B4 and B12.

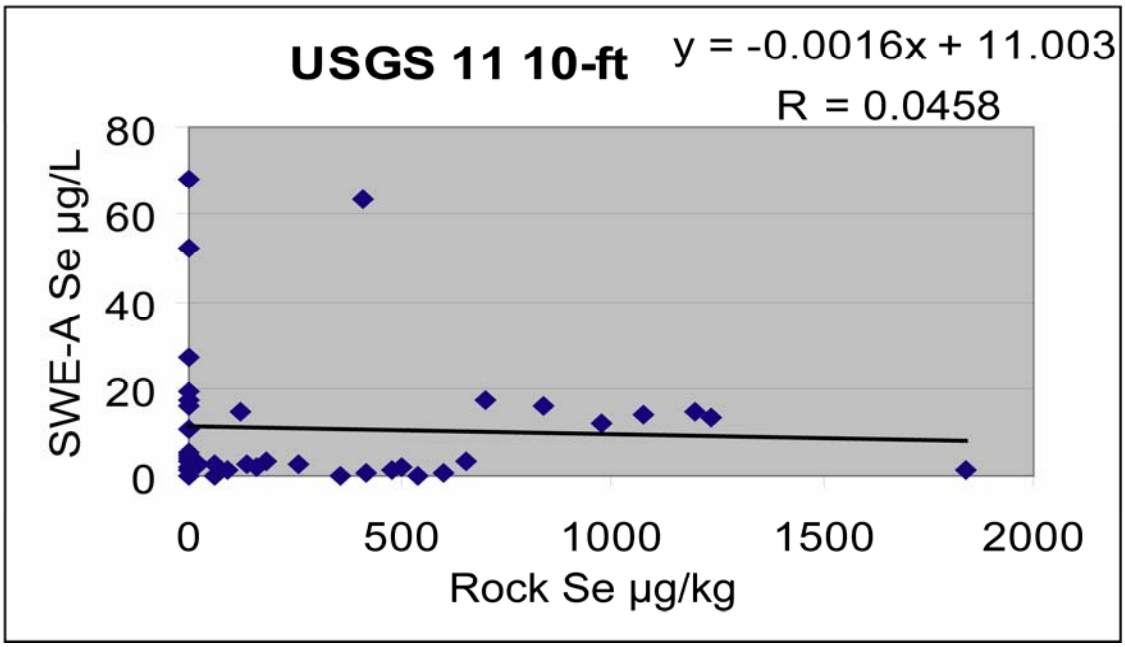


Figure 20. Se concentration (µg/L) in sequential water extraction first extract (SWE-A) versus Se concentration (µg/kg) in rock samples from USGS 11-10-ft.

Data are from Appendices B3 and B13.

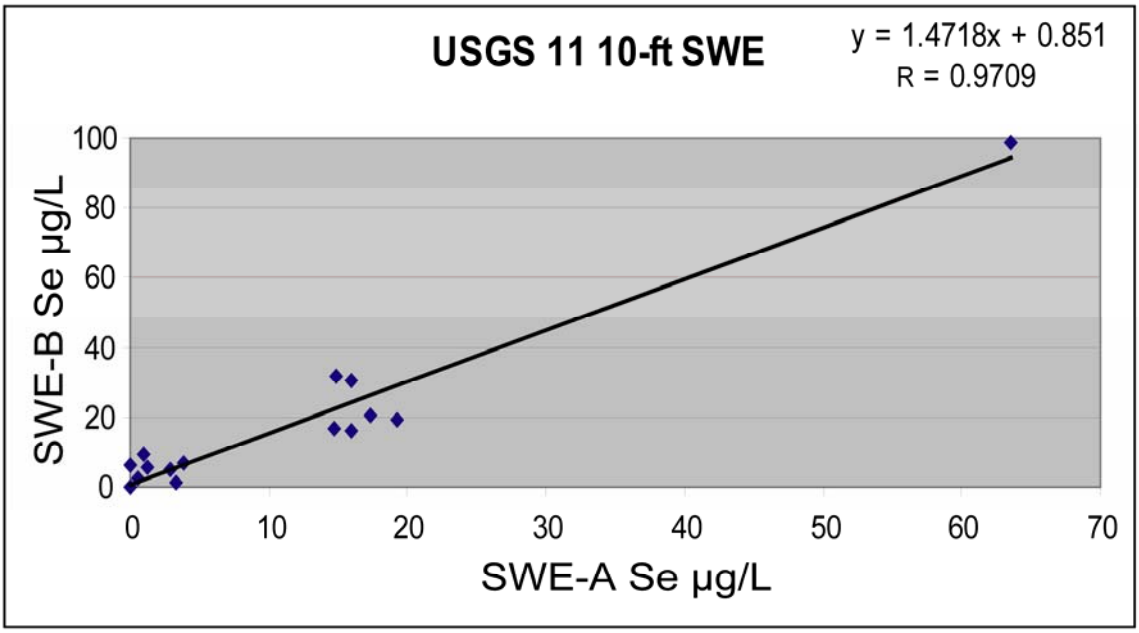


Figure 21. Se concentration (µg/L) in sequential water extraction first extract of rock sub-sample A (SWE-A) versus Se concentration (µg/L) in sequential water extraction first extract of rock sub-sample B (SWE-B) for USGS 11-10-ft samples.

Data are from Appendix B13.

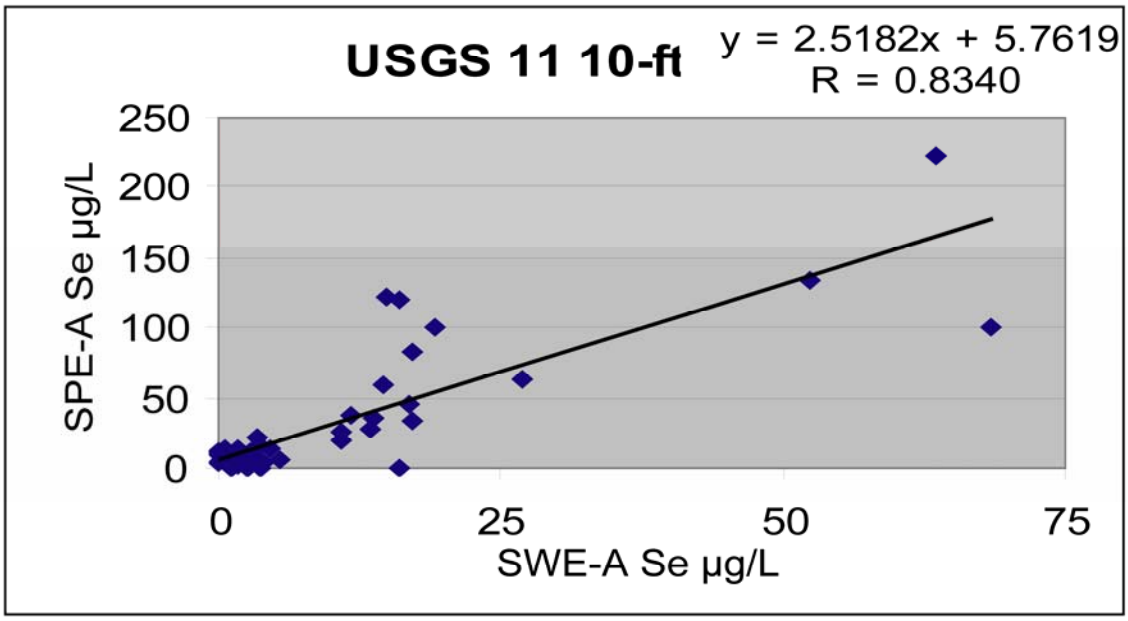


Figure 22. Se concentration (µg/L) in saturated paste extract (SPE-A) versus Se concentration (µg/L) in sequential water extraction first extract (SWE-A) for duplicate sub-samples of rock from USGS 11-10-ft.

Data are from Appendices B11 and B13.

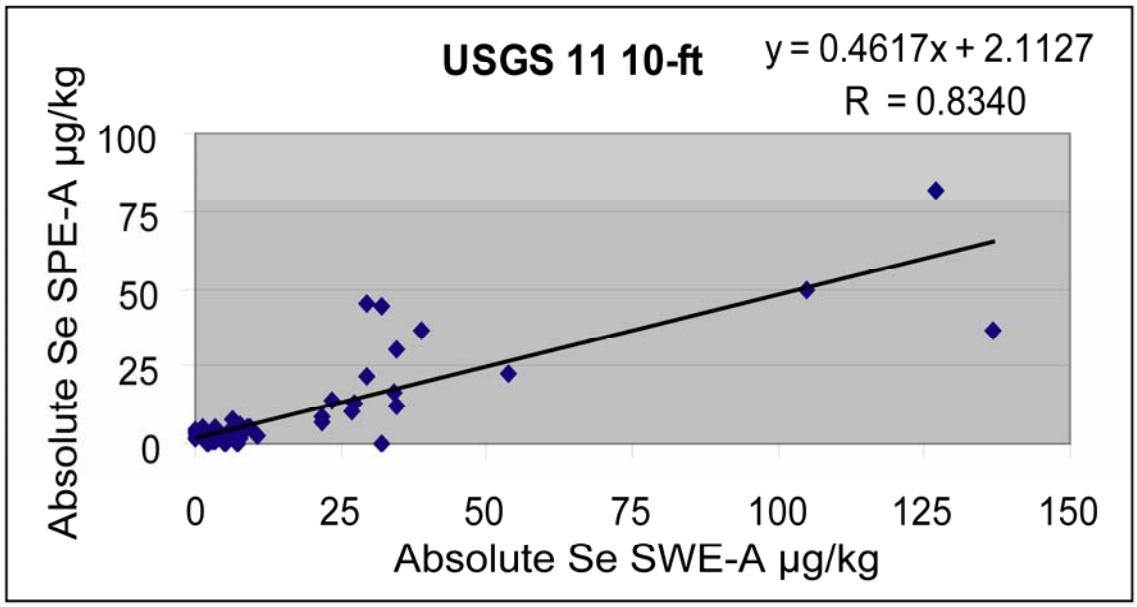


Figure 23. Absolute Se (µg Se in solution / kg of rock leached) in saturated paste extract (SPE-A) versus absolute Se (µg Se in solution / kg of rock leached) in sequential water extraction first extract (SWE-A) for duplicate sub-samples of rock from USGS 11-10-ft.

Data are calculated from Appendices B11 and B13.

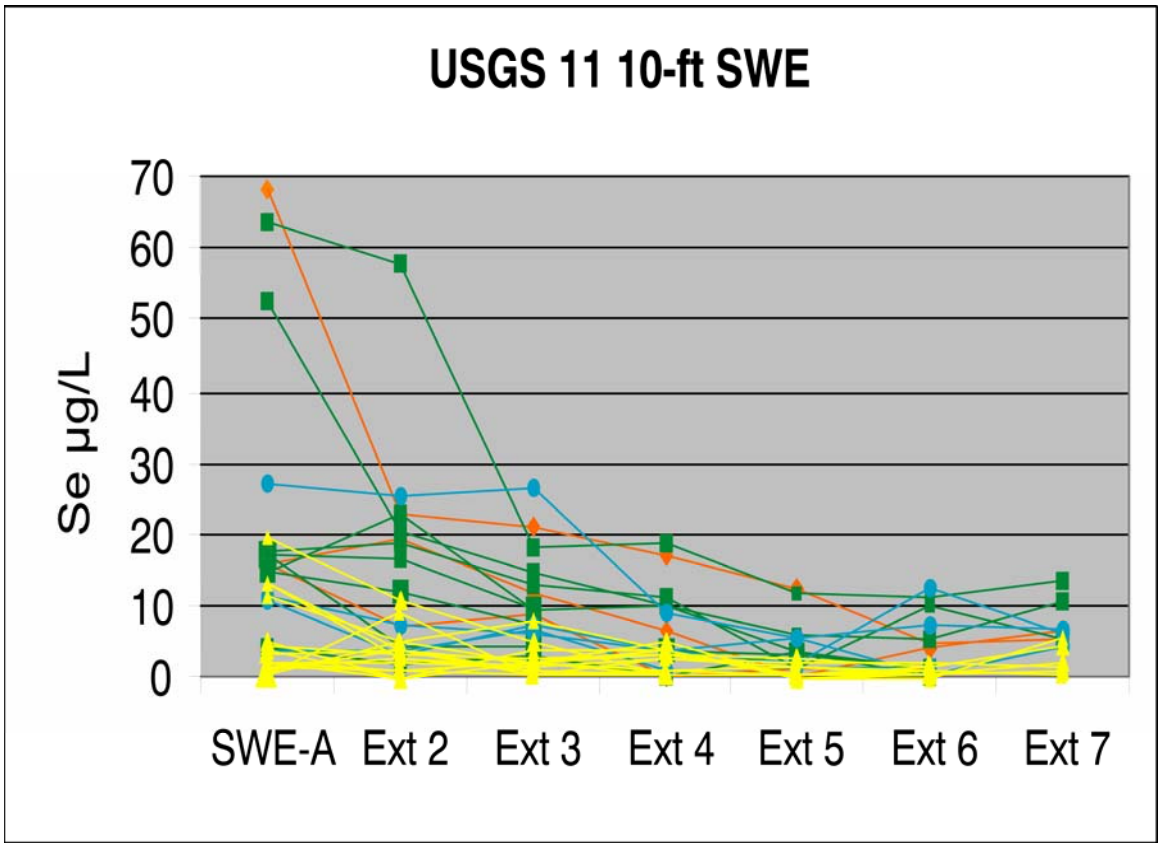


Figure 24. Se concentration (µg/L) in sequential water extractions (SWE-) for up to 7 sequential extractions of a rock sample, for samples from USGS 11-10-ft.

SWE-A is the first extract followed by 2nd, 3rd, 4th, 5th, 6th, and 7th extracts of the same rock material.

Data are from Appendix B13. [claystone = orange, shale = green, siltstone = blue, and sandstone = yellow]

Table 1. Trace element concentrations for 13 elements, including Se, reported in ASTM 3052 with certification by National Institute of Standards and Technology (NIST) for standard reference material (SRM) 2704

ASTM and NIST report the mean concentration and the 95 percent confidence interval (CI 95%) for each element. A normalized metric that is used in this study to indicate precision of results, is the CI 95% divided by the mean concentration. Data are from ASTM 3052 (1996), also available on the web at *http;//www.epa.gov/sw-846/pdfs/3052.pdf*.

[values in parens ( ) are not certified; --- = not analyzed or not reported]

		ASTM Analyzed		NIST Analyzed		ASTM	NIST
Element	Count	Mean µg/g	CI 95%	Mean µg/g	CI 95%	CI÷Mean	CI÷Mean
As	4	23.4	2.6	23.4	0.8	0.11	0.03
Cd	6	3.5	1.2	3.45	0.22	0.34	0.06
Cr	6	132.9	1.3	135	5	0.01	0.04
Cu	6	98.0	4.2	98.6	5.0	0.04	0.05
Pb	6	155	9.2	161	17	0.06	0.11
Hg	4	1.49	0.14	1.44	0.07	0.09	0.05
Ni	6	43.6	3.9	44.1	3.0	0.09	0.07
P	4	1016	16	998	28	0.02	0.03
Se	**4**	**1.13**	**0.9**	**(1.1)**	**---**	**0.80**	**---**
S	4	3.56	0.16	---	---	0.04	---
Tl	4	1.15	0.22	1.2	0.2	0.19	0.17
U	4	2.97	0.04	3.13	0.13	0.01	0.04
Zn	6	441.9	0.8	438	12	0.002	0.03

Table 2. Comparison of Se concentration in 12 samples coincident to both USGS 9-LITH and USGS 9-10-ft

The table indicates that the Se concentrations for samples selected by lithology (USGS 9-LITH) tend to be lower than the Se concentrations for samples collected at 10-foot intervals (USGS 9-10-ft). The correlation coefficient (R = 0.6712) is significant at the 0.05 level. However, the correlation is not significant at the 0.01 level. In order to test the equality of the means (mean Se concentration in USGS 9-LITH and mean Se concentration in USGS 9-10-ft), the variances must first be evaluated for equality with an F-test. Depending on the outcome of the F-test, either the variances are equal (E) or they are unequal (UE). Then a t-test tests for equality of the means (using the appropriate t-value for either equal or unequal variances) to determine if the means are equal (E) or unequal (UE). The variance of Se concentrations in USGS 9-LITH samples is equal to the variance of Se concentrations in USGS 9-10-ft samples. The mean Se concentration of USGS 9-LITH samples is equal to the mean Se concentration of USGS 9-10-ft samples.

[data are from Appendices B1 and B2; StdDev = standard deviation; ND = not detected and a value of 0 was used in calculations]

Sample ID interval ft	USGS 9 -LITH Se µg/kg	USGS 9 -10-ft Se µg/kg	USGS 9 -LITH vs 9-10-ft	Lithology
163-163	540	740	Lower	Siltstone
170-171	100	700	Lower	Siltstone
280-281	1140	1440	Lower	Siltstone
340-341	640	580	Higher	Sandstone
390-391	480	20	Higher	Sandstone
430-431	ND	400	Lower	Sandstone
460-461	ND	ND	ND	Mudstone
560-561	380	1520	Lower	Shale
570-571	120	ND	Higher	Shale
580-581	ND	ND	ND	Sandstone
600-601	ND	140	Lower	Claystone
650-651	ND	180	Lower	Sandstone

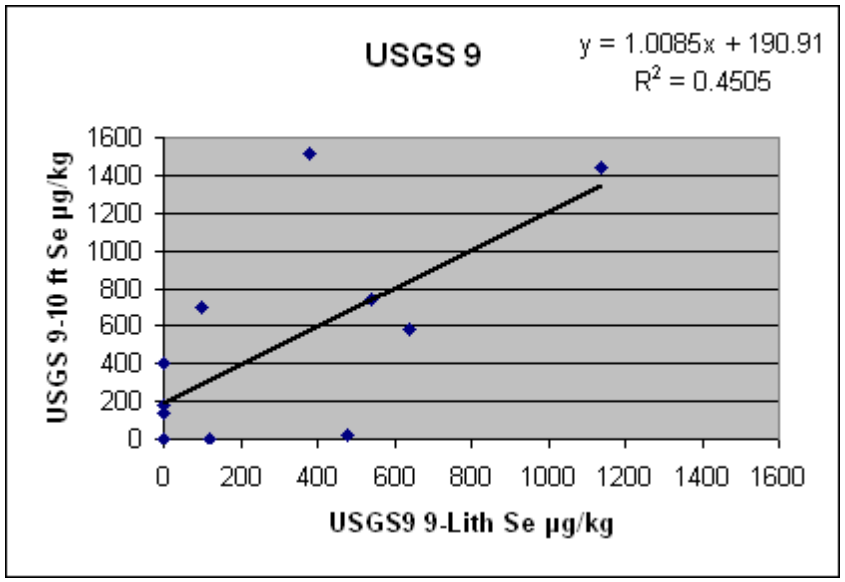


Table 2. cont.

	USGS 9 -LITH Se µg/kg	USGS 9 -10-ft Se µg/kg
Mean	283	477
StdDev	361	543
Median	110	290
Minimum	0	0
Maximum	1140	1520
Count	12	12
CI 95%	204	307

Compare	USGS 9-LITH vs USGS 9 10-ft
	Variance / Mean
	E / E

Critical Values: F 0.05 (11, 11) = 3.47 and T 0.05 (22) = 2.074
Calculated Values: F = 2.262 and T = 1.031
Calculated values are < critical values
Therefore variances are equal (E) to one another, as are the means

Table 3. Se concentrations in duplicate samples and replicate analyses of 12 samples coincident to both USGS 9-LITH and USGS 9-10-ft

Three replicate analyses (designated 1, 2, and 3) were conducted on each of 3 sub-samples (designated A, B, and C) of 12 samples. The 95 percent confidence interval (CI 95%) is an estimate of the precision of the mean Se concentration for the analytical method. The CI 95% divided by the mean is a normalized metric that can be used to compare relative dispersion of the mean, which can be used to compare the precision of Se concentration measurements for samples with differing Se concentrations.

[calculations use data in Appendix B14; StdDev = standard deviation; count = number of analyses; CI 95% = 95 percent confidence interval; CI 95% ÷ Mean = normalized metric used in this study]

Sample ID Interval ft	Mean Se µg/kg	StdDev	Count	CI 95%		CI÷Mean
163-164	453	461	9	301		0.66
170-171	524	613	9	400		0.76
280-281	631	515	9	337		0.53
340-341	149	270	9	176		1.18
390-391	196	344	9	225		1.15
430-431	433	628	9	410		0.95
460-461	269	335	9	219		0.81
560-561	600	657	9	429		0.72
570-571	373	437	9	286		0.77
580-581	329	325	9	212		0.65
600-601	267	280	9	183		0.69
650-651	273	288	9	188		0.69
					Mean =	**0.80**

Table 4. A test for stratigraphic variation of Se concentration, comparing the upper stratigraphic interval to the lower stratigraphic interval in each core (USGS 9-LITH, USGS 9-10-ft, USGS 11-10-ft, and USGS 12-10-ft), using univariate statistics and t-test comparisons

In order to compare the equality of the mean Se concentration in two stratigraphic intervals in each core, the variances must first be evaluated for equality with an F-test. Depending on the outcome of the F-test, either the variances are equal (E) or they are unequal (UE). Then a t-test is used to test for equality of the means (using the appropriate t-value for either equal or unequal variances) and determines if the mean Se concentrations in upper and lower stratigraphic intervals are equal (E) or unequal (UE).

For USGS 9-LITH, the mean Se concentration in the upper interval is greater than in the lower interval (variances are unequal to one another and the means are unequal).

For USGS 9-10-ft, the mean Se concentration in the upper interval is greater than in the lower interval (variances are equal to one another whereas the means are unequal).

For USGS 11-10-ft, the mean Se concentration in the upper interval is equal to the mean Se concentration in the lower interval (variances are equal to one another and the means are equal).
For USGS 12-10-ft, the mean Se concentration in the upper interval is equal to the mean Se concentration in the lower interval (variances are equal to one another and the means are equal).

[calculated from data in Appendices B1, B2, B3, and B4 (with Se values below detection limit set = 0); USGS 9-10-ft includes 1-ft samples selected close to coal beds; USGS 9-10-ft lower stratigraphic interval does not include high Se value 6820 µg/kg; StdDev = standard deviation; CI 95% = 95 percent confidence interval]

Upper Stratigraphic Interval (below Stockton A to above Chilton A)

Core Interval	USGS 9-LITH 114-446 ft Se µg/kg	USGS 9-10-ft 114-446 ft Se µg/kg	USGS 11-10-ft 239-652 ft Se µg/kg	USGS 12-10-ft 316-492 ft Se µg/kg
Mean	553	666	259	346
StdDev	456	425	327	335
Median	480	610	119	320
Minimum	0	0	0	0
Maximum	2440	1820	1200	1060
Count	46	38	41	17
CI 95%	132	135	100	159

Lower Stratigraphic Interval (below Chilton A to above Fire Clay)

Core Interval	USGS 9-LITH 448-690 ft Se µg/kg	USGS 9-10-ft 448-690 ft Se µg/kg	USGS 11-10-ft 653-828 ft Se µg/kg	USGS 12-10-ft 493-625 ft Se µg/kg
Mean	64	329	114	167
StdDev	163	518	203	264
Median	0	0	0	10
Minimum	0	0	0	0
Maximum	820	1620	540	740
Count	53	22	18	12
CI 95%	44	216	94	149

Table 4. cont.

Compare Upper Stratigraphic Interval versus Lower Stratigraphic Interval				
	USGS 9-LITH Upper vs Lower Variance / Mean	**USGS 9-10-ft Upper vs Lower Variance / Mean**	**USGS 11-10-ft Upper vs Lower Variance / Mean**	**USGS 12-10-ft Upper vs Lower Variance / Mean**
	UE / UE	E / UE	E / E	E / E

Table 5. A test for regional variation of Se concentration in each stratigraphic interval (upper and lower) compared among cores, using univariate statistics and t-test comparisons

In order to compare the equality of the mean Se concentration in each stratigraphic interval, the variances must first be evaluated for equality with an F-test. Depending on the outcome of the F-test, either the variances are equal (E) or they are unequal (UE). Then a t-test tests for equality of the means (using the appropriate t-value for either equal or unequal variances) and determines if the mean Se concentrations are equal (E) or unequal (UE).

For the upper stratigraphic interval: 1) the mean Se concentration in USGS 9-LITH is equal to the mean Se concentration in USGS 9-10-ft and USGS 12-10-ft (for both comparisons variances are equal to one another and means are equal), and greater than in USGS 11-10-ft (variances are unequal and the means are unequal) 2) the mean Se concentration in USGS 9-10-ft is greater than in USGS 11-10-ft and USGS 12-10-ft (for both comparisons variances are equal to one another and the means are unequal); and 3) the mean Se concentration in USGS 11-10-ft is equal to USGS 12-10-ft (variances are equal to one another and the means are equal).

For the lower stratigraphic interval: 1) the mean Se concentration in USGS 9-LITH is greater than the mean Se concentration in USGS 9-10-ft (the variances are unequal, as well as the means), and is equal to the mean Se concentration in USGS 11-10-ft (variances are equal to one another and means are equal) and USGS 12-10-ft (variances are unequal and the means are equal); 2) the mean Se concentration in USGS 9-10-ft is equal to USGS 11-10-ft and USGS 12-10-ft (for both comparisons variances are unequal to one another and the means are equal); and 3) the mean Se concentration in USGS 11-10-ft is equal to USGS 12-10-ft (variances are equal to one another and the means are equal).

[calculated from data in Appendices B1, B2, B3, and B4 (with Se values below detection limit set = 0); USGS 9-10-ft includes 1-ft samples selected close to coal beds; USGS 9-10-ft lower stratigraphic interval does not include high Se value 6820 µg/kg; StdDev = standard deviation; CI 95% = 95 percent confidence interval]

Upper Stratigraphic Interval (below Stockton A to above Chilton A) univariate statistics

Core Interval	USGS 9-LITH 114-446 ft Se µg/kg	USGS 9-10-ft 114-446 ft Se µg/kg	USGS 11-10-ft 239-652 ft Se µg/kg	USGS 12-10-ft 316-492 ft Se µg/kg
Mean	553	666	259	346
StdDev	456	425	327	335
Median	480	610	119	320
Minimum	0	0	0	0
Maximum	2440	1820	1200	1060
Count	46	38	41	17
CI 95%				
Table 5 cont.	132	135	100	159

Compare Upper Stratigraphic Intervals, F-test / t-test (variance / mean)

	USGS 9-LITH	USGS 9-10-ft	USGS 11-10-ft	USGS 12-10-ft
USGS 9-LITH	--	E / E	UE / UE	E / E
USGS 9-10-ft	--	--	E / UE	E / UE
USGS 11-10-ft	--	--	--	E / E

Lower Stratigraphic Interval (below Chilton A to above Fire Clay) univariate statistics

Core Interval	USGS 9-LITH 448-690 ft Se µg/kg	USGS 9-10-ft 448-690 ft Se µg/kg	USGS 11-10-ft 653-828 ft Se µg/kg	USGS 12-10-ft 493-625 ft Se µg/kg
Mean	64	329	114	167
StdDev	163	518	203	264
Median	0	0	0	10
Minimum	0	0	0	0
Maximum	820	1620	540	740
Count	53	22	18	12
CI 95%	44	216	94	149

Compare Lower Stratigraphic Intervals, F-test / t-test (variance / mean)

	USGS 9-LITH	USGS 9-10-ft	USGS 11-10-ft	USGS 12-10-ft
USGS 9-LITH	--	UE / UE	E / E	UE / E
USGS 9-10-ft	--	--	UE / E	UE / E
USGS 11-10-ft	--	--	--	E / E

Table 6. Frequency distribution and univariate statistics for Se concentration data in all samples collected at 10-foot intervals in USGS 9-10-ft, USGS 11-10-ft, and USGS 12-10-ft

A. Univariate statistics are calculated for all Se concentrations.

B. Univariate statistics are calculated for Se concentrations without the two highest Se values.

C. Univariate statistics are calculated for Se concentrations without the two highest Se values and replacing 0 values (not detected) with 5 (half the detection limit).

[calculated from data in Appendices B2, B3, and B4 (with Se values below detection limit set = 0 unless otherwise noted); USGS 9-10-ft includes 1-ft and p-ft samples (see Appendix B2); StdDev = standard deviation; CI 95% = 95 percent confidence interval]

Se µg/kg	Frequency	Percent	Cumulative Percent
0	78	33.1	33.1
10	2	0.8	33.9
20	5	2.1	36.0
54	1	0.4	36.4
60	4	1.7	38.1
80	2	0.8	39.0
90	1	0.4	39.4
100	6	2.5	41.9
115	1	0.4	42.4
119	1	0.4	42.8
120	2	0.8	43.6
124	1	0.4	44.1
140	3	1.3	45.3
160	3	1.3	46.6
180	5	2.1	48.7
193	1	0.4	49.2
200	3	1.3	50.4
220	3	1.3	51.7
233	1	0.4	52.1
240	1	0.4	52.5
260	1	0.4	53.0
272	1	0.4	53.4
280	1	0.4	53.8
285	1	0.4	54.2
300	3	1.3	55.5
320	5	2.1	57.6
340	2	0.8	58.5
355	1	0.4	58.9
360	3	1.3	60.2
371	1	0.4	60.6
380	1	0.4	61.0
400	6	2.5	63.6
413	1	0.4	64.0
420	1	0.4	64.4
440	2	0.8	65.3
460	2	0.8	66.1
480	3	1.3	67.4
500	2	0.8	68.2

A. All Data

	Se µg/kg
Mean	406
StdDev	628
Median	200
Minimum	0
Maximum	6820
Count	236
CI 95%	80

B. Remove 2 high Se values (6820 and 3300)

	Se µg/kg
Mean	366
StdDev	428
Median	200
Minimum	0
Maximum	1840
Count	234
CI 95%	55

C. Remove 2 high Se values (6820 and 3300) and change 0 values to 5

	Se µg/kg
Mean	368
StdDev	427
Median	200
Minimum	5
Maximum	1840
Count	234
CI 95%	55

520	2	0.8	69.1
540	2	0.8	69.9
560	4	1.7	71.6
580	3	1.3	72.9
600	5	2.1	75.0
620	1	0.4	75.4
640	1	0.4	75.8
660	4	1.7	77.5
680	1	0.4	78.0
700	3	1.3	79.2
708	1	0.4	79.7
720	1	0.4	80.1
739	1	0.4	80.5
740	3	1.3	81.8
760	1	0.4	82.2
777	1	0.4	82.6
780	1	0.4	83.1
800	3	1.3	84.3
820	1	0.4	84.7
840	2	0.8	85.6
860	1	0.4	86.0
900	2	0.8	86.9
940	2	0.8	87.7
960	2	0.8	88.6
980	1	0.4	89.0
1000	1	0.4	89.4
1040	3	1.3	90.7
1060	1	0.4	91.1
1080	1	0.4	91.5
1100	1	0.4	91.9
1140	2	0.8	92.8
1200	2	0.8	93.6
1240	2	0.8	94.5
1260	1	0.4	94.9
1320	1	0.4	95.3
1380	1	0.4	95.8
1440	1	0.4	96.2
1500	1	0.4	96.6
1520	2	0.8	97.5
1540	1	0.4	97.9
1620	1	0.4	98.3
1820	1	0.4	98.7
1840	1	0.4	99.2
3300	1	0.4	99.6
6820	1	0.4	100.0
Total	**236**	**100.0**	

Table 7. A test for lithologic variation of Se concentration in four dominant lithologies in USGS 9-LITH and USGS 9-10-ft samples, using univariate statistics and t-test comparison

The four dominant lithologies are claystone (CLST), shale (SH), siltstone (SLST), sandstone (SS).

Rank order of means in USGS 9-LITH is SLST > SS > SH > CLST. T-test comparison of mean Se concentrations among lithologies in USGS 9-LITH is as follows: CLST = SH, CLST < SLST, CLST < SS, SH < SLST, SH < SS, SLST = SS.

Rank order of means in USGS 9-10-ft is SLST > SS > CLST > SH. T-test comparison of mean Se concentration among lithologies in USGS 9-10-ft is as follows: CLST = SH, CLST < SLST, CLST = SS, SH = SLST, SH = SS, SLST > SS.

[calculated from data in Appendices B1 and B2 (with Se values below detection set = 0); USGS 9-10-ft includes 1-ft samples and does not include high outlier Se = 6820 µg/kg in a sandstone sample; StdDev = standard deviation; CI 95% = 95 percent confidence interval]

USGS 9-LITH, univariate statistics

	Claystone Se µg/kg	Shale Se µg/kg	Siltstone Se µg/kg	Sandstone Se µg/kg
Mean	33	65	523	322
StdDev	100	144	605	333
Median	0	0	400	250
Minimum	0	0	0	0
Maximum	300	540	2440	1000
Count	9	20	23	48
CI 95%	65	63	247	94

USGS 9-LITH, F-test / t-test

	Variance / Mean		
	Shale	Siltstone	Sandstone
Claystone	E / E	UE / UE	UE / UE
Shale	--	UE / UE	UE / UE
Siltstone	--	--	UE / E

Table 7. cont.

USGS 9-10-ft, univariate statistics

	Claystone Se µg/kg	Shale Se µg/kg	Siltstone Se µg/kg	Sandstone Se µg/kg
Mean	464	405	943	467
StdDev	506	745	547	395
Median	200	50	740	400
Minimum	0	0	320	0
Maximum	1320	1520	1820	1620
Count	10	4	7	52
CI 95%	314	730	405	107

USGS 9-10-ft, F-test / t-test

	Variance / Mean		
	Shale	Siltstone	Sandstone
Claystone	E / E	E / UE	E / E
Shale	--	E / E	UE / E
Siltstone	--	--	E / UE

Table 8. A test for lithologic variation of Se concentration in roof, parting, and floor samples from USGS 9, using univariate statistics and t-test comparisons

The means are equal to one another for the 3 sample groups: roof = parting = floor.

[calculated from data in Appendix B9; StdDev = standard deviation; CI 95% = 95 percent confidence interval]

Univariate Statistics	Roof Se µg/kg	Parting Se µg/kg	Floor Se µg/kg
Mean	798	1280	922
StdDev	732	649	1020
Median	550	1180	600
Minimum	140	500	0
Maximum	1940	2300	3340
Count	8	5	13
CI 95%	507	569	555

F-test / t-test	Variance / Mean	
	Parting	Floor
Roof	E / E	E / E
Parting	--	E / E

Table 9. Se concentration in USGS 9-RPF (combined roof, parting and floor samples from USGS 9), univariate statistics

[calculated from data in Appendix B9; StdDev = standard deviation; CI 95% = 95 percent confidence interval]

Univariate Statistics	RPF Se µg/kg
Mean	952
StdDev	864
Median	660
Minimum	0
Maximum	3340
Count	26
CI 95%	332

Table 10. A test for lithologic variation in Se concentration between USGS 9-RPF, roof, parting, and floor samples and four dominant lithologies in USGS 9-LITH and USGS 9-10-ft samples, using univariate statistics and t-test comparisons

RPF = combined roof, parting, and floor samples. The four dominant lithologies are claystone (= CLST), shale (= SH), siltstone (= SLST), and sandstone (= SS).

In USGS 9-PRF and USGS 9-LITH, rank order of the mean Se concentrations is RPF > SLST > SS > SH > CLST. T-test comparison of mean Se concentrations among RPF and dominant lithologies in USGS 9-LITH is as follows: RPF > CLST, RPF > SH, RPF = SLST, RPF > SS.

In USGS 9-PRF and USGS 9-10-ft, rank order of the mean Se concentrations is RPF > SLST > SS (without high Se value = 6820 µg/kg) > CLST > SH. T-test comparison of mean Se concentrations among RPF and dominant lithologies in USGS 9-10-ft is as follows: RPF > CLST, RPF = SH, RPF = SLST, RPF > SS.

[calculated from data in tables 7, 8, and 9]

USGS 9-LITH, F-test / t-test				
	Variance / Mean			
	Claystone	**Shale**	**Siltstone**	**Sandstone**
RPF	UE / UE	UE / UE	E / E	UE / UE
roof	UE / UE	UE / UE	E / E	UE / UE
parting	UE / UE	UE / UE	E / UE	UE / UE
floor	UE / UE	UE / UE	UE / E	UE / UE

USGS 9-10-ft, F-test / t-test				
	Variance / Mean			
	Claystone	**Shale**	**Siltstone**	**Sandstone**
RPF	UE / UE	E / E	E / E	UE / UE
roof	E / E	E / E	E / E	UE / E
parting	E / UE	E / E	E / E	E / UE
floor	UE / E	E / E	E / E	UE / UE

Table 11. Comparison of Se concentrations (µg/g or ppm) in various lithologies for published data and data reported in this study

	Claystone Se µg/g	Shale Se µg/g	Siltstone Se µg/g	Sandstone Se µg/g
Horn and Adams (1966), modeled global average				
Mean		0.60		0.525
Minimum		0.3		0.05
Maximum		0.9		1.0
Baedecker and others (1998), western US (see notes below)				
Mean		2.9	2.6	1.5
StdDev		5.7	5.9	7.3
Median		0.70	0.70	0.10
Minimum		0.05	0.10	0.05
Maximum		34	23	100
Count		247	23	672
CI 95%		0.72	2.4	0.56
Mullennex (2005), 5 cores at a mine site in southwest West Virginia				
Mean		0.75		0.09
StdDev		1.23		0.11
Count		102		211
CI 95%		0.24		0.01
This Study (data from Appendices B2, B3, B4), 3 cores (USGS 9-10-ft, 11-10-ft, 12 -10-ft) from southwest West Virginia [USGS 9-10-ft includes 1-ft and p-ft samples; does not include two high Se values 6.82 and 3.30 ppm in sandstone]				
Mean	0.46	0.42	0.56	0.32
StdDev	0.49	0.44	0.56	0.40
Median	0.20	0.32	0.41	0.16
Minimum	0.00	0.00	0.00	0.00
Maximum	1.32	1.52	1.82	1.84
Count	15	33	20	166
CI 95%	0.25	0.15	0.25	0.06

Data from Baedecker and others (1998):

1) 1439 data points, all shale and sandstone data with Se values

2) Samples are from western US, including Alaska

3) Use Geolex (http://ngmdb.usgs.gov/Geolex/geolex_home.html) to determine usage and age range for given information on Formations

4) Assign dominant lithology and lithologic modifier from Appendix A4.

5) Negative values are 'less than' values.

6) Assign the value 0.05 ppm to all negative Se values (289). 0.05 ppm is the absolute value of half the median value for all 'less than' values.

Table 11. cont.

Remove 497 samples:

1) Samples with “no information” for Formation (16)

2) Samples with Pre Cambrian for age (217)

3) Samples with ROOF, PART (parting), and SEAT (floor) for lithology associated with coal beds (all 19 samples from Alaska)

4) Samples with ROCK (no specific lithology information), SURF MAT (surface material), PYR (pyrite), BREC (breccia), CGL (conglomerate), LS (limestone), and CLST (claystone) for lithology (87)

5) Samples with lithologic modifier of ORE (ore), U (uranium mineralization), MIN (mineralization, usually sulfate), FEST (ironstone - goethite mineralization), and PYR (pyrite) (158)

The resultant data set, used above, is 942 samples:

857 range in age from Tertiary to Mississippian

85 sandstone samples (75 are from Utah) have no age data (no Formation given)

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Selenium speciation in soils after alkaline extraction

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Abstract

A speciation method for selenium in soils was developed to evaluate the distribution of Se species by using as an example a seleniferous soil from Ireland. First, a water extraction was applied in order to evaluate the Se fraction directly available to plants. Results have shown that only 2% of the total selenium was water soluble and this fraction contained mainly Se(VI). Then, an alkaline extraction was used to solubilize both humic substances and selenium. After optimization of this procedure, a single extraction with a 2 mol l^{-1} sodium hydroxide solution allowed the extraction of 50% of total Se from the soil, a recovery of 90% was obtained with a 10-step extraction procedure. The alkaline extract was acidified to pH 1.5 to divide the acid-soluble fraction (fulvic acids) from the humic acids fraction precipitated at this pH. Seventy percent of total soluble selenium were found in the fulvic acid fraction while 30% were present in the non-acid-soluble fraction. In each fraction, a speciation procedure was then performed in order to identify and determinate inorganic and organic selenium forms. In the acid-soluble fraction, the main Se form was Se(IV) (approx. 44%), non-negligible amounts of organic Se were found (approx. 41%) and Se(VI) represented approx. 15% of this fraction. In the non-acid-soluble fraction, only Se(IV) was determined and it represented approx. 60% of the total Se contained in this fraction. © 1997 Elsevier Science B.V.

Keywords: Selenium; Soil; Extraction; Speciation

1. Introduction

Depending on its concentration and chemical form, selenium functions as an essential element or potent toxicant to humans, livestock, plants, waterfowl and certain bacteria (Nève and Therond, 1991). Soil Se, which usually plays an important role in determining the Se level in food grains, vegetable and even drinking water, is the basis of the Se cycle in the geoecosystem (Mayland et al., 1989; Nève and Therond, 1991; Oldfield, 1992).

Total selenium concentrations in soil range

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from 0.1 μg Se g^{-1} (parts of China and Finland) to 100 μg Se g^{-1} (Ireland and some states of the U.S.) (Mayland et al., 1989; McNeal and Balistrieri, 1989; Nève and Therond, 1991). The concentration depends on the Se content of the parent material, which often increases with depth (Mayland et al., 1989; McNeal and Balistrieri, 1989), closeness to the sea, presence of fine particles and organic matter in the soil (Mayland et al., 1989; McNeal and Balistrieri, 1989; Tam et al., 1995). However, knowledge of the total selenium concentration is not sufficient to evaluate Se availability and toxicity. In soils, selenium generally seems to be present in inorganic forms, in the following oxidation states: selenides [Se(−II)], elemental Se [Se(0)], selenites [Se(IV)] and selenates [Se(VI)]. It is also possible to find organic selenium compounds. Availabilities of these physico–chemical forms are different and their distribution depends on soil properties such as acidity, aeration, the mineral and organic-matter contents, and the microbiological activity (Elrashidi et al., 1989; Masscheleyn et al., 1990; Oremland et al., 1990; Masscheleyn and Patrick, 1993; Tam et al., 1995; Jayaweera and Biggar, 1996; Zawislanski and Zavarin, 1996).

As soil is a complex multi-element system affected by many unstable factors, there is no commonly accepted research method suitable for studying Se speciation. Furthermore, the extraction reagent used must not modify the distribution of the physico–chemical forms of this element. Agronomists have for a long time used treatments intended to evaluate selenium fractions playing a particular role towards Se availability to plants. Hot water extraction is applicable to non-adsorbed selenium and selenium related to water-soluble organic matter (Wang and Sippola, 1990; Yamada and Hattori, 1990). Other treatments with the acid ammonium acetate — EDTA mixture (Wang and Sippola, 1990), Na_2SO_4 (Yamada and Hattori, 1990) or KH_2PO_4 (Gustafsson and Johnsson, 1992; Chao and Sanzolone, 1989) also release the exchangeable Se. These extraction procedures make possible the solubilization of 0.5–7% of total Se according to the studied soil (Yamada and Hattori, 1989, 1990; Gustafsson and Johnsson, 1992).

The acid extraction procedures [2 mol l^{-1} HNO_3 (Kang et al., 1991) or 4 mol l^{-1} HCl (Chao and Sanzolone, 1989)] removes selenium associated with calcium compounds or minerals and acid-soluble organic matter. The total Se solubilized ranges from 5 to 30% in function of the studied soil.

The alkaline extractions with sodium hydroxide permit the solubilization of selenium bound to humic substances (Cutter, 1985; Kang et al., 1991), clays (Bar-Yosef and Meek, 1987) and/or manganese, iron and aluminium oxyhydroxide (Barrow, 1992; Tam et al., 1995). Selenium extraction recoveries are higher, from 30% (Kang et al., 1991; Abrams and Burau, 1989) to 95% (Kang et al., 1991, 1993) depending on the soils characteristics.

It is also possible to evaluate the Se soil availability by using sequential fractionation (Chao and Sanzolone, 1989; Gustafsson and Johnsson, 1992; Tan et al., 1994; Manning and Burau, 1995; Zhang and Moore, 1996). The first steps are the ones described previously (non-adsorbed Se, exchangeable Se, Se associated with calcium compounds and Se bound to organic matter). Other fractions concerning Se bound to sulfides ($KClO_3$-HCl) (Chao and Sanzolone, 1989), Se associated with iron compounds (sodium citrate) (Tan et al., 1994), Se located in the internal parts of Fe and Al oxides or minerals (sodium dithionite) (Tan et al., 1994), Se associated with reducible oxide ($NH_2OH.HCl$) (Manning and Burau, 1995) or elemental Se (Na_2SO_3 1 mol l^{-1}) (Zhang and Moore, 1996) can also be extracted from the soil. In each case, the last step is an acid digestion to obtain the total residual Se (Chao and Sanzolone, 1989; Tan et al., 1994; Manning and Burau, 1995; Zhang and Moore, 1996).

Some authors consider that the non-adsorbed Se, the exchangeable Se and the Se associated to organic matter steps correspond to non-enveloped Se, which is available to plants (Yamada and Hattori, 1990; Gustafsson and Johnsson, 1992; Kang et al., 1991; Tan et al., 1994). For these reasons, a solubilization method of selenium by alkaline extraction is described in this study and a speciation procedure is developed in the extracts in order to identify and determinate a maximum

of inorganic and organic selenium forms in a seleniferous soil from Ireland.

2. Experimental

2.1. Analytical methods used for Se determination

In this work, two analytical methods were used to determine only Se in the + IV oxidation state. The first method, Differential Pulse Cathodic Stripping Voltammetry (DPCSV) is an electrochemical method based on the deposition of a mercury (II) selenide film on a hanging mercury drop electrode.

The principle of the hydride generation — quartz furnace atomic absorption spectrometry (HG-QFAAS) method is as follows. The reducing agent ($NaBH_4$) is added in the generator vessel to form selenium hydride (SeH_2) in acid medium from Se(IV). Then, SeH_2 is flushed by the carrier gas (He) and after a cryogenic trapping, is detected by atomic absorption spectrometry equipped with a quartz furnace in a H_2/O_2 flame.

These two analytical methods have been previously described and optimized in our laboratory (Lespes et al., 1994; Potin Gautier et al., 1994; Séby and Potin Gautier, 1996). The retained operating conditions in this work for the DPCSV and HG-QFAAS methods are listed in Table 1. These methods have been applied to a white clover sample certified for its total Se content (CRM 402) (Quevauviller et al., 1992). Taking into account standard deviations, the Se concentrations obtained by DPCSV (6.87 ± 0.41 μg Se g^{-1}) (Séby and Potin Gautier, 1996) and HG-QFAAS (6.9 ± 0.6 μg Se g^{-1}) (Lespes et al., 1994) are in good agreement with the BCR certified value (6.70 ± 0.45 μg Se g^{-1}).

All analyses have been performed in triplicate, and from triplicate analyses standard deviation have been calculated

2.2. Instrumentation

The DPCSV analyses were performed on a PAR apparatus comprising a voltammetric analyzer (Model 264A) in connection with the PAR Model 303 A device (hanging mercury drop electrode, silver/silver chloride/saturated KCl, saturated in AgCl reference electrode and platinum auxiliary electrode) and a magnetic stirrer PAR 305. Data were displayed on a Kipp and Zonen recorder.

The HG-QFAAS apparatus included a hydride generator vessel with a magnetic stirrer, an empty glass column (4-mm i.d.) with a square form (705-mm total length, 35-mm base width) used as a SeH_2 cryogenic trap. Detection is performed with

Table 1
Operating conditions for Se(IV) determination by DPCSV and HG-QFAAS

DPCSV		HG-QFAAS	
Supporting electrolyte	H_2SO_4 0.1 mol l^{-1}	Analytical medium	HCl 4 mol l^{-1}
Volume of solution in the analysis cell	10 ml	Volume of solution in the reactor	50 ml
Purge time	8 min	Reactor temperature	20°C
Initial potential	$E_i = -0.2$ V	$NaBH_4$ flow-rate	2 ml min^{-1}
Final potential	$E_f = -0.7$ V	$NaBH_4$ flow-time	180 s
Pulse amplitude	$\Delta E = 50$ mV	Furnace temperature	800°C
Scan rate	$v = 5$ mV s^{-1}	Helium flow-rate	400 ml min^{-1}
Deposition time	120 s	Oxygen flow-rate	40 ml min^{-1}
Rest time	30 s	Hydrogen flow-rate	300 ml min^{-1}
Potential of the film deposition peak	$E_{peak} = -0.45$ V	Absorption wavelength	196.0 nm
		Retention time of the SeH_2 peak	30s
Se(IV) detection limit in pure medium	25 ng l^{-1}	Se(IV) detection limit in pure medium	30 ng l^{-1}

a quartz tube atomizer (140-mm length, 12-mm i.d.) placed in a furnace (Perkin Elmer MHS 1) and a Varian SpectrAA-10 atomic absorption spectrometer. Data are recorded with a Shimadzu CR4A-Chromatopac integrator equipped with a PC16N I/O card for the automatization of the whole process.

2.3. Reagents

The Se(IV), Se(VI), selenomethionine and selenocystine stock solutions (1000 mg l^{-1}) were prepared monthly from sodium selenite ($Na_2SeO_3.5H_2O$; Merck suprapure), sodium selenate (Na_2SeO_4 98%; Aldrich suprapure), seleno-DL-methionine and seleno-DL-cystine (Sigma), respectively. All these solutions were stored in Teflon bottles at + 4°C. Working solutions (10 mg l^{-1} and 100 $\mu g\ l^{-1}$) were prepared daily.

The analytical media used for DPCSV (H_2SO_4 96%) and HG-QFAAS (HCl 37%) were prepared with Merck suprapure reagents.

For the HG-QFAAS determinations, the reducing solution was prepared with sodium tetrahydroborate ($NaBH_4$; Fluka) (10% m/v) and stabilized by the addition of 1% (m/v) NaOH (Merck suprapure). The solution was stored at + 4°C after decantation.

The different reagents used for the digestions (HNO_3 65%, H_2O_2 30%), the reduction of Se(VI) (HCl 37%) and for soil extraction (NaOH) were Merck suprapure products.

All solutions were prepared with suprapure water (18 MΩ) obtained from a Millipore system (MilliRO followed by MilliQ).

2.4. Determination of the Se forms in solution

The concentrations of different Se species have been determined according to the procedure illustrated in Fig. 1.

Direct analysis by DPCSV or HG-QFAAS allows the determination of the Se(IV) concentration. Se(VI) concentration is determined after reduction into the Se(IV) form. The optimal reduction yield was obtained with 6 mol l^{-1} HCl at 90°C in sealed glass tubes using a hot water bath

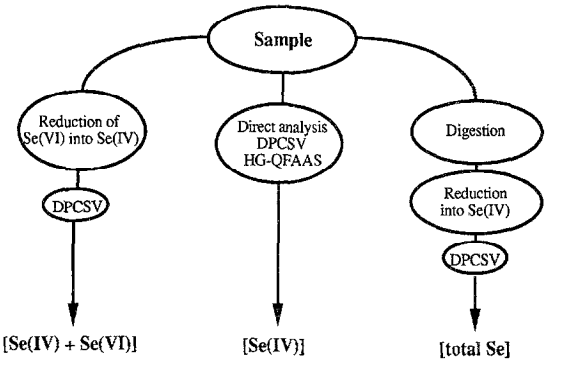

Fig. 1. Speciation schema of selenium in solution.

for 45 min. The Se(VI) concentration is then obtained from the difference between the mean values of the sum [Se(IV) + Se(VI)] and [Se(IV)].

The total selenium content is determined after a digestion of samples with a HNO_3/H_2O_2 mixture (2:1, v/v, respectively). This mixture is evaporated to dryness on a hot plate and the residue is then dissolved in 10 ml of suprapure water. Selenium contained in the digested extract is reduced into the Se(IV) form and analyzed.

2.5. Soil sample

The studied soil comes from a seleniferous area in Ireland. It is a neutral soil (pH 7.25) with a 4.70% organic carbon content. Its total selenium concentration has been determined by an interlaboratory program organized in 1991 by the MRT (French Research and Technology Office) (Potin-Gautier et al., 1991). A total Se concentration of (5.92 ± 0.50) μg Se g^{-1} has been determined.

2.6. Soil Se extraction procedure

The alkaline extraction was carried out as follows: 10 ml of sodium hydroxide solution (the NaOH concentration applied is optimized later on) are added to 1 g of soil in a closed flask. This mixture is submitted to stirring by sonication and centrifuged (4000 rpm) for 20 min.

The Se(IV) and total Se concentrations are determined in the supernatant according to Fig. 1 and the soil residue is analyzed for its total Se

Table 2
Selenium distribution in the soil-water extract

[Total Se] (μg Se g^{-1}) $\pm\sigma_n$ ($n = 3$)	[Se(IV)] (μg Se g^{-1}) $\pm\sigma_n$ ($n = 3$)	[Se(VI)] (μg Se g^{-1}) $\pm\sigma_n$ ($n = 3$)
0.117 ± 0.007	0.0327 ± 0.0007	0.078 ± 0.007

content. The extraction by water was carried out in the same way by replacing the hydroxide sodium solution by suprapure water.

2.7. Fractionation of the alkaline extract

The pH of the supernatant was adjusted to 1.5 with 1 mol l^{-1} sulphuric acid. After standing for 30 min, the acid-soluble fraction (FA) was separated from the precipitated fraction (HA) by centrifugation (20 min, 4000 rpm).

In the acid-soluble fraction, determination of the different Se forms is determined according to the procedure presented in Fig. 1. The non-acid-soluble fraction is analyzed for its total Se content and the Se(IV) concentration is determined by HG-QFAAS after dissolution of the precipitate in 10 ml of a 2 mol l^{-1} NaOH solution.

3. Results and discussion

3.1. Soil water-soluble selenium

An extraction with water was first applied to the soil. The total Se recovery and the Se speciation results are given in Table 2.

The Se total extraction recovery is ($2.0 \pm 0.1\%$). This proportion is low, but its determination is interesting because water-soluble soil Se is one of the major Se fraction that can be used by organisms. It also affects human and animal health by governing the Se content in drinking water and grains (Yamada and Hattori, 1989; Wang and Sippola, 1990; Yamada and Hattori, 1990; Tan et al., 1994).

Considering the speciation results and taking into account the standard deviations, this fraction mainly consists of selenites and selenates ([Se(IV) + Se(VI)] = $95 \pm 6\%$). Selenates are the major species ($67 \pm 6\%$) with regard to selenites ($28.0 \pm 0.6\%$). As it is shown in literature, Se(VI) is less fixed in soil than Se(IV) consequently its solubilization in water and its availability are easier (Bar-Yosef and Meek, 1987; Läuchly, 1993; Masscheleyn and Patrick, 1993).

3.2. Selenium speciation after alkaline extraction

3.2.1. Alkaline extraction of soil Se

Literature shows that the alkaline extraction can be used to obtain both the best Se recoveries and a good evaluation of the availability of Se from the soil (Abrams and Burau, 1989; Kang et al., 1991, 1993), this procedure has therefore been considered.

To obtain a maximal and reproducible Se extraction from the soil, different parameters have been studied, such as NaOH concentration (from 0.5 to 4 mol l^{-1}), the sonication stirring time (from 15 to 270 min) and the kind of flask material (glass or Teflon) submitted to stirring by sonication.

The maximal Se extraction recovery has been obtained by adding 10 ml of a 2 mol l^{-1} NaOH solution in a closed Teflon flask. The use of sodium hydroxide solutions at concentrations greater than 2 mol l^{-1} does not extract greater quantities of selenium from the soil, but induced a more important solubilization of organic matter making digestions less easy to perform.

The flask was maintained in the sonication bath for a period of 3 h. The Se extraction of the soil sample for longer periods of time does not result in an appreciable increase in the concentration of total Se found in the leachate.

With these conditions, the total selenium concentration extracted is 2.94 ± 0.07 μg Se g^{-1} with a repeatability (expressed as % R.S.D.) of 2.5% from six independent extractions (the recovery is $50 \pm 1\%$). The total Se content in the solid residue is 3.0 ± 0.2 μg Se g^{-1}. Hence, the total Se recovery in the soil is quantitative $100 \pm 4\%$ indicating

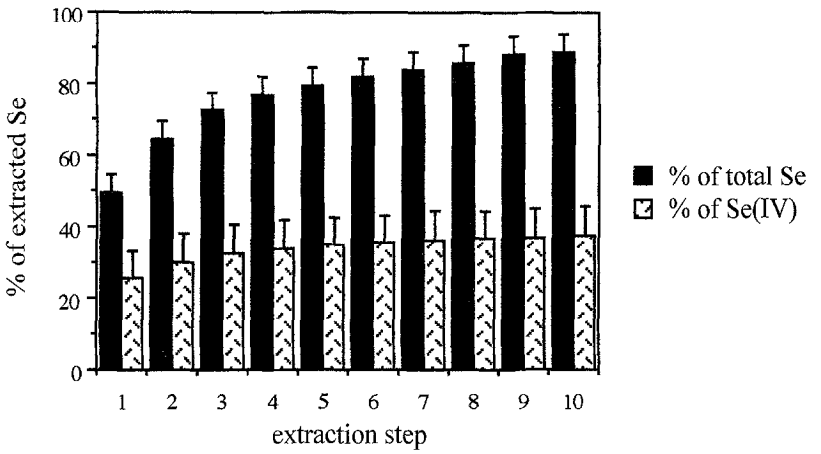

Fig. 2. Repeated extractions of soil with a 2 mol l^{-1} NaOH solution.

that no losses occurred during this single-step extraction procedure.

In order to improve Se solubilization, a procedure using repeated extractions from the same soil sample has been applied. The operating conditions used are those described before.

Results obtained from 10 consecutive extractions are presented in Fig. 2. The major part of the total Se is recovered by a single extraction with a 2 mol l^{-1} sodium hydroxide solution and the amount of extracted Se decreases with the repetition of the extraction. The total Se recovered by the 10-step extraction procedures is 90% of the total Se content of the soil.

The Se fraction that has not been extracted after this treatment (approx. 10% of total soil Se) is assumed to be linked to humins or soil inorganic particles (Kang et al., 1993; Masscheleyn and Patrick, 1993).

Given the highly alkaline conditions and elevated temperature of the extraction procedure, the more important release of selenium from the soil with the repetition of extraction could be the result of a slow and progressive oxidation of Se(−II) or Se(0) to selenite or selenate, more soluble. Furthermore, a soil is a complex medium and the presence of influent factors can promote these oxidation reactions.

The Se(IV) concentration in each of the successive extracts has also been determined by HG-QFAAS. Results (Fig. 2) show that the Se(IV) extracted amounts vary as those of total Se. The first extraction procedure solubilizes a large part of Se(IV) which represents 50% of the total extracted Se. With the repetition of extractions, the Se(IV) extracted amounts decrease. However, Se(IV) is present in all the solubilized fractions and, from the second extraction step, Se(IV) represents approx. 30% of total Se in each extract.

The high proportion of Se(IV) in the first extraction step can be mainly assigned to the high capacity of immobilization of this Se form on iron, manganese or aluminium oxyhydroxides (Barrow, 1992; Masscheleyn and Patrick, 1993; Tam et al., 1995) and humic substances (Gustafsson and Johnsson, 1994; Tam et al., 1995). The use of an extraction solution with pH > 8 allows then to solubilize adsorbed Se(IV). On the other hand, the important presence of Se(IV) in the following extracts can confirm the hypothesis of a slow oxidation of the reduced forms of Se into Se(IV).

3.2.2. Selenium speciation method

Independent 20 $\mu g\ l^{-1}$ solutions of Se(IV), Se(VI), selenomethionine and selenocystine have been prepared in 2 mol l^{-1} sodium hydroxide and submitted to a 3-h sonication period in order to evaluate the stability of these Se species during a single alkaline extraction procedure. The conservation study of elemental Se and inorganic Se(−II) in this medium has not been performed

Table 3
Stability of different Se compounds in alkaline solution (20 $\mu g\ l^{-1}$) during a single step extraction procedure

Se solutions	[Se(IV)] ($\mu g\ l^{-1}$) $\pm \sigma_n$ ($n = 3$)	[Se(VI)] ($\mu g\ l^{-1}$) $\pm \sigma_n$ ($n = 3$)	[Total Se] ($\mu g\ l^{-1}$) $\pm \sigma_n$ ($n = 3$)
Se(IV)	20.1 ± 0.2	n.d.	19.8 ± 0.8
Se(VI)	n.d.	19.9 ± 1.0	20.4 ± 0.6
Selenomethionine	n.d.	n.d.	19.5 ± 0.9
Selenocystine	4.6 ± 0.3	n.d.	20.1 ± 0.2

Note: n.d., non-detected.

because these Se compounds are not commercially available with a suprapure quality. The total Se, Se(IV) and Se(VI) concentrations have been determined in each solution; these values are given in Table 3.

Results show no detectable oxidation of selenite to selenate over the 3-h procedure. Niss et al. (1993) also found a quantitative recovery of these Se forms from spiked fly ash submitted to an alkaline extraction (4 h) in an ultrasonic bath. Selenomethionine does not seem to be affected by the extraction procedure because no transformation into Se(IV) or Se(VI) has been found. On the other hand, selenocystine is oxidized to Se(IV) with an efficiency of 23%.

Because of this last result concerning selenocystine and a possible oxidation of the different Se species with the repeated extractions, the following speciation study is only applied to the first step of the extraction procedure in order to minimize the oxidation of the reduced Se species.

The speciation schema of soil Se applied is illustrated in Fig. 3 which is based upon the fractionation of humic substances as a function of their solubility in acidic or basic solutions.

Three groups of molecules can be separated: humic acids (HA) only soluble in basic solutions; fulvic acids (FA) soluble both in acidic and alkaline media; and humins which are the non-soluble fraction (Chamayou and Legros, 1989).

The results obtained by the application of the selenium speciation schema to the studied soil are given in Fig. 4.

Seventy percent of the total selenium dissolved by one-step alkaline extraction are found in the acid-soluble fraction while 30% precipitates in the non-acid-soluble fraction.

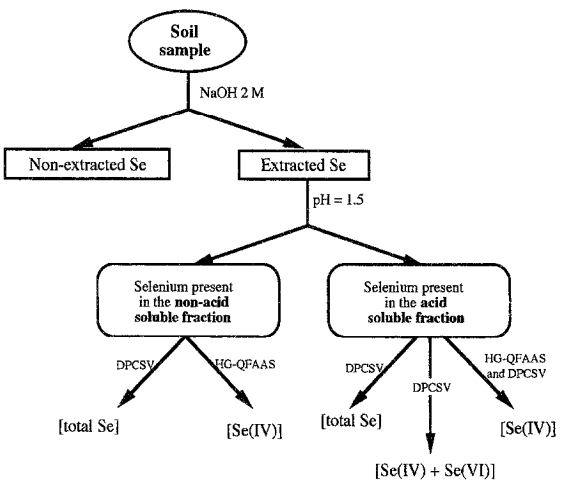

Fig. 3. Speciation schema of selenium in soil.

3.2.2.1. Forms of Se in the acid-soluble fraction (FA). In this fraction, the Se(IV) concentration has been measured by the two analytical methods as organic matter strongly disturbs the Se(IV) determinations by DPCSV, an optimization of the analytical procedure in presence of fulvic acids was necessary (Potin Gautier et al., 1994).

Results of Se(IV) determinations (Fig. 4) performed by both DPCSV and HG-QFAAS are in excellent agreement, DPCSV giving a much better reproducibility.

The Se(VI) concentration has been determined by DPCSV after reduction into Se(IV). The difference between mean concentration values of the sum [Se(IV) + Se(VI)] and total Se of this fraction can be assumed to represent the concentration of selenium which is organically bound. These compounds could correspond to seleno–amino acids such as selenomethionine, identified by Abrams et al. in soil samples (Abrams

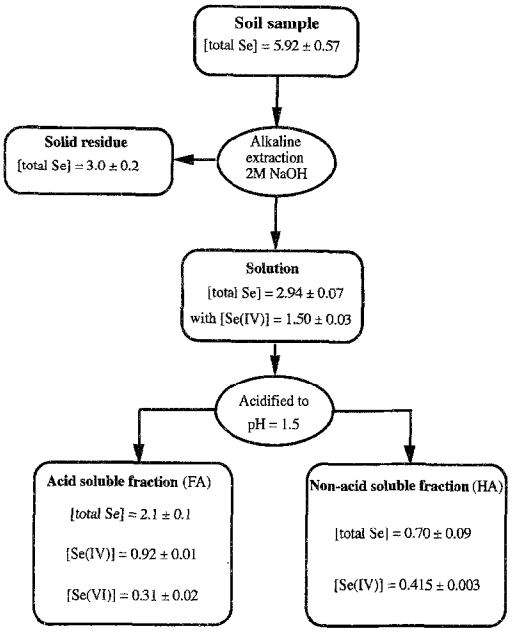

Fig. 4. Se concentration values obtained after the speciation study (expressed in μg Se g^{-1} dry soil).

and Burau, 1989; Abrams et al., 1990) or peptides and proteins because the Se(0) and Se(−II) inorganic forms are strongly fixed in soils and are insoluble in sodium hydroxide (Elrashidi et al., 1989; Masscheleyn et al., 1990).

The balance sheet of the selenium forms' distribution in the acid-soluble fraction (Fig. 4) shows that the main Se form is Se(IV) and Se(VI) is a minor component. Although an organic Se(−II) transformation into Se(IV) may be possible, this fraction contains significant amounts of organic Se. A recent study has shown that organic Se compounds as selenomethionine or selenourea can be immobilized on iron oxyhydroxide and an increase of pH to pH 6 results in a release of these forms (Tam et al., 1995).

3.2.2.2. Forms of Se in the non-acid-soluble fraction (HA). In this fraction, the Se(IV) concentration has been determined only by HG-QFAAS after dissolution of the precipitate in 2 mol l^{-1} NaOH. DPCSV cannot be used to evaluate Se(IV) because an emulsion is produced during the nitrogen purge, preventing measurements. From the results of Fig. 4, Se(IV) represents approx. 60% of total extracted Se. To our knowledge, direct Se(IV) determination has never been performed in the humic-acid fraction precipitated at acid pH. Only the total amount of Se is usually determined and selenium is therefore assumed to be essentially present in the form of seleno–amino acids (Yamada and Hattori, 1990; Gustafsson and Johnsson, 1992). However, from the results presented in Fig. 4, it is probable that Se is not totally present in the Se(IV) form part can result in an oxidation of organic Se(−II) to Se(IV) occurring during the whole treatment.

The selenate concentration has not been determined because the necessary reduction of Se(VI) into Se(IV) should be performed in a hydrochloric acid solution at a pH where humic acids precipitate and make uncertain the Se(VI) reduction.

The pH and redox potential factors have a great influence on the distribution and availability of selenium in soils (Elrashidi et al., 1989; Masscheleyn et al., 1990; Masscheleyn and Patrick, 1993; Jayaweera and Biggar, 1996; Tokunaga et al., 1996; Zawislanski and Zavarin, 1996). (Masscheleyn et al., 1990; Masscheleyn and Patrick, 1993) and Elrashidi et al. (1989) have shown that Se(IV) prevails for neutral soils with a moderated redox potential. As the pH of the studied soil is neutral, it seems expected that Se(IV) represents the main Se form [Se(IV) represents, respectively, 44%, 60% and 51% of the acid-soluble, non-acid-soluble fractions and the alkaline extraction]. The sum of the Se(IV) concentrations determined in the two fractions (HA and FA) (1.35 ± 0.05 μg Se g^{-1}) is not strictly identical to the total soluble Se(IV) concentration (1.50 ± 0.03 μg Se g^{-1}), but the difference is not highly significant owing to analytical difficulties involved.

3.2.2.3. Reproducibility of the speciation method. Reproducibility has been evaluated by means of calculation of the relative standard deviation (% R.S.D.) from three measurements on three independent treatments of soil sample.

The highest R.S.D. values have been obtained for the total Se determinations in the acid-soluble fraction (5%) and for the non-acid-soluble fraction (13%) because of the large number of sample treatment steps before analysis. On the other

hand, reproducibilities corresponding to direct Se(IV) determination (from 1 to 2%) or the [Se(IV) + Se(VI)] sum (4.8%) are satisfactory.

Resins have often been used in the literature to remove organic matter from soil extracts (Abrams and Burau, 1989; Fio and Fujii, 1990; Kang et al., 1993). The optimization of the analytical methods for the determination of Se(IV) in presence of humic substances (Lespes et al., 1994; Potin Gautier et al., 1994) has allowed us to establish this speciation schema without using resins, minimizing Se losses.

4. Conclusion

The speciation schema developed in this study has evaluated the Se species distribution in a soil. First, the water-soluble fraction has been extracted from the soil. The total selenium concentration recovered is low ($2.0 \pm 0.1\%$) and the speciation analysis have shown that only Se(IV) and Se(VI) are present in this water-soluble extract and Se(VI) is in the majority.

In order to obtain more information on the Se distribution in this Irish soil, an alkaline extraction has been applied and has facilitated a higher recovery ($50 \pm 1\%$). Then, the alkaline extract is acidified (pH 1.5) to separate the acid-soluble fraction (FA) from the solid fraction at this pH (HA). The two fractions contain selenium and the richer is the acid-soluble fraction. Results of the speciation analysis indicate that Se(IV) is the main Se form. Se(VI) represents only 15% of the total extracted Se in the acid-soluble fraction but this form cannot be determined in the other fraction.

Unidentified forms of selenium are present in large amounts in the studied soil, probably in the form of Se organic compounds. Their behaviour in soil are mostly unknown so it would be interesting to obtain such information for a better understanding of Se availability.

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Ground Water Issue

Behavior of Metals in Soils

Joan E. McLean* and Bert E. Bledsoe**

The Regional Superfund Ground-Water Forum is a group of scientists, representing EPA's Regional Superfund Offices, organized to exchange up-to-date information related to ground-water remediation at Superfund sites. One of the major issues of concern to the Forum is the mobility of metals in soils as related to subsurface remediation.

For the purposes of this Issue Paper, those metals most commonly found at Superfund sites will be discussed in terms of the processes affecting their behavior in soils as well as laboratory methods available to evaluate this behavior. The retention capacity of soil will also be discussed in terms of the movement of metals between the other environmental compartments including ground water, surface water, or the atmosphere. Long-term changes in soil environmental conditions, due to the effects of remediation systems or to natural weathering processes, are also discussed with respect to the enhanced mobility of metals in soils.

For further information contact Bert Bledsoe (405) 332-8800 or FTS 700-743-2324 at RSKERL-Ada.

Introduction

The purpose of this document is to introduce to the reader the fundamental processes that control the mobility of metals in the soil environment. This discussion will emphasize the basic chemistry of metals in soils and will provide information on laboratory methods used to evaluate the behavior of metals in soils. The metals selected for discussion in this document are the metals most commonly found at Superfund sites and will be limited to lead (Pb), chromium (Cr), arsenic (As), cadmium (Cd), nickel (Ni), zinc (Zn), copper (Cu), mercury (Hg), silver (Ag), and selenium (Se).

Metals are defined as any element that has a silvery luster and is a good conductor of heat and electricity. There are many terms used to describe and categorize metals, including trace metals, transition metals, micronutrients, toxic metals, heavy metals. Many of these definitions are arbitrary and these terms have been used loosely in the literature to include elements that do not strictly meet the definition of the term. Strictly speaking arsenic and selenium are not metals but are metalloids, displaying both metallic and non-metallic properties. For this paper, the term metal will be used to include all the elements under discussion.

The average concentration of select metals in soils is listed in Table 1. All soils naturally contain trace levels of metals. The presence of metals in soil is, therefore, not indicative of contamination. The concentration of metals in uncontaminated soil is primarily related to the geology of the parent material from which the soil was formed. Depending on the local geology, the concentration of metals in a soil may exceed the ranges listed in Table 1. For example, Se concentration in non-seleniferous soils in the U.S. range from 0.1 to 2 mg/Kg. In seleniferous soils, Se ranges from 1 to 80 mg/Kg, with reports of up to 1200 mg/Kg Se (McNeal and Balistrier, 1989). Use of common ranges or average concentration of trace metals in soils as an indicator of whether a soil is contaminated is not appropriate since the native concentration of metals in a specific soil may fall out of the listed ranges. Only by direct analysis of uncontaminated soils can background levels of metals be determined.

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Table 1. Content of Various Elements in Soils (Lindsay, 1979)

Metal	*Selected Average for Soils mg/kg*	*Common Range for Soils mg/kg*
Al	71,000	10,000-300,000
Fe	38,000	7,000-550,000
Mn	600	20-3,000
Cu	30	2-100
Cr	100	1-1000
Cd	0.06	0.01-0.70
Zn	50	10-300
As	5	1.0-50
Se	0.3	0.1-2
Ni	40	5-500
Ag	0.05	0.01-5
Pb	10	2-200
Hg	0.03	0.01-0.3

Metals associated with the aqueous phase of soils are subject to movement with soil water, and may be transported through the vadose zone to ground water. Metals, unlike the hazardous organics, cannot be degraded. Some metals, such as Cr, As, Se, and Hg, can be transformed to other oxidation states in soil, reducing their mobility and toxicity.

Immobilization of metals, by mechanisms of adsorption and precipitation, will prevent movement of the metals to ground water. Metal-soil interaction is such that when metals are introduced at the soil surface, downward transportation does not occur to any great extent unless the metal retention capacity of the soil is overloaded, or metal interaction with the associated waste matrix enhances mobility. Changes in soil environmental conditions over time, such as the degradation of the organic waste matrix, changes in pH, redox potential, or soil solution composition, due to various remediation schemes or to natural weathering processes, also may enhance metal mobility. The extent of vertical contamination is intimately related to the soil solution and surface chemistry of the soil matrix with reference to the metal and waste matrix in question.

Fate of Metals in the Soil Environment

In soil, metals are found in one or more of several "pools" of the soil, as described by Shuman (1991):

1) dissolved in the soil solution;
2) occupying exchange sites on inorganic soil constituents;
3) specifically adsorbed on inorganic soil constituents;
4) associated with insoluble soil organic matter;
5) precipitated as pure or mixed solids;
6) present in the structure of secondary minerals; and/or
7) present in the structure of primary minerals.

In situations where metals have been introduced into the environment through human activities, metals are associated with the first five pools. Native metals may be associated with any of the pools depending on the geological history of the area. The aqueous fraction, and those fractions in equilibrium with this fraction, i.e., the exchange fraction, are of primary importance when considering the migration potential of metals associated with soils.

Multiphase equilibria must be considered when defining metal behavior in soils (Figure 1). Metals in the soil solution are subject to mass transfer out of the system by leaching to ground water, plant uptake, or volatilization, a potentially important mechanism for Hg, Se, and As. At the same time metals participate in chemical reactions with the soil solid phase. The concentration of metals in the soil solution, at any given time, is governed by a number of interrelated processes, including inorganic and organic complexation, oxidation-reduction reactions, precipitation/dissolution reactions, and adsorption/desorption reactions. The ability to predict the concentration of a given metal in the soil solution depends on the accuracy with which the multiphase equilibria can be determined or calculated.

Most studies of the behavior of metals in soils have been carried out under equilibrium conditions. Equilibrium data indicate which reactions are likely to occur under prescribed conditions, but do not indicate the time period involved. The kinetic aspect of oxidation/reduction, precipitation/dissolution, and adsorption/desorption reactions involving metals in soil matrix suffers from a lack of published data. Thus the kinetic component, which in many cases is critical to predict the behavior of metals in soils, cannot be assessed easily. Without the kinetic component, the current accepted approach is to assume that local equilibrium occurs in the soil profile. Equilibrium thermodynamic data can then be applied not only to predict which precipitation/dissolution, adsorption/ desorption, and/or oxidation/reduction reactions are likely to occur under a given set of conditions, but also to estimate the solution composition, i.e., metal concentration in solution, at equilibrium. This approach relies heavily on the accuracy of thermodynamic data that can be found in the literature.

Soil Solution Chemistry

Metals exist in the soil solution as either free (uncomplexed) metal ions (e.g., Cd^{2+}, Zn^{2+}, Cr^{3+}), in various soluble complexes with inorganic or organic ligands (e.g., $CdSO_4^o$, $ZnCl^+$, $CdCl_3^-$), or associated with mobile inorganic and organic colloidal material. A complex is defined as an unit in which a central metal ion is bonded by a number of associated atoms or molecules in a defined geometric pattern, e.g $ZnSO_4^o$, $CdHCO_3^+$, $Cr(OH)_4^-$. The associated atoms or molecules are termed ligands. In the above examples, SO_4^{2-}, HCO_3^-, and OH^- are ligand. The total concentration of a metal, Me_T, in the soil solution is the sum of the free ion concentration $[Me^{z+}]$, the concentration of soluble organic and inorganic metal complexes, and the concentration of metals associated with mobile colloidal material.

Metals will form soluble complexes with inorganic and organic ligands. Common inorganic ligands are SO_4^{2-}, Cl^-, OH^-, PO_4^{3-}, NO_3^- and CO_3^{2-}. Soil organic ligands include low molecular weight aliphatic, aromatic, and amino acids and soluble constituents of fulvic acids. Formation constants for various metal complexes are available in the literature (e.g., see Nordstrom and Munoz, 1985; Lindsay, 1979; Martell and Smith, 1974 -1982). Organic complexation of metals in soil is not as well defined as inorganic complexation because of the difficultly of identifying the large number of organic ligands that

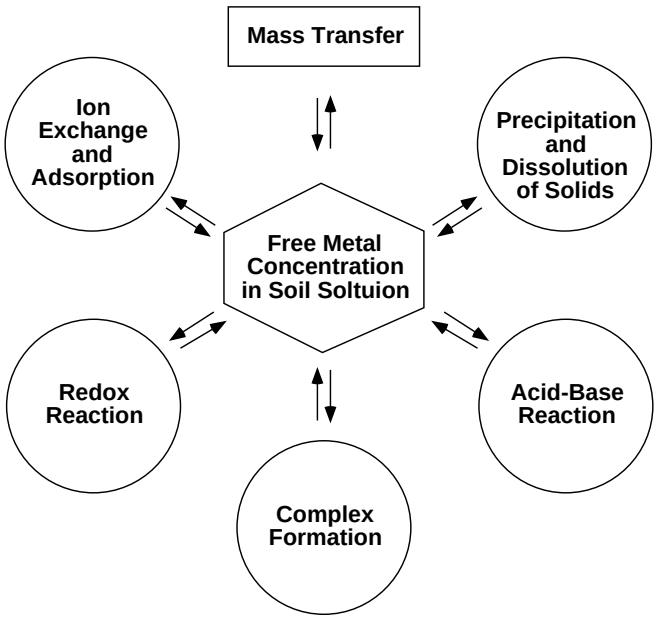

Figure 1. Principal controls on free trace metal concentrations in soils solution (Mattigod, et al., 1981).

may be present in soils. Most of the metal-organic complex species identified in the literature were generated from metal interaction with fulvic acids extracted from sewage sludges (Baham, et al., 1978; Baham and Sposito, 1986; Behel, et al., 1983; Boyd et al., 1979; Boyd et al., 1983; Dudley, et al., 1987; Lake et al., 1984; Sposito et al., 1979; Sposito et al., 1981; Sposito et al., 1982). The soluble metal organic complexes that may form in other waste systems, however, have not been identified.

The presence of complex species in the soil solution can significantly affect the transport of metals through the soil matrix relative to the free metal ion. With complexation, the resulting metal species may be positively or negatively charged or be electrically neutral (e.g., $CdCl_3^+$, $CdCl^-$, $CdCl_2^o$). The metal complex may be only weakly adsorbed or more strongly adsorbed to soil surfaces relative to the free metal ion. A more detailed discussion on the effect complex formation has on metal mobility is given in the section: Effect of anions on adsorption and precipitation. Speciation not only affects mobility of metals but also the bioavailability and toxicity of the metal. The free metal ion is, in general, the most bioavailable and toxic form of the metal.

Several metals of environmental concern exist in soils in more than one oxidation state: arsenic, As(V) and As(III), selenium, Se(VI) and Se(IV), chromium, Cr(VI) and Cr(III), and mercury, Hg(II) and Hg(I). The oxidation state of these metals determines their relative mobility, bioavailability, and toxicity. For example, hexavalent Cr is relatively mobile in soils, being only weakly sorbed by soils. Hexavalent Cr is also extremely toxic and a known carcinogen. Trivalent Cr, on the other hand, is relatively immobile in soil, being strongly sorbed by soils and readily forming insoluble precipitates, and it is of low toxicity.

Atomic absorption spectrophotometers (AA) and inductively coupled plasma emission spectrometers (ICP) are commonly used to determine the metal concentration in soil solutions. Both techniques measure the total metal concentration in the solution without distinguishing metal speciation or oxidation state. Free metal, complexed metal ion concentrations and concentration of metals in different oxidation states can be determined using ion selective electrodes, polarography, colorimetric procedures, gas chromatography-AA, and high performance liquid chromatography-AA (see Kramer and Allen, 1988). While these specific methods are necessary for accurate measurements of metal speciation and oxidation state, these methods are not routinely performed by commercial laboratories nor are these procedure standard EPA methods.

Metal concentrations determined by AA or ICP are often used as inputs into a thermodynamic computer program, such as MINTEQA2 (USEPA, 1987). This program can be used to calculate the speciation and oxidation state of metals in soil solution of known composition. Formation constants are known for many metal complexes. There is, however, only limited information for metal-organic complexes, including formation constants for many naturally occurring ligands and those in waste disposal systems. The required input data for these models include: the concentration of the metal of interest, the inorganic and organic ligands, and the major cations and other metal ions, and pH. In specific cases the redox potential and pCO_2 also may be required. Output consists of an estimation of the concentration of free metals and complexed metals at equilibrium for the specified conditions.

Many predictive methods, based on solution and solid phase chemistry, do not adequately describe transport of metals under field conditions. Solution chemistry considers the interaction between dissolved species, dissolved being defined as substances that will pass a 0.45µm filter. However, in addition to dissolved metal complexes, metals also may associate with mobile colloidal particles. Colloidal size particles are particles with a diameter ranging from 0.01 and 10µm (Sposito, 1989). Gschwend and Reynolds (1987) reported that colloidal particles of intermediate diameter, 0.1µm to 1µm, were the most mobile particles in a sandy medium. Colloidal particles include iron and manganese oxides, clay minerals, and organic matter. These surfaces have a high capacity for metal sorption. Puls et al. (1991) reported a 21 times increase in arsenate transport in the presence of colloidal material compared with dissolved arsenate. This increased transport of contaminants associated with mobile colloidal material has been termed facilitated transport.

Solid Phase Formation

Metals may precipitate to form a three dimensional solid phase in soils. These precipitates may be pure solids (e.g., $CdCO_3$, $Pb(OH)_2$, ZnS_2) or mixed solids (e.g., $(Fe_xCr_{1-x})(OH)_3$, $Ba(CrO_4,SO_4)$). Mixed solids are formed when various elements co-precipitate. There are several types of co-precipitation, inclusion, adsorption and solid solution formation, distinguished by the type of association between the trace element and the host mineral (Sposito, 1989). Solid solution formation occurs when the trace metal is compatible

with the element of the host mineral and thus can uniformly replace the host element throughout the mineral. An example of solid solution formation is the substitution of Cd for Ca in calcium carbonate. Cadmium and Ca have almost identical ionic radii so that Cd can readily substitute of Ca in this carbonate mineral. Mechanisms of retention, whether surface adsorption, surface precipitation, co-precipitation, and pure solid formation are often difficult to distinguish experimentally. Retention involves a progression of these processes. The term sorption is used when the actual mechanism of metal removal from the soil solution is not known.

Stability diagrams are used as a convenient technique for illustrating how the solubility of metal compounds varies with soil pH and with metal concentration (or activity). The diagrams also allow some prediction of which solid phase regulates metal activity in the soil solution. Methods for constructing such diagrams is given in Sposito (1989) and Lindsay (1979). Santillan-Medrano and Jurinak (1975) used stability diagrams for predicting the formation of precipitates of Pb and Cd in a calcareous soil. The stability diagrams (Figures 2 and 3) illustrate the decrease in Pb and Cd solubility with increasing pH, which is the usual trend with cationic metals. Solution activity of Cd is consistently higher than that for Pb indicating that Cd may be more mobile in the environment. Lead phosphate compounds at lower pH and a mixed Pb compound at pH>7.5 could be the solid phases regulating Pb in solution. The authors concluded that cadmium solution activity is regulated by the formation of $CdCO_3$ and $Cd(PO_4)_2$ or a mixed Cd solid at pH<7.5. At higher pH, the system is undersaturated with respect to the Cd compounds considered.

The formation of a solid phase may not be an important mechanism compared to adsorption in native soils because of the low concentration of trace metals in these systems (Lindsay, 1979). Precipitation reactions may be of much greater importance in waste systems where the concentration of metals may be exceedingly high. McBride (1980)

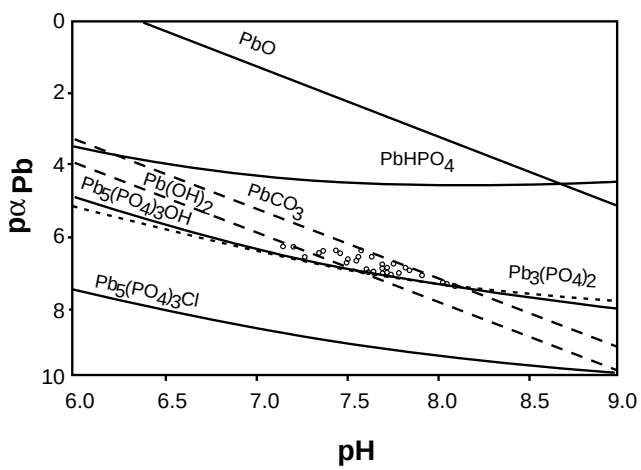

Figure 2. The solubility diagram for Pb in Nibley clay loam soil (Santillan-Medrano and Jurinak, 1975).

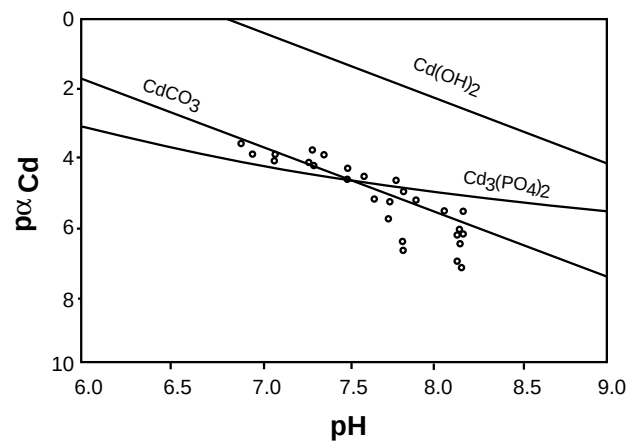

Figure 3. The solubility diagram for Cd in Nibley clay loam soil (Santillan-Medrano and Jurinak, 1975).

concluded that calcite ($CaCO_3$) serves as a site for adsorption of Cd^{2+} at low concentrations of Cd, while $CdCO_3$ precipitation, possibly as a coating on the calcite, occurs only at higher Cd concentrations.

Surface Reactions

Adsorption is defined as the accumulation of ions at the interface between a solid phase and an aqueous phase. Adsorption differs from precipitation in that the metal does not form a new three dimensional solid phase but is instead associated with the surfaces of existing soil particles. The soil matrix often includes organic matter, clay minerals, iron and manganese oxides and hydroxides, carbonates, and amorphous aluminosilicates.

Soil organic matter consists of 1) living organisms, 2) soluble biochemicals (amino acids, proteins, carbohydrates, organic acids, polysaccharides, lignin, etc.), and 3) insoluble humic substances. The biochemicals and humic substances provide sites (acid functional groups, such as such as carboxylic, phenolics, alcoholic, enolic-OH and amino groups) for metal sorption. A discussion of the nature of soil organic matter and its role in the retention of metals in soil is given by Stevenson (1991) and Stevenson and Fitch (1990). The biochemicals form water soluble complexes with metals, increasing metal mobility, as discussed in a previous section. The humic substances consists of insoluble polymers of aliphatic and aromatic substances produced through microbial action. Humic substances contain a highly complex mixture of functional groups. Binding of metals to organic matter involves a continuum of reactive sites, ranging from weak forces of attraction to formation of strong chemical bonds. Soil organic matter can be the main source of soil cation exchange capacity, contributing >200meq/100 g of organic matter in surface mineral soils. Organic matter content, however, decreases with depth, so that the mineral constituents of soil will become a more important surface for sorption as the organic matter content of the soil diminishes.

There have been numerous studies of the adsorptive properties of clay minerals, in particular montmorillonite and

kaolinite, and iron and manganese oxides. Jenne (1968) concluded that Fe and Mn oxides are the principal soil surface that control the mobility of metals in soils and natural water. In arid soils, carbonate minerals may immobilize metals by providing an adsorbing and nucleating surface (Santillan-Medrano and Jurinak, 1975; Cavallaro and McBride, 1978; McBride, 1980; Jurinak and Bauer, 1956; McBride and Bouldin, 1984; Dudley et al., 1988; Dudley et al., 1991).

Soil surfaces carry either a net negative or positive charge depending on the nature of the surface and the soil pH. The permanent net negative charge on surfaces is due to charge imbalance resulting from the isomorphous substitution of Al^{3+} for Si^{4+} in the tetrahedral layers and/or substitution of Mg^{2+}, Fe^{2+}, etc. for Al^{3+} in the octahedral layers of aluminosilicate clays. The charge on the surface is not affected by changes in soil pH and hence it is termed a permanent charged surface. pH dependent charged surfaces are associated with the edges of clay minerals, with the surfaces of oxides, hydroxides and carbonates, and with organic matter (acid functional groups). The charge arises from the association and dissociation of protons from surface functional groups. Using an iron oxide surface functional group as an example, the association of protons with the functional group results in a positive charge [$-Fe-OH_2^+$] and dissociation of protons, under more alkaline conditions, results in a negative charge [$-Fe-O^-$]. At the point of zero net proton charge (PZNPC) the functional group is neutral [$-Fe-OH^o$]. For all pH dependent charged surfaces, whether organic or inorganic, as the pH decreases, the number of negatively charged sites diminishes. Under more acidic conditions, the majority of pH dependent surfaces will be positively charged and under more alkaline conditions, the majority of sites will be negatively charged. The pH dependent charged surfaces in soils differ widely in their PZNPC.

The structural charge developed on either a permanent charged surface or a pH dependent charged surface must be balanced by ions of opposite charge at or near the surface. The cation exchange capacity is a measure of the negatively charged sites for cation adsorption and anion exchange capacity is a measure of the positively charged sites for anion adsorption. The anion capacity is, however, very small relative to the cation adsorption capacity of soils.

A surface complexation model is often used to describe adsorption behavior (Sposito, 1989). Several types of surface complexes can form between a metal and soil surface functional groups and are defined by the extent of bonding between the metal ion and the surface (Figure 4). Metals in a diffuse ion association or in an outer sphere complex are surrounded by waters of hydration and are not directly bonded to the soil surface. These ions accumulate at the interface of the charged surfaces in response to electrostatic forces. These reactions are rapid and reversible with only a weak dependence on the electron configuration of the surface group and the adsorbed ion. These two metal-surface interactions have also been termed exchange reactions because the introduction of other cations into the system, in sufficient concentration, causes the replacement or exchange of the original cations. Metals associated with exchange sites may, depending on the environment, be relatively mobile. Exchangeable metals may be the most significant reserve of potentially mobile metals in soil (Silveira and Sommers, 1977; Latterell et al., 1978).

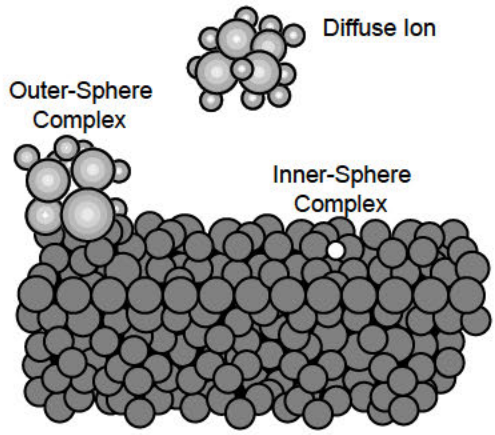

Figure 4. The three mechanisms of cation adsorption on a siloxane surface (e.g., montmorillonite). (Spositi, 1989).

With inner sphere complexation, the metal is bound directly to the soil surface, no waters of hydration are involved. It is distinguished from the exchangeable state by having ionic and/or covalent character to the binding between the metal and the surface. A much higher bonding energy is involved than in exchange reactions, and the bonding depends on the electron configuration of both the surface group and the metal. This adsorption mechanism is often termed specific adsorption. The term specific implies that there are differences in the energy of adsorption among cations, such that other ions, including major cations, Na, Ca, Mg, do not effectively compete for specific surface sites. Specifically adsorbed metal cations are relatively immobile and unaffected by high concentrations of the major cations due to large differences in their energies of adsorption.

At low concentrations, metals are adsorbed by the specific adsorption sites. These adsorbed metals are not removed by the input of major cations. With increasing concentration of the metal, the specific sites become saturated and the exchange sites are filled (Hendrickson and Corey, 1981; Lehmann and Harter, 1984; Garcia-Miragaya et al., 1986; O'Connor et al., 1984; O'Connor et al., 1983). Metals associated with these nonspecific sites are exchangeable with other metal cations and are thus potentially mobile. For example, in an adsorption study using Cd, O'Connor et al.(1984) showed two mechanisms were responsible for metal retention by soil. The authors attributed the first mechanism, active at low concentration (0.01-10mg/L added Cd), to specific adsorption. At higher concentrations (100-1000mg/L added Cd), adsorption was attributed to exchange reactions. Desorption studies showed that the added Cd at low concentration was not removed by 0.05M calcium solutions, whereas at the higher loading rates, the calcium salt removed significant amounts of the adsorbed Cd. These results indicate that the observed affinity of a metal for soil surfaces is concentration dependent. These results also emphasize the importance of using literature or laboratory generated values that cover the range of metal concentration of interest at a specific location. Use of data generated in the wrong concentration range may lead to misinterpretation of the metal binding strength of the soil.

The relative affinity of a soil surface for a free metal cation increases with the tendency of the cation to form strong bonds, i.e., inner sphere complexes, with the surface. The general order of preference for monovalent cations by montmorillonite is Cs > Rb > K = NH_4 > Na > Li. For the alkaline earth metals the order is Ba > Sr > Ca > Mg. The preference series indicates a greater attraction of the surface for the less hydrated cations that can fit closer to the clay surface. For transition metals, the size of the hydrated cation cannot be used as the only predictor of adsorption affinity since the electron configuration of a metal plays an important role in adsorption. Table 2 reports on results from various researches on the relative sorption affinity of metals onto a variety of soils and soil constituents. Although there is consistently a higher affinity of these surfaces for Pb and Cu compared with Zn or Cd, the specific order of sorption affinity depends on the properties of the metals, surface type, and experimental conditions.

Anions in the Soil Environment

Common anionic contaminants of concern include: arsenic (AsO_4^{3-} and AsO_2^{-}), selenium (SeO_3^{2-} and SeO_4^{2-}), and chromium in one of its oxidation states (CrO_4^{2-}). Soil particles, though predominantly negatively charged, also may carry some positive charges. The oxide surfaces, notably iron, manganese, and aluminum oxides, carbonate surfaces, and insoluble organic matter can generate a significant number of positive charges as the pH decreases. The edges of clay minerals also carry pH dependent charge. These edge sites may be important sites of retention of anions at pHs below the point of zero charge (PZC).

Clay minerals, oxides, and organic matter exert a strong preference for some anions in comparison to other anions, indicating the existence of chemical bonds between the surface and the specific anion. Phosphate has been the most extensively studied anion that exhibits this specific adsorption (inner sphere complex) phenomenon. Selenite (SeO_3^{2-}) and arsenate (AsO_4^{3-}) are adsorbed to oxides and soils through specific binding mechanisms (Rajan, 1979; Neal, et al., 1987b). Selenite (SeO_4^{2-}) and hexavalent chromium are only weakly bound to soil surfaces and are thus easily displaced by other anions. Balistrieri and Chao (1987) found the sequence of adsorption of anions onto iron oxide to be: phosphate = silicate = arsenate > bicarbonate/carbonate > citrate = selenite > molybdate > oxalate > fluoride = selenate > sulfate. The adsorption capacity for anions is, however, small relative to cation adsorption capacity of soils.

Soil Properties Affecting Adsorption

The adsorption capacity (both exchange and specific adsorption) of a soil is determined by the number and kind of sites available. Adsorption of metal cations has been correlated with such soil properties as pH, redox potential, clay, soil organic matter, Fe and Mn oxides, and calcium carbonate content. Anion adsorption has been correlated with Fe and Mn oxide content, pH, and redox potential. Adsorption processes are affected by these various soil factors, by the form of the metal added to the soil, and by the solvent introduced along with the metal. The results of these interactions may increase or decrease the movement of metals in the soil water.

Korte et al. (1976) qualitatively ranked the relative mobilities of 11 metals added to 10 soils (Table 3) to simulate movement of metals under an anaerobic landfill situation. The leachate used was generated in a septic tank, preserved under carbon dioxide and adjusted to pH of 5. Of the cationic metals studied lead and copper were the least mobile and mercury(II) was the most mobile (Figure 5). The heavier textured soils with higher pHs (Molokai, Nicholson, Mohaveca and Fanno) were effective in attenuating the metals, while sandy soils and/or soils with low pH did not retain the metals effectively. For the anionic metals, clay soils containing oxides with low pH were relatively effective in retaining the anions (Figure 6). As with the cationic metals, the light textured soils were the least effective in retaining the anions. Chromium (VI) was the most mobile of the metals studied. Griffin and Shimp (1978) found the relative mobility of nine metals through montmorillonite and kaolinite to be: Cr(VI) > Se > As(III) > As(V) > Cd > Zn > Pb > Cu > Cr(III).

Table 2. Relative affinity of metals for soils and soil constituents

Soil or Soil Constituent	*Relative Order of Sorption*	*Reference*
goethite	Cu>Pb>Zn>Co>Cd	Forbes et al., 1976
Fe oxide	Pb>Cu>Zn>Cd	Benjamin and Leckie, 1981
montmorillonite	Cd=Zn>Ni	Puls and Bohn, 1988
kaolinite	Cd>Zn>Ni	Puls and Bohn, 1988
soils	Pb>Cu>Zn>Cd>Ni	Biddappa et al., 1981
soils	Zn>Ni>Cd	Tiller et al., 1984
mineral soils	Pb>Cu>Zn>Cd	Elliott et al., 1986
organic soils	Pb>Cu>Cd>Zn	Elliott et al., 1986
soil	Pb>Cu>Zn>Ni	Harter, 1983

Table 3. Characteristics of the soils (Korte et al., 1976)

Soil	*Order*	*pH meq/100g*	*CEC m2/g*	*Surface Area %*	*Free Fe oxides %*	*Clay*	*Texture*
Wagram	Ultisol	4.2	2	8.0	0.6	4	loamy sand
Ava	Alfisol	4.5	19	61.5	4	31	silty clay loam
Ka kaska	Spodosol	4.7	10	8.9	1.8	5	sand
Davidson	Ultisol	6.2	9	61.3	17	61	clay
Molokai	Oxisol	6.2	14	67.3	23	52	clay silty clay
Chalmers	Mollisol	6.6	26	125.6	3.1	35	loam
Nicholson	Alfisol	6.7	37	120.5	5.6	49	silty day
Fanno	Alfisol	7	33	122.1	3.7	46	clay
Mohave	Aridisol	7.3	10	38.3	1.7	11	sandy loam
Mohave ca	Aridisol	7.8	12	127.5	2.5	40	clay loam
Anthony	Entisol	7.8	6	19.8	1.8	15	sandy loam

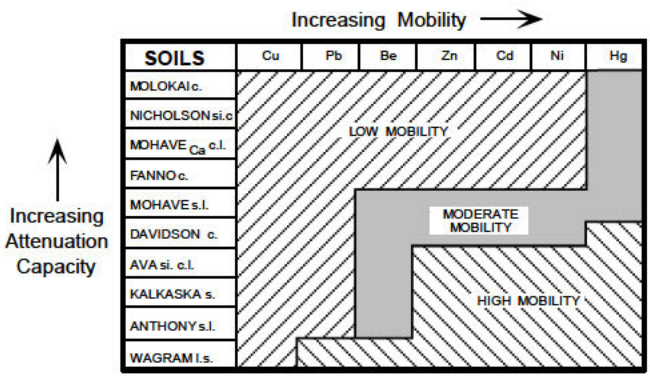

Figure 5. Relative mobility of cations through soil. (From Korte, Skopp, Fuller, Niebla, and Alesii, 1976).

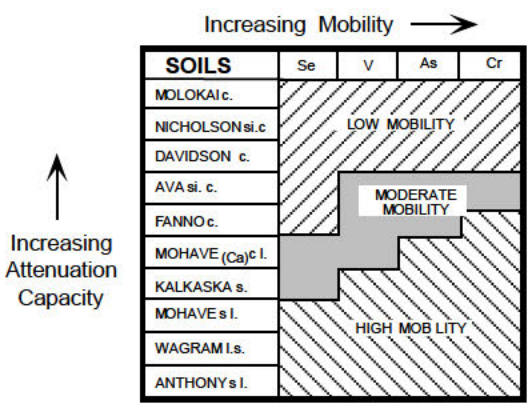

Figure 6. Relative mobility of anions through soil. (From Korte, Skopp, Fuller, Niebla, and Alesii, 1976).

Factors Affecting Adsorption and Precipitation Reactions

Although the principles affecting sorption and precipitation are similar for cationic and anionic metals, for clarity, the following section will concentrate on a general discussion of factors affecting the behavior of cationic metals in soils. Factors affecting anion adsorption and precipitation will be discussed for each individual metal anion in a later section.

Effect of competing cations

For specific adsorption sites, trace cationic metals are preferentially adsorbed over the major cations (Na, Ca, Mg) and trace anionic metals are preferentially adsorbed over major anions (SO_4^-, NO_3^-, soluble ionized organic acids). However, when the specific adsorption sites become saturated, exchange reactions dominate and competition for these sites with soil major ions becomes important. Cavallaro and McBride (1978) found that adsorption of Cu and Cd decreased in the presence of 0.01M $CaCl_2$. They attributed this decrease to competition with Ca for adsorption sites. Cadmium adsorption was more affected by the presence of Ca than Cu. The mobility of Cd may be greatly increased due to such competition. Likewise, Harter (1979) indicated the Ca in solution had a greater effect on Pb adsorption than on Cu. In another study, Harter (1992) added Cu, Ni and Co to calcium saturated soils. The presence of Ca, a common ion in soils with pH>5.6, did not affect Cu sorption but did limit the sorption of Co and Ni. The author emphasized the importance of these results in that standard management practice for metal contaminated soils is to raise the pH to 7, often using a Ca buffered system. The addition of Ca, as low as 0.01M Ca, may increase the mobility of some metals by competing for sorption sites.

Trace metals also will compete with each other for adsorption sites. Although there have been several studies on the relative adsorption affinities of trace metals by soils and soil constituents (see Table 2), these studies have compared how much of each metal, added to the soils as individual

components, was adsorbed and not whether the adsorption of one metal will interfere with that of another. Few studies have looked directly at the competitive adsorption of metals. Kuo and Baker (1980) reported that the presence of Cu interfered with the adsorption of Zn and Cd. Adsorbed Cu was not significantly affected by added Zn but the presence of Cu, at concentrations as low as 15 µg/L, completely prevented Zn adsorption in one soil with a low cation exchange capacity (Kurdi and Doner, 1983). In contrast, McBride and Blasiak (1979) found that Cu was ineffective in competing for Zn adsorption sites over a pH range of 5-7. The inability of Cu to block Zn adsorption in this study was taken as evidence that Zn and Cu were preferentially adsorbed at different sites. Simultaneous addition of Cd and Zn to Mn oxide lowered the adsorption of both metals (Zasoski and Burau, 1988).

The presence of other cations, whether major or trace metals, can significantly effect the mobility of the metal of interest. Use of data from the literature, generation of laboratory data, or use of computer models that do not reflect the complex mixture of metals specific to a site may not be useful to understand or accurately predict metal mobility.

Effect of complex formation

Metal cations form complexes with inorganic and organic ligands. The resulting association has a lower positive charge than the free metal ion, and may be uncharged or carry a net negative charge. For example, the association of cadmium with chloride results in the following series of charged and uncharged cadmium species: Cd^{2+}, $CdCl^{+}$, $CdCl_2^{o}$, $CdCl_3^{-}$. Benjamin and Leckie (1982) stated that the interaction between metal ions and complexing ligands may result in either a complex that is weakly adsorbed to the soil surface or in a complex that is more strongly adsorbed relative to the free metal ion. In general, the decrease in positive charge on the complexed metal reduces adsorption to a negatively charged surface. One noted exception is the preferential adsorption of hydrolyzed metals ($MeOH^{+}$) versus the free bivalent metal (James and Healy, 1972). The actual effect of complex formation on sorption depends on the properties of the metal of interest, the type and amount of ligands present, soil surface properties, soil solution composition, pH and redox conditions, as is illustrated by the follow research results.

In the presence of the inorganic ligands Cl^{-} and SO_4^{2-}, the adsorption of Cd on soil and soil constituents was inhibited (O'Connor, et al., 1984; Hirsch et al., 1989; Egozy, 1980; Garcia-Miragaya and Page, 1976; Benjamin and Leckie, 1982) due to the formation of cadmium complexes that were not strongly adsorbed by the soils. Using much higher concentrations of salt than normally encountered in soil solutions (0.1 to 0.5M NaCl), Doner (1978) concluded that the increased mobility of Ni, Cu, and Cd through a soil column was due to complex formation of the metals with Cl^{-}. The mobility of Cd increased more than that of Ni and Cu, Ni being the least mobile. These observed mobilities are in the same order as that of the stability constants of the chloride complexes of these metals. Within normal concentration of electrolytes in soil solution, Elrashidi and O'Connor (1982) found no measurable change in Zn adsorption by alkaline soils due to complex formation of Zn with Cl^{-}, NO_3^{2-}, or SO_4^{2-} ions. Under these conditions (anion concentration of 0.1M), anion complex formation did not compete with the highly selective adsorption sites for Zn. Shuman (1986), using acid soils, observed a decreased adsorption of Zn in the presence of Cl^{-} at the concentration of $CaCl_2$ used by Elrashidi and O'Connor (1982) but no effect at lower concentrations. McBride (1985), using aluminum oxide, and Cavallaro (1982), using clays, found that high levels of phosphate suppressed adsorption of Cu and Zn. Phosphate did not form strong complexes with Cu or Zn but it was strongly adsorbed to soil surfaces thus physically blocking the specific adsorption sites of Cu and Zn. Other researchers (Kuo and McNeal, 1984; Stanton and Burger, 1970; Bolland et al., 1977), using lower concentrations of added phosphate, demonstrated enhanced adsorption of Zn and Cd on oxide surfaces. At the concentration of phosphate used in these studies, the adsorption of phosphate onto the oxide surfaces increased the negative charge on the oxide surface, thus enhancing adsorption of the metal cations.

Complex formation between metals and organic ligands affects metal adsorption and hence mobility. The extent of complexation between a metal and soluble organic matter depends on the competition between the metal-binding surface sites and the soluble organic ligand for the metal. Metals that readily form stable complexes with soluble organic matter are likely to be mobile in soils. Overcash and Pal (1979) reported that the order of metal-organic complex stabilities, for the system they studied, was Hg > Cu > Ni > Pb > Co > Zn > Cd. Khan et al. (1982) showed that the mobility of metals through soil followed the order: Cu > Ni > Pb > Ag > Cd. The high mobility of Cu and Ni was attributed to their high complexing nature with soluble soil organic matter. Amrhein, et al. (1992) also showed the increased mobility of Cu, Ni, and Pb in the presence of dissolved organic matter. In this study, the Cd leached from the columns was not associated with dissolved organic carbon but was associated with Cl or acetate anions. Metals, such as Cd and Zn, that do not form highly stable complexes with organic matter are not as greatly affected by the presence of dissolved organic matter in the soil solution as metals that do form stable complexes, such as Cu, Pb, or Hg. Dunnivant et al. (1992) and Neal and Sposito (1986), however, demonstrated that dissolved organic matter does reduce Cd sorption due to complexation formation under their experimental conditions.

In systems where the organic ligand adsorbs to the soil surface, metal adsorption may be enhanced by the complexation of the metal to the surface-adsorbed ligand. Haas and Horowitz (1986) found that, in some cases, the presence of organic matter enhanced Cd adsorption by kaolinite. They interpreted these findings to suggest that the presence of an adsorbed layer of organic matter on the clay surface served as a site for Cd retention. Davis and Leckie (1978) found Cu adsorption to iron oxide increased in the presence of glutamic acid and 2,3 pyrazinendicarboxylic acid (2,3 PDCA) but decreased in the presence of picolinic acid. Picolinic acid complexed Cu and the resulting complex was not adsorbed by the oxide surface. The glutamic acid and 2,3 PDCA were adsorbed to the oxide surface, then complexed the added Cu. Using natural organic matter, Davis (1984) demonstrated the adsorption of Cu but not Cd to an organic coated aluminum oxide.

The effect of complexation formation on sorption is dependent on the type and amount of metal present, the type and amount of ligands present, soil surface properties, soil solution composition, pH and redox. The presence of complexing ligands may increase metal retention or greatly increase metal

mobility. Use of literature or laboratory data that do not include the presence of complexing ligands, both organic and inorganic, present at the particular site of interest, may lead to significant overestimation or underestimation of metal mobility.

Effect of pH

The pH, either directly or indirectly, affects several mechanisms of metal retention by soils. Figure 7 shows the impact of soil pH on the adsorption of Pb, Ni, Zn, and Cu by two soils adjusted to various pHs ranging from approximately 4.3 to 8.3 (Harter, 1983). As is true for all cationic metals, adsorption increased with pH. The author, however, points out that the retention of the metals did not significantly increase until the pH was greater than 7. Figure 8 illustrates the adsorption of selenite, SeO_3^{2-}, on five soils adjusted to various pHs. As is true with all oxyanions, i.e., arsenic, selenium and hexavalent chromium, sorption decreases with pH.

The pH dependence of adsorption reactions of cationic metals is due, in part, to the preferential adsorption of the hydrolyzed metal species in comparison to the free metal ion (McBride, 1977; McLauren and Crawford, 1973; Davis and Leckie, 1978; Farrah and Pickering, 1976a,b; James and Healy, 1972; McBride, 1982; Cavallaro and McBride, 1980; Harter, 1983). The proportion of hydrolyzed metal species increases with pH.

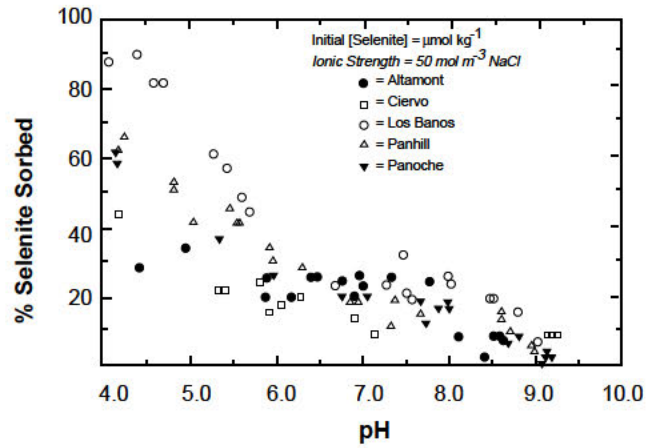

Figure 8. Selenite adsorption envelope for five alluvial soils. The intitial total selenite concentration was approximately 2 µmol kg^{-1} (Neal, et al., 1987a).

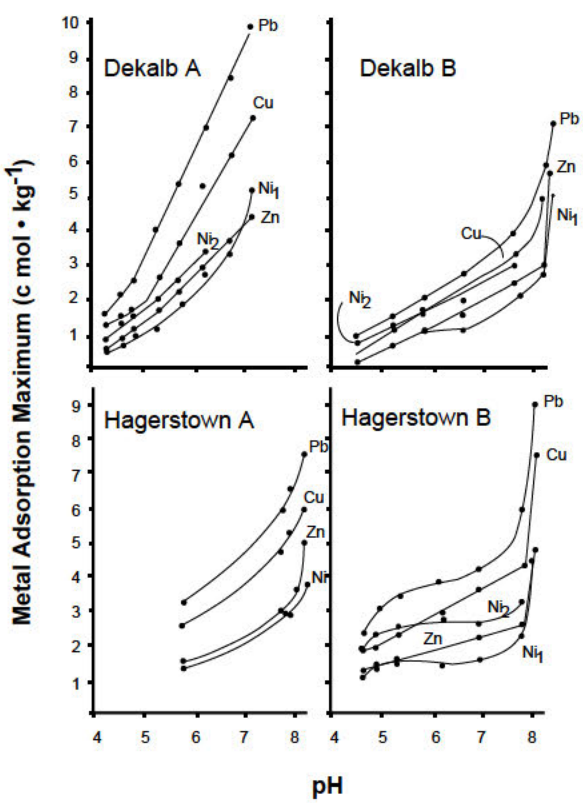

Figure 7. Effect of soil pH level on maximum Pb, Cu, Zn, and Ni retention by Dekalb and Hagerstown A and B horizons. Ni1 and Ni2 refer to two apparent sorption maxima. (Harter, 1983).

Cavallaro and McBride (1980) found that copper adsorption by soils showed a stronger pH dependence than Cd. This finding is consistent with the hypothesis that hydrolysis of Cu at pH 6 increases its retention by soil, while cadmium does not hydrolyze until pH 8. Zinc was shown to be retained in an exchangeable form at low pH in four Fe and Mn oxide dominated soils but became nonexchangeable as the pH was increased above 5.5 (Stahl and James, 1991). The researchers attributed this change in mechanism of sorption as being due to the hydrolysis of Zn and the adsorption of the hydrolysis species by the oxide surfaces.

Many adsorption sites in soils are pH dependent, i.e., Fe and Mn oxides, organic matter, carbonates, and the edges of clay minerals. As the pH decreases, the number of negative sites for cation adsorption diminishes while the number of sites for anion adsorption increases. Also as the pH becomes more acidic, metal cations also face competition for available permanent charged sites by Al^{3+} and H^+.

All trace metal hydroxide, oxide, carbonate, and phosphate precipitates form only under alkaline conditions (Lindsay, 1979). The dissolution of these metal precipitates is strongly dependent on the pH of the system. Jenne (1968) stated that hydrous oxides of Fe and Mn play a principal role in the retention of metals in soils. Solubility of Fe and Mn oxides is also pH-related. Below pH 6, the oxides of Fe and Mn dissolve, releasing adsorbed metal ions to solution (Essen and El Bassam, 1981).

Work by McBride and Blasiak (1979) showed increased retention of Zn with increasing pH, as is usual for metal cations. When the pH was increased above 7.5, however, the solution concentration of Zn increased. This phenomena has been observed in other studies when acid soils were adjusted to pH>7 (Kuo and Baker, 1980) and it has been attributed to

the solubilization of organic complexing ligands which effectively compete with the soil surfaces for the metal cation. Most functional groups of complexing ligands are weak acids, thus the stability of the metal complex is pH-dependent with little association in acid media. The degree of association increases with pH. Baham and Sposito (1986) and Inskeep and Baham (1983) demonstrated that the adsorption of Cu to montmorillonite, in the presence of water soluble ligands extracted from sludges and various other organic materials, decreased with increasing pH. This behavior is the opposite of the typical relationship between metal adsorption and pH. Figure 9, taken from Baham and Sposito (1986), illustrates that nearly 100% of the Cu added to the clay in the absence of the organic ligands was removed from solution at pH>7. In the presence of the organic ligands, the maximum amount of Cu removed from solution was at pH³5.5. As the pH was increased above 5.5, adsorption of Cu decreased. The explanation for this phenomena is that at low pH, H+ competes with the Cu for complexation with the organic matter. As the pH increases, more of the Cu can be complexed with the organic matter and less is therefore adsorbed by the clay. This phenomena has important implications with regards to the practice of liming acid soils to raise the pH increasing metal retention. In soils with significant levels of dissolved organic matter, increasing soil pH may actually mobilize metal due to complex formation.

The pH of the soil system is a very important parameter, directly influencing sorption/desorption, precipitation/ dissolution, complex formation, and oxidation-reduction reactions. In general, maximum retention of cationic metals occurs at pH>7 and maximum retention of anionic metals occurs at pH<7. Because of the complexity of the soil-waste system, with its myriad of surface types and solution composition, such a generalization may not hold true. For example, cationic metal mobility has been observed to increase with increasing pH due to the formation of metal complexes with dissolved organic matter.

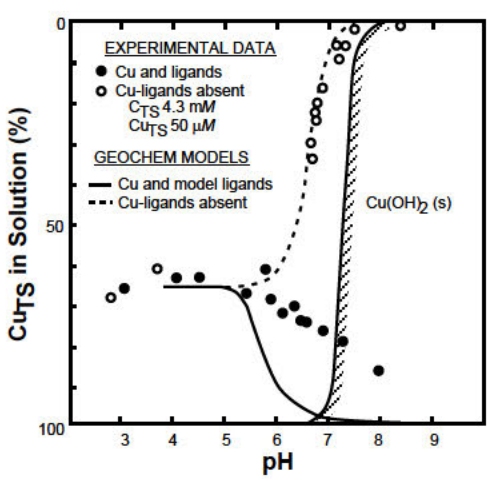

Figure 9. Adsorption of Cu [50 mmol m-3 (50 mM)] by Na-montmorillonite in the presence and absence of water soluble extract of sewage sludge (WSE). GEOCHEM simulations were constructed employing the "mixture model" (Baham and Sposito, 1986).

Effect of oxidation-reduction

Almost half of the metals under consideration have more than one oxidation state in the soil environment and are directly affected by changes in the oxidation-reduction (redox) potential of the soil. The redox potential of a soil system is the measure of the electrochemical potential or availability of electrons within a system. A chemical reaction in which an electron transfer takes place is called an oxidation-reduction process. Metals or elements which gain electrons and lose in valence are undergoing reduction, while those losing electrons and gaining in valence are becoming oxidized. A measure of the redox potential (electron availability) indicates whether the metals are in an oxidize or reduced state.

In soils, reducing conditions are brought about by the absence of oxygen (anaerobic). This is caused by the oxygen being utilized or consumed at a greater rate that it can be transported into the soil system. This can be caused by water-logged soils or soils contaminated with oxygen consuming compounds. The consumption could either be chemical or biological. The biological consumption of oxygen is the results of microbes utilizing the organic contaminant which have entered the soil system. Oxidizing conditions (aerobic) are normally found in well-drained soils as well as soils that have not been subjected to contamination by spills or leaks.

The degree of oxidation or reduction is indicated by the redox potential measurement. The four general ranges of redox conditions as suggested by Patrick and Mahapatra (1968) which may be encountered in soils are at pH 7, oxidized soils > +400 millivolts (mv); moderately reduced soils, from +400 to +100 mv; reduced soils, from +100 to -100 mv; highly reduced soils, -100 to -300 mv. The redox state of a soil, as discussed above, usually is closely related to the microbial activity and the type of substrate available to the organisms.

Redox reactions can greatly affect contaminant transport, in slightly acidic to alkaline environments, Fe(III) precipitates as a highly adsorptive solid phase (ferric hydroxide), while Fe(II) is very soluble and does not retain other metals. The reduction of Fe(III) to Fe(II) will bring about the release of ferrous iron to the pore waters and also any metals that were adsorbed to the ferric hydroxide surfaces. The behavior of chromium and selenium also illustrates the importance of redox conditions to metals movement in soils. Hexavalent Cr(VI) is both toxic and a relatively mobile anion while trivalent Cr(III) is far less toxic, relatively insoluble, and strongly adsorbs to surfaces. Selenate (Se(VI) is mobile, but less toxic than selenite (Se(IV) which is more toxic, but less mobile. In general, oxidizing conditions favor retention of metals in soils, while reducing conditions contribute to accelerated migration.

Effect of co-waste

Most soil-metal interaction studies have been performed using a specific, well characterized background solution, such as an inorganic salt solution (0.01M $CaCl_2$, Na_2SO_4, etc.) or a water soluble extraction of organic matter (leaf litter, sewage sludges, etc.). These studies, as reported above, have led to an understanding of the effects that metal type, metal concentration, solution composition, and soil surface type have on the retention of metals by soils. The behavior of metals associated with various industrial or mining wastes in

soil systems has not been extensively studied, however. In such wastes the metal concentration may be much greater than used in studies of native metals and metals associated with the controlled application of fertilizers and sewage sludges, and may be associated with a myriad of inorganic and organic chemicals that have not been characterized but may have a great effect on predicting metal mobility. Below are examples in which investigators have used various waste mixture for the background solution in sorption studies. In all cases, the results were highly dependent on the waste type used. These examples have been included to emphasize the importance of performing laboratory studies or using literature data that mimic the actual matrix of the waste or soils-waste system being investigated.

The retention of Cd, Cu, and Zn by two calcareous soils using a water extract of an acidic milling waste as the background solution (pH=4.0, dominant major cation was Ca and anion was sulfate) was studied by Dudley et al. (1988, 1991). The presence of carbonate minerals is known to effectively immobilize Cd and Cu by providing an adsorbing or nucleating surface and by buffering pH (Santillan-Medrano and Jurinak, 1975; Cavallaro and McBride, 1978; McBride and Bouldin, 1984). For the soil with a lower carbonate content (0.2% $CaCO_3$), the sorption of Cd and Zn was slow to reach equilibrium (114 hours) due to the complex set of reactions that occurred when the soil (pH 8.6) and acid milling extract (pH 4.0) were combined. The dissolution of carbonates in the acid medium controlled the rate and extent of Cd and Zn sorption. The authors concluded that Cd and Zn were retained by an exchange mechanism only after the pH of the system reached equilibrium (pH 5.5), allowing time for significant transport of these metals. Copper sorption was independent of calcite dissolution. The soil with the higher carbonate content (30%) showed a significant drop in pH (pH 9.1 to 6.6) with the addition of the acid leachate but had sufficient carbonates to buffer the system and sorbed all three metals.

Kotuby-Amacher and Gambrell (1988) studied the retention of Cd and Pb on subsurface soils using a synthetic municipal waste leachate and a synthetic acid metal waste leachate, compared with $Ca(NO_3)_2$ as the background solution. Sorption of the two metals was diminished in the presence of both synthetic leachates. The presence of competing cations and complexing organic and inorganic ligands in the synthetic wastes decreased the retention of Cd and Pb by the soils. Boyle and Fuller (1987) used soil columns packed with five different soils to evaluate the mobility of Zn in the presence of simulated municipal solid waste leachate with various amounts of total organic carbon (TOC) and total soluble salts (TSS). Zinc transport was enhanced in the presence of higher TOC and TSS. Soil properties considered important for retaining Zn in this study were surface area, CEC, and percent clay content. The authors, however, concluded that the leachate composition was more important than soil properties for determining the mobility of Zn.

Puls et al. (1991) studied the sorption of Pb and Cd on kaolinite in the presence of three organic acids, 2,4-dinitrophenol, p-hydroxybenzoic acid, and o-toluic acid. The acids were selected based on their frequent occurance at hazardous waste sites and their persistence in soils. Sorption of Pb decreased in the presence of all the acids due to the formation of 1:2 metal-organic complex resulting in an uncharged form of Pb. Sorption of Cd decreased in the presence of two of the acids but increased in the presence of 2,4-dinitrophenol. The authors attributed the increase in sorption as being due to either direct sorption of the acid to the clay with the subsequent sorption of Cd or to the enhanced sorption of the 1:1 complex formed between Cd and the acid.

Sheets and Fuller (1986) studied the transport of Cd through soil columns with 0 to 100% ethylene glycol or 2-propanol as the leaching solution. Soils sorbed less Cd from the ethylene glycol solutions than when the columns were leached with water. The 2-propanol increased sorption in one of the soils tested. The effect on Cd sorption was attributed to the change in soil permeability and surface characterization due to the presence of the solvents.

Metal mobility in soil-waste systems is determined by the type and quantity of soil surfaces present, the concentration of metal of interest, the concentration and type of competing ions and complexing ligands, both organic and inorganic, pH, and redox status. Generalization can only serve as rough guides of the expected behavior of metals in such systems. Use of literature or laboratory data that do not mimic the specific site soil and waste system will not be adequate to describe or predict the behavior of the metal. Data must be site specific. Long term effects also must be considered. As organic constituents of the waste matrix degrade, or as pH or redox conditions change, either through natural processes of weathering or human manipulation, the potential mobility of the metal will change as soil conditions change. Few long term studies have been reported.

Behavior of Specific Metals

Copper

Copper is retained in soils through exchange and specific adsorption mechanisms. At concentrations typically found in native soils, Cu precipitates are unstable. This may not be the case in waste-soil systems and precipitation may be an important mechanism of retention. Cavallaro and McBride (1978) suggested that a clay mineral exchange phase may serve as a sink for Cu in noncalcareous soils. In calcareous soils, specific adsorption of Cu onto $CaCO_3$ surfaces may control Cu concentration in solution (Cavallaro and McBride, 1978; Dudley, et al., 1988; Dudley et al., 1991; McBride and Bouldin, 1984). As reported in the adsorption sequence in Table 2, Cu is adsorbed to a greater extent by soils and soil constituents than the other metals studied, with the exception of Pb. Copper, however, has a high affinity for soluble organic ligands and the formation of these complexes may greatly increase Cu mobility in soils.

Zinc

Zinc is readily adsorbed by clay minerals, carbonates, or hydrous oxides. Hickey and Kittrick (1984), Kuo et al. (1983), and Tessier et al. (1980) found that the greatest percent of the total Zn in polluted soils and sediments was associated with Fe and Mn oxides. Precipitation is not a major mechanism of retention of Zn in soils because of the relatively high solubility of Zn compounds. Precipitation may become a more important mechanism of Zn retention in soil-waste systems. As with all cationic metals, Zn adsorption increases with pH.

Zinc hydrolysizes at pH>7.7 and these hydrolyzed species are strongly adsorbed to soil surfaces. Zinc forms complexes with inorganic and organic ligands that will affect its adsorption reactions with the soil surface.

Cadmium

Cadmium may be adsorbed by clay minerals, carbonates or hydrous oxides of iron and manganese or may be precipitated as cadmium carbonate, hydroxide, and phosphate. Evidence suggests that adsorption mechanisms may be the primary source of Cd removal from soils (Dudley et al., 1988, 1991). In soils and sediments polluted with metal wastes, the greatest percentage of the total Cd was associated with the exchangeable fraction (Hickey and Kittrick, 1984; Tessier et al., 1980; Kuo et al., 1983). Cadmium concentrations have been shown to be limited by $CdCO_3$ in neutral and alkaline soils (Santillan-Medrano and Jurinak, 1975). As with all cationic metals, the chemistry of Cd in the soil environment is, to a great extent, controlled by pH. Under acidic conditions Cd solubility increases and very little adsorption of Cd by soil colloids, hydrous oxides, and organic matter takes place. At pH values greater than 6, cadmium is adsorbed by the soil solid phase or is precipitated, and the solution concentrations of cadmium are greatly reduced. Cadmium forms soluble complexes with inorganic and organic ligands, in particular Cl-. The formation of these complexes will increase Cd mobility in soils.

Lead

Soluble lead added to the soil reacts with clays, phosphates, sulfates, carbonates, hydroxides, and organic matter such that Pb solubility is greatly reduced. At pH values above 6, lead is either adsorbed on clay surfaces or forms lead carbonate. Of all the trace metals listed in Table 2, Pb is retained by soils and soil constituents to the greatest extent under the conditions of these studies. Most studies with Pb, however, have been performed in well defined, simple matrices, i.e., 0.01M $CaCl_2$. Puls et al. (1991), and Kotuby-Amacher and Gambrell (1988) have demonstrated decrease sorption of Pb in the presence of complexing ligands and competing cations. Lead has a strong affinity for organic ligands and the formation of such complexes may greatly increase the mobility of Pb in soil.

Nickel

Nickel does not form insoluble precipitates in unpolluted soils and retention for Ni is, therefore, exclusively through adsorption mechanisms. Nickel will adsorb to clays, iron and manganese oxides, and organic matter and is thus removed from the soil solution. The formation of complexes of Ni with both inorganic and organic ligands will increase Ni mobility in soils.

Silver

Published data concerning the interaction of silver with soil are rare. As a cation it will participate in adsorption and precipitation reactions. Silver is very strongly adsorbed by clay and organic matter and precipitates of silver, AgCl, Ag_2SO_4 and $AgCO_3$, are highly insoluble (Lindsay, 1979). Silver is highly immobile in the soil environment.

Mercury

The distribution of mercury species in soils, elemental mercury (Hg^o), mercurous ions (Hg_2^{2+}) and mercuric ions (Hg^{2+}), is dependent on soil pH and redox potential. Both the mercurous and mercuric mercury cations are adsorbed by clay minerals, oxides, and organic matter. Adsorption is pH dependent, increasing with increasing pH. Mercurous and mercuric mercury are also immobilized by forming various precipitates. Mercurous mercury precipitates with chloride, phosphate, carbonate, and hydroxide. At concentrations of Hg commonly found in soil, only the phosphate precipitate is stable. In alkaline soils, mercuric mercury will precipitate with carbonate and hydroxide to form a stable solid phase. At lower pH and high chloride concentration, $HgCl_2$ is formed. Divalent mercury also will form complexes with soluble organic matter, chlorides, and hydroxides that may contribute to its mobility (Kinniburgh and Jackson, 1978).

Under mildly reducing conditions, both organically bound mercury and inorganic mercury compounds may be degraded to the elemental form of mercury, Hg^o. Elemental mercury can readily be converted to methyl or ethyl mercury by biotic and abiotic processes (Roger, 1976, 1977). These are the most toxic forms of mercury. Both methyl and ethyl mercury are volatile and soluble in water. Griffin and Shimp (1978) estimated that the removal of Hg from a leachate was not due to adsorption by clays, but was due to volatilization and/or precipitation. This removal of mercury increased with pH. Rogers (1979) also found large amounts of mercury volatilized from soils. Amounts of mercury volatilized appeared to be affected by the solubility of the mercury compounds added to soil. Volatilization was also found to be inversely related to soil adsorption capacity. The form of Hg lost from the soil, whether elemental Hg or methylmercury, was not determined in this study.

Arsenic

In the soil environment arsenic exists as either arsenate, As(V) (AsO_4^{3-}), or as arsenite, As(III) (AsO_2^-). Arsenite is the more toxic form of arsenic.

The behavior of arsenate in soil is analogous to that of phosphate, because of their chemical similarity. Like phosphate, arsenate forms insoluble precipitates with iron, aluminum, and calcium. Iron in soils is most effective in controlling arsenate's mobility. Arsenite compounds are reported to be 4-10 times more soluble than arsenate compounds.

Griffin and Shimp (1978), in a study of arsenate adsorption by kaolinite and montmorillonite, found maximum adsorption of As(V) to occur at pH 5. Adsorption of arsenate by aluminum and iron oxides has shown an adsorption maximum at pH 3-4 followed by a gradual decrease in adsorption with increasing pH (Hingston et al., 1971; Anderson et al., 1976). The mechanism of adsorption has been ascribed to inner sphere complexation (specific adsorption), which is the same mechanism controlling the adsorption of phosphate by oxide surfaces (Hingston et al., 1971; Anderson et al., 1976; Anderson and Malotky, 1979).

The adsorption of arsenite, As(III), is also strongly pH-dependent. Griffin and Shimp (1978) observed an increase in

sorption of As (III) by kaolinite and montmorillonite over a pH range of 3-9. Pierce and Moore (1980) found the maximum adsorption of As(III) by iron oxide occurred at pH 7. Elkhatib et al. (1984b) found adsorption of As(III) to be rapid and irreversible on ten soils. They determined, in this study and another study (Elkhatib et al., 1984a), that Fe oxide, redox, and pH were the most important properties in controlling arsenite adsorption by these soils.

Both pH and the redox are important in assessing the fate of arsenic in soil. At high redox levels, As(V) predominates and arsenic mobility is low. As the pH increases or the redox decreases As (III) predominates. The reduced form of arsenic is more subject to leaching because of its high solubility. The reduction kinetics are, however, slow. Formation of As (III) also may lead to the volatilization of arsine (AsH_3) and methyl-arsines from soils (Woolson 1977a). Under soil conditions of high organic matter, warm temperatures, adequate moisture, and other conditions conducive to microbial activity, the reaction sequence is driven towards methylation and volatilization (Woolson 1977a). Woolson's (1977b) study showed that only 1 to 2 percent of the sodium arsenate applied at a rate of 10 ppm was volatilized in 160 days. The loss of organic arsenical compounds from the soil was far greater than for the inorganic source of arsenic. Arsenite, As(III), can be oxidized to As(V). Manganese oxides are the primary electron acceptor in this oxidation (Oscarson et al., 1983).

Selenium

The behavior of selenium in soils has received great attention in recent years. Studies were stimulated by the high incidence of deformity and mortality of waterfowl at the Kesterson National Wildlife Refuge in California that resulted from the input of agricultural drainage water from the western San Joaquin Valley that was high in Se. Such studies have led to a better understanding of the distribution and movement of Se in soils and ground water.

Selenium exists in the soil environment in four oxidation states: selenide (Se^{2-}), elemental selenium (Se^{o}), selenite (SeO_3^{2-}), and selenate (SeO_4^{2-}). The concentration and form of Se in soil is governed by pH, redox, and soil composition. Selenate, Se(VI), is the predominant form of selenium in calcareous soils and selenite, Se(IV), is the predominant form in acid soil.

Selenite, Se (IV) binds to sesquioxides, especially to Fe oxides. Balistriera and Chao (1987) found the removal of selenite by iron oxide to increase with decreasing pH. This study not only demonstrates the effect of pH on selenite adsorption but also the effect of concentration. The decrease in the percentage of selenite adsorbed with increasing concentration of selenite at a given pH indicated multiple sites of selenite retention. At the two lower concentrations, high energy specific adsorption sites were available. As the concentration of selenite was increased these sites became saturated and the lower energy sites were utilized. Griffin and Shimp (1978) found maximum adsorption of selenite on montmorillonite and kaolinite to occur at pH 2-3. Neal et al. (1987a) used five soils from the San Joaquin Valley and found that selenite adsorption by the soils decreased with increasing pH in the range of 4-9. Selenite adsorption to oxides and soils occurs through an inner sphere complexation (specific adsorption) mechanism (Rajan, 1979; Neal et al., 1987b).

In studies of competitive adsorption using phosphate, sulfate, and chloride (Neal, et al., 1987b) and phosphate and various organic acids (Balistrieri and Chao, 1987), selenite adsorption decreased dramatically in the presence of phosphate and the organic acids but was not affected by the presence of sulfate or chloride. Balistrieri and Chao (1987), using Fe oxide, found the sequence of adsorption to be: phosphate = silicate = arsenate > bicarbonate carbonate > citrate = selenite > molybdate > oxalate > fluoride = selenate > sulfate. Precipitation is not a major mechanism of retention of selenite in soils. Manganese selenite may form, however, in strongly acidic environments (Elrashidi et al., 1989).

Selenate dominates under alkaline conditions. In contrast to selenite, selenate, Se(VI), is highly mobile in soils. Benjamin (1983) found that selenate was adsorbed by amorphous iron oxide as a function of pH. Maximum removal was at pH 4.5 and adsorption decreased with increasing pH. Bar-Yosef and Meek (1987) found some indication of selenate adsorption by kaolinite below pH 4. Selenate seems to be adsorbed by weak exchange mechanisms similar to sulfate (Neal and Sposito, 1989), in contrast to selenite that is specifically adsorbed by soils and soil constituents. There has been some evidence that selenate was adsorbed by alkaline soils (Singh et al., 1981), but Goldberg and Glaubig (1988) found no removal of selenate by calcareous montmorillonite. Neal and Sposito (1989), using soils from the San Joaquin Valley, showed no adsorption of added selenate over a pH range from 5.5-9.0. Fio et al. (1991) also observed no sorption of selenate by alkaline soil from the San Joaquin Valley, but did observe the rapid sorption of selenite by this soil. No stable precipitates of selenate are expected to form under the pH and redox conditions of most soils (Elrashidi, et al., 1989).

Similar to other anionic species, selenium is more mobile at higher pHs. Soil factors favoring selenium mobility, as summarized by Balistrieri and Chao (1987) are; alkaline pH, high selenium concentration, oxidizing conditions, and high concentrations of additional anions that strongly adsorb to soils, in particular phosphate.

Under reduced conditions, selenium is converted to the elemental form. This conversion can provide an effective mechanism for attenuation since mobile selenate occurs only under well aerated, alkaline conditions.

Organic forms of selenium are analogous to those of sulfur, including seleno amino acids and their derivatives. Like sulfur, selenium undergoes biomethlyation forming volatile methyl selenides.

Chromium

Chromium exists in two possible oxidation states in soils: the trivalent chromium, Cr(III) and the hexavalent chromium, Cr(VI). Forms of Cr(VI) in soils are as chromate ion, $HCrO_4^-$ predominant at pH<6.5, or CrO_4^{2-}, predominant at pH 6.5, and as dichromate, $Cr_2O_7^{2-}$ predominant at higher concentrations (>10mM) and at pH 2-6. The dichromate ions pose a greater health hazard than chromate ions. Both Cr(VI) ions are more toxic than Cr(III) ions. Reviews of the processes that control the fate of chromium in soil and the effect these processes have on remediation are given in Bartlett (1991) and Palmer and Wittbrodt (1991).

Because of the anionic nature of Cr(VI), its association with soil surfaces is limited to positively charged exchange sites, the number of which decreases with increasing soil pH. Iron and aluminum oxide surfaces will adsorb CrO_4^{2-} at acidic and neutral pH (Davis and Leckie, 1980; Zachara et al., 1987; Ainsworth et al., 1989). Stollenwerk and Grove (1985) concluded that the adsorption of Cr(VI) by ground-water alluvium was due to the iron oxides and hydroxides coating the alluvial particles. The adsorbed Cr(VI) was, however, easily desorbed with the input of uncontaminated ground water, indicating nonspecific adsorption of Cr(VI). The presence of chloride and nitrate had little effect on Cr(VI) adsorption, whereas sulfate and phosphate inhibited adsorption (Stollenwerk and Grove, 1985). Zachara et al. (1987) and Zachara et al. (1989) found SO_4^{2-} and dissolved inorganic carbon inhibited Cr(VI) adsorption by amorphous iron oxyhydroxide and subsurface soils. The presence of sulfate, however, enhanced Cr(VI) adsorption to kaolinite (Zachara et al., 1988). Rai et al. (1988) suggested that BaCrO4 may form in soils at chromium contaminated waste sites. No other precipitates of hexavalent compounds of chromium have been observed in a pH range of 1.0 to 9.0 (Griffin and Shimp, 1978). Hexavalent chromium is highly mobile in soils.

In a study of the relative mobilities of 11 different trace metals for a wide range of soils, Korte et al. (1976) found that clay soil, containing free iron and manganese oxides, significantly retarded Cr(VI) migration (see Figure 6). Hexavalent chromium was found to be the only metal studied that was highly mobile in alkaline soils. The parameters that correlated with Cr(VI) immobilization in the soils were free iron oxides, total manganese, and soil pH, whereas the soil properties, cation exchange capacity, surface area, and percent clay had no significant influence on Cr(VI) mobility.

Rai et al. (1987) reported that Cr(III) forms hydroxy complexes in natural water, including $Cr(OH)_2^+$, $Cr(OH)^{2+}$, $Cr(OH)_3^o$, and $Cr(OH)_4^-$. Trivalent chromium is readily adsorbed by soils. In a study of the relative mobility of metals in soils at pH 5, Cr(III) was found to be the least mobile (Griffin and Shimp, 1978). Hydroxy species of Cr(III) precipitate at pH 4.5 and complete precipitation of the hydroxy species occurs at pH 5.5.

Hexavalent chromium can be reduced to Cr(III) under normal soil pH and redox conditions. Soil organic matter has been identified as the electron donor in this reaction (Bartlett and Kimble, 1976; Bloomfield and Pruden, 1980). The reduction reaction in the presence of organic matter proceeds at a slow rate at environmental pH and temperatures (Bartlett and Kimble, 1976; James and Bartlett, 1983a,b,c). Bartlett (1991) reported that in natural soils the reduction reaction may be extremely slow, requiring years. The rate of this reduction reaction, however, increases with decreasing soil pH (Cary et al., 1977; Bloomfield and Pruden, 1980). Soil organic matter is probably the principal reducing agent in surface soils. In subsurface soils, where organic matter occurs in low concentration, Fe(II) containing minerals reduce Cr(VI) (Eary and Rai, 1991). Eary and Rai (1991), however, observed that this reaction only occurred in the subsurface soil with a pH<5. The reduction of Cr(VI) occurred in all four subsurface soils tested by decreasing the pH to 2.5.

Bartlett and James (1979), however, demonstrated that under conditions prevalent in some soils, Cr(III) can be oxidized. The presence of oxidized Mn, which serves as an electron acceptor, was determined as an important factor in this reaction.

Industrial use of chromium also includes organic complexed Cr(III). Chromium (III) complexed with soluble organic ligands will remain in the soil solution (James and Bartlett, 1983a). In addition to decreased Cr(III) adsorption, added organic matter also may facilitate oxidation of Cr(III) to Cr(VI).

Computer Models

Several equilibrium thermodynamic computer programs are available for modeling soil solution and solid phase chemistry by proving information on the thermodynamic possibility of certain reaction to occur. In addition to calculating the equilibrium speciation of chemical elements in the soil solution and precipitate/dissolution reactions, models such as GEOCHEM (Mattigod and Sposito, 1979) and MINTEQA2 (USEPA, 1987) provide information on cation exchange reactions and metal ion adsorption. These models are used to:

1) calculate the distribution of free metal ions and metal-ligand complexes in a soils solution,

2) predict the fate of metals added to soil by providing a listing of which precipitation and adsorption reactions are likely to be controlling the solution concentration of metals, and

3) provide a method for evaluating the effect that changing one or more soil solution parameters, such as pH, redox, inorganic and organic ligand concentration, or metal concentration, has on the adsorption/precipitation behavior of the metal of interest.

These models are equilibrium models and as such do not consider the kinetics of the reactions. These models are also limited by the accuracy of the thermodynamic data base available.

Analysis of Soil Samples

Total concentration of metals in soil

Measurement of the total concentration of metals in soils is useful for determining the vertical and horizontal extent of contamination and for measuring any net change (leaching to ground water, surface runoff, erosion) in soil metal concentration over time. The methods do not, however, give an indication as to the chemical form of the metal in the soil system.

The complete dissolution of all solid phase components in soils requires a rigorous digestion using either a heated mixture of nitric acid, sulfuric acid, hydrofluoric acid, and perchloric acid (Page et al., 1982) or a fusion of the soil with sodium carbonate (Page et al., 1982). Both methods require special equipment and special safety considerations. A more commonly used procedure is the hot nitric acid-hydrogen peroxide procedure outlined in SW-846 Method 3050 (USEPA, 1986). This is a partial digestion of the soil solid phase. The method probably releases metals associated

with a recent pollution source, i.e., exchangeable, specifically adsorbed to clays, oxides or organic matter, and most precipitates, but would not release metals associated within solid phases that are not dissolved by the hot nitric acid and oxidizing agent, i.e., within the structure of insoluble minerals.

Sequential extractions of metals in soils

Since the potential migration of metals in soil systems is dependent on the chemical form of the metal, extraction procedures have been developed to selectively remove metals from these various geochemical forms. While these procedures cannot be used to identify the actual form of a given metal in a soil, they are useful in categorizing the metals into several operationally defined geochemical fractions, such as exchangeable, specifically adsorbed, and metals associated with carbonates, organic matter, and/or iron and manganese oxides.

Numerous extraction procedures have been developed for metal cations (Sposito et al., 1984; Hickey and Kittrick, 1984; Tessier et al., 1979; Grove and Ellis, 1980; Kuo et al., 1983) and anions (Chao and Sanzolone, 1989; Gruebel et al., 1988). Lake et al. (1984) reviewed a number of the procedures used for cationic metal extraction. The extraction procedures consist of reacting a soil sample with increasing strengths of chemical solutions. Typically water or a salt solution (KNO_3, $CaCl_2$, etc.) is the first extractant used. These are followed by mild acids, bases, chelating agents, and oxidizing solutions. Table 4 illustrates the wide variety of extractants that have been used in the literature for metal cations.

The aqueous fraction and those fractions in equilibrium, i.e., the exchange fraction, with this fraction are of primary importance when considering the migration potential of metals in soils. In theory, mild extractants, such as salt solutions, are more likely to extract metals that could be released to the soil solution with input of water than metals associated with stronger binding mechanisms, such as specifically adsorbed or precipitated metals. Work by Silveira and Sommers (1977) and Latterell et al. (1978) suggests that salt extractable metals represent the potentially mobile portion of the total concentration of metals in soils. Harrison et al. (1981) likewise suggested that the mobility of metals decreases in the order of the extraction sequence. Rigorous evaluation, however, of the appropriateness of any extraction procedure for defining the mobile fraction of metals in soils has not been reported in the literature.

Hickey and Kittrick (1984) used a sequential extraction procedure to separate Cd, Cu, Ni, and Zn in metal polluted soils and sediments into five operationally defined geochemical fractions: exchangeable (1.0M $MgCl_2$), metals associated with carbonates (acetate buffer, pH 5), metals associated with Mn and Fe oxides (0.04M $NH_4OH{\cdot}HCl$), metals associated with organic matter (0.02M HNO_3+H_2O_2), and residual metals (HF+$HClO_4$). Figure 10 shows the average distribution of the metals among the defined geochemical fractions. Approximately 37% of the total Cd and a significant portion of the Zn were in the exchange fraction indicating the potential mobility of these two metals. Only a small portion of the Cu and Ni were in the exchange fraction. A significant portion of the Cu was associated with the organic fraction, in agreement with the known affinity of Cu for organic material. Nickel was mostly associated with the residual

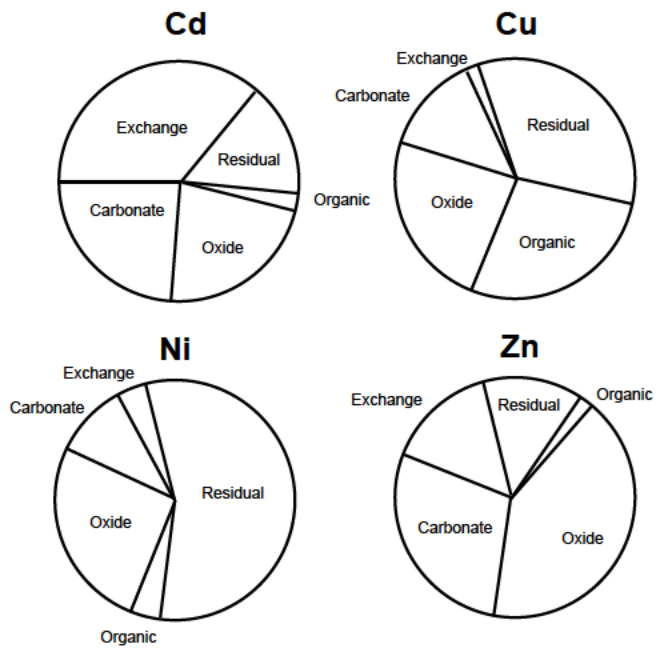

Figure 10. Proportions of Cd, Cu, Ni, and Zn in each of the operationally defined geochemical fractions of the experimental samples (Hickey and Kittrick, 1984).

fraction and significant portions of Zn and Cu were associated with the oxides. The authors concluded from this study that the relative mobility of the metals followed: Cd > Zn > Cu = Ni.

There has been recent criticism of these sequential extraction procedures (Miller et al., 1986; Kheboian and Bauer, 1987; Gruebel et al., 1988; Tipping et al., 1985; Rapin et al., 1986; Calvet et al., 1990). The methods are not entirely specific for a geochemical fraction of the soil and the extractant also may remove metals associated with other fractions. Secondly, readsorption of the extracted metals to the remaining solid phase of the soil may occur leading to artificially low concentrations of the metal being associated with that fraction. Finally, no one extraction procedure would be universally applicable for all metals and all soils. Perhaps the most suitable extractant for defining the mobile fraction of metals in soils under specific site conditions is one that simulates that soil or soil-waste solution chemistry.

TCLP

The Toxicity Characterization Leaching Procedure (TCLP) (USEPA, 1986) is a single extraction procedure, using 0.1M acetic acid, developed to simulate the leaching a waste might undergo if disposed of in a municipal landfill. This method is frequently used to determine the leaching potential of cationic metals in landfill situations where, due to microbial degradation of the waste under anaerobic conditions, acetic acid is produced. While this procedure is appropriate for demonstrating whether an excavated metal contaminated soil is defined as hazardous for disposal at a landfill, its application

Table 4. Some bibliographic data on the extraction of heavy metals present in soils and sediments (Colvet, et al., 1990)

Authors	*Exchangeable*	*Fraction associated with carbonates*	*Fraction associated with oxides*	*Fraction associated with organic matter*	*Total amount and residual fraction*
McLaren Crawford[11] (1973)	0.05 N $CaCl_2$	2.5% CH_3COOH	0.1 M $(COOH)_2$ +0.175 M $(COONH_4)_2$ pH = 3.5	1 M $K_4P_2O_7$	HF
Stover et al.[12] (1976)	1 M KNO_3 +NaF		0.1 M EDTA pH = 6.5	0.1 M $Na_4P_2O_7$	1 M HNO_3
Gatehouse et al.[13] (1977)		1 M CH_3COONH_4 +CH_3COOH pH = 4.5	0.1 M NH_2OH +1 M CH_3COONH_4 pH = 4.5	30% H_2O_2	HF-$HClO_4$
Filipek and Owen[14] (1979)		1 M CH_3COOH	0.25 M NH_2OH, HCl in 25% (v/v) CH_3 COOH	Acidified 30% H_2O_2	HNO_3-HF-$HClO_4$
Tessier et al.[3] (1979)	1 M $MgCl_2$ or 1 M CH_3COONa at pH = 8.2	1 M CH_3COONa + 1 M CH_3COOH at pH = 5.0	0.04 M NH_2OH, HCl in 25% (v/v) CH_3COOH at 96 ± 3°C or 0.3 M $Na_2S_2O_4$ +0.175 M Na—citrate +0.025 M citric acid	0.02 M HNO_3+ 30% H_2O_2, pH = 2 at 85 ± 2°C, 2 h +30% H_2O_2+HNO_3, pH = 2 at 85 ± 2°C, 3 h 3.2 M CH_3COONH_4 in 20% HNO_3	HF-$HClO_4$
Förstner et al. [2] (1979)	0.2 M $BaCl_2$		0.1 M NH_2OH, HNO_3 + 25% (v/v) CH_3COOH + HCl	30% H_2O_2 + NH_4OH	HF-$HClO_4$
Schalscha et al.[4] (1980)	1 M KNO_3	0.5 M NaF pH = 6.5	0.1 M EDTA pH = 6.5 double extraction	0.1 M $Na_4P_2O_5$	1 M HNO_3
Garcia-Miragaya[15] (1981)	1 N $CaCl_2$	2.5% CH_3COOH	0.05 M EDTA pH = 7	0.1 N $Na_4P_2O_5$	HF
Badri and Aston[16] (1981)		1 M CH_3COONH_4 +0.5 M $(CH_3COO)_2$ Mg	0.25 M NH_2OH, HCl pH = 2	30% H_2O_2 + 1 M CH_3COONH_4	
Förstner et al.[17] (1981)	1 M CH_3COONH_4 pH = 7		(1) 0.1 M NH_2OH, ClH +0.0I M HNO_3, pH = 2 (2) 0.2 M $(COONH_4)2$ +0.2 M (COOH)2, pH = 3	30% H_2O_2, HNO_3 pH = 2 at 85°C extraction with 1 M CH_3COONH_4	HNO_3 at 180°C
Greffard et al.[6] (1981)		resin-H^+	(1) $(COONa)_2$ (2) $(COONa)_2$ + UV	30% H_2O_2 at 40°C	
Sposito et al.[10]	0.5 M KNO_3		0.5 M Na_2 EDTA	0.5 M NaOH	4 M HNO_3 at 80°C
Dekeyser et al.[18] (1983)		1M CH_3COONH_4 pH = 4.5	(1) 0.1 M NH_2OH, HCl (2) 0.2 M $(COONH_4)_2$ (HCOOH)2, pH = 3.3 obscurité (3) Same as (2)+UV		HNO_3-HF-HCl
Kuo et al.[7] (1983)	1 M $MgCl_2$		(1) (COONa)2 (2) Citrate dithionite bicarbonate	6% $NaClO_4$ at 85°C	HNO_3-$HClO_4$
Meguelatti et al.[5] (1983)	1 M $BaCl_2$	1 M CH_3COOH +0.6 M CH_3COONa	0.1 M NH_2OH +25% (v/v) CH_3COOH	30% H_2O_2 +0.02 M HNO_3 +3.2 M CH_3COONH_4	HF-HCI
Shuman[19] (1985)	1 M $Mg(NO_3)_2$ pH = 7		(1) 0.1 M NH_2OH, HCl pH = 2 (2) 0.2 M $(COONH_4)2$ +0.2 M (COOH)2, pH = 3 (3) Same as (2) + ascorbic acid	0.7 M NaOCI pH = 8.5	HF-HNO_3-HCI
Gibson and Farmer[20] (1986)	1 M CH_3COONH_4 pH = 7	1 M CH_3COONa pH = 5	(1) 0.1 M NH_2OH, CIH +0.01 M HNO_3 (2) 1 M NH_2OH, CIH in 25% (v/v) CH_3COOH	30% H_2O_2 +0.02 M HNO_3 at 85 °C	Aqua regia + HF

for evaluating the mobility of metals under field conditions has been questioned (Dragun et al., 1990). Production of acetic acid does not commonly occur in soils. In certain soil-waste systems, leaching tests using acetic acid may be appropriate, but it is not universally representative of the leaching solution for soil-waste systems. The acetic acid leaching procedure was developed for cationic metals. The procedure is not appropriate for extraction of anionic metals. Bartlett (1991) reported that this procedure actually causes the reduction of Cr(VI) to Cr(III) leading to a false measurement of the leachability of Cr(VI) in soil. A more appropriate leaching solution would mimic the specific waste or waste-soil matrix.

Hickey and Kittrick (1984) used an acetate buffer solution in their sequential extraction scheme to remove metals associated with carbonates. This is a similar solution to the TCLP solution except that it is buffered to pH 5. This buffered solution fully dissolves the carbonate minerals in the soil. The unbuffered acetic acid solution used in the TCLP solution cannot maintain a low enough pH in calcareous soils to dissolve carbonates. The metals extracted by the TCLP solution are not related to any definable geochemical fraction and the fraction of metals extracted using this procedure have not been correlated with the mobile fraction of metals in soil.

Evaluating the Behavior of Metals in Soils

Sorption studies

Soil sorption studies are commonly performed to evaluate the extent of metal retention by a soil or soil constituent. Sorption studies are often used in an attempt to generate the equilibrium distribution coefficient (Kd), the ratio of metal sorbed to metal in solution at equilibrium, which may be utilized in transport models. Sorption studies are also used for comparison of the relative retention of several metals by a soil or the relative retention of a metal by several soils, and are used extensively in correlation studies to determine the relative importance of a soil's chemical and physical properties for metal retention. Sorption studies also can be used to evaluate the effect that changing a soil solution parameter, e.g., adjustment of pH, ionic strength, addition of competing cations, or addition of inorganic or organic ligands, has on metal retention by a soil.

In a sorption study, the soil is reacted with solutions containing varying quantities of the metal(s) of interest for a specified time period using either batch or column techniques. The concentration range used in the study should overlap the concentration of environmental concern. A background electrolyte solution also should be used to simulate normal soil's solution chemistry or the waste matrix and to equalize the ionic strength across all soils. The reaction time should approach thermodynamic equilibrium, usually determined by a preliminary kinetics experiment. After the specified time period the soil and solution are separated by centrifugation and/or filtration. The soil and/or solution phases are then analyzed by atomic absorption spectrophotometry or inductively coupled plasma emission spectrometry. With these techniques it is not possible to distinguish between true adsorption and precipitation reactions. For that reason the term sorption will be used.

Two techniques, batch and column studies, may be used to generate sorption isotherms. The batch technique involves placing the soil and the solutions containing the various concentrations of the metals into a vessel and mixing the samples for a prescribed time period. This is the most commonly used technique because of its ease of laboratory operation and ease of data handling. The disadvantages of the technique are 1) results are sensitive to the soil:solution ratio used, 2) soil:solution ratios in actual soil systems cannot be done in batch studies, so scaling of data from batch studies to soils systems is uncertain, 3) results are sensitive to the mixing rate used, 4) separation techniques may affect results, and 5) many investigators have found that batch generated sorption coefficients are not adequate to describe the behavior of metals in flow through systems.

The column method consists of packing a glass or plastic column with soil. The solutions containing various concentrations of the metals of interest are pumped through the columns and the effluents are collected and analyzed by AA or ICP. Breakthrough occurs when the effluent concentration equals the influent concentration. The advantages of this technique are 1) low soil:solution ratios can be used, 2) separation of the soil and solution phase is not required, 3) mechanical mixing is not required and 4) column studies more closely simulate field conditions than batch methods. The disadvantages are 1) results depend on flow rates used, 2) columns are difficult to set-up and maintain, 3) uniform packing of the column is difficult often leading to channel flow, and 4) fewer columns can be operated at one time compared with the number of batch reactors.

Equilibrium sorption is described by a sorption isotherm. A sorption isotherm is the relationship between the amount of metal sorbed and the equilibrium concentration of the metal or, more correctly, the activity of the free metal in the soil solution. A typical sorption isotherm is shown in Figure 11. If the relationship is linear over the concentration range studied then the sorption process can be described by a single coefficient, the distribution coefficient, Kd. For metals, however, the relationship is seldom linear and other equations with two or more coefficients must be used to describe the data.

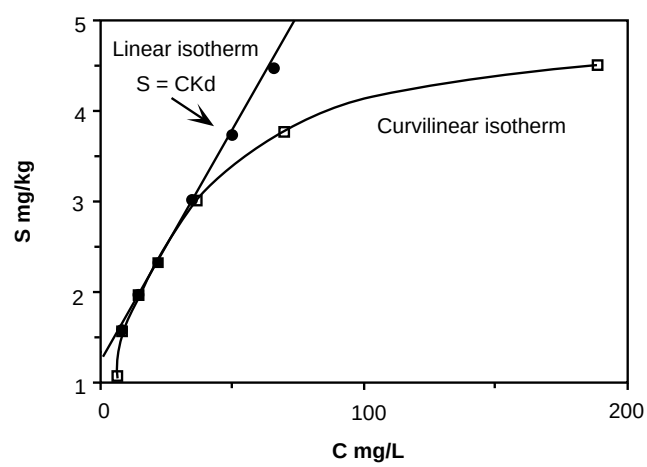

Figure 11. Sorption isotherms.

Equations most frequently used, because of their relative simplicity, to describe the curvilinear sorption behavior of metals in soil are the Langmuir and the Freundlich equations. The Langmuir equation was developed to model gas adsorption on solid surfaces. The derivation of the equation was based on the assumption that adsorption is independent of surface coverage, that there is no interaction between adsorbed ions, and that only a monolayer of adsorption occurs on the surface. These conditions are not typically met with metals sorption on soils.

The linearized form of the Langmuir equation is:

$$\frac{C}{S} = \frac{C}{M} + \frac{1}{Mb} \qquad (1)$$

where C is the concentration or activity of the free metal in solution, S is the quantity of the metal ion sorbed by the soil (i.e., mg metal sorbed/Kg soil), M is the maximum sorption capacity of the soil, and b is the coefficient related to bonding energy. When C/S is plotted as a function of C, the slope is the reciprocal of the sorption capacity, M, and the intercept is 1/Mb.

The Freundlich expression is an empirically derived equation to describe the logarithmic decrease in adsorption energy with increasing surface coverage. The linearized form of the Freundlich equation is:

$$\log S = (N)\log C + \log K \qquad (2)$$

where S and C have the same definition as above and N and K are constants fitted from the experimental data. When the slope, N, equals 1, the equation simplifies to:

$$S = CK_d \text{ or } K_d = S/C \qquad (3)$$

where K_d is the distribution coefficient. In most studies reported in the literature for metal sorption, the slope of the Freundlich isotherm is seldom equal to 1 and the simplified expression and its single term, K_d, are not appropriate to describe the data.

Figure 12 illustrates the use of the Langmuir expression to describe Cu sorption by a soil (Cavallaro and McBride, 1978). The equation describes the behavior of Cu over all concentrations used in this study. Often, however, nonlinear behavior over the concentration range studied is observed with the use of either the Langmuir or Freundlich equations. In Figure 13, the Langmuir expression was used to describe the sorption behavior of Cd and Zn by hydrous manganese oxide (Zasoski and Burau, 1988). This non-linear behavior when using the Langmuir equation has been noted by numerous researchers using various metals and soils and soil constituents (Benjamin and Leckie, 1981; Shuman, 1975; Loganathan and Burau, 1973). Non-linearity of metal sorption using the Freundlich equation has also been noted by Zasoski and Burau (1988) Benjamin and Leckie (1981), Catts and Langmuir (1986), O'Connor et al. (1984), O'Connor et al. (1983), and Elrashdi and O'Connor (1982). This non-linear behavior has been interpreted to indicate multiple sites of sorption that have different energies of retention. The mechanisms at low concentrations have been attributed to specific adsorption, whereas the mechanisms at higher concentrations have been considered to be exchange

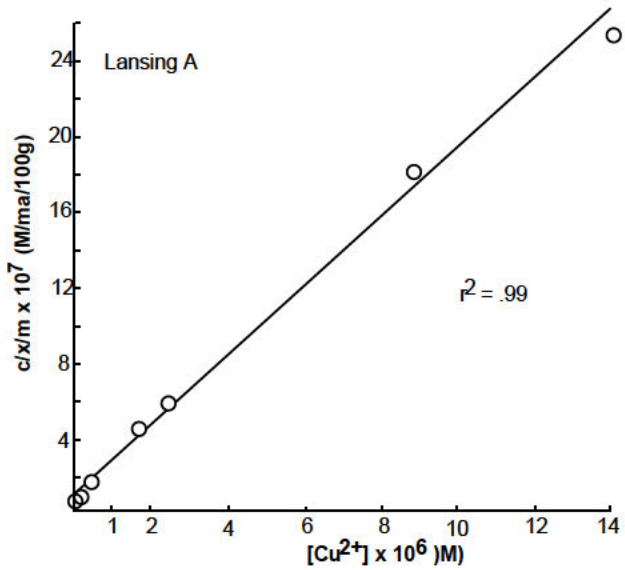

Figure 12. Langmuir adsorption isotherm for Cu^{2+} adsorption on the Lansing A soil (Cavallaro and McBride 1978).

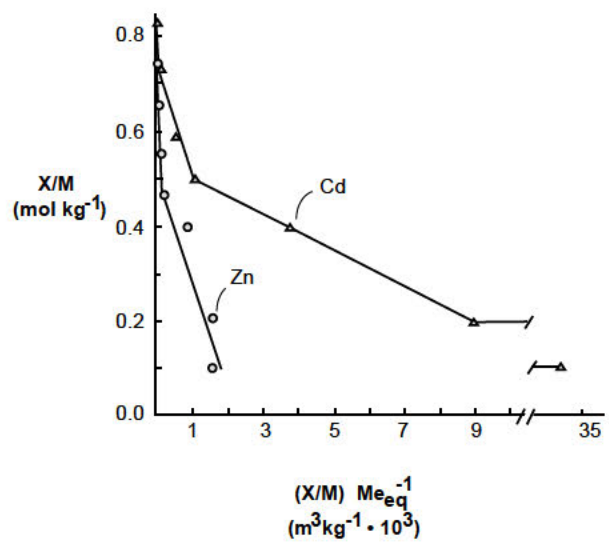

Figure 13. Langmuir plots of Cd and Zn sorbed on δ- MnO_2 for the noncompetitive pH 4 data (Zasoski and Burau, 1988).

reactions or precipitation. These results illustrate the importance of generating sorption data over the concentration range of interest for a particular application. Large error in predicting sorptive behavior may result from using data generated in one system and applied to a system with higher or lower metal concentration.

Several researchers have, however, suggested that other equations, for example the two-surface Langmuir equation (Sposito, 1982; Travis and Etnier, 1981) or the competitive Langmuir equation (Griffin and Au, 1977; Travis and Etnier,

1981), be used to describe the non-linear behavior encountered with the Langmuir equation (Sposito, 1982).

The Langmuir and Freundlich isotherm expressions have proven valuable in interpreting metal behavior in soils. The adsorption isotherm equations were, however, developed for modeling gas adsorption on solids. The sorption of metals by soils violates many of the assumptions associated with these equations. Also, the mechanism described by these equations is adsorption, but it is impossible in a soil system to distinguish between adsorption and precipitation reactions. Adsorption isotherm equations should not be used to indicate adsorption mechanisms without collaborative evidence, but they can be used for an empirical description of the data. Harter (1984) warned against over interpreting the sorption maximum and "bonding energy" determined using the Langmuir equation. The applicability of adsorption isotherm equations to the interpretation of soil chemical phenomena is a subject of controversy. For further discussion of this controversy see Elprince and Sposito (1981), Griffin and Au (1977), Veith and Sposito (1977), Sposito (1979), Harter and Baker (1977), and Harter (1984).

Desorption

Desorption studies are often performed to determine the reversibility of the sorption reactions. This gives an idea of the strength of the association of the metal with the soil surface. An example of the reversibility of a sorption reaction (Figure 14) is taken from Dudley et al. (1988). In this study, two calcareous soils were reacted with various concentrations of Cd. The soils were then desorbed with $CaCl_2$. For the low carbonate soil (Kidman) virtually all of the sorbed Cd was desorbed by the Ca. Only 10-15 percent of the sorbed Cd on the highly calcareous Skumpah soil was desorbed by Ca. These results suggest that Cd was held by the Kidman soil as an exchangeable cation, whereas in the Skumpah, Cd was specifically adsorbed by the $CaCO_3$.

Desorption studies are performed after completion of the sorption study. They can be carried out using either batch or column techniques. For the batch technique the soils used in the sorption are reacted with a salt solution, typically 0.01N $CaCl_2$ or a matrix representative of the soil-waste system being studied. Samples are shaken for a specified time period. The soil and liquid are then separated by centrifugation and/or filtration and the solution is analyzed for the metals by AA or ICP. This process is repeated several times. For a column study, the metal equilibrated soil column is flushed with an appropriate solution until the system reaches steady state conditions.

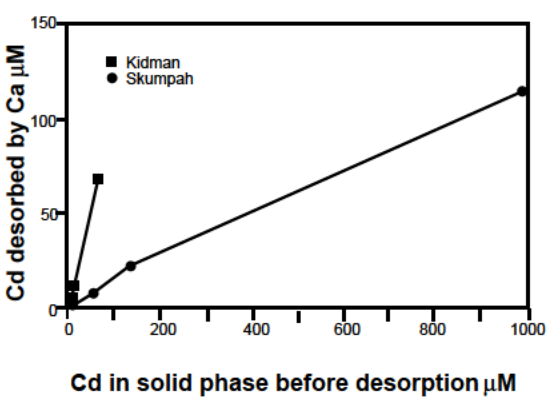

Figure 14. Desorption of Cd from Kidman and Skumpah soil by 0.01 *M* $CaCl_2$ at a soil:solution ratio of 1:25 (Dudley, et al., 1988).

Kinetics

Attention has been mainly given in the literature to equilibrium processes in soils but soil processes are never at equilibrium. Soil systems are dynamic and are thus constantly changing. Most kinetic studies have been performed to establish the proper time interval for use in equilibrium sorption/desorption studies. Most studies assume that ion exchange processes are rapid in soils and that 16 to 24 hours mixing periods, common time periods used in sorption studies, are adequate. This assumption may not be appropriate if other reactions in addition to simple ion exchange, i.e., specific adsorption and precipitation, are involved in metals retention (Harter and Lehmann, 1983). McBride (1980) found that the initial adsorption of Cd on calcite was very rapid, while $CdCO_3$ precipitation of higher Cd^{2+} concentrations was slow. Lehmann and Harter (1984) used kinetics of desorption to study the strength of Cu bonding to a soil. A plot of concentration of Cu in solution versus time indicates an initial rapid release of the Cu followed by a slow reaction. They interpreted these results to indicate that Cu was held at two sites: the rapidly released Cu being loosely held on the soil surfaces and the slowly released Cu being tightly bound.

Each metal-soil system should be tested to determine the time necessary for the individual system to come to equilibrium. Figure 15 illustrates the different time periods required for equilibrium for three metals sorbed by a calcareous soil (Dudley, et al., 1988). Copper reached equilibrium within a few hours whereas Cd and Zn did not approach steady state conditions for 144 hours. Use of the time interval appropriate for Cu equilibrium for this soil would mean that only 50 percent of the Cd and Zn adsorbed under steady state conditions would have been determined.

Kinetic studies are being more widely performed because of their importance in determining the transport of metals in soil systems. Many mathematical transport models now allow a kinetic term for sorption. Equilibrium studies predict whether a reaction will occur but give no indication of the time necessary for the reaction to take place. Kinetic studies also contribute to an understanding of reaction mechanisms not discernible from thermodynamic studies (Zasoski and Burau, 1988; Harter and Smith, 1981; Sparks, 1989).

Kinetic studies are similar to sorption procedures, using either batch or column techniques, except samples are collected over time. Several equations have been used to describe the kinetics of sorption reactions of ions on soils and soil constituents. These equations include: first-order, second-order, Elovich equation, parabolic diffusion equation, and power function equation. An excellent review of kinetic processes in soil systems is given by Sparks (1989).

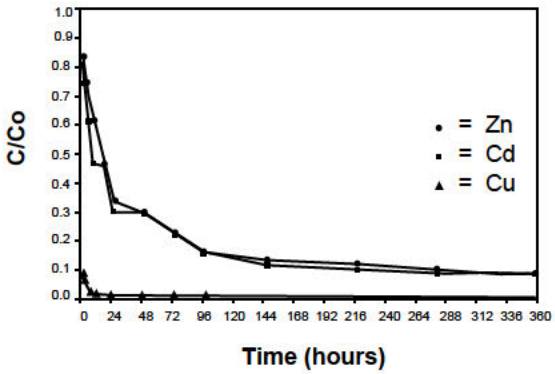

Figure 15. Change with time in reduced concentration of metals in suspensions of the Skumpah soils. C_o was the concentration of metal ions at time = 0 (Dudley, et al., 1988).

Summary

Metals added to soil will normally be retained at the soil surface. Movement of metals into other environmental compartments, i.e., ground water, surface water, or the atmosphere, should be minimal as long as the retention capacity of the soil is not exceeded. The extent of movement of a metal in the soil system is intimately related to the solution and surface chemistry of the soil and to the specific properties of the metal and associated waste matrix.

The retention mechanisms for metals added to soil include adsorption of the metal by the soil solid surfaces and precipitation. The retention of cationic metals by soil has been correlated with such soil properties as pH, redox potential, surface area, cation exchange capacity, organic mater content, clay content, iron and manganese oxide content, and carbonate content. Anion retention has been correlated with pH, iron and manganese oxide content, and redox potential. In addition to soil properties, consideration must be given to the type of metal and its concentration and to the presence of competing ions, complexing ligands, and the pH and redox potential of the soil-waste matrix. Transport of metals associate with various wastes may be enhanced due to (Puls et al., 1991):

1. facilitated transport caused by metal association with mobile colloidal size particles,
2. formation of metal organic and inorganic complexes that do not sorb to soil solid surfaces,
3. competition with other constituents of waste, both organic and inorganic, for sorption sites, and
4. deceased availability of surface sites caused by the presence of a complex waste matrix.

Because of the wide range of soil characteristics and various forms by which metals can be added to soil, evaluating the extent of metal retention by a soil is site/soil/waste specific. Changes in the soil environment over time, such as the degradation of the organic waste matrix, changes in pH, redox potential, or soil solution composition, due to various remedation schemes or to natural weathering processes also may enhance metal mobility. The extent of vertical contamination is intimately related to the soil solution and surface chemistry of the soil matrix with reference to the metal and waste matrix.

Laboratory methods for evaluating the behavior of metals in soils are available in the literature. Thermodynamic equilibrium computer models are also available to assist with this evaluation. The advantages and disadvantages of some of the available procedures have been presented in this document.

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Selenium Location and Mode of Occurrence in the Kanawha Formation Rocks in West Virginia

WEST VIRGINIA MINE DRAINAGE TASK FORCE SYMPOSIUM
April 18-19, 2006

Dorothy J. Vesper and Mimi Roy
West Virginia University

Hydrogeology Research Center of the WV Water Research Institute

Outline

- Objectives & Purpose
- Project summary
- Total Se distribution
- Se mode of occurrence
- Next steps

Project Objectives

1. How do Se concentrations change in a single core?
   - Stratigraphy (depth), rock type, other chemical parameters

2. How is Se chemically bound to the rocks? (mode of occurrence)
   - Rock type

Purpose

- Better understand the chemistry of selenium in coals and related strata
- Help predict where selenium is most likely to be encountered

Samples Used

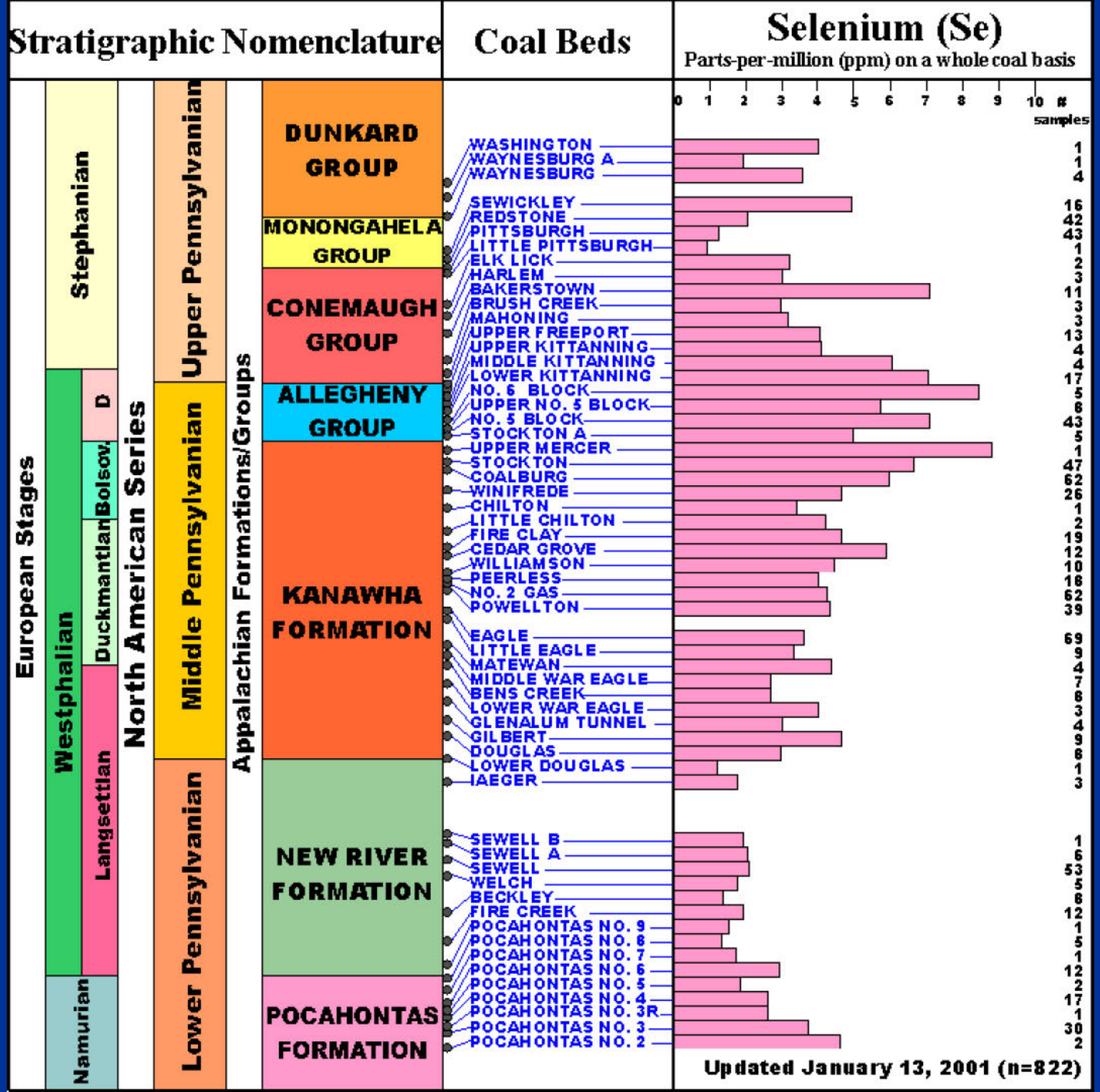
1 core from south-central WV

63 samples

- 11 Coal, 25 shale, 9 mudstone, 12 sandstone, 6 carbolith
- Kanawha Formation (Coalburg – Winifrede coal beds)

Sample prep by Research Environmental & Industrial Consultants (REIC)

- Lithology described
- Ground to <60 mesh by lithology
  - <0.5 feet: completely composited
  - >0.5 – 5 feet: ~1-inch interval from top, middle, & bottom of each 1-foot length. Ground to 1/16 inch, composited, then 500 g ground to <60 mesh



WVGES, 2002

(coals only)

Bulk Analyses

Data provided by REIC

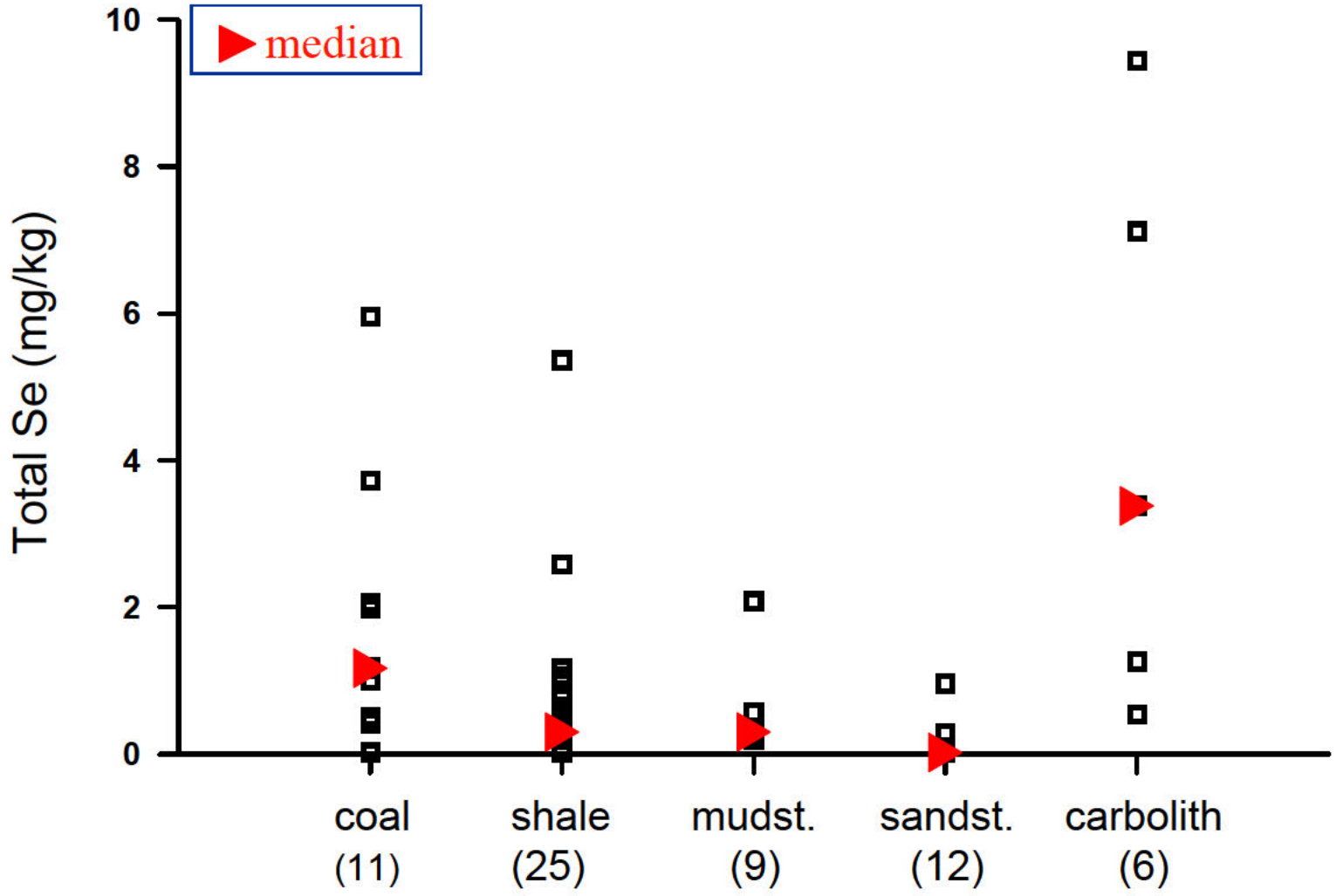
- Acid-base accounting
- Paste pH
- Total organic carbon (TOC)
- Total Se
- Sulfur

Outline

- Objectives & Purpose
- Project summary
- Total Se distribution (objective 1)
- Se mode of occurrence
- Next steps

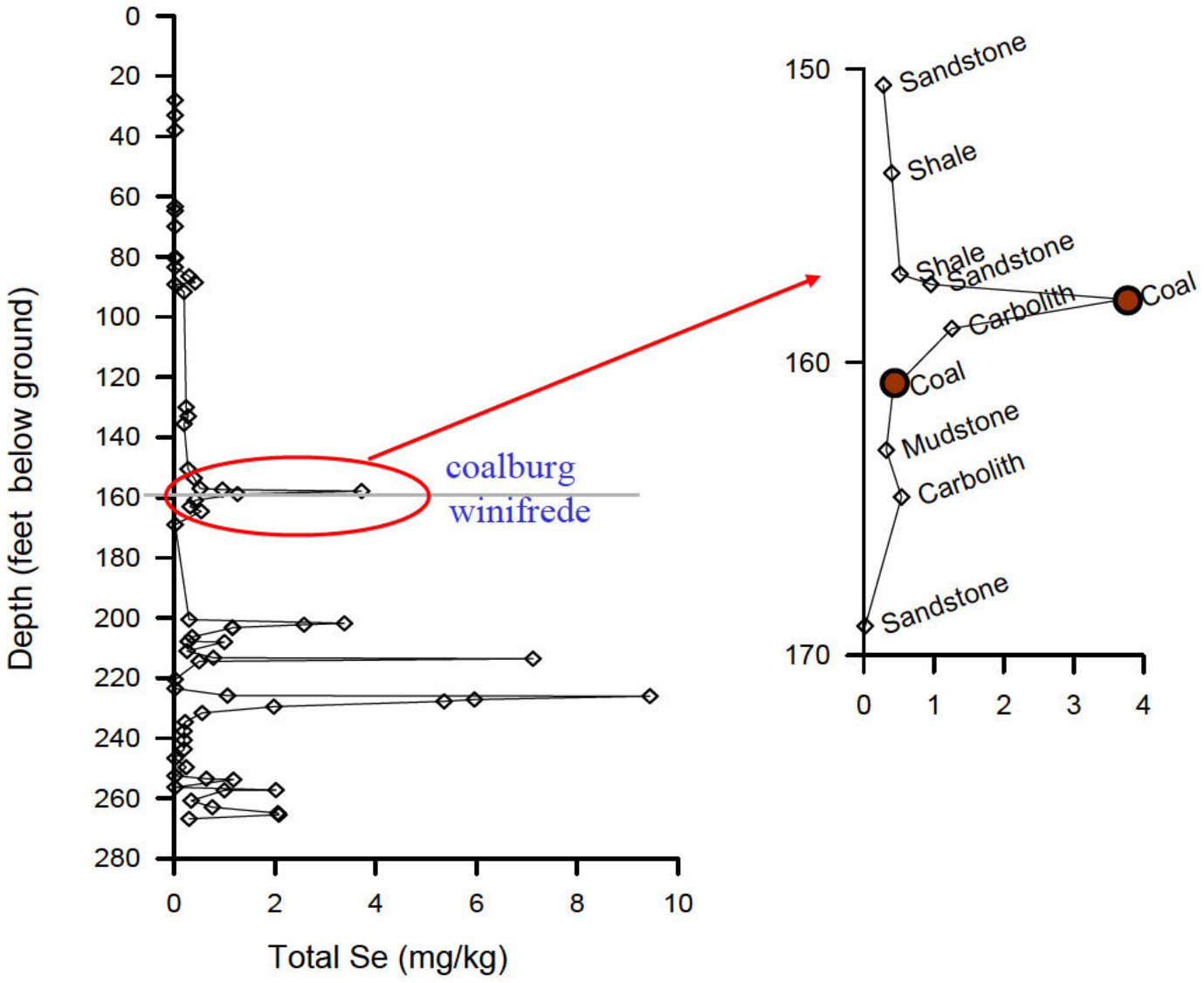
Se by rock type

Total Se Distribution



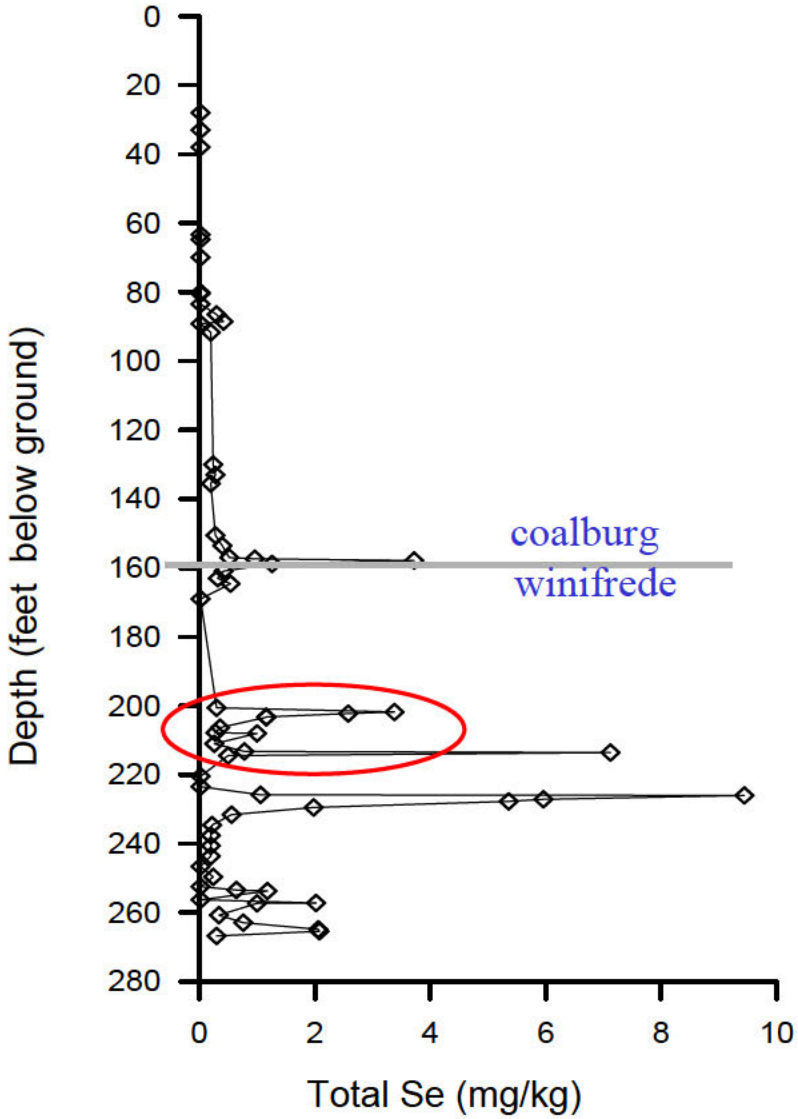
Se by depth

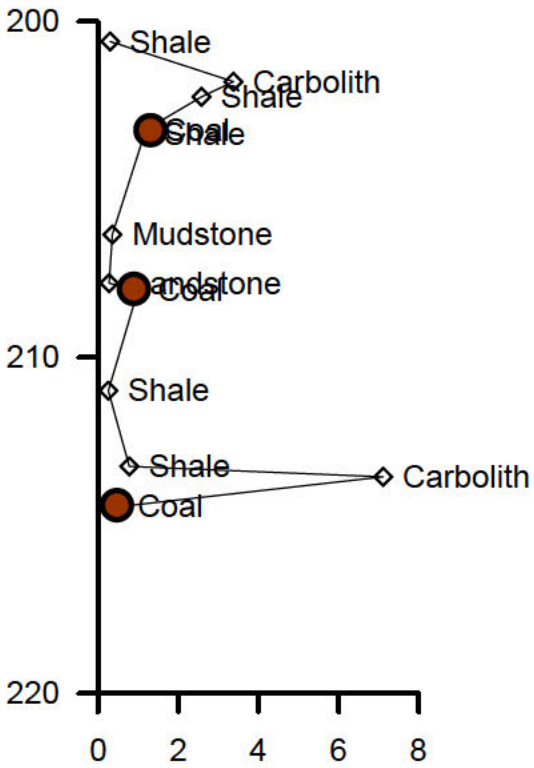
Total Se Distribution



Se by depth

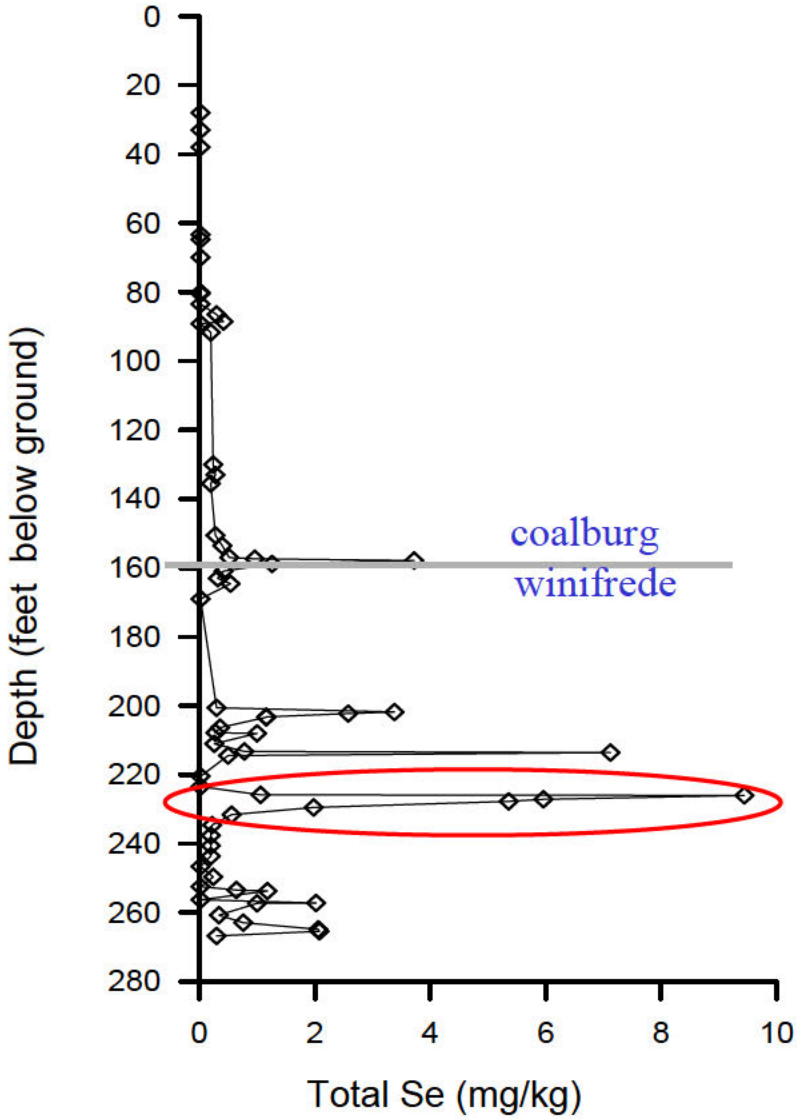
Total Se Distribution

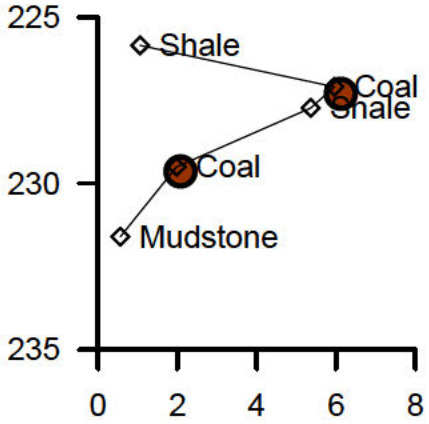




Se by depth

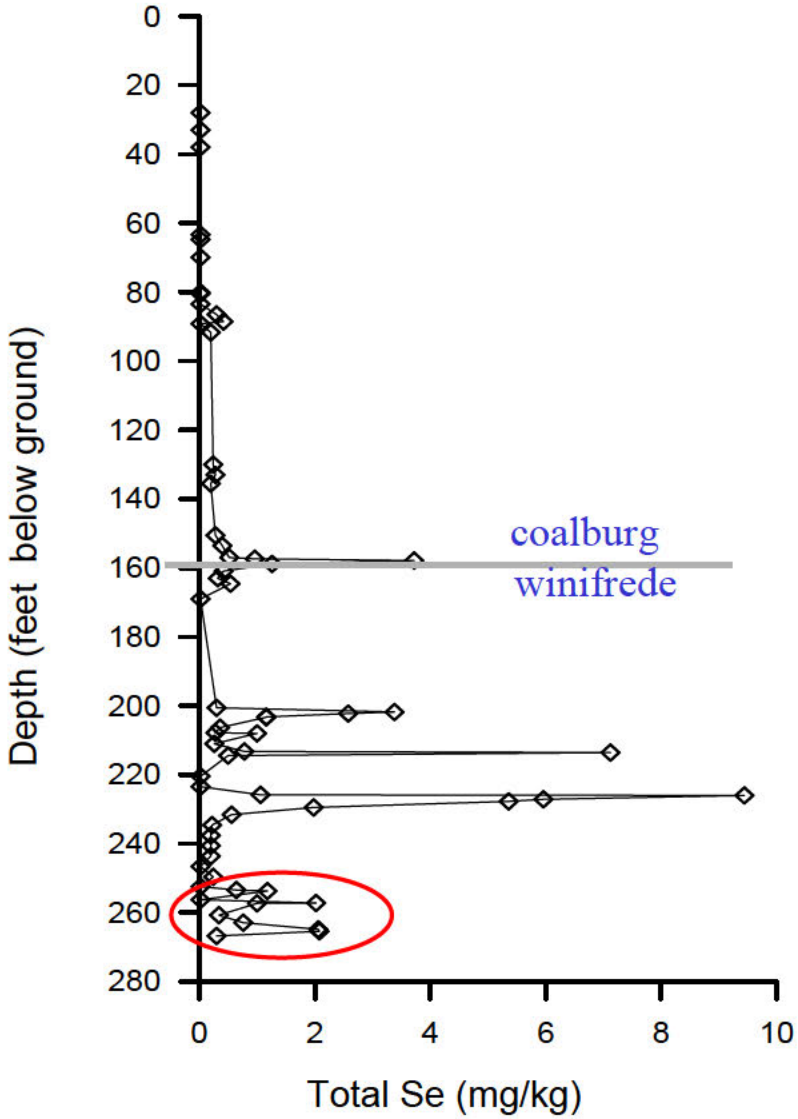
Total Se Distribution

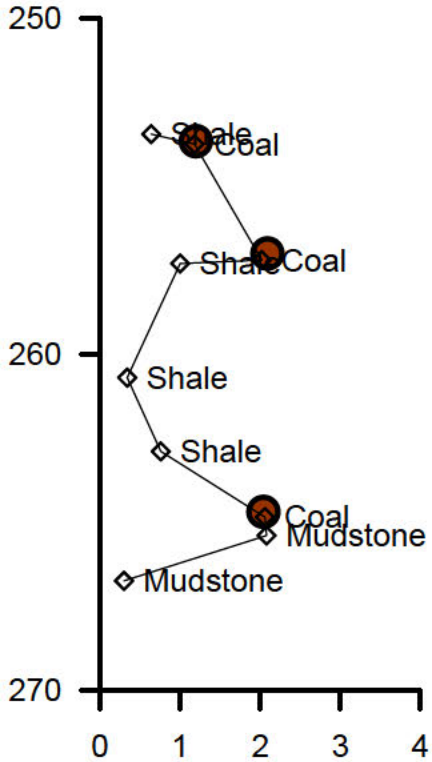




Se by depth

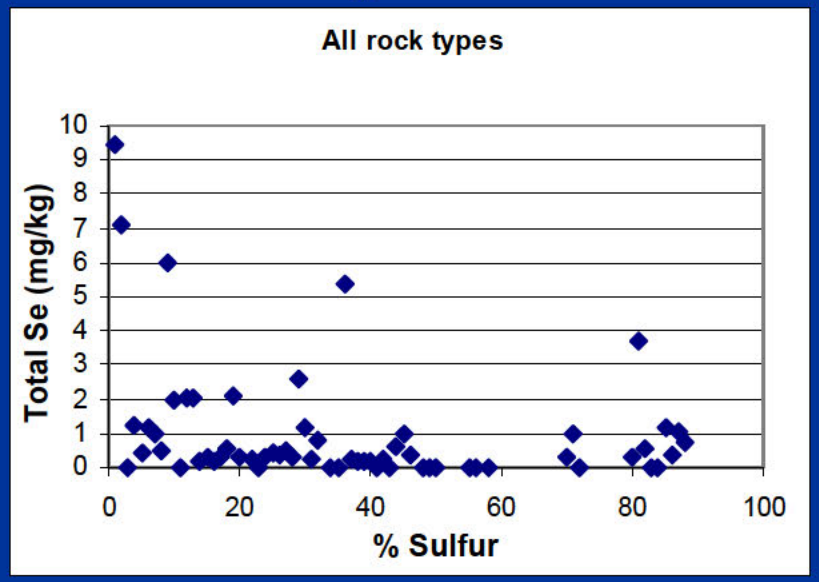
Total Se Distribution

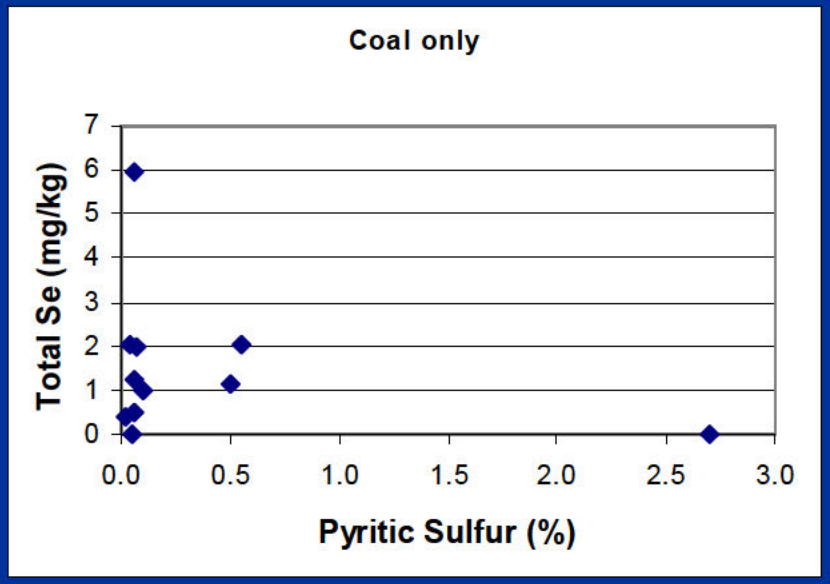




Se vs. other parameters

Does sulfur predict Se concentrations?





Sulfur is not a good predictor

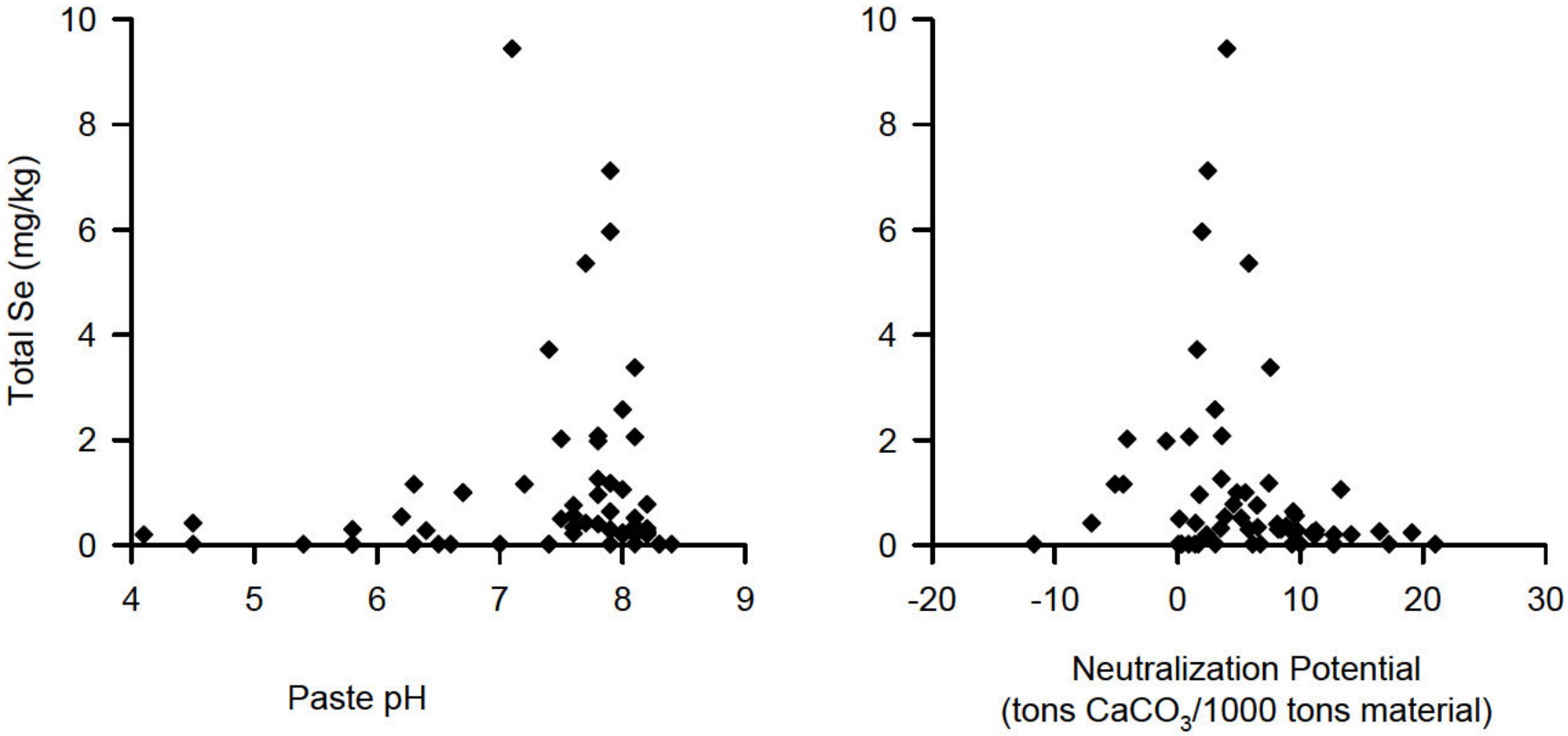
- Coleman et al. (1993) – Eastern coals
- Neuzil et al. (2005) – Appalachian Plateau coals
- Mullennex (2005) – Southern WV strata

Suggests that not all Se in bound in a sulfide minerals

Se vs. other parameters

Total Se Distribution

What seems to work?



Higher Se conc. more likely to be found in rocks with "neutral characteristics'

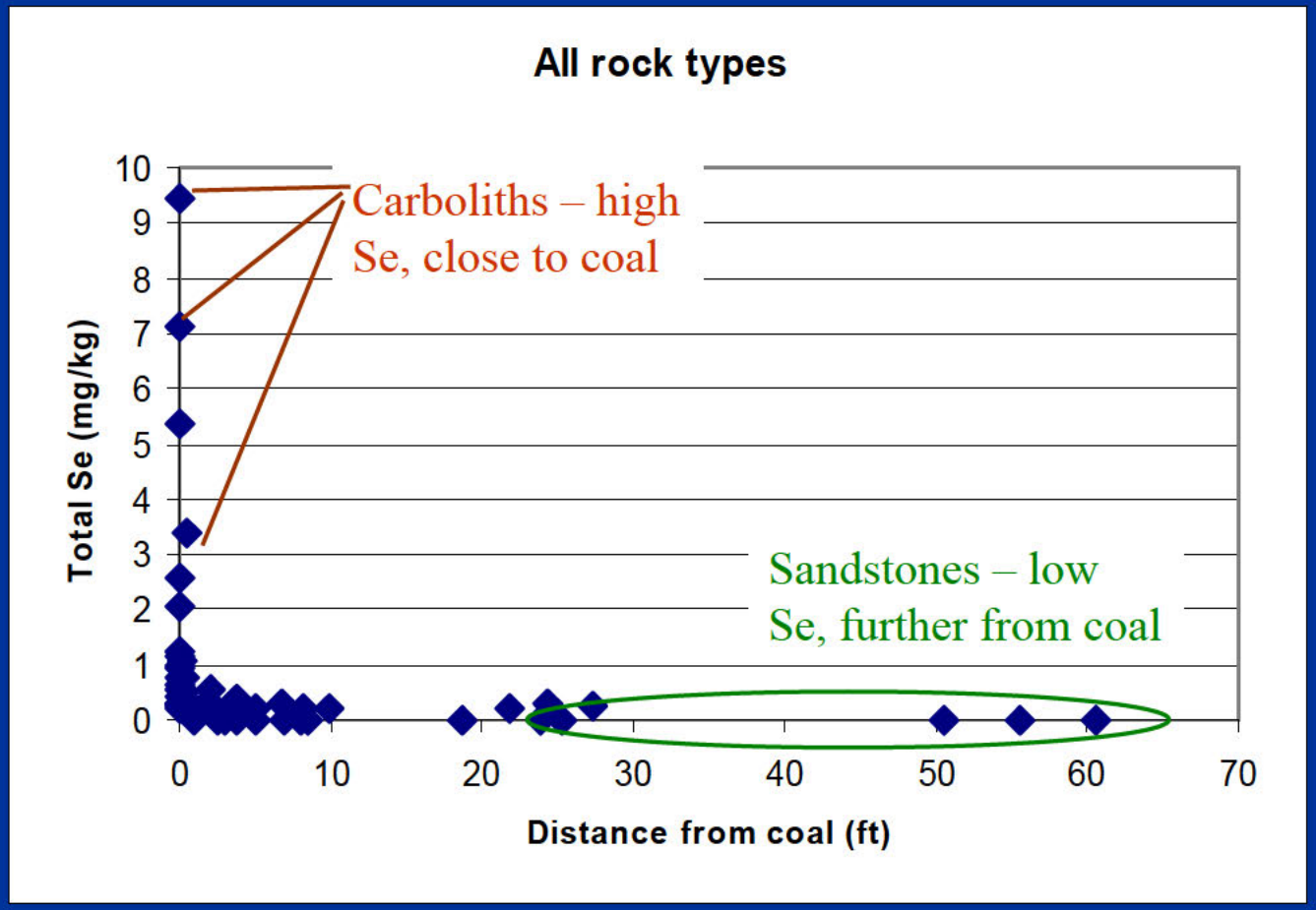
Coal-proximate layers

Total Se Distribution

Layers closer to coal – typically have higher Se

But is there a bias by rock type?

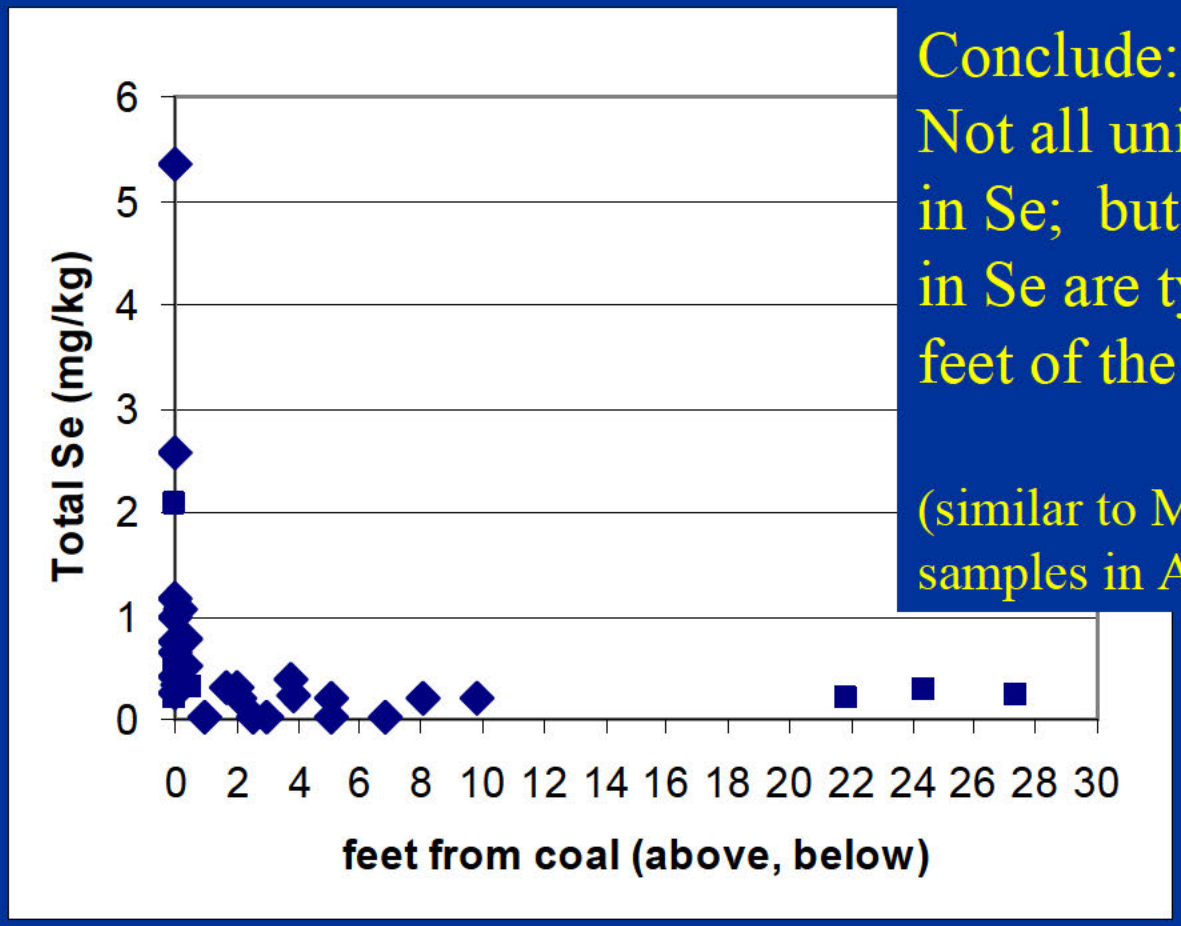
Consider a lithology found both close and far from coals



Coal-proximate layers

Total Se Distribution

Same trends for shale and mudstones (34 total)



Conclude:
Not all units close to coal are high in Se; but the layers that are high in Se are typically found with two feet of the coals

(similar to Mullennex 2005 - >400 samples in Allegheny & Kanawha Fms)

Outline

- Objectives & Purpose
- Project summary
- Total Se distribution
- Se mode of occurrence (objective 2)
- Next steps

Modes & Methods

Se mode of occurrence

	Defined via a reaction with:
Residual	
Sulfides	Ascorbic acid + peroxide
Organics	Na Pyrophosphate
Oxide coatings	Hydroxylamine hydrochloride
Exchangeable	Potassium Phosphate
Soluble	De-ionized Water

Modes & Methods

Se mode of occurrence

Residual

Sulfides

Organics

Oxide coatings

Exchangeable

Soluble

A few details

- 46 samples
- Duplicate & triplicate
- Process blanks fine
- % recovery good
- Analyzed for total Se (some S)

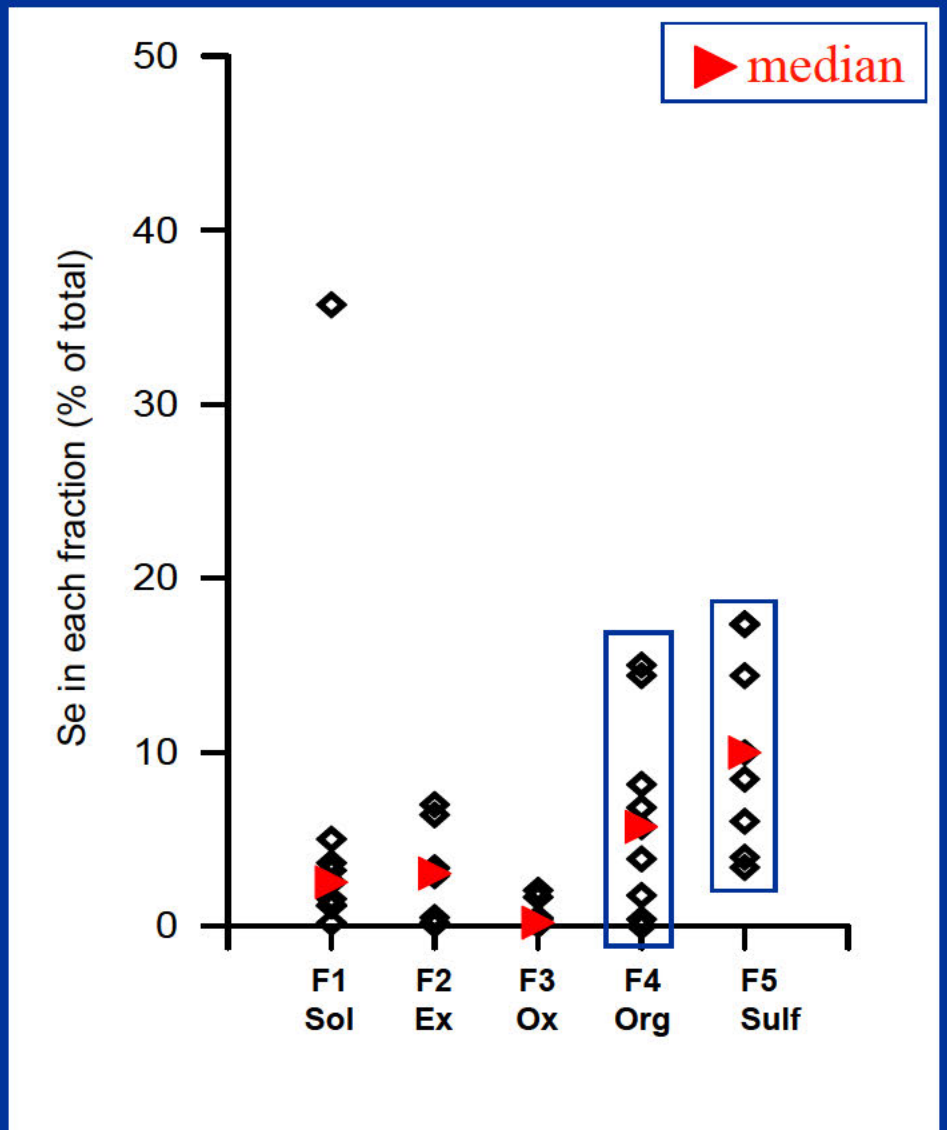
MEANING

Methods designed to target specific chemical reactions – for determining modes of occurrence

Not designed to be a direct measure of what would leach in nature

Distribution in coal samples

Se mode of occurrence



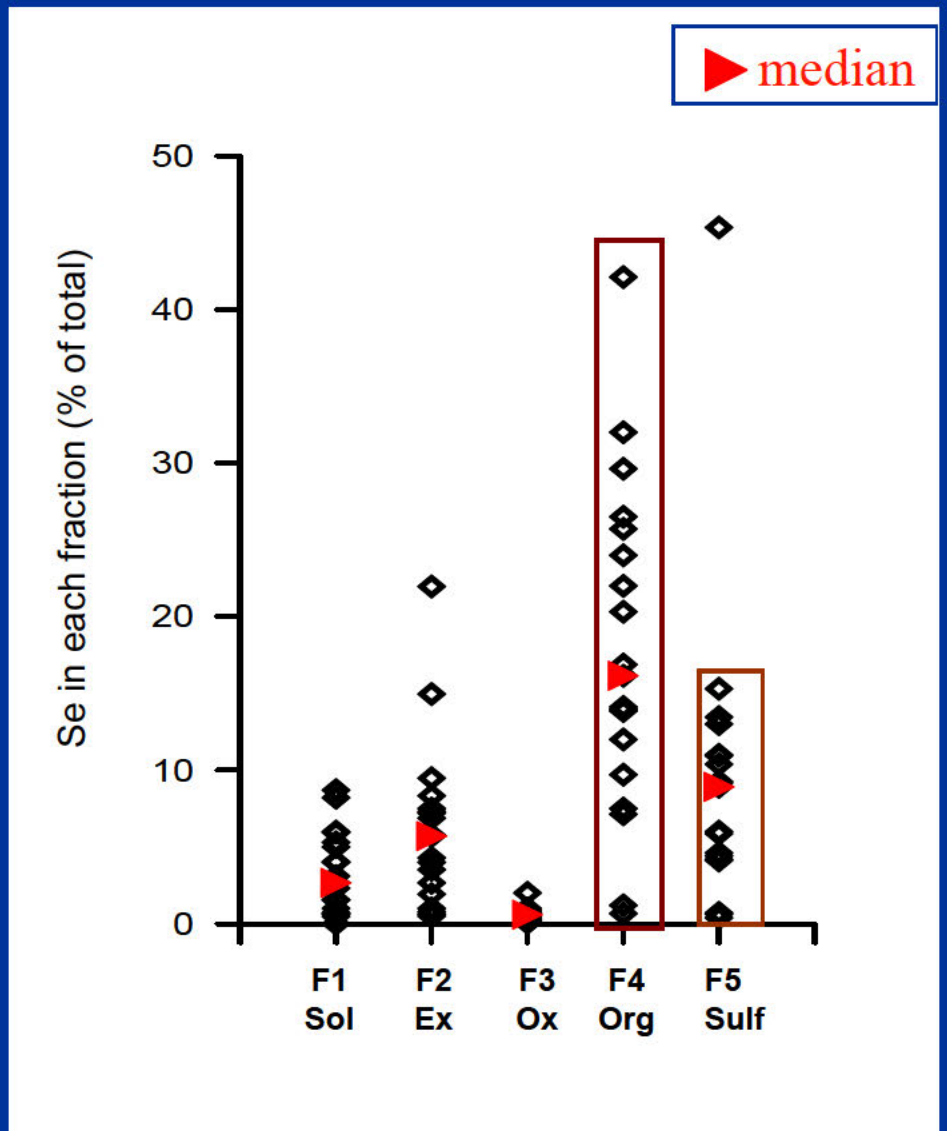
9 coal samples

Regions overlap, but in 8/9 samples there was as much or more Se found in the sulfide than in the organic fraction

Generally, more Se is detected in the sulfide fraction than the organic fraction

Distribution in mudst-shale

Se mode of occurrence



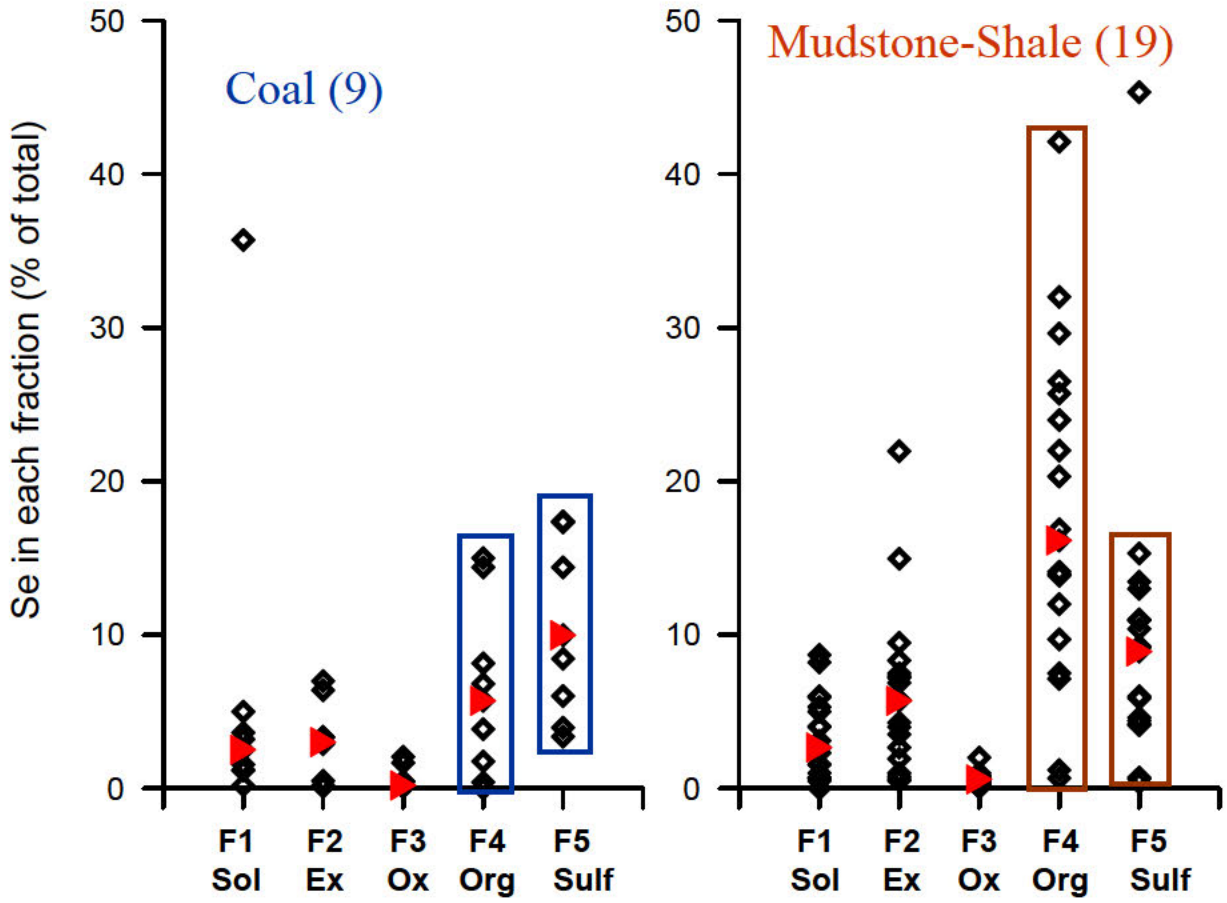
19 samples

Regions overlap, but in 15/19 samples there was as much or more Se found in the organic than in the sulfide fraction

Generally, more Se is detected in the organic fraction than the sulfide fraction

Comparing rock types

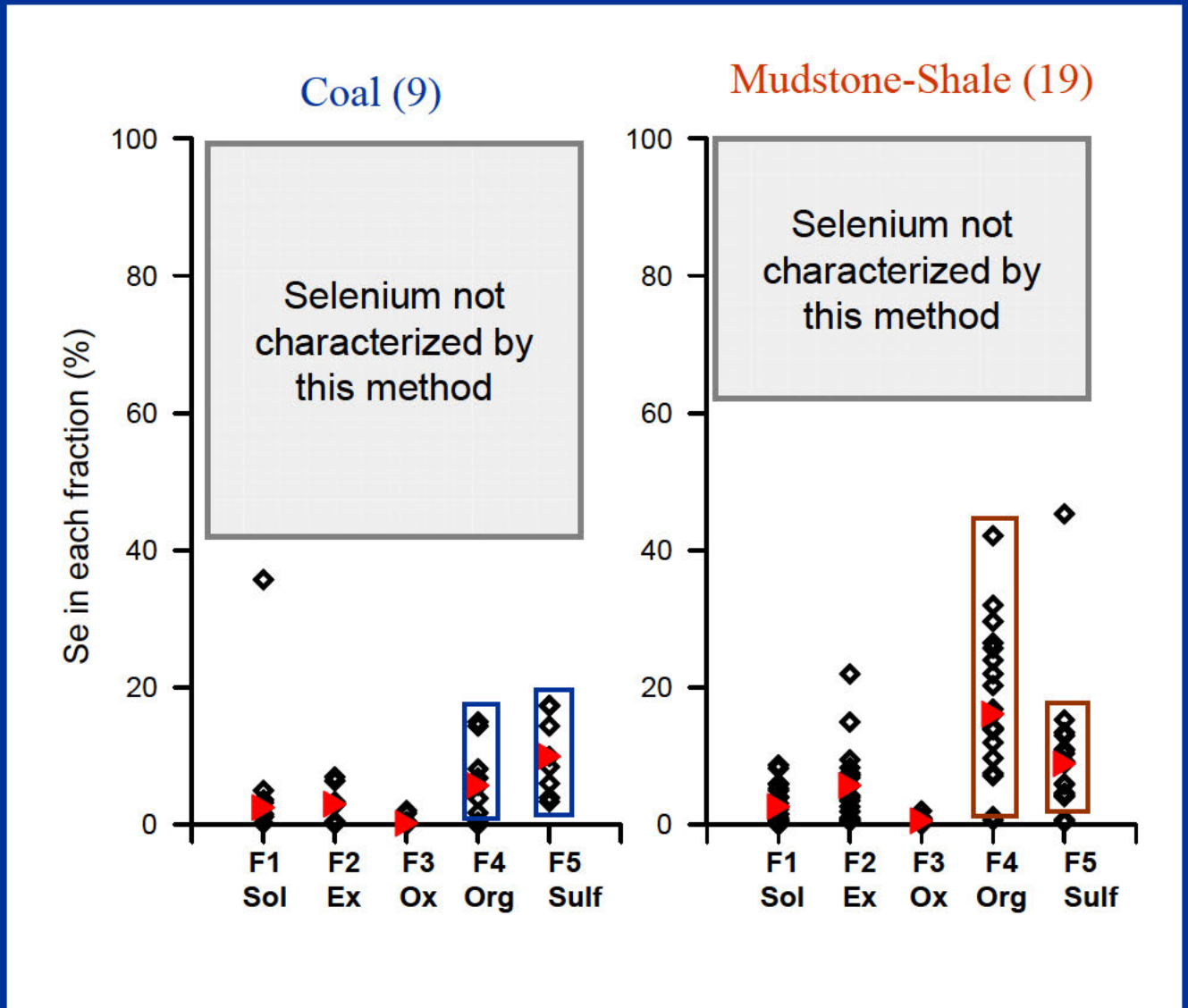
Se mode of occurrence



- Both rock types have Se bound in sulfide & organic fractions
- Usually… Sulfide-Se dominates for coal & organic-Se dominates for shales and mudstones

What's left behind?

Se mode of occurrence



Different y-axis

Is Se in residue generally unavailable? Or is this a function of the test used?

Outline

- Objectives & Purpose
- Project summary
- Total Se distribution
- Se mode of occurrence
- Next steps

Limitations

- Only a single core
- Extraction studies are NOT leaching studies
- Modes of occurrence operationally defined

Total Se

Do the total-Se conclusions apply to a wider area? Compare to:

- Additional cores at site
- Other available data sets

Extract vs. Leach

How do mode-of-occurrence studies compare to leaching tests?

- Conduct both types of studies on the same samples
  - ADTI (Brady, Hornberger) samples
  - Leaching "round robin"

Acknowledgements

- U.S. Department of Interior Office of Surface Mining (OSM)
- West Virginia Water Research Institute
- REIC (Tim Keeney)

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THE OCCURRENCE OF SELENIUM IN THE UPPER KANAWHA FORMATION OF THE PENNSYLVANIAN SYSTEM IN THE SOUTHERN WEST VIRGINIA COAL FIELDS

George Jenkins and Nick Schaer
WVDEP

ABSTRACT A search of the literature on selenium reveals that there are little or no studies available on the concentrations of selenium in rock overburden anywhere in the United States. The Environmental Protection Agency's (EPA) concern with the in-stream concentrations of selenium in the Draft Programmatic Environmental Impact Statement conducted in 6 watersheds in West Virginia for mountaintop mining, brought the lack of data on selenium to the attention of West Virginia's Department of Environmental Protection (DEP). To acquire data for a mining National Pollution Discharge Elimination System Permit (NPDES), the DEP's Water Resource section required the drilling of holes to secure data on selenium in the overburden of selected surface mine permits. The results, procedures and conclusions drawn from the initial drilling under this requirement are presented in this paper.

DISCUSSION

The EPA conducted extensive water testing in 6 watersheds in West Virginia in conjunction with the mountaintop mining EIS (*28).* This study was started in 1999 and a draft report on findings is available. In addition to the typical metals that are analyzed for in a surface mine (SMCRA) permit, selenium was noted as a trace metal of concern by the EPA. This concern arose from selenium concentrations in excess of the 5 ppb in-stream chronic water quality limit that exists in West Virginia (*39*). Because the EIS study purposely picked areas that were/are being surface mined in the state, the conclusion has been drawn that surface mining areas, particularly valley fills, are contributing to the selenium concentrations noted. A literature search on selenium revealed that extensive research on selenium in fly ash (Lemly) and soils (Vance) were available, but no papers or research was noted on the concentrations of selenium in rock overburden. This was important to the WVDEP, because we needed to know where the selenium was concentrated on a surface mine job to suggest ways to handle overburden or use other techniques to mine the coal without harming the aquatic environment with toxic selenium, which can cause harm to fish tissue, animals etc. through bio-concentration *30,31,40).* A study by the West Virginia Geologic Survey (WVGS) was posted on the internet that indicated that coal seams of the Upper Kanawha Formation of the Pennsylvanian System (*34,35)* was much higher in selenium than other strata in the coal areas of the Appalachians. The principal mineable seams in this geological section are the Winifrede, Coalburg, Stockton and #5 Block seams.

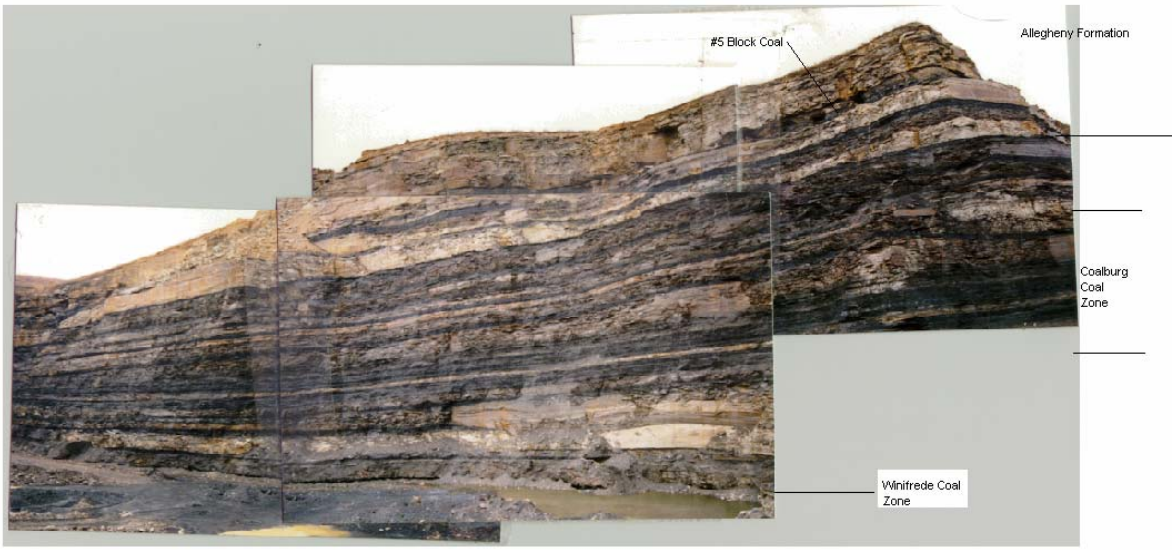

Figure1. Highwall covering the Winifrede to 6-Block coal seams. Picture taken near Sharples, West Virginia at the now inactive Dal-Tex strip mine complex.

This WVGS study was done by measuring the trace metals in the fly ash of the coal seams that were burned in the state, and back calculating the amount of selenium in the total coal seam. The WVGS study, and other research reviewed, plus conversations with analytical laboratory personnel (*41,42)*, indicated that the selenium was associated with organic/carbon based material, like coal seams, carbonaceous shale, etc. Previous work on coal ash and associated materials by one of the authors of this paper for various coal companies also indicated that the coal seams and associated "pit cleanings" (carbonaceous roof, floor and parting material) held the highest concentrations of selenium in the overburden. If the vertical location of the selenium in the "pit cleanings" was correct, then it was possible to design a materials handling plan to isolate this material that would be not cost prohibitive in the mining sequence.

PROTOCOL USED TO ACQUIRE AND ANALYZE THE OVERBURDEN SAMPLES FOR SELENIUM

1. Since 1999, the WVDEP has required that all of the baseline water sites that are submitted for a surface mine permit be tested for trace metals and other compounds, such as phenols, on a one time basis. This data, plus data from several other sources (1.) NPDES renewal Table IV-C analyses. (2.) Data from the Department of Environmental Protection (DEP) trend sites. (3) Data from the EIS in certain watersheds. (4) Data from Water Resources for TMDL's (Total Maximum Daily Loads) etc. (5) and the latest 303(d)

impaired streams list from the Division of Water Resources are checked to see if Selenium or any other metal is above the Title 46-1 State Water Quality Limits (*39)* or of concern.. Any area that has had previous mining and reflects over 5 ppb selenium (current instream chronic water quality standard for selenium) will be selected for drilling to sample the overburden.

2. The drilling will be on approximately 2000' spacing, or other spacing required by the geologist reviewing the surface mining (SMCRA) permit. The holes will be located on the tops of the ridges and drilled down to 10' below the lowest seam to be mined. This will insure that all the overburden to be removed is covered in it's entirety.
3. The core from the drilling will be broken down into vertical sections of 5' or less if the strata type changes. The object is to break the core down into small recognizable sections that can be separated by high selenium content in the mining sequence. This breakdown will also mirror the acid/base testing breakdown, which has been used for decades in surface mining in WV.
4. Each 5' or less section is then analyzed for total selenium by the 3050B (for Acid digestion of Solids) method. Any strata that has a total selenium concentration of 1mg/kg (*25,33,36)* or greater is considered potentially toxic and will have to undergo further testing or an encapsulation/isolation plan provided to deal with the selenium laden overburden.
5. There are several leachate tests available for the next level, if the applicant does not want to do the materials handling plan based on the total selenium analyses. They are (1) Column Leaching (2) Soxhlet (3) Phosphate(*25)* etc. Any leachate test that results in a reading of greater that 5 ug/kg will be considered toxic for selenium and will be included in a specific materials handling plan.

RESULTS FROM DRILLING IN LOGAN AND MINGO COUNTIES IN SOUTHERN WEST VIRGINIA

The protocol was applied to 3 mining areas in the spring of 2004. The results of 1 hole from northern Logan County, 5 holes from southern Logan County and 1 hole from Mingo County (locations shown in figure 2) are included in this report. All of these drilling areas were or are going to be mountaintop mined for the Coalburg and above/Upper Kanawha strata The cross section of the Phoenix #4 area in southern Logan County, and the drill logs with selenium content in the other two areas indicate that the selenium is concentrated in the "pit cleanings" as theorized at the beginning of the study. These "pit cleanings" are the immediate dark shale roof of the Coalburg, Stockton and Five Block coal seams, partings in the coal seams and sometimes the immediate floor of the coal seams. These strata exhibit selenium concentrations of almost one order of magnitude above the background concentrations of selenium in the sandstones, limestones and other strata encountered in the mining sequence. That is .05 to .25 mg/kg in the sandstones and .5 to 1+ mg/kg in the carbonaceous shales, coal partings, floor of the coal seam and the seam itself (see Table 1). The potentially toxic selenium concentrations of 1mg/kg and above are almost solely concentrated in the coal seams, partings and roof and floor of the seams to be mined. Leachate tests on these holes are in

progress and could be the subject of a follow-up paper. The current results definitively indicate that the selenium has an affinity for organic material in the overburden column.

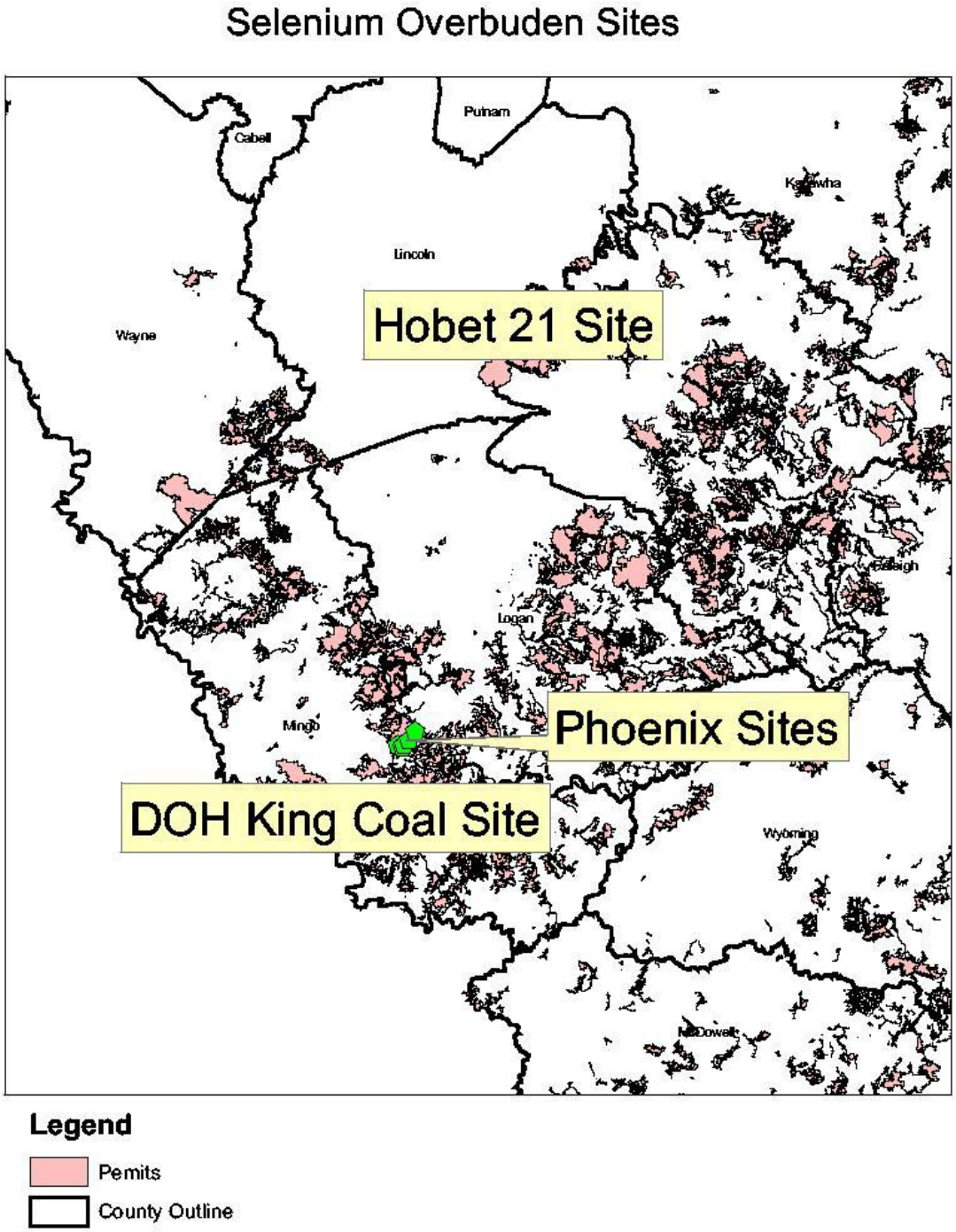

Figure 2. Location of selenium overburden sampling in southern West Virginia.

RECOMMENDED MATERIALS HANDLING PLAN

1. Because the toxic selenium material that needs to be isolated is concentrated in small vertical zones that have to be set aside to recover the coal seam, and the material is a black/dark gray material that is visibly differentiated in the field, the mining company can split this material out in the coal pits. (see figure 3).

Figure 3. #5 Block coal and other black "Pit Cleanings" gathered in piles for removal to special handling areas. Pen Coal strip mine in Wayne County, West Virginia.

2. It is important to rip up 6" to 1' of the floor of the bottom coal seam so that no selenium laden material is left to contaminate the water/rock interface.
3. The toxic material should be removed to an area on the job that is high and dry away from water courses, and under no circumstance should any of this material be put in a valley fill.
4. The material should then be put on a free draining pad of @10' of coarse non-selenium laden material and covered with at least 4' of the most impervious material on the surface mine job. This method will keep water from leaching through the selenium laden overburden.

CONCLUSIONS

It is apparent from the analytical results and research to date that the selenium is concentrated in the "pit cleanings" and particularly in the Upper Kanawha strata in West Virginia. The cut-off of 1 mg/kg limit for identifying the material that has to

undergo further leachate testing looks valid in differentiating the high selenium material to be isolated from the lower concentration material. The visual difference of the black /darker selenium laden material from the other overburden in the Upper Kanawha series is very useful in separating the toxic material from the non-toxic in the field. Further work needs to be done on the different methods of leachate tests to calculate what percentage of selenium in the overburden will be mobilized into the hydrologic environment. Also, it is imperative that a study of how selenium is dispersed in flowing streams versus standing bodies of water is critical to the understanding of what impact selenium may have to the aquatic environment. The moral to the story is to isolate the black/darker selenium laden material and to keep any of this material from the valley fills. This material, besides having high concentrations of selenium, is also typically high in iron and manganese and other trace metals, as well as more acidic, so that the materials handling plan suggested will pay extra dividends.

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41. Private conversations with John Sturm of Sturm Environmental Services, Anmoore, WV

42. Private conversations with personnel at REIC laboratories, Beckley, WV

Table 1. Sample Selenium Data from Phoenix Coal site shown in figure 2. Data from core PX-04-10. REIC Job#: 0405081

SAMPLE NUMBER	SAMPLE INTERVAL	THICKNESS (feet)	ROCK TYPE	SELENIUM (mg/kg)
1	23.00-27.50	4.50	Sandstone	ND
2	43.00-45.00	2.00	Sandstone	ND
3	45.00-45.90	0.90	Shale	0.82
4	45.90-46.15	0.25	Coal	0.94
5	46.40-46.65	0.25	Shale	2.74
6	**46.65-51.25**	**4.60**	**Coal**	**1.14**
7	51.25-52.20	0.95	Shale/Sandstone	1.80
8	52.20-57.00	4.80	Sandstone	ND
9	57.00-62.00	5.00	Sandstone	ND
10	62.00-67.00	5.00	Sandstone	ND
11	67.00-72.00	5.00	Sandstone	ND
12	72.00-77.00	5.00	Sandstone	ND
13	77.00-82.00	5.00	Sandstone	ND
14	82.00-87.00	5.00	Sandstone	ND
15	87.00-92.00	5.00	Sandstone	ND
16	92.00-95.70	3.70	Sandstone	ND
17	95.70-96.60	0.90	Sandstone/ Mudstone/ Coal	0.40
18	96.60-99.75	3.15	Sandstone	0.20
19	99.75-100.30	0.55	Shale	0.34
20	**100.30-101.80**	**1.59**	**Coal**	**0.48**
21	101.80-102.30	0.50	Mudstone	2.28*
22	102.30-105.00	2.70	Shale	0.42
23	105.00-108.00	3.00	Shale	0.20
24	108.00-111.00	3.00	Shale	0.24
25	111.00-114.00	3.00	Shale	0.36
26	114.00-117.00	3.00	Shale	0.36
27	117.00-120.00	3.00	Shale	0.46
28	120.00-123.00	3.00	Shale	0.40
29	123.00-125.00	2.00	Shale	0.44
30	125.00-126.95	1.95	Shale	0.38
31	126.95-129.30	2.35	Shale	1.32
32	129.30-129.50	0.20	Shale	2.12
33	129.50-131.03	1.53	Coal	1.82
SAMPLE NUMBER	SAMPLE INTERVAL	THICKNESS (feet)	ROCK TYPE	SELENIUM (mgflcg)
34	131.03-131.37	0.34	Shale/Coal	3.00

35	131.37-131.70	0.33	Coal	1.90
36	131.70-132.90	1.20	Shale	0.82
37	132.90-135.00	2.10	Mudstone/ Shale	ND
38	135.00-137.00	2.00	Sandstone/ Mudstone	0.20
39	137.00-139.85	2.85	Shale	0.54
40	139.85-140.60	0.75	Shale/Coal	2.60
41	140.60-141.60	1.00	Coal	5.08
42	141.60-143.00	1.40	Mudstone	1.48
43	143.00-146.00	3.00	Mudstone	ND
44	146.00-149.35	3.35	Sandstone	ND
45	149.35-150.40	1.05	Shale	ND
46	150.40-155.00	4.60	Sandstone	ND
47	155.00-160.00	5.00	Sandstone	ND
48	160.00-165.00	5.00	Sandstone	ND
49	165.00-170.00	5.00	Sandstone	ND
50	170.00-175.00	5.00	Sandstone	ND
51	175.00-180.00	5.00	Sandstone	ND
52	180.00-183.65	3.65	Sandstone	ND
53	183.65-184.50	0.85	Shale/Sandstone	ND
54	184.50-189.00	4.50	Sandstone	ND
55	189.00-194.00	5.00	Sandstone	ND
56	194.00-199.00	5.00	Sandstone	ND
57	199.00-204.00	5.00	Sandstone	ND
58	204.00-209.00	5.00	Sandstone	ND
59	209.00-213.00	4.00	Sandstone	0.30
60	213.00-217.00	4.00	Sandstone	ND
61	217.00-220.20	3.20	Mudstone/Sandstone	0.32
62	220.20-225.00	4.80	Sandstone	ND
63	225.00-230.00	5.00	Sandstone	ND
64	230.00-235.00	5.00	Sandstone	ND
65	235.00-240.00	5.00	Sandstone	ND
66	240.00-244.90	4.90	Sandstone	ND
67	244.90-248.60	3.70	Sandstone	ND
68	248.60-250.70	2.10	Sandstone	1.26
69	250.70-251.64	0.94	Coal	3.98
70	251.64-253.10	1.46	Coal	1.60
71	253.10-253.55	0.45	Carbolith	2.64
72	253.55-254.46	0.91	Carbolith/Coal	2.66

73	254.46-254.93	0.47	Coal	2.80
74	254.93-256.45	1.52	Coal	2.54

SAMPLE NUMBER	SAMPLE INTERVAL	THICKNESS (feet)	ROCK TYPE	SELENIUM (mg/kg)
75	256.45-257.05	0.60	Shale	3.28
76	257.05-260.00	2.95	Sh	0.62
77	260.00-260.85	0.85	Shale/Coal	2.38
78	260.85-261.15	0.30	Coal	1.20
79	261.15-261.45	0.30	Carbolith	1.40
80	261.45-263.50	2.05	Coal	0.92
81	263.50-264.25	0.75	Shale	0.62
82	264.25-267.10	2.85	Shale	0.28
83	267.10-269.95	2.85	Shale	ND
84	269.95-271.95	2.00	Sandstone/ Shale	0.26
85	271.95272.41	0.46	Coal	1.86
86	272.41-274.10	1.69	Shale	0.26
87	274.10-277.00	2.90	Mudstone	ND
88	277.00-280.00	3.00	Sandstone/Shale	ND
89	280.00-283.00	3.00	Shale	ND
90	283.00-285.50	2.50	Shale	0.38
91	**285.50-285.92**	**0.42**	Coal	**1.60**
92	**285.92-286.15**	**0.23**	Carbolith	**8.64**
93	**286.15-287.55**	**1.40**	Coal	**2.10**
94	287.55-287.75	0.20	Shale	0.76
95	287.75-293.00	5.25	Sandstone	0.20
96	293.00-298.00	5.00	Sandstone	ND
97	298.00-303.00	5.00	Sandstone	ND
98	303.00-308.00	5.00	Sandstone	ND
99	308.00-313.00	5.00	Sandstone	ND

ND - Not Detected at the MDL of 0.2 mg/kg.

* - The matrix spike for selenium exceeded method control limits due to matrix interference.

Matthew Klasen/DC/USEPA/US
01/10/2011 04:04 PM

To Jeff Lape
cc
bcc
Subject Fw: Add'l Spruce OST reviews (in addition to fish tissue)

Hi Jeff,

Sorry for the slight delay in sending this. These are the additional questions on which we need a quick review. We're well on our way with the other fish tissue Se responses.

Let me know if you have any questions. If folks could review ideally by COB today, that would be great.

Thanks,
Matt

Matt Klasen
U.S. Environmental Protection Agency
Office of Water (IO)
202-566-0780
cell (202) 380-7229
----- Forwarded by Matthew Klasen/DC/USEPA/US on 01/10/2011 04:03 PM -----

From: Matthew Klasen/DC/USEPA/US
To: Lynn Zipf/DC/USEPA/US@EPA
Cc: Gregory Peck/DC/USEPA/US@EPA, Joe Beaman/DC/USEPA/US@EPA, Betsy Behl/DC/USEPA/US@EPA
Date: 01/10/2011 01:55 PM
Subject: Add'l Spruce OST reviews (in addition to fish tissue)

Hi Lynn,

We had a good discussion this morning with Betsy and Joe on the fish tissue Se issues, and we're well on our way to getting that resolved.

There are three other Spruce responses that we'd like OST review of to make sure there aren't any problematic programmatic or policy statements.

Responses are attached, and they address the following:
(b) (5) [redacted]

I'm guessing Joe or Betsy is the right person to review the first group, but not sure who is right for the second one. Can you let me know whether these looks OK after forwarding to the appropriate folks? COB today would be great, and again, the goal is just to ensure we're not overstepping policy- or program-wise with our specific responses on Spruce.

Happy to help explain more by phone if that would help.

Thanks,
Matt

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2011-01-10 99A, 100A, 147A for OST.docx

Matt Klasen
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Office of Water (IO)
202-566-0780
cell (202) 380-7229

Matthew Klasen/DC/USEPA/US
01/10/2011 04:12 PM

To Kevin Minoli
cc Karyn Wendelowski, Stefania Shamet, Gregory Peck, Christopher Hunter
bcc
Subject Three more for your review (146A, 150A, 154A)

Hi Kevin,

See attached for responses to three of the comments we didn't give you the first time around: 146A, 150A, and 154A. These all relate to impacts to higher trophic level biota.

Thanks,
Matt

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2011-01-10 146A, 150A, 154A for Kevin.docx

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cell (202) 380-7229

William Early/R3/USEPA/US
01/10/2011 04:22 PM

To Jeffrey Lapp
cc Jessica Martinsen, John Pomponio
bcc
Subject Re: Fw: Draft end of 60 day letter for Spring Branch No. 3

Jeff - will review.

Thanks.

bill e.

William C. Early
Deputy Regional Administrator
Middle Atlantic Region
U. S. Environmental Protection Agency
215 814 2626
215 814 2901 (Fax)
Early.William@epa.gov

Jeffrey Lapp | Randy and Bill - Here is the draft letter and briefi... | 01/10/2011 03:56:40 PM

From: Jeffrey Lapp/R3/USEPA/US
To: John Pomponio/R3/USEPA/US@EPA, William Early/R3/USEPA/US
Cc: Jessica Martinsen/R3/USEPA/US@EPA
Date: 01/10/2011 03:56 PM
Subject: Fw: Draft end of 60 day letter for Spring Branch No. 3

Randy and Bill -

Here is the draft letter and briefing paper for this ECP permit which has been placed on the 60 day clock.

We are sending this to HQ staff to begin their review as well.

(b) (5) [redacted]

Please let us know if you have any questions/comments.

Thanks,
Jeff

----- Forwarded by Jeffrey Lapp/R3/USEPA/US on 01/10/2011 03:40 PM -----

From: Jessica Martinsen/R3/USEPA/US
To: Jeffrey Lapp/R3/USEPA/US@EPA
Cc: Allison Graham/R3/USEPA/US@EPA
Date: 01/10/2011 03:23 PM
Subject: Draft end of 60 day letter for Spring Branch No. 3

Jeff,
For your review. Allison has completed the drafts for the briefing document and the close out letter. Here are those drafts for your review and comment.

Mining_ECP_Briefing Paper_SpBrNo3 1-10-11a.doc SpBrNo3 end of 60 day letter 1-10-11.doc

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Jessica Martinsen
U.S. EPA Region III
Office of Environmental Programs
1650 Arch St. (3EA30)
Philadelphia, PA 19103
215-814-5144 (office)
215-814-2783 (fax)

Christopher Hunter/DC/USEPA/US
01/10/2011 05:09 PM

To Denise Keehner, Tanya Code
cc Brian Frazer, David Evans, Jim Pendergast
bcc
Subject Fw: Revised Spruce Qs&As

Hi Denise,
we're having an end-of-day wrap up call on Spruce, and Greg indicated that we was going to send the PR and Q&A's to the press office. I asked him to hold off until I checked with you since I knew you had concerns with the Q&As. Some of the health language has been edited, but it's still generally in there. I"ve reviewed and highlighted some areas. If you want to take a quick look, Greg said he would wait until hearing from me, but probably no later than tomorrow morning.

Thanks
Chris

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2011-01-10 Draft Spruce Q&As - CH.doc

Chris Hunter
U.S. Environmental Protection Agency
Office of Wetlands, Oceans, & Watershed
(202) 566-1454
hunter.christopher@epa.gov

----- Forwarded by Christopher Hunter/DC/USEPA/US on 01/10/2011 05:06 PM -----

From: Matthew Klasen/DC/USEPA/US
To: Gregory Peck/DC/USEPA/US@EPA
Cc: Christopher Hunter/DC/USEPA/US@EPA, Brian Frazer/DC/USEPA/US@EPA, Jim Pendergast/DC/USEPA/US@EPA, Kevin Minoli/DC/USEPA/US@EPA, Karyn Wendelowski/DC/USEPA/US@EPA, Stefania Shamet/R3/USEPA/US@EPA, Michael Dunn/R3/USEPA/US@EPA, David Evans/DC/USEPA/US@EPA, Denise Keehner/DC/USEPA/US@EPA, Nancy Stoner/DC/USEPA/US@EPA, Travis Loop/CBP/USEPA/US@EPA
Date: 01/10/2011 03:23 PM
Subject: Revised Spruce Qs&As

Hey Greg,

See attached for an updated set of Qs&As on Spruce, building upon the draft developed on Friday. This includes comments from Nancy, Denise, Karyn, Chris, and Stef.. This is significantly revised from Friday's version, including a few new questions, so I'm attaching a clean version only.

Recognizing that Betsaida was interested in at least a subset of these Qs&As being public, I noted a few questions that reviewers or I thought should stay internal.

(b) (5)
[redacted]

Thanks,
Matt

Matt Klasen
U.S. Environmental Protection Agency
Office of Water (IO)
202-566-0780
cell (202) 380-7229

Christopher Hunter/DC/USEPA/US
01/10/2011 05:11 PM

To Gregory Peck, Matthew Klasen, Stefania Shamet
cc
bcc
Subject Revised Executive Summary

Executive Summary.docx

ATTACHMENT REDACTED - DELIBERATIVE

Chris Hunter
U.S. Environmental Protection Agency
Office of Wetlands, Oceans, & Watershed
(202) 566-1454
hunter.christopher@epa.gov

Gregory Peck/DC/USEPA/US
01/10/2011 05:19 PM

To Jeff Lape
cc Lynn Zipf, Matthew Klasen
bcc
Subject Fw: Add'l Spruce OST reviews (in addition to fish tissue)

Jeff - Could really use your input by noon tomorrow.

Thanks!
Greg

----- Forwarded by Gregory Peck/DC/USEPA/US on 01/10/2011 05:18 PM -----

From: Matthew Klasen/DC/USEPA/US
To: Lynn Zipf/DC/USEPA/US@EPA
Cc: Gregory Peck/DC/USEPA/US@EPA, Joe Beaman/DC/USEPA/US@EPA, Betsy Behl/DC/USEPA/US@EPA
Date: 01/10/2011 01:55 PM
Subject: Add'l Spruce OST reviews (in addition to fish tissue)

Hi Lynn,

We had a good discussion this morning with Betsy and Joe on the fish tissue Se issues, and we're well on our way to getting that resolved.

There are three other Spruce responses that we'd like OST review of to make sure there aren't any problematic programmatic or policy statements.

Responses are attached, and they address the following:
(b) (5) [redacted]

I'm guessing Joe or Betsy is the right person to review the first group, but not sure who is right for the second one. Can you let me know whether these looks OK after forwarding to the appropriate folks? COB today would be great, and again, the goal is just to ensure we're not overstepping policy- or program-wise with our specific responses on Spruce.

Happy to help explain more by phone if that would help.

Thanks,
Matt

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2011-01-10 99A, 100A, 147A for OST.docx

Matt Klasen
U.S. Environmental Protection Agency
Office of Water (IO)
202-566-0780
cell (202) 380-7229

Christopher Hunter/DC/USEPA/US

01/10/2011 06:05 PM

To Ann Campbell, Ben Ghosh, Beth Walls, Bharat Mathur, Bob Sussman, Brian Frazer, Chris Thomas, Christopher Hunter, Cliff Rader, Daniel Holliman, Darren Reid, David Evans, Denis Borum, Denise Keehner, Duncan Powell, Evelyn MacKnight, Georgia Bednar, Grace Robiou, Gregory Peck, Janice Donlon, Jeffrey Lapp, Jim Giattina, John Forren, John Pomponio, Jon Capacasa, Jordan Dorfman, Justin Wright, Karyn Wendelowski, Kevin Minoli, Kevin Pierard, Larinda Tervelt, Mahri Monson, Marcus Zobrist, Mark Nuhfer, Matthew Klasen, Melissa Raack, Michael Dunn, Michael Slimak, MichaelG Lee, Naimah Karim, Nanci Gelb, Nancy Stoner, Palmer Hough, Peter Silva, Peter Swenson, Philip Mancusi-Ungaro, Rebecca Cover, Robert Klepp, Rosemary Hall, Ross Geredien, Sharmin Syed, Shawn Garvin, Stan Meiburg, Stefania Shamet, Stephanie Fulton, Susan Cormier, Susan Norton, Tanya Code, Timothy Landers, Tinka Hyde, Todd Bowers, Tom Laverty, Tom Welborn, Wendy Melgin, William Early, Elaine Suriano, Caroline Whitehead, Amy Newbold, Brian Topping, Bridget Staples, Eric Somerville, Chad Harsh, Jessica Martinsen, Susan Hansen, Tom Marshall, Larry Long, Kip Tyler, Sonia Alteri, Glenn Suter, CynthiaN Johnson

cc

bcc

Subject Weekly Mining Call Agenda 1-11-11

Hello all,
Attached is the agenda for tomorrow's call. I apologize for not sending out a draft earlier today, but we can accept additional topics on the call.

Thanks,
Chris

ATTACHMENT REDACTED - DELIBERATIVE

Mining Call Agenda 1-11-11.doc

Chris Hunter
U.S. Environmental Protection Agency
Office of Wetlands, Oceans, & Watershed
(202) 566-1454
hunter.christopher@epa.gov

Marcel Tchaou/DC/USEPA/US
01/10/2011 06:08 PM

To Matthew Klasen
cc
bcc
Subject Reference Appendix

Matt,
This is the latest. I am still working on it.

ATTACHMENT REDACTED - DELIBERATIVE

Appendix 7 FD Marcel version 1-10-2011Harmonized.doc

****

Marcel K. Tchaou, Ph.D., P.E., P.H.
Environmental Engineer
Wetlands & Aquatic Resources Regulatory Branch
Office of Wetlands, Oceans and Watersheds
U.S. EPA
1200 Pennsylvania Avenue, NW (MC 4502T)
Washington, DC 20460
202-566-1904

Matthew Klasen/DC/USEPA/US
01/10/2011 06:12 PM

To Marcel Tchaou
cc Christopher Hunter
bcc
Subject Fw: Three more for your review (146A, 150A, 154A)

Hey Marcel,

See below for a couple more responses with references. I think one of them in 150A (Mordecai et al.) isn't currently on the list.

Thanks,
Matt

Matt Klasen
U.S. Environmental Protection Agency
Office of Water (IO)
202-566-0780
cell (202) 380-7229
----- Forwarded by Matthew Klasen/DC/USEPA/US on 01/10/2011 06:10 PM -----

From: Matthew Klasen/DC/USEPA/US
To: Kevin Minoli/DC/USEPA/US@EPA
Cc: Karyn Wendelowski/DC/USEPA/US@EPA, Stefania Shamet/R3/USEPA/US@EPA, Gregory Peck/DC/USEPA/US@EPA, Christopher Hunter/DC/USEPA/US@EPA
Date: 01/10/2011 04:12 PM
Subject: Three more for your review (146A, 150A, 154A)

Hi Kevin,

See attached for responses to three of the comments we didn't give you the first time around: 146A, 150A, and 154A. These all relate to impacts to higher trophic level biota.

Thanks,
Matt

ATTACHMENT REDACTED - DELIBERATIVE

2011-01-10 146A, 150A, 154A for Kevin.docx

Matt Klasen
U.S. Environmental Protection Agency
Office of Water (IO)
202-566-0780
cell (202) 380-7229

Marcel Tchaou/DC/USEPA/US
01/10/2011 07:08 PM

To Matthew Klasen
cc Christopher Hunter
bcc
Subject Re: Fw: Three more for your review (146A, 150A, 154A)

Latest most updated Reference list

ATTACHMENT REDACTED - DELIBERATIVE

Appendix 7 FD Marcel version 1-10-2011Harmonized.doc

****
Marcel K. Tchaou, Ph.D., P.E., P.H.
Environmental Engineer
Wetlands & Aquatic Resources Regulatory Branch
Office of Wetlands, Oceans and Watersheds
U.S. EPA
1200 Pennsylvania Avenue, NW (MC 4502T)
Washington, DC 20460
202-566-1904

Matthew Klasen	Hey Marcel, See below for a couple more respo...	01/10/2011 06:12:08 PM

From: Matthew Klasen/DC/USEPA/US
To: Marcel Tchaou/DC/USEPA/US@EPA
Cc: Christopher Hunter/DC/USEPA/US@EPA
Date: 01/10/2011 06:12 PM
Subject: Fw: Three more for your review (146A, 150A, 154A)

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Thanks,
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Office of Water (IO)
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cell (202) 380-7229
----- Forwarded by Matthew Klasen/DC/USEPA/US on 01/10/2011 06:10 PM -----

From: Matthew Klasen/DC/USEPA/US
To: Kevin Minoli/DC/USEPA/US@EPA
Cc: Karyn Wendelowski/DC/USEPA/US@EPA, Stefania Shamet/R3/USEPA/US@EPA, Gregory Peck/DC/USEPA/US@EPA, Christopher Hunter/DC/USEPA/US@EPA
Date: 01/10/2011 04:12 PM
Subject: Three more for your review (146A, 150A, 154A)

Hi Kevin,

See attached for responses to three of the comments we didn't give you the first time around: 146A, 150A, and 154A. These all relate to impacts to higher trophic level biota.

Thanks,
Matt

[attachment "2011-01-10 146A, 150A, 154A for Kevin.docx" deleted by Marcel Tchaou/DC/USEPA/US]

Matt Klasen
U.S. Environmental Protection Agency
Office of Water (IO)
202-566-0780
cell (202) 380-7229

Christopher Hunter/DC/USEPA/US

01/10/2011 07:40 PM

To Matthew Klasen, Gregory Peck, Kevin Minoli, Karyn Wendelowski

cc

bcc

Subject Meeting notes from consultation

This was the format used in Yazoo, and the simplest one to convert Matt's and my notes. Our notes were very similar, so I'm comfortable with the representation of the meeting, and I've tried to cut some of the duplicative statements, but I would appreciate others reviewing this to see if other changes need to be made.

Thanks,
Chris

ATTACHMENT REDACTED - DELIBERATIVE

Consultation Notes 1-10-11.docx

Chris Hunter
U.S. Environmental Protection Agency
Office of Wetlands, Oceans, & Watershed
(202) 566-1454
hunter.christopher@epa.gov

Matthew Klasen/DC/USEPA/US
01/10/2011 08:44 PM

To Christopher Hunter
cc Gregory Peck, Karyn Wendelowski, Kevin Minoli
bcc
Subject Re: Meeting notes from consultation

Nice work. I identified one area in which the meaning isn't clear (with respect to WQS), but otherwise just made editorial edits (removing contractions, and trying to eliminate the use of "we" for EPA).

Spruce FR notice will follow later tonight for everyone's review. I've let the OW reg and budget folks know the package is coming, as Chris and Greg have seen.

Thanks,
Matt

ATTACHMENT REDACTED - DELIBERATIVE

Consultation Notes 1-10-11 - mk.docx

Matt Klasen
U.S. Environmental Protection Agency
Office of Water (IO)
202-566-0780
cell (202) 380-7229

Christopher Hunter | This was the format used in Yazoo, and the sim... | 01/10/2011 07:40:57 PM

From: Christopher Hunter/DC/USEPA/US
To: Matthew Klasen/DC/USEPA/US@EPA, Gregory Peck/DC/USEPA/US@EPA, Kevin Minoli/DC/USEPA/US@EPA, Karyn Wendelowski/DC/USEPA/US@EPA
Date: 01/10/2011 07:40 PM
Subject: Meeting notes from consultation

This was the format used in Yazoo, and the simplest one to convert Matt's and my notes. Our notes were very similar, so I'm comfortable with the representation of the meeting, and I've tried to cut some of the duplicative statements, but I would appreciate others reviewing this to see if other changes need to be made.

Thanks,
Chris
[attachment "Consultation Notes 1-10-11.docx" deleted by Matthew Klasen/DC/USEPA/US]

Chris Hunter
U.S. Environmental Protection Agency
Office of Wetlands, Oceans, & Watershed
(202) 566-1454
hunter.christopher@epa.gov

Gregory Peck/DC/USEPA/US
01/10/2011 08:50 PM

To Christopher Hunter
cc Karyn Wendelowski, Kevin Minoli, Matthew Klasen
bcc
Subject Re: Meeting notes from consultation

Hey Chris.

You clearly took detailed notes! (b) (5) Deliberative Process and Attorney-Client Privilege [redacted] I've attached some edits - but don't change the basic approach you have proposed here in characterizing the substance of the conversation. The alternative would to provide a more general characterization of the key issues discussed during the meeting?

Thanks for getting this done!

Greg

ATTACHMENT REDACTED - DELIBERATIVE

Consultation Notes 1-10-11 gep edits.docx

Christopher Hunter This was the format used in Yazoo, and the sim... 01/10/2011 07:40:56 PM

From: Christopher Hunter/DC/USEPA/US
To: Matthew Klasen/DC/USEPA/US@EPA, Gregory Peck/DC/USEPA/US@EPA, Kevin Minoli/DC/USEPA/US@EPA, Karyn Wendelowski/DC/USEPA/US@EPA
Date: 01/10/2011 07:40 PM
Subject: Meeting notes from consultation

This was the format used in Yazoo, and the simplest one to convert Matt's and my notes. Our notes were very similar, so I'm comfortable with the representation of the meeting, and I've tried to cut some of the duplicative statements, but I would appreciate others reviewing this to see if other changes need to be made.

Thanks,
Chris
[attachment "Consultation Notes 1-10-11.docx" deleted by Gregory Peck/DC/USEPA/US]

Chris Hunter
U.S. Environmental Protection Agency
Office of Wetlands, Oceans, & Watershed
(202) 566-1454
hunter.christopher@epa.gov

Matthew Klasen/DC/USEPA/US
01/11/2011 08:35 AM

To Beaman.Joe
cc "Betsy Behl", "Cynthia Simbanin", "Jeff Lape", "Lynn Zipf", "Gregory Peck"
bcc
Subject Fw: Response Supplement #67 Selenium - Support for the 4 ppm whole body threshold

Joe: They should be in the Word attachment below. Thanks!

-Matt

Matt Klasen
U.S. Environmental Protection Agency
Office of Water
(202) 566-0780
Cell (202) 380-7229
Matthew Klasen

----- Original Message -----
From: Matthew Klasen
Sent: 01/07/2011 09:14 AM EST
To: Gregory Peck
Subject: Fw: Response Supplement #67 Selenium - Support for the 4 ppm whole body threshold

Greg: Attached are all the questions we need help with from OST. Please also forward along Frank's email below. The critical scientific question for a week has been the Se fish tissue numbers, and we really need that answered from a science perspective.

We have answers for the other two groups of questions (WV criteria/standards; and the aquatic life criteria derivation methodology) but the responses have implications for OST programs. So we really need their review. They drafted many of the responses to the criteria/standards answers but text may have changed.

I'm happy to walk all of this through with someone over there (Lynn?) to make this all make sense. That may be more productive than just sending over.

Thanks,
Matt

ATTACHMENT REDACTED - DELIBERATIVE

2011-01-07 Spruce responses for OST review.docx

Matt Klasen
U.S. Environmental Protection Agency
Office of Water (IO)
202-566-0780
cell (202) 380-7229

----- Forwarded by Matthew Klasen/DC/USEPA/US on 01/07/2011 09:11 AM -----

From: Frank Borsuk/R3/USEPA/US
To: Stefania Shamet/R3/USEPA/US@EPA, John Forren/R3/USEPA/US@EPA, Margaret Passmore/R3/USEPA/US@EPA, borsuk.frank@epa.gov
Cc: Matthew Klasen/DC/USEPA/US@EPA, Christopher Hunter/DC/USEPA/US@EPA, David

Rider/R3/USEPA/US@EPA, David Kargbo/R3/USEPA/US@EPA
Date: 12/29/2010 11:21 AM
Subject: Response Supplement #67 Selenium - Support for the 4 ppm whole body threshold

Stef:

(b) (5)

[redacted]

Hamilton_2003.pdf Peterson et al 2009 selenium.pdf

Hamilton

(b) (5) [redacted]

(b) (5)

[redacted]

Frank Borsuk, Ph.D.
Aquatic/Fisheries Biologist
Freshwater Biology Team
USEPA-Region 3 (Wheeling Office)
Office of Monitoring & Assessment (3EA50)
Environmental Assessment & Innovation Division
1060 Chapline Street, Suite 303
Wheeling, WV 26003-2995
304-234-0241 Phone
304-234-0260 Fax
borsuk.frank@epa.gov

Please visit our website at http://epa.gov/reg3esd1/3ea50.htm

Christopher Hunter/DC/USEPA/US
01/11/2011 08:39 AM

To Matthew Klasen
cc Frank Borsuk, Margaret Passmore, Michael Dunn, Stefania Shamet
bcc
Subject Re: Units -- Re: One more thing that needs running down

I've been replacing them as I find them, but they creep back in. Thanks

Matthew Klasen	We'll do that as a find-and-replace before we fini...	01/11/2011 08:38:54 AM

From: Matthew Klasen/DC/USEPA/US
To: Margaret Passmore/R3/USEPA/US@EPA, Frank Borsuk/R3/USEPA/US@EPA
Cc: Michael Dunn/R3/USEPA/US@EPA, Stefania Shamet/R3/USEPA/US@EPA, "Christopher Hunter" <Hunter.Christopher@epamail.epa.gov>
Date: 01/11/2011 08:38 AM
Subject: Re: Units -- Re: One more thing that needs running down

We'll do that as a find-and-replace before we finish up the responses; thanks!

mk

Matt Klasen
U.S. Environmental Protection Agency
Office of Water
(202) 566-0780
Cell (202) 380-7229

Margaret Passmore

----- Original Message -----
From: Margaret Passmore
Sent: 01/11/2011 08:16 AM EST
To: Frank Borsuk
Cc: Matthew Klasen; Michael Dunn; Stefania Shamet
Subject: Re: Units -- Re: One more thing that needs running down

I see "u" used for the micro symbol all the time.

If you want to use the real micro symbol, you will need to use the insert symbol function in word.

m

Margaret Passmore
Freshwater Biology Team
Office of Monitoring and Assessment (3EA50)
Environmental Assessment and Innovation Division
USEPA Region 3
1060 Chapline Street, Suite 303
Wheeling, WV 26003-2995
(p) 304-234-0245
(f) 304-234-0260
passmore.margaret@epa.gov

Visit our website at http://epa.gov/reg3esd1/3ea50.htm

Frank Borsuk Stef:: It may not be a big issue; however, the unit... 01/11/2011 08:14:25 AM

From: Frank Borsuk/R3/USEPA/US
To: Stefania Shamet/R3/USEPA/US@EPA
Cc: Margaret Passmore/R3/USEPA/US@EPA, Matthew Klasen/DC/USEPA/US@EPA, Michael Dunn/R3/USEPA/US@EPA
Date: 01/11/2011 08:14 AM
Subject: Units -- Re: One more thing that needs running down

Stef::

It may not be a big issue; however, the units are not u in ug/L or ug/g rather these:

µg/L or µg/g

The special symbol
µg/L or µg/g does not translate well in email. It is just a unit issue which may or may not be an issue but the industry likes to point out these things.

Frank

Frank Borsuk, Ph.D.
Aquatic/Fisheries Biologist
Freshwater Biology Team
USEPA-Region 3 (Wheeling Office)
Office of Monitoring & Assessment (3EA50)
Environmental Assessment & Innovation Division
1060 Chapline Street, Suite 303
Wheeling, WV 26003-2995
304-234-0241 Phone
304-234-0260 Fax
borsuk.frank@epa.gov

Please visit our website at http://epa.gov/reg3esd1/3ea50.htm

Stefania Shamet Mike -- Could you run down one last thing? (b) [redacted] 01/11/2011 06:19:59 AM

From: Stefania Shamet/R3/USEPA/US
To: Michael Dunn/R3/USEPA/US@EPA, Frank Borsuk/R3/USEPA/US@EPA
Cc: Matthew Klasen/DC/USEPA/US@EPA, Margaret Passmore/R3/USEPA/US@EPA
Date: 01/11/2011 06:19 AM
Subject: One more thing that needs running down

Mike -- Could you run down one last thing? (b) (5) [redacted]

(b) (5)

(b) (5)

(b)
(5)

[redacted]

[redacted]

(b) (5)

[redacted]

[redacted]

[redacted]

[redacted]

[redacted]

(b) (5)

[redacted]

Matthew Klasen/DC/USEPA/US
01/11/2011 09:59 AM

To Christopher Hunter
cc Karyn Wendelowski
bcc
Subject Fw: Remaining RD comments

Here's what Stef sent this morning. Materials handling is the first response on here (#14A). I know Karyn had discussed that we want a brief "comparison to Dal-Tex" description in the FD, and I think the set of bullets in #14A about the deficiencies in the materials handling plan could be condensed pretty easily.

Thanks,
Matt

Matt Klasen
U.S. Environmental Protection Agency
Office of Water (IO)
202-566-0780
cell (202) 380-7229

----- Forwarded by Matthew Klasen/DC/USEPA/US on 01/11/2011 09:57 AM -----

From: Stefania Shamet/R3/USEPA/US
To: Matthew Klasen/DC/USEPA/US@EPA
Date: 01/11/2011 06:13 AM
Subject: Remaining RD comments

Draft responses attached in these documents. Did NOT use Track Changes uniformly. Did use it where I thought it was important for you to see the change. I responded with my own comments (identified as SDS) in several comment bubbles.

(b) (5) [redacted]

[redacted]

[redacted]

14A20A21A22A24A30A33A49A50A51A52A53A54A.doc revised 74A-end.doc

ATTACHMENTS REDACTED - DELIBERATIVE

Matthew Klasen/DC/USEPA/US
01/11/2011 10:21 AM

To Gregory Peck
cc
bcc
Subject Qs&As

Here they are. I took out the highlighting on the health sections because I think Chris and Denise should be comfortable with the way the health issues are referenced.

Thanks,
Matt

ATTACHMENT REDACTED - DELIBERATIVE

2011-01-11 Draft Spruce Qs&As.doc

Matt Klasen
U.S. Environmental Protection Agency
Office of Water (IO)
202-566-0780
cell (202) 380-7229

Marcel Tchaou/DC/USEPA/US
01/11/2011 10:47 AM

To Stefania Shamet
cc Carrie Traver, Christopher Hunter, Matthew Klasen
bcc
Subject Re: Spruce -- Two more references to check.

Thanks Stefania. I appreciate your reply. I asked the question just for coordination purpose and wanted to make sure you have the most updated document. As of today, attached is the most updated reference list.
Kind Regards

ATTACHMENT REDACTED - DELIBERATIVE

Appendix 7 FD Marcel version 1-10-2011Harmonized.doc

****

Marcel K. Tchaou, Ph.D., P.E., P.H.
Environmental Engineer
Wetlands & Aquatic Resources Regulatory Branch
Office of Wetlands, Oceans and Watersheds
U.S. EPA
1200 Pennsylvania Avenue, NW (MC 4502T)
Washington, DC 20460
202-566-1904

Stefania Shamet | When we receive revised responses to comment... | 01/11/2011 10:40:44 AM

From: Stefania Shamet/R3/USEPA/US
To: Marcel Tchaou/DC/USEPA/US@EPA
Cc: Carrie Traver/R3/USEPA/US@EPA, Christopher Hunter/DC/USEPA/US@EPA, Matthew Klasen/DC/USEPA/US@EPA
Date: 01/11/2011 10:40 AM
Subject: Re: Spruce -- Two more references to check.

When we receive revised responses to comments from the technical staff, they sometimes are including a list of full citations at the end. Where the technical staff uses the abbreviated citation, I assume that means that they've cited that article before. When they list the full citation at the end of the response, I assume that means that the particular staffer has not cited to the article before and believes we have not. Since it's better to err on the side of overinclusion than under, I've been forwarding. Perhaps there's a better way.

Marcel Tchaou | Stefania, I see that since yesterday you've been... | 01/11/2011 09:22:09 AM

From: Marcel Tchaou/DC/USEPA/US
To: Stefania Shamet/R3/USEPA/US@EPA
Cc: Carrie Traver/R3/USEPA/US@EPA, Christopher Hunter/DC/USEPA/US@EPA
Date: 01/11/2011 09:22 AM
Subject: Re: Spruce -- Two more references to check.

Stefania,

I see that since yesterday you've been sending a lots of references that I have already updated last week. Where are you getting these new references? I am asking this for coordination purposes. Thanks

****
Marcel K. Tchaou, Ph.D., P.E., P.H.
Environmental Engineer
Wetlands & Aquatic Resources Regulatory Branch
Office of Wetlands, Oceans and Watersheds
U.S. EPA
1200 Pennsylvania Avenue, NW (MC 4502T)
Washington, DC 20460
202-566-1904

Stefania Shamet	Wiley, J.B., R.D. Evaldi, J.H. Eychaner and D.B....	01/11/2011 05:53:03 AM

From: Stefania Shamet/R3/USEPA/US
To: Marcel Tchaou/DC/USEPA/US@EPA, Carrie Traver/R3/USEPA/US@EPA
Date: 01/11/2011 05:53 AM
Subject: Spruce -- Two more references to check.

Wiley, J.B., R.D. Evaldi, J.H. Eychaner and D.B. Chambers. 2001. Reconnaissance of stream geomorphology, low streamflow, and stream temperature in the mountaintop coal-mining region, southern West Virginia, 1999-2000. Water-Resources Investigations Report 01-4092. U.S. Department of the Interior, U.S. Geological Survey, Charleston, WV.

(Johnson et al. 2010)

Gregory Peck/DC/USEPA/US
01/11/2011 10:48 AM

To Nancy Stoner, Bob Sussman, Betsaida Alcantara, Seth Oster, Arvin Ganesan, David McIntosh, Shawn Garvin, Early.William
cc Travis Loop, Amy Han, Matthew Klasen, Karyn Wendelowski, Christopher Hunter, Kevin Minoli, Stefania Shamet, Denis Borum, Ann Campbell, Jordan Dorfman
bcc
Subject Spruce Communication Materials

Attached please find the final draft of communications materials for Thursday's Spruce announcement. The Q's and A's include both internal and external information. We'll be preparing a seperate document for the web that separates the external Q's and A's for posting. Please let us know if you have any questions.

Best,
Greg

2011-01-11 Draft Spruce Qs&As.doc
Mining Spruce DRAFT Press Release JAN 10 11.docx
Mining Spruce Draft Fact Sheet JAN 10 11.doc

ATTACHMENTS REDACTED - DELIBERATIVE

Christopher Hunter/DC/USEPA/US
01/11/2011 10:51 AM

To Stefania Shamet
cc
bcc
Subject Re: Starting work on FD -- was going to use Karyn's most recent draft. -- You mentioned on the 930 call (I was on for less than 5 minutes) that you had sent a clean draft. I haven't received it. Do you want to send that and I'll work from that, or should I use Karyn's

I misspoke, I actually meant to say "FR" not "FD", but in any case, here is my latest clean version.

Spruce FD 011111 draft clean.docx

ATTACHMENT REDACTED - DELIBERATIVE

Chris Hunter
U.S. Environmental Protection Agency
Office of Wetlands, Oceans, & Watershed
(202) 566-1454
hunter.christopher@epa.gov

Stefania Shamet 01/11/2011 10:46:41 AM

From: Stefania Shamet/R3/USEPA/US
To: Christopher Hunter/DC/USEPA/US@EPA
Date: 01/11/2011 10:46 AM
Subject: Starting work on FD -- was going to use Karyn's most recent draft. -- You mentioned on the 930 call (I was on for less than 5 minutes) that you had sent a clean draft. I haven't received it. Do you want to send that and I'll work from that, or should I use Karyn's

Christopher Hunter/DC/USEPA/US
01/11/2011 10:59 AM

To Karyn Wendelowski
cc Gregory Peck, Kevin Minoli, Matthew Klasen
bcc
Subject Re: Draft FR notice on Spruce

and my few edits to the FR draft.

ATTACHMENT REDACTED - DELIBERATIVE

2011-01-10 Draft FD FR Notice - CH.docx

Chris Hunter
U.S. Environmental Protection Agency
Office of Wetlands, Oceans, & Watershed
(202) 566-1454
hunter.christopher@epa.gov

Karyn Wendelowski | a few edits: | 01/11/2011 10:29:05 AM

From: Karyn Wendelowski/DC/USEPA/US
To: Matthew Klasen/DC/USEPA/US@EPA
Cc: Christopher Hunter/DC/USEPA/US@EPA, Gregory Peck/DC/USEPA/US@EPA, Kevin Minoli/DC/USEPA/US@EPA
Date: 01/11/2011 10:29 AM
Subject: Re: Draft FR notice on Spruce

a few edits:

[attachment "2011-01-10 Draft FD FR Notice kw edits.docx" deleted by Christopher Hunter/DC/USEPA/US]

Matthew Klasen | Hey team, See attached for a draft FR notice on... | 01/11/2011 01:07:03 AM

From: Matthew Klasen/DC/USEPA/US
To: Gregory Peck/DC/USEPA/US@EPA, Christopher Hunter/DC/USEPA/US@EPA, Karyn Wendelowski/DC/USEPA/US@EPA, Kevin Minoli/DC/USEPA/US@EPA
Date: 01/11/2011 01:07 AM
Subject: Draft FR notice on Spruce

Hey team,

See attached for a draft FR notice on Spruce. Not wanting to distract Stef from the important FD and RTC work she's engaged in, I thought she could jump in a bit later in the review process rather than right now.

Attached is a first shot at a notice. A few thoughts:

- (b) (5) [redacted]
- [redacted]
- [redacted]
- [redacted]

(b) (5) [redacted]

Let me know your thoughts when you get around to taking a look. I'm thinking that if we have a good draft by COB today (Tuesday), we'll be in a good spot to get this ready for Pete on Wednesday afternoon. In the meantime, I'll be working up the paperwork.

(b) (6) [redacted]

Thanks,
Matt

Matt Klasen
U.S. Environmental Protection Agency
Office of Water (IO)
202-566-0780
cell (202) 380-7229[attachment "2011-01-10 Draft FD FR Notice.docx" deleted by Karyn Wendelowski/DC/USEPA/US]

Matthew Klasen/DC/USEPA/US
01/11/2011 12:40 PM

To Stefania Shamet
cc
bcc
Subject 51A, 52A

Here are the two I still think need something. Call me when you have a chance to take a look.

Thanks,
Matt

(b) (5) [redacted]

51A 52A.docx

ATTACHMENT REDACTED - DELIBERATIVE

Matt Klasen
U.S. Environmental Protection Agency
Office of Water (IO)
202-566-0780
cell (202) 380-7229

Matthew Klasen/DC/USEPA/US
01/11/2011 01:17 PM

To Kevin Minoli, Karyn Wendelowski
cc
bcc
Subject Quick OGC review of PD 156

Karyn or Kevin:

In response to a comment from Stef, can you take a look at the Track Changes response to PD 156 (attached)? Kevin had reviewed the remainder but Stef had an additional comment.

Thanks,
Matt

PD 156 for OGC.docx

ATTACHMENT REDACTED - DELIBERATIVE

Matt Klasen
U.S. Environmental Protection Agency
Office of Water (IO)
202-566-0780
cell (202) 380-7229

Gregory Peck/DC/USEPA/US
01/11/2011 01:28 PM

To Matthew Klasen, Christopher Hunter, Karyn Wendelowski, Kevin Minoli, Stefania Shamet
cc
bcc
Subject Spruce Consultation Summary

Chris - can you send me the list of participants or insert it in the attached summary. Let me know if you all have comments.

Thanks,
Greg

ATTACHMENT REDACTED - DELIBERATIVE

Mining Spruce Consultation Summary JAN 11 11.docx

Matthew Klasen/DC/USEPA/US
01/11/2011 01:31 AM

To Kevin Minoli, Karyn Wendelowski
cc Christopher Hunter
bcc
Subject Help w/ legal issue on PD comments (#154)

Kevin and Karyn,

(b) (5) Deliberative Process and Attorney-Client Privilege [redacted]

[redacted]

Thanks,
Matt

Matt Klasen
U.S. Environmental Protection Agency
Office of Water (IO)
202-566-0780
cell (202) 380-7229

ATTACHMENT REDACTED - DELIBERATIVE

- 2011-01-11 PD #154 for OGC.docx

Matthew Klasen/DC/USEPA/US
01/11/2011 01:55 PM

To Christopher Hunter
cc
bcc
Subject PD comment triage

All should be dealt with other than 29, which Stef will work on tonight. I'll give you a call in a sec with an update.

Thanks,
Matt

ATTACHMENT REDACTED - DELIBERATIVE

2011-01-11 PD Comment Triage.xlsx

Matt Klasen
U.S. Environmental Protection Agency
Office of Water (IO)
202-566-0780
cell (202) 380-7229

Christopher Hunter/DC/USEPA/US
01/11/2011 01:57 PM

To Karyn Wendelowski
cc
bcc
Subject Re: FD

Clean and pretty and hopefully accurate.

Spruce FD 011111 clean.docx

ATTACHMENT REDACTED - DELIBERATIVE

Chris Hunter
U.S. Environmental Protection Agency
Office of Wetlands, Oceans, & Watershed
(202) 566-1454
hunter.christopher@epa.gov

Karyn Wendelowski	Hi Chris - I have to leave the office early today,...	01/11/2011 10:09:38 AM

From: Karyn Wendelowski/DC/USEPA/US
To: Christopher Hunter/DC/USEPA/US@EPA
Date: 01/11/2011 10:09 AM
Subject: FD

Hi Chris - I have to leave the office early today, but I like to review things in hard copy rather than on screen, so could you send me the FD at whatever stage it's in at 2:00 so I can print it out? You can email the completely polished version (including whenever we get Stef's selenium edits) tonight and I'll provide comments on that version, so we won't have a version control problem.

Thanks - Karyn

Kevin Minoli/DC/USEPA/US
01/11/2011 01:59 PM

To Matthew Klasen
cc
bcc
Subject 146

Here are a few edits to make it clearer.

ATTACHMENT REDACTED - DELIBERATIVE

2011-01-10 146A, 150A, 154A for Kevin.ksm.docx

Travis Loop
<tloop@chesapeakebay.net>
01/11/2011 02:28 PM

To Gregory Peck, Matthew Klasen
cc
bcc
Subject FW: Spruce Communication Materials

3 attachments

2011-01-11 Draft Spruce Qs&As.doc Mining Spruce DRAFT Press Release JAN 10 11.docx

ATTACHMENTS REDACTED - DELIBERATIVE

Mining Spruce Draft Fact Sheet JAN 10 11.doc

Greg and Matt

I sent an email yesterday morning around 9 with suggested edits to the press release, but I see that none of them were incorporated. Did you not receive the email or decide against the edits? Thanks for clarifying.

Travis Loop
Office of Water
U.S. Environmental Protection Agency
office: 202.564.0183
cell: 443.510.1571

-----Original Message-----
From: Peck.Gregory@epamail.epa.gov [mailto:Peck.Gregory@epamail.epa.gov]
Sent: Tuesday, January 11, 2011 10:48 AM
To: Stoner.Nancy@epamail.epa.gov; Sussman.Bob@epamail.epa.gov; Alcantara.Betsaida@epamail.epa.gov; Oster.Seth@epamail.epa.gov; Ganesan.Arvin@epamail.epa.gov; McIntosh.David@epamail.epa.gov; Garvin.Shawn@epamail.epa.gov; Early.William@epamail.epa.gov
Cc: Loop.Travis@epamail.epa.gov; Han.Amy@epamail.epa.gov; Klasen.Matthew@epamail.epa.gov; wendelowski.karyn@epamail.epa.gov; Hunter.Christopher@epamail.epa.gov; Minoli.Kevin@epamail.epa.gov; Shamet.Stefania@epamail.epa.gov; Borum.Denis@epamail.epa.gov; Campbell.Ann@epamail.epa.gov; Dorfman.Jordan@epamail.epa.gov
Subject: Spruce Communication Materials

Attached please find the final draft of communications materials for Thursday's Spruce announcement. The Q's and A's include both internal and external information. We'll be preparing a seperate document for the web that separates the external Q's and A's for posting. Please let us know if you have any questions.

Best,
Greg

(See attached file: 2011-01-11 Draft Spruce Qs&As.doc) (See attached file: Mining Spruce DRAFT Press Release JAN 10 11.docx) (See attached file: Mining Spruce Draft Fact Sheet JAN 10 11.doc)

Matthew Klasen/DC/USEPA/US
01/11/2011 02:40 PM

To Sandy Evalenko
cc
bcc
Subject Re: Spruce Final Determination FR notice

Hi Sandy,

This still needs a bit more review here in the IO and with Region 3, but can you take a look at the attached FR notice and see if you see any major issues?

Thanks,
Matt

ATTACHMENT REDACTED - DELIBERATIVE

2011-01-11 Draft FD FR Notice.docx

Matt Klasen
U.S. Environmental Protection Agency
Office of Water (IO)
202-566-0780
cell (202) 380-7229

Matthew Klasen	Hi Sandy, Pete is expected to sign the Final Det...	01/10/2011 08:05:31 PM

From: Matthew Klasen/DC/USEPA/US
To: Sandy Evalenko/DC/USEPA/US@EPA
Cc: Gregory Peck/DC/USEPA/US@EPA, Christopher Hunter/DC/USEPA/US@EPA, Macara Lousberg/DC/USEPA/US@EPA
Date: 01/10/2011 08:05 PM
Subject: Spruce Final Determination FR notice

Hi Sandy,

Pete is expected to sign the Final Determination on the Spruce No. 1 Mine this Wednesday evening. Concurrently with his signature on the Final Determination, we'd like him to also sign a Federal Register notice, which we would then deliver to OP first thing Thursday for getting to OFR that day, and publication early next week.

I'm familiar with the FR paperwork from the past couple times around the block, so I'll be working to pull everything together tomorrow. I'm planning to put together a draft notice tonight, which folks will be reviewing tomorrow (OWOW, OW, and OGC). I'll work with Lori to get the funding piece squared away.

Just wanted to give you a heads up so that you're aware, and so that you can alert OP. I'll be in touch tomorrow with the paperwork; I know we had a question last time of whether you could act as the "Federal Register designee," but you seemed to fill that role quite well last time. (However, let me know if I should target anyone else signing the typesetting request reform other than Greg (Requesting Officer) and you (FR designee).

Thanks,
Matt

Matt Klasen

U.S. Environmental Protection Agency
Office of Water (IO)
202-566-0780
cell (202) 380-7229

Matthew Klasen/DC/USEPA/US
01/11/2011 03:57 PM

To Christopher Hunter
cc
bcc
Subject RD comments

Here are the current drafts. I'll start walking over in a minute and I'll stop by your desk.

mk

2011-01-11 Compiled WVDEP and Corps RD Comment Responses.doc

2011-01-11 Compiled H&W RD Comment Responses.docx

ATTACHMENT REDACTED - DELIBERATIVE

Matt Klasen
U.S. Environmental Protection Agency
Office of Water (IO)
202-566-0780
cell (202) 380-7229

Matthew Klasen/DC/USEPA/US
01/11/2011 04:16 PM

To "Lynn Zipf"
cc
bcc
Subject Fw: Updated draft Spruce Se response (comment #67A)

Matt Klasen
U.S. Environmental Protection Agency
Office of Water
(202) 566-0780
Cell (202) 380-7229
Matthew Klasen

----- Original Message -----
From: Matthew Klasen
Sent: 01/10/2011 01:06 PM EST
To: Betsy Behl; Joe Beaman
Cc: Stefania Shamet; Christopher Hunter; Frank Borsuk; Gregory Peck; Karyn Wendelowski; Margaret Passmore
Subject: Updated draft Spruce Se response (comment #67A)

Betsy and Joe:

Thanks again for your help in our efforts on Spruce. (b) (5) [redacted]

[redacted]

[redacted]

Let me know your thoughts on this when you get a chance. We'll follow up with revised paragraphs of the Final Determination tomorrow morning, which will reflect the discussion this morning and any edits you provide to this response. Let me know if you have any questions, and thanks again!

Thanks,
Matt

ATTACHMENT REDACTED - DELIBERATIVE

2011-01-10 Spruce Se Response (67A).docx

Matt Klasen
U.S. Environmental Protection Agency
Office of Water (IO)
202-566-0780
cell (202) 380-7229

Christopher Hunter/DC/USEPA/US
01/11/2011 05:53 PM

To Stefania Shamet
cc
bcc
Subject Language on WVSCI @ 72

Might have to change the table in Appendix 2, but otherwise, seems alright to me. Please see what you think.

Thanks

ATTACHMENT REDACTED - DELIBERATIVE

WVSCI threshold language.docx

Chris Hunter
U.S. Environmental Protection Agency
Office of Wetlands, Oceans, & Watershed
(202) 566-1454
hunter.christopher@epa.gov

Gregory Peck/DC/USEPA/US
01/11/2011 06:14 PM

To "Kevin Minoli"
cc
bcc
Subject Fw: Spruce press release

Gregory E. Peck
Chief of Staff
Office of Water
U.S. E.P.A.
Betsaida Alcantara

----- Original Message -----
From: Betsaida Alcantara
Sent: 01/11/2011 06:11 PM EST
To: Arvin Ganesan; Bob Sussman; Gregory Peck; Nancy Stoner
Cc: Jordan Dorfman; Travis Loop <tloop@chesapeakebay.net>
Subject: Spruce press release

Here;s the press release with my edits and the factsheet. Bob, if you can take a look, that'd be great. I'll send over the internal qs and as and external qs and as tomorrow.

factsheet.doc press release.docx

ATTACHMENTS REDACTED - DELIBERATIVE

Matthew Klasen/DC/USEPA/US
01/11/2011 06:19 PM

To Gregory Peck, Karyn Wendelowski, Kevin Minoli, Christopher Hunter, Stefania Shamet, Brian Frazer
cc Macara Lousberg, Sandy Evalenko, Denise Keehner, David Evans, Tanya Code
bcc

Subject Updated draft Spruce FR notice -- comments by 10 am tomorrow

Hi everyone,

See attached below for a draft FR notice on Spruce. We began coordination on this draft notice last night, and I've received and incorporated comments from Chris and Karyn so far.

The plan is to have Pete sign this concurrently with the FD tomorrow afternoon. Because this overlaps significantly with the text of the executive summary, I don't expect the content here to be a surprise to anyone.

Please send me any comments by **10 am tomorrow** so we can get the package ready by mid-afternoon tomorrow for Pete's signature, concurrently with the Final Determination.

Thanks,
Matt

ATTACHMENT REDACTED - DELIBERATIVE

2011-01-11 Draft Spruce FD FR Notice.docx

Matt Klasen
U.S. Environmental Protection Agency
Office of Water (IO)
202-566-0780
cell (202) 380-7229

Matthew Klasen/DC/USEPA/US
01/11/2011 06:50 PM

To Gregory Peck
cc
bcc
Subject Fw: Response Supplement #67 Selenium - Support for the 4 ppm whole body threshold

(b) (5) [redacted]

Matt Klasen
U.S. Environmental Protection Agency
Office of Water (IO)
202-566-0780
cell (202) 380-7229
----- Forwarded by Matthew Klasen/DC/USEPA/US on 01/11/2011 06:49 PM -----

From: Betsy Behl/DC/USEPA/US
To: Gregory Peck/DC/USEPA/US@EPA
Cc: Ephraim King/DC/USEPA/US@EPA, stoner.nancy@epa.gov, Matthew Klasen/DC/USEPA/US@EPA, Joe Beaman/DC/USEPA/US@EPA
Date: 01/11/2011 06:30 PM
Subject: Fw: Response Supplement #67 Selenium - Support for the 4 ppm whole body threshold

Greg: I will get together first thing in the morning with Joe and Charlie to include some summary of Seng Creek, if possible. I need to touch base with the m quickly re the conductivity responses, as this is the first I have seen them. Will do my best to respond early tomorrow.
Betsy
----- Forwarded by Betsy Behl/DC/USEPA/US on 01/11/2011 06:28 PM -----

From: Lynn Zipf/DC/USEPA/US
To: Betsy Behl/DC/USEPA/US@EPA
Cc: Cynthia Simbanin/DC/USEPA/US@EPA
Date: 01/07/2011 03:30 PM
Subject: Fw: Response Supplement #67 Selenium - Support for the 4 ppm whole body threshold

Can you please coordinate with Greg?

_____
Lynn Zipf
Special Assistant
Office of Science and Technology
Office of Water

P: (202) 564-1509

Gregory Peck

----- Original Message -----
From: Gregory Peck
Sent: 01/07/2011 09:26 AM EST
To: Lynn Zipf
Cc: Ephraim King; Matthew Klasen; Nancy Stoner
Subject: Fw: Response Supplement #67 Selenium - Support for the 4 ppm whole body threshold

Hey Lynn:

I know how busy folks are - (b) (5) [redacted] Please call me if you have any questions.

Best,
Greg
----- Forwarded by Gregory Peck/DC/USEPA/US on 01/07/2011 09:22 AM -----

From:	Matthew Klasen/DC/USEPA/US
To:	Gregory Peck/DC/USEPA/US@EPA
Date:	01/07/2011 09:14 AM
Subject:	Fw: Response Supplement #67 Selenium - Support for the 4 ppm whole body threshold

Greg: Attached are all the questions we need help with from OST. Please also forward along Frank's email below. (b) (5) [redacted]

I'm happy to walk all of this through with someone over there (Lynn?) to make this all make sense. That may be more productive than just sending over.

Thanks,
Matt

[attachment "2011-01-07 Spruce responses for OST review.docx" deleted by Betsy Behl/DC/USEPA/US]

Matt Klasen
U.S. Environmental Protection Agency
Office of Water (IO)
202-566-0780
cell (202) 380-7229
----- Forwarded by Matthew Klasen/DC/USEPA/US on 01/07/2011 09:11 AM -----

From:	Frank Borsuk/R3/USEPA/US
To:	Stefania Shamet/R3/USEPA/US@EPA, John Forren/R3/USEPA/US@EPA, Margaret Passmore/R3/USEPA/US@EPA, borsuk.frank@epa.gov
Cc:	Matthew Klasen/DC/USEPA/US@EPA, Christopher Hunter/DC/USEPA/US@EPA, David Rider/R3/USEPA/US@EPA, David Kargbo/R3/USEPA/US@EPA
Date:	12/29/2010 11:21 AM
Subject:	Response Supplement #67 Selenium - Support for the 4 ppm whole body threshold

Stef:

(b) (5) [redacted]

(b) (5)

(b) (5) [redacted]

[redacted]

Frank Borsuk, Ph.D.
Aquatic/Fisheries Biologist
Freshwater Biology Team
USEPA-Region 3 (Wheeling Office)
Office of Monitoring & Assessment (3EA50)
Environmental Assessment & Innovation Division
1060 Chapline Street, Suite 303
Wheeling, WV 26003-2995
304-234-0241 Phone
304-234-0260 Fax
borsuk.frank@epa.gov

Please visit our website at http://epa.gov/reg3esd1/3ea50.htm

Jaclyn McIlwain/R3/USEPA/US
01/11/2011 06:51 PM

To Evelyn MacKnight
cc Bette Conway, Brian Trulear, Mark Smith, Peter Weber
bcc
Subject Re: Fw: Preparing for DRA Session Before January SEM Meeting - Lots of info needed on permit objections - Action needed

Hello Everyone!

(b) (5) [redacted]

[redacted]

If you have any suggestions (formatting or otherwise) please let me know.

ATTACHMENT REDACTED - DELIBERATIVE

Region X objections to state NPDES permits.docx

Thanks!

Jaclyn McIlwain
NPDES Permits Branch (3WP41)
Water Protection Division
U.S. EPA Region III
1650 Arch Street
Philadelphia, PA 19103

Ph: 215.814.2713
Fax: 215.814.2302
mcilwain.jaclyn@epa.gov

Evelyn MacKnight (b) (5) [redacted] 01/04/2011 06:35:57 PM

From: Evelyn MacKnight/R3/USEPA/US
To: Brian Trulear/R3/USEPA/US@EPA, Peter Weber/R3/USEPA/US@EPA, Mark Smith/R3/USEPA/US@EPA, Bette Conway/R3/USEPA/US@EPA, Jaclyn Mcilwain/R3/USEPA/US@EPA
Cc: Linda Boornazian/DC/USEPA/US@EPA, Francisco Cruz/R3/USEPA/US@EPA
Date: 01/04/2011 06:35 PM
Subject: Fw: Preparing for DRA Session Before January SEM Meeting - Lots of info needed on permit objections - Action needed

(b) (5) [redacted] We can talk tomorrow.

Evelyn S. MacKnight
Chief, NPDES Permits Branch (3WP41)
Water Protection Division
Phone: 215-814-5717

Fax: 215-814-2301
email: macknight.evelyn@epa.gov
----- Forwarded by Evelyn MacKnight/R3/USEPA/US on 01/04/2011 06:32 PM -----

From:	William Early/R3/USEPA/US
To:	Jon Capacasa/R3/USEPA/US@EPA, Linda Miller/R3/USEPA/US@EPA, Linda Boornazian/R3/USEPA/US@EPA, Evelyn MacKnight/R3/USEPA/US@EPA
Cc:	Amy Caprio/R3/USEPA/US@EPA
Date:	01/04/2011 01:50 PM
Subject:	Fw: Preparing for DRA Session Before January SEM Meeting

(b) (5) [redacted] I would appreciate your reviewing the questions and providing responses by January 13. This will enable me to review the responses prior to forwarding them on Jan. 14.

Thanks for your help.

bill e.

William C. Early
Deputy Regional Administrator
Middle Atlantic Region
U. S. Environmental Protection Agency
215 814 2626
215 814 2901 (Fax)
Early.William@epa.gov
----- Forwarded by William Early/R3/USEPA/US on 01/04/2011 01:44 PM -----

From:	Andrew Anderson/R5/USEPA/US
To:	DRA
Cc:	Alan Walts/R5/USEPA/US@EPA, Morgan Jencius/R5/USEPA/US@EPA, Roger Janson/R1/USEPA/US@EPA, DRA Assistants
Date:	12/30/2010 01:40 PM
Subject:	Preparing for DRA Session Before January SEM Meeting

I am sending out the message below on behalf of Alan Walts and Morgan Jencius.

****
DRAs:

This email is a follow up to the 12/23 email below. If you have not already responded, please let us know if you plan to attend this session and if the proposed time frame works for you.

(b) (5) [redacted]

[redacted]

(b) (5) [redacted]

ATTACHMENT REDACTED - DELIBERATIVE

Region X objections to state NPDES permits.docx

(b) (5) [redacted]

[redacted]

ATTACHMENT REDACTED - DELIBERATIVE

CWA Action Plan Administrator Briefing 11-22-2010 am draft.pptx

Clean Water Act Action Plan Interim Guidance:

ATTACHMENT REDACTED - DELIBERATIVE

June 22 Memo re Interim Guidance for CWA Action Plan.pdf Interim Guidance on CWA Action Plan 6-15-10.docx

Clean Water Act Action Plan:

CWA Action Plan 10-15-2009.pdf

==========

From: Alan Walts/R5/USEPA/US

To: DRA

Cc: Morgan Jencius/R5/USEPA/US@EPA, DRA Assistants

Date: 12/23/2010 03:23 PM

Subject: DRA Session on January 25, 2011 (evening before Senior Enforcement Managers Meeting in New Orleans)

(b) (5)

[redacted]

(b) (5)

Alan Walts
Director, Office of Enforcement and Compliance Assurance (OECA)
U.S. EPA, Region 5
77 W. Jackson Blvd, Chicago, IL 60604
Phone: (312) 353-8894
Fax: (312) 582-5151

UNITED STATES ENVIRONMENTAL PROTECTION AGENCY
WASHINGTON, D.C. 20460

JUN 22 2010

MEMORANDUM

SUBJECT: Interim Guidance to Strengthen Performance in the NPDES Program

FROM: Cynthia Giles
Office of Enforcement and Compliance Assurance

Peter Silva
Office of Water

TO: Regional Administrators
Deputy Regional Administrators
Regional Enforcement Directors
Regional Enforcement Coordinators
Regional Water Division Directors

This memorandum is to initiate actions outlined in the Clean Water Act (CWA) Action Plan aimed to focus our NPDES planning and resources on the most significant sources of water quality impairment and ensure consistent enforcement across states that maintains a fair and level playing field for the regulated community and all Americans.

The Office of Enforcement and Compliance Assurance and the Office of Water together are asking the regions to work with each of their states partners to identify water quality priorities at the national, regional and state level and to use those priorities to guide the investment of our limited resources toward addressing the most significant water quality problems and the most serious violations. Where states are experiencing significant resource reductions, regions and states should engage in discussions about how to get the most important work done by exploring work-sharing and other creative approaches. Planning should include data analysis and targeting efforts, and address opportunities for improvement identified in permit and enforcement reviews.

This memorandum also directs the regions to work with states to resolve long-standing issues that create barriers to implementing significant aspects of the NPDES permit program or to identifying serious violations and taking appropriate enforcement actions sufficient to achieve compliance, deter others from violating the law, and making

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it more expensive to violate the law than to comply. This may include where a state has not regularly taken actions to protect water quality, where a state program has not taken action in particular regulated sectors that have a significant impact on water quality, or where a permit quality or enforcement program review has identified significant issues that a state has not taken steps to remedy that affects their ability to maintain the integrity of the NPDES program. These actions would be taken in addition to regularly occurring oversight activities.

The goal is to emphasize the value of deterrence and to establish a minimal national consistency by taking actions across the country so that no one state is singled out. It is not about states that are struggling now due to budget constraints but that otherwise run a credible program. Regions are asked to focus oversight resources to the most pressing performance problems in states. Actions taken to address the performance issues should work toward the goal of demonstrably improving state performance.

These steps from the CWA Action Plan are among the first to be implemented, hence the title "Interim Guidance." As the new approaches being explored under the Action Plan are developed, additional changes to our oversight of state programs may be needed. These steps are directed at improving our overall protection of the environment and the public, and will start us on the path toward fulfilling the vision of the Action Plan for FY2011 and beyond.

US Environmental Protection Agency

Office of Enforcement and Compliance Assurance (OECA)

Clean Water Act Action Plan

(Prior to February 22, 2010, known as the Clean Water Act Enforcement Action Plan)

October 15, 2009

Clean Water Act Enforcement Action Plan

EXECUTIVE SUMMARY

Despite progress reducing water pollution from the largest sources, our country still faces serious pollution challenges. Violations are still too widespread, and enforcement too uneven. We need to do better controlling pollution from large pipes, while we develop new strategies to address water quality threats from other sources. To follow through on the commitment of this Administration to clean and safe water, the Environmental Protection Agency (EPA) is revamping enforcement of clean water laws.

Target enforcement to the most important water pollution problems

Over the last 30 years, water enforcement focused mostly on pollution from the biggest individual sources, such as factories and sewage treatment plants. Now we face different challenges. The regulated universe has expanded from the roughly 100,000 traditional point sources to nearly one million far more dispersed sources such as animal feeding operations and storm water runoff. Many of the nation's waters are not meeting water quality standards, and the threat to drinking water sources is growing. To address these challenges, we must revamp federal and state enforcement to tackle sources posing the biggest threats to water quality while we intensify vigorous civil and criminal enforcement against traditional end-of-pipe pollution.

Strengthen oversight of the states

EPA is responsible for assuring that the protections of the Clean Water Act extend to all citizens. Many states have strong water quality protection and enforcement programs, but state compliance and enforcement vigor is uneven. Without consistent enforcement by EPA and states, there exists an unlevel playing field for businesses that do comply with the law, and also for our citizens who are not provided equal protection under our environmental legal framework. States labor under different political and resource constraints; nonetheless, EPA must ensure that states protect water quality and consistently apply the law by issuing protective permits and by pursuing vigorous enforcement. EPA must clearly articulate where the bar is for acceptable state programs, and consistently hold states – and EPA where it implements the law – accountable. Where states are not meeting these expectations, EPA needs to strengthen water quality protection by disapproving permits that are not protective and by pursuing federal enforcement against serious violators.

Improve transparency and accountability

The American public has a right to know what the threats are to water quality, where violations are occurring, and what we are doing about them. Moreover, the vastly increased and dispersed numbers of pollution sources require us to target enforcement to the biggest problems. We can work towards both goals by requiring reports to be submitted electronically. Using 21st century technologies will free up time to tackle pollution problems. At the same time, we can provide more complete, accurate and timely information to both regulators and the public, enlisting an informed public as a powerful ally to press for stronger performance and accountability from the regulated community.

Clean Water Act Enforcement Action Plan

October 15, 2009

Introduction

On July 2, 2009, EPA Administrator Jackson charged the Office of Enforcement and Compliance Assurance (OECA) with revamping the clean water enforcement program to ensure it is protecting and defending our nation's waters. She asked OECA to raise the bar of federal and state enforcement performance, to inform the public clearly and fully about serious Clean Water Act violations and actions to address them, and to use 21st Century technology to transform the collection, use, and availability of EPA data. This Action Plan describes the challenges we face as a nation in improving our enforcement efforts to improve water quality and describes the actions we will take to overcome them.

I. Clean Water Act Water Quality and Enforcement Challenges

Much has changed concerning the state of water quality and water pollution control in the United States since the passage of the Clean Water Act (CWA) 37 years ago. While EPA and states have made notable improvements to water quality, challenges remain as we strive to meet the CWA's goal of providing fishable and swimmable waters and protecting the sources of our nation's drinking water. There are significant water quality problems facing too many communities; there are expanding universes of diffuse pollution sources, many which are not effectively regulated by the CWA; and there are significant limitations that affect EPA's ability to identify serious problems quickly and take prompt action to correct them. Among these limitations are two Supreme Court decisions – its 2001 decision in *Solid Waste Agcy. of Northern Cook Cty. v. United States Army Corps of Engineers*, 531 U.S. 159 (2001) ("*SWANCC*") and its 2006 decision in *Rapanos v. United States*, 547 U.S. 715 (2006) ("*Rapanos*") – that added layers of confusion regarding which water bodies are covered by the CWA in many parts of the country.

Our portfolio of water pollution threats has evolved from the very visible pipes coming out of factories and sewage treatment plants into rivers and lakes to the hundreds of thousands of sources of industrial and municipal storm water runoff, agricultural runoff, mining wastes and sewage spills from aging sewer system infrastructure. Some of these sources of contaminated runoff are known as point sources and are regulated by the National Pollutant Discharge Elimination System (NPDES) permit program, including concentrated animal feeding operations (CAFOs), industrial sites (including construction sites) and municipal separate storm sewer systems (MS4s). Many others are known as non-point sources and are not regulated by the CWA. These sources, such as suburban storm water or agricultural farm runoff, require new and innovative approaches to reduce their impacts on water quality. The sheer magnitude of the expanding universe of the NPDES program itself, from roughly 100,000 traditional point sources to nearly a million sources – 95 percent of which are covered by general permits – presents challenges in how we regulate and enforce the laws of this country.

National information on significant segments of the NPDES regulated universe, their violations, their specific impacts to local water bodies, and states' compliance and enforcement efforts is seriously deficient. States conduct monitoring to identify which waters are passing or failing state water quality standards, and the causes and sources of impairments, and report this information biennially to EPA under Section 305(b) and 303(d) of the Clean Water Act. Only 16 percent of the nation's river and stream miles, 39 percent of its lake and reservoir acres, and 29 percent of its bay and estuarine square miles have been monitored, according to the most recent state-reported assessment findings from 2004. This means we don't know the quality of the vast majority of the nation's waters. Those limited assessments show that 44 percent, 64 percent, and 30 percent respectively were impaired, meaning they were not clean enough to support their designated uses, such as swimming or fishing. EPA and states are also encountering significant impacts to sources of drinking water in many parts of the country due to contamination from many of these same dischargers (such as CAFOs) to surface waters. This is significant, as approximately 66 percent of the U.S. gets its drinking water from surface water sources. Thus, pollution in rivers and streams can make it harder for drinking water suppliers to meet standards for safe drinking water.

EPA established the NPDES program after the enactment of the CWA in 1972 to control discharges by establishing permits with discharge limits protective of water quality standards, and enforcing against those permits. With only a few exceptions, EPA has authorized states to implement and enforce these programs across the country.[1] EPA retains independent enforcement authority in authorized states and has responsibility to ensure that state programs are nationally consistent in writing quality permits and enforcing them. To secure the public health and environmental benefits of our regulations, enforcement programs must consistently apply the law and pursue vigorous, effective and fair actions to address violations and to protect water quality. Effective enforcement programs create incentives for compliance by penalizing those who do not follow the law. They establish a level playing field between those members of the regulated community who comply and those who do not. Enforcement ensures fair treatment – companies that compete against each other should not face wide disparities in treatment across the country, such as mandatory minimum penalties for a violation in one state and no enforcement in another. Ultimately, enforcement is critical to ensure that the public receives the services and protections promised by our laws. Unfortunately, data shows us that we are not getting the compliance envisioned by our laws to protect clean water. While many states have strong NPDES programs, EPA needs to take prompt actions where a state is not acting to issue protective permits or taking effective enforcement. EPA's goal in taking these actions is to ensure equal protection, to strengthen those state programs, and hold states accountable for needed improvements.

EPA's oversight of state NPDES programs has focused primarily on how well states are addressing the largest direct discharge facilities that have continuing problems. EPA has fairly complete information about these biggest facilities, as the facilities are required to submit monthly reports of their compliance with their permit limits in submissions called Discharge Monitoring Reports (DMRs). These reports, along with other information about these facilities and the actions that states take to ensure their compliance, are required to be reported by states to

[1] A list of the status of state authorization for the NPDES program can be found at: http://cfpub2.epa.gov/npdes/statestats.cfm.

EPA data systems. Even with this focus, the rate of significant noncompliance at these facilities is approximately 24 percent, meaning that one out of every four had significant violations. Significant noncompliance (SNC) describes violations that are considered to be more serious and significant to water quality, although the term only applies to the largest facilities under EPA's current policy. So, while many serious violations by smaller facilities or other point sources are not included in the term, it does provide some insight into the serious nature of violations at the largest facilities.

Most SNC is related to illegal or unpermitted discharges to the environment. Of facilities designated in SNC in 2008, 46 percent were due to effluent violations – or exceedances for multiple months of their permit limits, which were set to be protective of water quality. Eleven per cent of the 2008 SNC were due to violations of a compliance order and thus related to exceedances of their permit limits as well. Forty-one per cent of the facilities were in SNC because EPA had not received the required discharge monitoring data. This means that EPA lacked critical information on whether these facilities were complying with their limits. Some of these facilities may have submitted their DMRs in a timely manner to the state, but the state did not provide these data to EPA as required. Reporting violations are important as they are the only indicator of the compliance level of a facility with its permit. If a facility isn't reporting, we don't know whether it is violating its permit limits.

Enforcement across states in responding to SNC violations is another important gauge of performance. Both the Permitting for Environmental Results and the State Review Framework found that enforcement levels across states varied considerably. Some states rarely take enforcement action against facilities in significant noncompliance, while other states do pursue timely and appropriate formal enforcement actions. Still, state and EPA data indicate that formal enforcement action was taken against only approximately 26 percent of the facilities in SNC in 2008.

For smaller facilities that submit DMRs, EPA has not required the same focus from states and has not required states to submit data about these facilities to EPA. EPA does not, therefore, have a national rate for significant noncompliance for these facilities. However, 28 states (and 4 territories and the District of Columbia) have entered some of these data into the national system, and these data show a rate of serious noncompliance at these facilities of around 45 percent; states report taking enforcement action against less than six percent of these facilities with a serious noncompliance problem. As with the larger facilities, there is significant variability across states, with some pursuing formal enforcement at a much greater rate than others.

State enforcement response to serious violations, whether at large or smaller facilities, is not what it should be. Without complete and accurate data, it is hard to know how critical the noncompliance at smaller facilities is to water quality. It is likely that these smaller but more numerous sources are of critical concern, especially where there are clusters of permitted facilities around impaired waters. EPA and states need consistent, national data to be able to formulate appropriate strategies for ensuring compliance from these facilities, and to target enforcement resources to the sources most affecting water quality.

Critical information concerning "wet weather" sources – or sources that discharge during storms or other wet weather events – is also missing. There is an incomplete inventory of CAFOs, industrial and municipal storm water entities, occurrences of significant sewer overflows and very limited information concerning actions states are taking to address violations at these sources. Obtaining data for these sources and for state actions is essential to ensure adequate oversight and transparency. This Plan is an opportunity to address concerns about high noncompliance, low enforcement rates, and absence of data across regulated NPDES sources and states.

EPA must bring together whatever existing data the Agency and states have on water quality, permitting and violations to help target our enforcement actions to those that will have the most impact. The Agency has created some important links to other EPA databases, such as Ask Waters, to improve our ability to show regulated sources with respect to the water bodies into which they are discharging and whether those bodies are impaired by pollutants discharged by those sources. These comparisons of water quality and compliance and enforcement information are important to make sure that an increased focus on enforcement does not create the incentive to make permit limits easier to comply with. Both protective permits and enforcement of permit limits should help to attain improved water quality. Linking information and making information more available and transparent can help engage the public in pressing businesses to improve compliance and be more accountable. However, much work remains to be done to create the integrated data set that holistically supports our scientific water quality work and legal work.

Surface waters that serve as drinking water sources can also be negatively affected by the permitted facilities, such as CAFOs, whose illegal or unpermitted discharges are impairing our water bodies. EPA and state tools under the Safe Drinking Water Act (SDWA) also may not be adequate to address these issues, requiring the need for new approaches. Solving many of these problems will require further Agency-wide collaborative efforts between OECA, the Office of Water, EPA regions, states and tribes to strengthen water quality assessment, monitoring, permitting, and enforcement, and to create an information network vital to all stakeholders. Solutions to these sources of pollution, whether point sources regulated under the NPDES program or non-point sources, are paramount to the protection of our waters and their critical uses.

EPA's challenges in protecting the nation's waters have been increased by recent court decisions in *SWANCC* and *Rapanos*. EPA supports legislative changes to remove the barriers these decisions have created in clean water enforcement. A May 20, 2009 letter from the EPA Administrator, along with other members of the Administration, to Senator Boxer, Chair of the Senate Committee on Environment and Public Works, stated that "enactment of legislation amending the Clean Water Act that will broadly protect the nation's waters, make the definition of covered waters predictable and manageable, promote consistency between Clean Water Act and agricultural wetlands programs, and recognize long-standing practices, would go a long way toward addressing the substantial confusion and uncertainty arising from those decisions." These decisions have negatively impacted EPA's ability to enforce by significantly increasing the amount of time and resources it takes to bring enforcement actions necessary to protect our waters.

II. Outreach for Ideas on How to Revamp the NPDES Enforcement Program

To garner a full range of ideas from different perspectives, OECA reached out to other EPA program offices, the Agency's regional offices, state environmental commissioners and state water program managers, Indian Tribes and tribal organizations, environmental and environmental justice community groups, industry representatives, and the academic community. EPA held face-to-face and telephonic listening sessions with each of these groups of interested stakeholders, and also received written comments from a number of the participants. EPA also solicited comments directly from the general public through an EPA blog site. Many of these ideas have been captured in the Action Plan.

There were common themes that emerged from this outreach. One theme was a common desire for greater transparency in EPA's enforcement and compliance program through an increase in the amount, detail and quality of data. Stakeholders expressed an interest in understanding a holistic picture of environmental conditions and actions that EPA and states are taking in order to determine how best to engage in helping to protect our water resources.

Suggestions for upgrading EPA's data systems included methods for presenting more understandable data, and making inspection reports and discharge monitoring reports publicly available. Environmental organizations and academics advocated posting information about the frequency of exceedances of CWA permit limits at individual facilities to allow better linkage of water quality data with compliance information. Industry and the National Association of Clean Water Agencies were particularly interested in EPA doing a better job of correcting data errors. States also agreed with the need for transparency, but expressed a desire to find ways to make sure that data is both accurate and presented in useful context.

Most commenters also endorsed strengthening state and federal enforcement programs, both in terms of particular changes in program focus and through improved state and federal program performance overall. Specific activities cited by the public and environmentalists for increased enforcement were curbing discharges from concentrated animal feeding operations and addressing construction and industrial storm water violations.

There was extensive and thoughtful input on improving overall program performance, from revision of EPA enforcement policies to reworking the structure of the state/federal enforcement relationship and establishing more accountability for underperforming programs. Ideas were submitted by academics, environmentalists, environmental justice community organizations, the Environmental Council of States, the Association of State and Interstate Water Pollution Control Administrators, and others with respect to stronger oversight, improved coordination, more frequent communication, more joint planning, and the ability to tap into more federal resources to produce better environmental results. Tribes advocated that EPA do more to increase tribal enforcement capacity-building while, at the same time, building a greater federal enforcement presence in Indian Country.

III. Improvements to the NPDES Compliance and Enforcement Program

New approaches in enforcement can and must play a pivotal role in ensuring that permitted dischargers comply with their permits, thus achieving the maximum benefits to water quality from our existing laws and regulations. But enforcement is not the only answer, as many of the sources contributing to water quality impairments are not covered by current regulations. Enforcement can play a key role now to better address the expanded NPDES universe and improve compliance of those sources with their permits, while EPA tackles the hard issues surrounding the currently unregulated pollution challenges. To begin to address the serious water quality problems we now face, EPA's enforcement program must work hand-in-hand with the Office of Water, EPA regions, states, and tribes.

In order to fulfill our responsibilities, we must find new, resource efficient ways of collecting, using, and making public information about where these sources are, what pollution they produce, their relationship to water quality, and where violations are most severe. These sources are vastly greater in number from our traditional focus on the 6,700 biggest industrial and municipal sources – for example, there are an estimated 19,000 concentrated animal feeding operations, 89,000 industrial storm water sources and over 200,000 construction storm water sites. These challenges call for EPA programs and states to work together to ensure that the limited civil and criminal enforcement resources available to regulatory agencies at all levels are used effectively to address the most serious water issues. EPA must do everything it can to support strong state programs and fulfill its oversight responsibilities by taking action where states underperform.

The input that EPA received from its outreach efforts was surprising in its coalescence around the following three major themes for action. This Action Plan describes these themes and identifies key actions to advance the protection of our nation's waters.

A. Target Enforcement to the Most Important Water Pollution Problems

State and Federal water enforcement programs must reshape their efforts to address significant new threats to water quality. New approaches are needed to revamp our enforcement program to tackle violations of existing law by the sources of pollution posing the biggest threats to water quality and public health, while we maintain and improve on the progress we have already made. The program's existing focus on the biggest facilities and the associated policies for designating and addressing violations do not consider the full range of the NPDES regulated universe and may not always allow for responses to be tailored to the type of violation and its impact. New approaches, policies and procedures to focus enforcement on the most serious violations adversely affecting water quality are long overdue.

Specific Actions:

To bring about long term change, EPA will <u>develop and implement a new approach</u> for ensuring appropriate responses to water quality problems and related violations of NPDES permits across the full universe of regulated facilities. The existing focus on the biggest (or "major") facilities with individual permits and on enforcement responses to significant

noncompliance are not easily applied to the expansion of the regulated universe and to the expanding use of general permits. When these policies were developed in the 1980s, the universe totaled around 100,000 facilities. Today, the universe has expanded roughly tenfold to nearly one million facilities, and 95 percent of dischargers are regulated through general permits. This growth demands new approaches and new tools to focus limited resources toward addressing these challenges to our water quality.

We will work with states to develop this new approach. We will establish an EPA/State Work Group to assess the regulated universe and determine appropriate responses. Analysis of sectors will determine whether problems related to water quality are due to regulatory issues, inadequate permits, or compliance related issues. Once problems are defined, responses can be tailored to the specifics of that sector and the specific water quality challenges. Responses might include enforcement actions, fixes to unclear or problematic regulations, or permit modification or reissuance to be more protective of water quality. Associated with this review, the effect of clusters of permitted facilities and their cumulative impact on water quality also needs to be reviewed.

This new approach will require the creation of new tools to integrate information and assist in targeting dischargers for compliance monitoring and enforcement, the establishment of clear and transparent expectations for state programs in implementing this new approach, and the design of regulatory changes necessary to implement this new approach.

A critical first and immediate step we will take to initiate this new approach is to link environmental information to compliance data to inform the targeting of our compliance and enforcement efforts. EPA will incorporate data about water quality standards, existing water quality status (including information developed in conjunction with establishing Total Maximum Daily Loads for impaired water bodies), permit limits and effluent violations to evaluate where violations contribute to water quality impairment. These data currently reside in different systems and have not been routinely used together to help target serious problems. This effort would also include analyzing newly available information on pollutant loadings and toxicity against compliance history and watershed impairment information to identify facilities that require additional compliance monitoring or civil or criminal enforcement attention. This analysis will identify where good compliance performance at the biggest facilities may allow a shift of enforcement attention on other sources that are causing more significant water quality impacts. Where there are significant information gaps concerning water quality, the locations of point source discharges, or compliance, EPA will work with states to fill these gaps in order to make informed decisions on how to deploy limited enforcement resources.

Once we have identified significant point source violations across the spectrum of regulated facilities that adversely affect water quality, we will work with state programs to commence appropriate federal and state civil and criminal enforcement actions.

During the process of developing its new approach, EPA commits to making timely, easily accessible and understandable information available to the public concerning violations/violators, actions EPA and states are taking to address them, and the effects of our actions on water quality.

B. Strengthen Oversight of Clean Water Enforcement Performance

EPA has a responsibility to assure that the protections of the CWA extend to everyone. Although EPA has authorized 46 states to run the NPDES program, including enforcement of its requirements, EPA retains the responsibility to ensure that states are protecting water quality and consistently applying the law through vigorous enforcement. In those states where EPA retains primary enforcement responsibility, the Agency will set the same expectations for its own compliance and enforcement programs as those for authorized states. EPA also has direct implementation responsibilities for territories and Indian Country and must ensure that its performance meets these same expectations. EPA recognizes that it must be sensitive to the need to tailor its compliance and enforcement programs for territories and Indian Country to address the unique challenges faced in these areas.

Many authorized states have strong water quality protection programs. As envisioned by Congress, states are the first line of environmental defense. States take the lion's share of inspection and enforcement actions in the programs they implement. States often act as laboratories where new ideas can be piloted and tested before national deployment. In the Chesapeake Bay, for example, states and EPA are working together to try new approaches to dealing with non-point sources that, if successful, might be implemented at the national level. We can work with and learn from states willing to take a leadership role. However, where states are not acting to issue protective permits or are not taking enforcement actions to achieve compliance and remove economic incentives to violate the law, EPA needs to act to strengthen those programs to protect public health and the environment.

EPA needs to address issues already identified in state performance. Reviews have been completed of state and regional permit and enforcement programs which have identified program weaknesses and prescribed steps to improve performance. EPA's Office of Water's Permitting for Environmental Results and Regional Permit Quality Reviews have evaluated performance in permit issuance and quality, and OECA's State Review Framework has been used to evaluate enforcement programs. While none of these reviews offer a definitive determination of the quality of a state or regional program, they have identified a lack of consistency in performance across states and highlighted common issues such as permit backlogs, failure to identify significant noncompliance, or to take timely and appropriate enforcement. EPA must consistently respond to these issues and press states and ourselves to make the appropriate improvements in order to achieve equitable protection to the public, a level playing field for competing businesses, and fairness across states in how our environmental laws are enforced.

Specific Actions:

Much of the regulatory framework, including policies and guidance, driving the CWA program was developed in the 1980s. Memoranda of Agreement were entered into between EPA and states when each of the 46 states and the 1 territorial agency received program approval. Thus, they were negotiated over a 30 year period, each reflecting what was viewed as most important to include in authorization agreements at the time. These agreements contain different provisions on a state-by-state and region-by-region basis. As new problems have emerged, as federal and state programs have matured and as program requirements have broadened, the

expectations for program implementation have become even more unclear. EPA needs to clearly articulate where the bar is set for acceptable state clean water programs, and hold states and ourselves accountable for achieving it. This requires clarity of expectations and more consistent and clear communications between EPA and states to make sure we are addressing the most important water quality problems and most serious violations. A formal and consistent planning and coordination process will help to accomplish this.

EPA needs to set clear expectations for what acceptable performance is and how performance will be measured. EPA will define and clarify expectations for water permitting and enforcement programs. Those expectations will be the basis for the development of performance metrics for permitting and enforcement, which will be made public to hold both EPA and states accountable. EPA will develop these expectations in dialogue with authorized states.

Once developed, EPA will use the standard set of expectations as a basis for negotiating consistent enforcement agreements with each state, remedying the outdated, inconsistent and sometimes problematic Memoranda of Agreement that were developed over time for state program authorizations. This consistent baseline will do much to assure that states understand expectations and have the appropriate tools to achieve them.

EPA will also incorporate these new expectations and metrics into a number of formal planning processes:

- EPA and state senior management will annually include water quality standards, permitting and enforcement in planning discussions about appropriate goals, performance expectations, permitting and enforcement program improvements identified in program reviews, inspection and enforcement targeting, roles and responsibilities, work sharing and the avoidance of duplication of effort.
- Progress will be reviewed periodically throughout the year in meetings between EPA and states to holistically discuss the attainment of annual water quality, permitting and enforcement goals and expectations.
- Water quality, permitting and enforcement expectations should be contributing to the achievement of the same environmental goals. Enforcement expectations should be a part of the Water National Program Managers Guidance, which already includes guidance for the use of CWA §106 grant funds for state water quality monitoring and permitting. Ensure that the inclusion of performance expectations for the enforcement program in the grant guidance results in commitments in annual (or biannual) grant work plans that will achieve both enforcement and water quality goals.

While new approaches and expectations are being designed, ongoing oversight can work to raise the bar of performance under our current system. Strong enforceable permits are the cornerstone for effective enforcement, and the two work together to protect the nation's waters. EPA will pull results together from permit quality and enforcement reviews to determine if states are meeting minimum expectations for NPDES program performance. In the short term, this will include the implementation of the State Review Framework and the permit quality reviews currently being conducted. In the longer term, these tools need to be assessed against the new

approaches that OECA and the Office of Water are contemplating to ensure alignment with new directions. Where a state is underperforming, EPA will disapprove permits that are not protective of water quality and initiate enforcement actions against dischargers to address serious violations and protect public health and the environment.

EPA will also explore the concerns of citizen groups that some state enforcement actions have not been effective in achieving compliance. In their input into this Action Plan, some citizen groups voiced concern that in some cases when they provided a state notice of intent to file suit, some states would move to block their suit by issuing an administrative order that did not bring about compliance. To examine this issue, EPA will look into places where this practice is alleged to be widespread and determine if federal action is necessary.

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C. Improve Accountability and Transparency

EPA lacks nationally consistent and complete information on the facilities, permits, pollutant discharges and compliance status of most NPDES-regulated facilities. This affects the ability of EPA and states to identify violations, target their actions, connect violations to water quality impacts, and to share information with the public. Data problems between EPA and states include data quality, accuracy, and completeness. Responses to these problems are hindered by the reporting and data processing burden associated with the breadth and expanding scope of the NPDES regulated universe.

Analyses to identify additional data needs for EPA's permitting and enforcement program have estimated that, to obtain the level of facility-specific data needed to fully understand the impact of wet weather discharges and other universes of facilities subject to CWA requirements (such as biosolids or pretreatment) on our nation's waters, would cost over $100 million/year. Ninety per cent of the burden to enter the needed data is related to the DMRs, which are provided by permitees to states who then submit the information to EPA. While the burden can be whittled down considerably by phasing in sources and limiting reporting to when violations are found or enforcement actions are taken, it is still a considerable investment. In today's economic situation, where resources are scarce to conduct ongoing work, this state reporting burden is difficult to justify. EPA needs to explore new ways and new uses of technology to collect, analyze, use, and make information available to the public in a cost efficient and effective way.

Transparent information is a powerful self policing tool for reducing pollution and improving compliance. As we have seen with the advent and use of the Toxics Release Inventory, sharing information on environmental discharges with the public puts pressure on regulated facilities to increase compliance, limit environmental damage and be more accountable. Transparency is not a replacement for regulatory enforcement, but can be an effective driver for improved performance and accountability.

Specific Actions:

A consensus suggestion across co-regulators and stakeholder groups was to implement electronic reporting from facilities that are required to submit reports to a regulatory agency.

Electronic reporting utilizes 21st Century technologies to get information more quickly and efficiently, enables the real-time use of that information to target serious violations and sources of water pollution, improves data quality, and provides a more informative and complete picture to the public. The requirement for permitted facilities to report DMRs monthly results is a huge reporting burden – for facilities to submit paper DMRs, for states and EPA to manually enter DMR data into data systems, and for states to then transmit the data to EPA's national database. EPA and states are constantly dealing with data quality issues and struggling to meet data timeliness, completeness, and accuracy standards.

In order to ease the reporting burden, increase data accuracy, make real-time data available to regulators and the public, and allow the more efficient use of limited resources, EPA recently deployed a new electronic reporting tool called NetDMR (www.epa.gov/netdmr) that enables regulated facilities to submit their DMRs electronically to the national data system or to a state system. That information can then be shared immediately between state and federal systems through EPA's National Environmental Information Exchange Network. OECA can significantly increase the electronic submission of data by immediately encouraging the promotion and use of NetDMR or other electronic DMR reporting tools in direct implementation programs and authorized states. EPA will also initiate an aggressive marketing campaign to the regulated community to promote electronic reporting. This would include working with small business to develop capacity and incentives to ensure that they have the ability to electronically report.

To fully realize the transformation of reporting and data management into the 21st Century, OECA will develop a rule to require NPDES permittees to provide DMRs electronically to EPA or states, using either NetDMR or an equivalent state electronic DMR system, phasing out paper DMR forms. Pilot projects using electronic reporting tools show limited rates of success unless the tool is mandated. The full benefits of electronic DMR reporting can only be achieved when implementation is close to 100 percent. EPA estimates that conversion from hard copy to electronically-submitted DMRs may save EPA, states, and the regulated sources more than $50 million per year when fully implemented. Real-time information on discharges and compliance, and their connection to water quality, will increase accountability for results and enlist the public as allies in the push for better compliance.

EPA will explore other reporting from facilities and authorized states over the next year to determine if it is feasible and cost effective to implement electronic solutions. Some examples include: electronic Notices of Intent to Discharge for general permits, non-DMR compliance reports, inspection results, and electronic permits. Another idea to explore is whether electronic reporting may provide an opportunity to require a compliance certification by regulated facilities that currently do not have reporting requirements. This would fill a void by providing regular data about the discharges and compliance status of those facilities, and better inform regulators and the public of their status. This will provide a more complete picture of discharges to the environment and will help to link those discharges to water quality conditions.

Finally, EPA will move immediately toward making additional data that is not enforcement confidential available to the public, increasing the transparency of its enforcement program. We will consult users to help simplify EPA's Enforcement and Compliance History

On-Line (ECHO) public web tool, developing better ways to display data and trends that bring data to life – including interactive maps and new, simpler reports.

D. Short Term Actions

While we are working to revamp water enforcement to better protect water quality, there are actions we can take right now to address known compliance and water quality issues.

First, EPA will pursue new strategies to enforce existing rules limiting pollution from concentrated animal feeding operations (CAFOs), especially where they occur in areas close to imperiled waters. CAFOs have become larger and more densely located, placing more stress on waters in proximity to these locations. CAFOs result in a large pollution load to the environment[2] and have been cited as an environmental justice concern in some areas.[3] Where facilities with large numbers of animals are discharging without a permit or in violation of their permits, they can cause significant pollution problems of concern to communities. Many of the comments EPA received during its outreach for this Action Plan emphasized the need for EPA to move now to reduce pollution and address violations by these operations. EPA will review its existing enforcement tools to find ways to make progress in reducing violations and water pollution from these facilities, while additional solutions for reducing this pollution are being developed.

Second, EPA will revisit the division of work with states, many of which are facing near term serious resource problems. We will review with each state how best to target the resources we jointly have, so we make sure in the near term that we are addressing the most serious water pollution violations. As we revamp our enforcement program to more systematically address the new water pollution challenges, we will work with states now, utilizing the combination of existing data and targeting tools, to go after the violations we already know are serious problems for water quality.

Third, EPA will press aggressively for immediate electronic reporting. NetDMR is available now for facilities to use to electronically report their DMRs. We will urge facilities to shift to electronic reporting right away, to reduce data entry costs and increase the accuracy and timeliness of the information we make available to the public.

IV. Resource Issues

The NPDES permitting and enforcement program has expanded its regulated universe more than tenfold as water quality problems have shifted to smaller, less discrete sources. Problems have grown more complex, while at the same time court decisions have made our regulatory authorities less clear. During this expansion, program resources have generally remained static. Many states are experiencing large reductions in state resources which have seriously hampered compliance programs. In these tough economic times, it is especially important to protect responsible businesses that invest in complying with the law by taking

[2] An Urgent Call To Action: Report of the State-EPA Nutrient Innovations Task Group, August 2009
[3] Environmental Injustice in North Carolina's Hog Industry; Wing et. al.; Environmental Health Perspectives, Vol. 108, March 2000

enforcement against violators. We know that the existing level of resources at EPA and the states will not be enough to solve all of our water quality problems. In order to carry out this Action Plan, EPA and the states will need to engage in serious discussions on directing resources to the most important water quality problems and most serious violations. We need to ensure that we utilize the limited resources we do have on the most important sources of pollution and the most important violations that, if addressed, can result in improvements in water quality and in people's lives.

V. Conclusion

To help meet this country's expectation that the waters that sustain us are clean and safe, EPA must revamp its enforcement and compliance program to focus it on the most significant sources of water pollution and the most significant violations from those facilities. Our water pollution problems cannot be solved through enforcement alone, as we still do not have effective rules for many of the threats to clean water. But enforcement can make a significant difference in improving water quality and upholding our commitments to the rule of law and transparency in government. Through this Plan, enforcement will work hand-in-hand with water quality standards and permits to protect the environment and the American public. We will hold states, and ourselves, to a higher standard of performance. And we will make information about threats to clean water, violations, and enforcement actions available to the public. This information will serve as a powerful ally in encouraging businesses to do better, and giving the public the tools to demand greater compliance and accountability from the regulated community.

Stefania Shamet/R3/USEPA/US
01/11/2011 06:51 PM

To Christopher Hunter
cc
bcc
Subject App 1 & 2 & 72

(b) (5)
re-read w/fresh eyes later tonite.

ATTACHMENT REDACTED - DELIBERATIVE

WVSCI threshold language.docx

Matthew Klasen/DC/USEPA/US
01/11/2011 07:03 PM

To Lynn Zipf
cc
bcc
Subject Fw: Response Supplement #67 Selenium - Support for the 4 ppm whole body threshold

FYI. We'll survive if we get responses by 10 am tomorrow, but just barely.

Thanks for your help!

mk

Matt Klasen
U.S. Environmental Protection Agency
Office of Water (IO)
202-566-0780
cell (202) 380-7229
----- Forwarded by Matthew Klasen/DC/USEPA/US on 01/11/2011 07:01 PM -----

From: Betsy Behl/DC/USEPA/US
To: Gregory Peck/DC/USEPA/US@EPA
Cc: Ephraim King/DC/USEPA/US@EPA, stoner.nancy@epa.gov, Matthew Klasen/DC/USEPA/US@EPA, Joe Beaman/DC/USEPA/US@EPA
Date: 01/11/2011 06:30 PM
Subject: Fw: Response Supplement #67 Selenium - Support for the 4 ppm whole body threshold

Greg: I will get together first thing in the morning with Joe and Charlie to include some summary of Seng Creek, if possible. (b) (5) [redacted] Will do my best to respond early tomorrow.
Betsy
----- Forwarded by Betsy Behl/DC/USEPA/US on 01/11/2011 06:28 PM -----

From: Lynn Zipf/DC/USEPA/US
To: Betsy Behl/DC/USEPA/US@EPA
Cc: Cynthia Simbanin/DC/USEPA/US@EPA
Date: 01/07/2011 03:30 PM
Subject: Fw: Response Supplement #67 Selenium - Support for the 4 ppm whole body threshold

Can you please coordinate with Greg?

_____
Lynn Zipf
Special Assistant
Office of Science and Technology
Office of Water

P: (202) 564-1509

Gregory Peck

----- Original Message -----
From: Gregory Peck
Sent: 01/07/2011 09:26 AM EST
To: Lynn Zipf
Cc: Ephraim King; Matthew Klasen; Nancy Stoner

Subject: Fw: Response Supplement #67 Selenium - Support for the 4 ppm whole body threshold

Hey Lynn:

I know how busy folks are - (b) (5) [redacted] Please call me if you have any questions.

Best,
Greg

----- Forwarded by Gregory Peck/DC/USEPA/US on 01/07/2011 09:22 AM -----

From:	Matthew Klasen/DC/USEPA/US
To:	Gregory Peck/DC/USEPA/US@EPA
Date:	01/07/2011 09:14 AM
Subject:	Fw: Response Supplement #67 Selenium - Support for the 4 ppm whole body threshold

Greg: Attached are all the questions we need help with from OST. Please also forward along Frank's email below. (b) (5) [redacted]

I'm happy to walk all of this through with someone over there (Lynn?) to make this all make sense. That may be more productive than just sending over.

Thanks,
Matt

[attachment "2011-01-07 Spruce responses for OST review.docx" deleted by Betsy Behl/DC/USEPA/US]

Matt Klasen
U.S. Environmental Protection Agency
Office of Water (IO)
202-566-0780
cell (202) 380-7229

----- Forwarded by Matthew Klasen/DC/USEPA/US on 01/07/2011 09:11 AM -----

From:	Frank Borsuk/R3/USEPA/US
To:	Stefania Shamet/R3/USEPA/US@EPA, John Forren/R3/USEPA/US@EPA, Margaret Passmore/R3/USEPA/US@EPA, borsuk.frank@epa.gov
Cc:	Matthew Klasen/DC/USEPA/US@EPA, Christopher Hunter/DC/USEPA/US@EPA, David Rider/R3/USEPA/US@EPA, David Kargbo/R3/USEPA/US@EPA
Date:	12/29/2010 11:21 AM
Subject:	Response Supplement #67 Selenium - Support for the 4 ppm whole body threshold

Stef:

(b) (5) [redacted]

(b) (5)

(b) (5)

[redacted]

Frank Borsuk, Ph.D.
Aquatic/Fisheries Biologist
Freshwater Biology Team
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borsuk.frank@epa.gov

Please visit our website at http://epa.gov/reg3esd1/3ea50.htm

Marcel Tchaou/DC/USEPA/US
01/11/2011 07:48 PM

To Christopher Hunter
cc Matthew Klasen, Stefania Shamet
bcc
Subject Re: Reference Appendix

Here is the Reference Appendix 7 as of 1/11/11 7:48PM

ATTACHMENT REDACTED - DELIBERATIVE

Appendix 7 FD Marcel version 1-11-2011Harmonized.doc

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Marcel K. Tchaou, Ph.D., P.E., P.H.
Environmental Engineer
Wetlands & Aquatic Resources Regulatory Branch
Office of Wetlands, Oceans and Watersheds
U.S. EPA
1200 Pennsylvania Avenue, NW (MC 4502T)
Washington, DC 20460
202-566-1904

Christopher Hunter | Marcel is about halfway through confirming the r... | 01/11/2011 05:42:09 PM

From: Christopher Hunter/DC/USEPA/US
To: Stefania Shamet/R3/USEPA/US@EPA, Matthew Klasen/DC/USEPA/US@EPA
Cc: Marcel Tchaou/DC/USEPA/US@EPA
Date: 01/11/2011 05:42 PM
Subject: Reference Appendix

Marcel is about halfway through confirming the references in the FD main body. Once he is finished for the night, he will send out an updated Reference Appendix to this group, and then finish up tomorrow morning on the main body.
Stef, if you can find someone to help with the RtC, that would be great, and Marcel will start in on the Appendices when he's finished with the main body.

Thanks

Chris Hunter
U.S. Environmental Protection Agency
Office of Wetlands, Oceans, & Watershed
(202) 566-1454
hunter.christopher@epa.gov

Sandy Evalenko/DC/USEPA/US
01/11/2011 10:38 PM

To Vickie Reed, Leona Montano
cc Matthew Klasen
bcc
Subject Fw: Updated draft Spruce FR notice -- comments by 10 am tomorrow

We have an urgent and sensitive FRN that our AA needs to sign notice tomorrow. Do either of you have time for a quick review? We would appreciate any comments by 10 am tomorrow.
Matthew Klasen

----- Original Message -----
From: Matthew Klasen
Sent: 01/11/2011 06:19 PM EST
To: Gregory Peck; Karyn Wendelowski; Kevin Minoli; Christopher Hunter; Stefania Shamet; Brian Frazer
Cc: Macara Lousberg; Sandy Evalenko; Denise Keehner; David Evans; Tanya Code
Subject: Updated draft Spruce FR notice -- comments by 10 am tomorrow

Hi everyone,

See attached below for a draft FR notice on Spruce. We began coordination on this draft notice last night, and I've received and incorporated comments from Chris and Karyn so far.

The plan is to have Pete sign this concurrently with the FD tomorrow afternoon. Because this overlaps significantly with the text of the executive summary, I don't expect the content here to be a surprise to anyone.

Please send me any comments by **10 am tomorrow** so we can get the package ready by mid-afternoon tomorrow for Pete's signature, concurrently with the Final Determination.

Thanks,
Matt

ATTACHMENT REDACTED - DELIBERATIVE

2011-01-11 Draft Spruce FD FR Notice.docx

Matt Klasen
U.S. Environmental Protection Agency
Office of Water (IO)
202-566-0780
cell (202) 380-7229

Karyn Wendelowski/DC/USEPA/US
01/11/2011 11:26 PM

To Christopher Hunter
cc Kevin Minoli
bcc
Subject FD comments

It's looking good. Here are my (last?) comments. I eagerly await the selenium section from Stef.

ATTACHMENT REDACTED - DELIBERATIVE

Spruce FD 011111 clean kw edits.docx

Matthew Klasen/DC/USEPA/US
01/12/2011 03:08 AM

To Stefania Shamet
cc
bcc
Subject RD comments current

Just for cross-referencing purposes -- using Track Changes in the PD comments (the file I sent a few minutes ago labeled Appendix 6 should be the place to start, and I'm done up to 28.

Matt Klasen
U.S. Environmental Protection Agency
Office of Water (IO)
202-566-0780
cell (202) 380-7229 - 2011-01-12 Compiled H&W RD Comment Responses.docx

ATTACHMENT REDACTED - DELIBERATIVE

Margaret Passmore/R3/USEPA/US
01/12/2011 08:19 AM

To Stefania Shamet
cc Frank Borsuk, John Forren
bcc
Subject Re: One last selenium response (I hope)-- needs a second pair of eyes

Stef,

(b) (5) [redacted]

[redacted]

M

Margaret Passmore
Freshwater Biology Team
Office of Monitoring and Assessment (3EA50)
Environmental Assessment and Innovation Division
USEPA Region 3
1060 Chapline Street, Suite 303
Wheeling, WV 26003-2995
(p) 304-234-0245
(f) 304-234-0260
passmore.margaret@epa.gov

Visit our website at http://epa.gov/reg3esd1/3ea50.htm

Stefania Shamet (b) (5) [redacted] 01/12/2011 05:33:35 AM

From: Stefania Shamet/R3/USEPA/US
To: Margaret Passmore/R3/USEPA/US@EPA, Frank Borsuk/R3/USEPA/US@EPA
Cc: John Forren/R3/USEPA/US@EPA
Date: 01/12/2011 05:33 AM
Subject: One last selenium response (I hope)-- needs a second pair of eyes

(b) (5) [redacted]

[redacted]

[redacted]

(b) (5)

(b) (5) [redacted]

[redacted]

Table A1.12. Total Recoverable Selenium (µg/L) for Outfalls 015, 017 and 028 for NPDES Permit WV1017021, Mingo Logan Coal Company Spruce No. 1 Mine. Note: Shaded areas indicate selenium concentrations exceeding 5 µg/L.

Site Code	Site Location	Report Date	Min Value	Avg. value	Max value
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017	Outlet 017	12/31/2008	0.00	0.00	0.00
017	Outlet 017	9/30/2009	19.20	19.20	19.20
028	Outlet 028	12/31/2008	5.70	5.70	5.70
028	Outlet 028	1/31/2009	9.80	9.80	9.80
028	Outlet 028	2/28/2009	3.90	3.90	3.90
028	Outlet 028	3/31/2009	0.60	1.00	1.40
028	Outlet 028	4/30/2009	1.70	1.70	1.70
028	Outlet 028	5/31/2009	2.50	2.50	2.50
028	Outlet 028	6/30/2009	3.20	3.30	3.40
028	Outlet 028	8/31/2009	1.25	3.48	5.70
028	Outlet 028	9/30/2009	4.60	6.05	7.50
028	Outlet 028	10/31/2009	3.00	3.00	3.00
028	Outlet 028	11/30/2009	1.40	1.85	2.30
028	Outlet 028	12/31/2009	1.80	1.85	1.90
028	Outlet 028	1/31/2010	3.40	3.80	4.20
028	Outlet 028	2/28/2010	3.80	4.50	5.20
028	Outlet 028	3/31/2010	4.70	6.10	7.50
028	Outlet 028	4/30/2010	3.8	4.40	5.00
028	Outlet 028	5/31/2010	4.70	7.60	10.50
028	Outlet 028	6/30/2010	11.40	11.50	11.60
028	Outlet 028	7/31/2010	6.40	8.50	10.40
028	Outlet 028	8/31/2010	4.80	10.65	14.80
028	Outlet 028	9/30/2010	4.80	9.40	11.00

(b) (5) [redacted]

[redacted]

(b) (5)

(b) (5)

[redacted]

[redacted]

[redacted]

[redacted]

Matthew Klasen/DC/USEPA/US
01/12/2011 08:55 AM

To Stefania Shamet
cc
bcc
Subject DEP RD comments

These are totally done except comments in the margins.

mk

ATTACHMENT REDACTED - DELIBERATIVE

2011-01-12 Compiled WVDEP and Corps RD Comment Responses.doc

Matt Klasen
U.S. Environmental Protection Agency
Office of Water (IO)
202-566-0780
cell (202) 380-7229

Margaret Passmore/R3/USEPA/US
01/12/2011 09:25 AM

To Frank Borsuk
cc John Forren
bcc
Subject Re: One last selenium response (I hope)-- needs a second pair of eyes

Thanks Frank. Really appreciate you taking another look at the actual numbers. Were the roads bad?

M

Margaret Passmore
Freshwater Biology Team
Office of Monitoring and Assessment (3EA50)
Environmental Assessment and Innovation Division
USEPA Region 3
1060 Chapline Street, Suite 303
Wheeling, WV 26003-2995
(p) 304-234-0245
(f) 304-234-0260
passmore.margaret@epa.gov

Visit our website at http://epa.gov/reg3esd1/3ea50.htm

Frank Borsuk | Stef: First, I have attached the summary tables f... | 01/12/2011 09:22:37 AM

From: Frank Borsuk/R3/USEPA/US
To: Stefania Shamet/R3/USEPA/US@EPA
Cc: John Forren/R3/USEPA/US@EPA, Margaret Passmore/R3/USEPA/US@EPA
Date: 01/12/2011 09:22 AM
Subject: Re: One last selenium response (I hope)-- needs a second pair of eyes

Stef:

First, I have attached the summary tables for Oldhouse Branch and Pigeonroost Branch (Time Period December 2008 to March 2010) just to put my comments in context.
PLEASE NOTE THE TYPO ON THE DATE IN TABLE 12(b) for the last entry 3/31/2009 should be 3/31/2010. has it been corrected?

It took me awhile but I have inserted my comments and suggested text (highlighted) in the email below.

I will be available all day if needed to clarify anything.

Frank

Table 12(b). Monthly Total Recoverable Selenium (µg/L) for ambient water quality monitoring station: DOB (Downstream Oldhouse Branch) within the Spruce Watershed for the Mingo-Logan Coal Company.

Site Code	Site Location	Sample Date	Min Value	Ave. value	Max value
DOB	Oldhouse Branch Downstream	12/31/2008	0.00	0.00	0.00
DOB	Oldhouse Branch Downstream	1/31/2009	0.60	0.60	<0.60
DOB	Oldhouse Branch Downstream	2/28/2009	0.60	0.60	<0.60
DOB	Oldhouse Branch Downstream	3/31/2009	0.60	0.60	<0.60
DOB	Oldhouse Branch Downstream	4/30/2009	0.60	0.60	<0.60
DOB	Oldhouse Branch Downstream	5/31/2009	0.60	0.60	<0.60
DOB	Oldhouse Branch Downstream	6/30/2009	0.60	0.60	<0.60
DOB	Oldhouse Branch Downstream	7/31/2009	0.60	0.60	0.90
DOB	Oldhouse Branch Downstream	8/31/2009	0.60	0.60	<0.60
DOB	Oldhouse Branch Downstream	9/30/2009	0.60	0.60	<0.60
DOB	Oldhouse Branch Downstream	10/31/2009	0.60	0.60	<0.60
DOB	Oldhouse Branch Downstream	11/30/2009	0.60	0.60	<0.60
DOB	Oldhouse Branch Downstream	12/31/2009	0.60	0.60	<0.60
DOB	Oldhouse Branch Downstream	1/31/2010	0.60	0.60	<0.60
DOB	Oldhouse Branch Downstream	2/28/2010	0.60	0.60	<0.60
DOB	Oldhouse Branch Downstream	3/31/2010	0.60	0.60	<0.60
DOB	Oldhouse Branch Downstream	**3/31/2009**	0.60	0.60	<0.60

Table 12(c). Monthly Total Recoverable Selenium (µg/L) for ambient water quality monitoring station: DPB (Downstream Pigeonroost Branch) within the Spruce Watershed for the Mingo-Logan Coal Company.

Site Code	Site Location	Sample Date	Min Value	Ave. value	Max value
DPB	Pigeonroost Branch Downstream	12/31/2008	0.00	0.00	0.00
DPB	Pigeonroost Branch Downstream	1/31/2009	0.60	0.60	<0.60
DPB	Pigeonroost Branch Downstream	2/28/2009	0.60	0.60	<0.60
DPB	Pigeonroost Branch Downstream	3/31/2009	0.60	0.60	<0.60
DPB	Pigeonroost Branch Downstream	4/30/2009	0.60	0.60	<0.60
DPB	Pigeonroost Branch Downstream	5/31/2009	0.60	0.60	<0.60
DPB	Pigeonroost Branch Downstream	6/30/2009	0.60	0.60	<0.60
DPB	Pigeonroost Branch Downstream	7/31/2009	0.60	0.60	<0.60
DPB	Pigeonroost Branch Downstream	8/31/2009	0.70	1.30	1.90
DPB	Pigeonroost Branch Downstream	9/30/2009	0.60	0.60	<0.60
DPB	Pigeonroost Branch Downstream	10/31/2009	0.60	0.60	<0.60
DPB	Pigeonroost Branch Downstream	11/30/2009	0.60	0.60	<0.60
DPB	Pigeonroost Branch Downstream	12/31/2009	0.60	0.60	<0.60
DPB	Pigeonroost Branch Downstream	1/31/2010	0.60	0.60	<0.60
DPB	Pigeonroost Branch Downstream	2/28/2010	0.60	0.60	<0.60
DPB	Pigeonroost Branch Downstream	3/31/2010	0.60	0.60	<0.60

To: Margaret Passmore/R3/USEPA/US@EPA, Frank Borsuk/R3/USEPA/US@EPA
Cc: John Forren/R3/USEPA/US@EPA
Date: 01/12/2011 05:33 AM
Subject: One last selenium response (I hope)-- needs a second pair of eyes

(b) (5)

(b) (5)

[redacted]

[redacted]

[redacted]

Table A1.12. Total Recoverable Selenium (µg/L) for Outfalls 015, 017 and 028 for NPDES Permit WV1017021, Mingo Logan Coal Company Spruce No. 1 Mine. Note: Shaded areas indicate selenium concentrations exceeding 5 µg/L.

Site Code	Site Location	Report Date	Min Value	Avg. value	Max value
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(b) (5)

(b) (5)

(b) (5)

Frank Borsuk/R3/USEPA/US
01/12/2011 09:26 AM

To Margaret Passmore
cc
bcc
Subject Yes, the roads were bad. Re: One last selenium response (I hope)-- needs a second pair of eyes

Frank Borsuk, Ph.D.
Aquatic/Fisheries Biologist
Freshwater Biology Team
USEPA-Region 3 (Wheeling Office)
Office of Monitoring & Assessment (3EA50)
Environmental Assessment & Innovation Division
1060 Chapline Street, Suite 303
Wheeling, WV 26003-2995
304-234-0241 Phone
304-234-0260 Fax
borsuk.frank@epa.gov

Please visit our website at http://epa.gov/reg3esd1/3ea50.htm

Margaret Passmore | Thanks Frank. Really appreciate you taking an... | 01/12/2011 09:25:50 AM

From: Margaret Passmore/R3/USEPA/US
To: Frank Borsuk/R3/USEPA/US@EPA
Cc: John Forren/R3/USEPA/US@EPA
Date: 01/12/2011 09:25 AM
Subject: Re: One last selenium response (I hope)-- needs a second pair of eyes

Thanks Frank. Really appreciate you taking another look at the actual numbers. Were the roads bad?

M

Margaret Passmore
Freshwater Biology Team
Office of Monitoring and Assessment (3EA50)
Environmental Assessment and Innovation Division
USEPA Region 3
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Wheeling, WV 26003-2995
(p) 304-234-0245
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Visit our website at http://epa.gov/reg3esd1/3ea50.htm

Frank Borsuk | Stef: First, I have attached the summary tables f... | 01/12/2011 09:22:37 AM

From: Frank Borsuk/R3/USEPA/US
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Cc: John Forren/R3/USEPA/US@EPA, Margaret Passmore/R3/USEPA/US@EPA
Date: 01/12/2011 09:22 AM
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DOB	Oldhouse Branch Downstream	5/31/2009	0.60	0.60	<0.60
DOB	Oldhouse Branch Downstream	6/30/2009	0.60	0.60	<0.60
DOB	Oldhouse Branch Downstream	7/31/2009	0.60	0.60	0.90
DOB	Oldhouse Branch Downstream	8/31/2009	0.60	0.60	<0.60
DOB	Oldhouse Branch Downstream	9/30/2009	0.60	0.60	<0.60
DOB	Oldhouse Branch Downstream	10/31/2009	0.60	0.60	<0.60
DOB	Oldhouse Branch Downstream	11/30/2009	0.60	0.60	<0.60
DOB	Oldhouse Branch Downstream	12/31/2009	0.60	0.60	<0.60
DOB	Oldhouse Branch Downstream	1/31/2010	0.60	0.60	<0.60
DOB	Oldhouse Branch Downstream	2/28/2010	0.60	0.60	<0.60
DOB	Oldhouse Branch Downstream	3/31/2010	0.60	0.60	<0.60
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Table 12(c). Monthly Total Recoverable Selenium (µg/L) for ambient water quality monitoring station: DPB (Downstream Pigeonroost Branch) within the Spruce Watershed for the Mingo-Logan Coal Company.

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DPB	Pigeonroost Branch Downstream	11/30/2009	0.60	0.60	<0.60
DPB	Pigeonroost Branch Downstream	12/31/2009	0.60	0.60	<0.60
DPB	Pigeonroost Branch Downstream	1/31/2010	0.60	0.60	<0.60
DPB	Pigeonroost Branch Downstream	2/28/2010	0.60	0.60	<0.60
DPB	Pigeonroost Branch Downstream	3/31/2010	0.60	0.60	<0.60

Stefania Shamet (b) (5) [redacted] 01/12/2011 05:33:35 AM

From: Stefania Shamet/R3/USEPA/US
To: Margaret Passmore/R3/USEPA/US@EPA, Frank Borsuk/R3/USEPA/US@EPA
Cc: John Forren/R3/USEPA/US@EPA
Date: 01/12/2011 05:33 AM
Subject: One last selenium response (I hope)-- needs a second pair of eyes

(b) (5) [redacted]

(b) (5)

[redacted]

[redacted]

[redacted]

[redacted]

[redacted]

[redacted]

[redacted]

Table A1.12. Total Recoverable Selenium (µg/L) for Outfalls 015, 017 and 028 for NPDES Permit WV1017021, Mingo Logan Coal Company Spruce No. 1 Mine. Note: Shaded areas indicate selenium concentrations exceeding 5 µg/L.

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028	Outlet 028	8/31/2009	1.25	3.48	5.70
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028	Outlet 028	10/31/2009	3.00	3.00	3.00
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028	Outlet 028	4/30/2010	3.8	4.40	5.00
028	Outlet 028	5/31/2010	4.70	7.60	10.50
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028	Outlet 028	9/30/2010	4.80	9.40	11.00

(b) (5) [redacted]

[redacted]

[redacted]

(b) (5)

[redacted]

[redacted]

[redacted]

[redacted]

(b) (5)

[redacted]

[redacted]

[redacted]

Christopher Hunter/DC/USEPA/US
01/12/2011 10:09 AM

To Karyn Wendelowski, Kevin Minoli
cc
bcc
Subject Selenium sections

As they currently stand. The references in yellow to Seng Creek are to confirm those are confusing references to Seng Creek vs. Seng Camp Creek

Selenium sections.docx

ATTACHMENT REDACTED - DELIBERATIVE

Chris Hunter
U.S. Environmental Protection Agency
Office of Wetlands, Oceans, & Watershed
(202) 566-1454
hunter.christopher@epa.gov

Matthew Klasen/DC/USEPA/US
01/12/2011 10:17 AM

To Kevin Minoli
cc Christopher Hunter, Karyn Wendelowski, Steven Neugeboren
bcc
Subject Re: OW Needs Your Concurrence on Spruce FR Notice

And here is the final.

Thanks,
Matt

ATTACHMENT REDACTED - DELIBERATIVE

2011-01-12 Final Spruce FD FR Notice.docx

Matt Klasen
U.S. Environmental Protection Agency
Office of Water (IO)
202-566-0780
cell (202) 380-7229

Kevin Minoli | Hey Steve- Can you please send the folks on thi... | 01/12/2011 09:50:10 AM

From: Kevin Minoli/DC/USEPA/US
To: Steven Neugeboren/DC/USEPA/US@EPA
Cc: Karyn Wendelowski/DC/USEPA/US@EPA, Matthew Klasen/DC/USEPA/US@EPA, Christopher Hunter/DC/USEPA/US@EPA
Date: 01/12/2011 09:50 AM
Subject: OW Needs Your Concurrence on Spruce FR Notice

Hey Steve- Can you please send the folks on this email OGC's concurrence in their decision to sign an FR notice announcing the Spruce 404(c) Final Determination? Karyn and I reviewed and are ok with it. They intend to sign it later this afternoon. Thanks.

Stefania Shamet/R3/USEPA/US
01/12/2011 10:53 AM

To Christopher Hunter
cc Michael Dunn, David Rider, Frank Borsuk
bcc
Subject Re: Disconnect

Ok.

Chris -- get them on to the index. We physically have them in the Region, so it's ok so long as they are on the index.

Mike -- Can you see if they are on Dave's desk.

Dave/Frank -- if you're checking email -- can you send electronically?

Christopher Hunter I don't think we have copies of the December 08... 01/12/2011 10:48:19 AM

From: Christopher Hunter/DC/USEPA/US
To: Stefania Shamet/R3/USEPA/US@EPA
Date: 01/12/2011 10:48 AM
Subject: Re: Disconnect

I don't think we have copies of the December 08-March 10 DMR for the admin file.

Chris Hunter
U.S. Environmental Protection Agency
Office of Wetlands, Oceans, & Watershed
(202) 566-1454
hunter.christopher@epa.gov

Stefania Shamet (b) (5) [redacted] 01/12/2011 07:24:34 AM

From: Stefania Shamet/R3/USEPA/US
To: Christopher Hunter/DC/USEPA/US@EPA
Date: 01/12/2011 07:24 AM
Subject: Disconnect

(b) (5) [redacted]

(b) (5)

[redacted]

[redacted]

[redacted]

Table A1.12. Total Recoverable Selenium (µg/L) for Outfalls 015, 017 and 028 for NPDES Permit WV1017021, Mingo Logan Coal Company Spruce No. 1 Mine. Note: Shaded areas indicate selenium concentrations exceeding 5 µg/L.

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028	Outlet 028	1/31/2010	3.40	3.80	4.20
028	Outlet 028	2/28/2010	3.80	4.50	5.20
028	Outlet 028	3/31/2010	4.70	6.10	7.50
028	Outlet 028	4/30/2010	3.8	4.40	5.00
028	Outlet 028	5/31/2010	4.70	7.60	10.50

028	Outlet 028	6/30/2010	11.40	11.50	11.60
028	Outlet 028	7/31/2010	6.40	8.50	10.40
028	Outlet 028	8/31/2010	4.80	10.65	14.80
028	Outlet 028	9/30/2010	4.80	9.40	11.00

(b) (5) [redacted]

[redacted]

[redacted]

[redacted]

(b) (5)

[redacted]

[redacted]

[redacted]

[redacted]

[redacted]

Christopher Hunter/DC/USEPA/US
01/12/2011 11:04 AM

To Ross Geredien
cc
bcc
Subject Fw: Instructions and attachments for reviews 30 questions at a time

Chris Hunter
U.S. Environmental Protection Agency
Office of Wetlands, Oceans, & Watershed
(202) 566-1454
hunter.christopher@epa.gov

----- Forwarded by Christopher Hunter/DC/USEPA/US on 01/12/2011 11:04 AM -----

From: Matthew Klasen/DC/USEPA/US
To: Christopher Hunter/DC/USEPA/US@EPA, Stefania Shamet/R3/USEPA/US@EPA
Date: 01/12/2011 10:57 AM
Subject: Re: Fw: Instructions and attachments for reviews 30 questions at a time

Chris and Stef:

Here are the other chunks of RD comments for when people are ready.

ATTACHMENT REDACTED - DELIBERATIVE

mk 181A-210A.docx

Matt Klasen
U.S. Environmental Protection Agency
Office of Water (IO)
202-566-0780
cell (202) 380-7229

Christopher Hunter | Spruce Team, here are the batches of response... | 01/12/2011 09:36:55 AM

From: Christopher Hunter/DC/USEPA/US
To: Ross Geredien/DC/USEPA/US@EPA, Julia McCarthy/R8/USEPA/US@EPA, Palmer Hough/DC/USEPA/US@EPA
Cc: Marcel Tchaou/DC/USEPA/US@EPA, Matthew Klasen/DC/USEPA/US@EPA, Stefania Shamet/R3/USEPA/US@EPA
Date: 01/12/2011 09:36 AM
Subject: Fw: Instructions and attachments for reviews 30 questions at a time

Spruce Team,
here are the batches of responses to comments that need to be checked for references, instructions, and the latest draft of the Reference Appendix. Focus on the references first, then circle back for the cross-references if you have time.

Thanks!

Ross - please take 1-30
Julia - 31-60

Palmer - 61-90

[attachment "Appendix 7 FD Marcel version 1-11-2011Harmonized.doc" deleted by Matthew Klasen/DC/USEPA/US]

Chris Hunter
U.S. Environmental Protection Agency
Office of Wetlands, Oceans, & Watershed
(202) 566-1454
hunter.christopher@epa.gov
----- Forwarded by Christopher Hunter/DC/USEPA/US on 01/12/2011 09:32 AM -----

From:	Matthew Klasen/DC/USEPA/US
To:	Christopher Hunter/DC/USEPA/US@EPA, Stefania Shamet/R3/USEPA/US@EPA
Cc:	Marcel Tchaou/DC/USEPA/US@EPA
Date:	01/12/2011 09:30 AM
Subject:	Instructions and attachments for reviews 30 questions at a time

Chris / Stef:

Here are instructions and responses, broken up in 30-question increments. Chris: Why don't you assign the first couple groups of these, and let Stef know; she can then farm out the next batch to R3.

Thanks,
Matt

Instructions: Go through and do the following:

- **Go through the document once and check for citations.** Verify that each citation included in the response is included in the reference list. If it isn't, make a note of the reference (e.g., Silva 2010) and a sentence for context (e.g., Silva (2010) found that birds are important).
- **Send citations that are missing and context (in groups of five, or once you're done going through the whole document, to Marcel, and copy Matt.** Make sure you include the questions # so Matt can make a note in the master document.
- **Once you're done going through citations, then go back through and check to make sure references to FD/RD/PD or Appendices or Figures/Tables are correct. If not, keep a running list and email Matt all of the changes (just note in an email, not in Track Changes).**

Call Matt (202-566-0780) or Chris (202-566-1454) with any questions.

For Distributing to Volunteers
[attachment "121A-150A.docx" deleted by Matthew Klasen/DC/USEPA/US] [attachment "1A-30A.docx" deleted by Matthew Klasen/DC/USEPA/US] [attachment "31A-60A.docx" deleted by Matthew Klasen/DC/USEPA/US] [attachment "61A-90A.docx" deleted by Matthew Klasen/DC/USEPA/US] [attachment "91A-120A.docx" deleted by Matthew Klasen/DC/USEPA/US]

Background Material (Chris: Also <u>send folks the FD and appendices</u>, especially the reference list. Probably too big for one email.

Matt Klasen
U.S. Environmental Protection Agency
Office of Water (IO)

202-566-0780
cell (202) 380-7229

Christopher Hunter/DC/USEPA/US
01/12/2011 11:06 AM

To Julia McCarthy
cc
bcc
Subject Fw: Instructions and attachments for reviews 30 questions at a time

Chris Hunter
U.S. Environmental Protection Agency
Office of Wetlands, Oceans, & Watershed
(202) 566-1454
hunter.christopher@epa.gov
----- Forwarded by Christopher Hunter/DC/USEPA/US on 01/12/2011 11:06 AM -----

From: Christopher Hunter/DC/USEPA/US
To: Julia McCarthy/R8/USEPA/US@EPA
Date: 01/12/2011 10:58 AM
Subject: Fw: Instructions and attachments for reviews 30 questions at a time

---

Chris Hunter
U.S. Environmental Protection Agency
Office of Wetlands, Oceans, & Watershed
(202) 566-1454
hunter.christopher@epa.gov
----- Forwarded by Christopher Hunter/DC/USEPA/US on 01/12/2011 10:58 AM -----

From: Matthew Klasen/DC/USEPA/US
To: Christopher Hunter/DC/USEPA/US@EPA, Stefania Shamet/R3/USEPA/US@EPA
Date: 01/12/2011 10:57 AM
Subject: Re: Fw: Instructions and attachments for reviews 30 questions at a time

---

Chris and Stef:

Here are the other chunks of RD comments for when people are ready.

mk

151A-180A.docx

ATTACHMENT REDACTED - DELIBERATIVE

Matt Klasen
U.S. Environmental Protection Agency
Office of Water (IO)
202-566-0780
cell (202) 380-7229

Christopher Hunter	Spruce Team, here are the batches of response...	01/12/2011 09:36:55 AM

From: Christopher Hunter/DC/USEPA/US
To: Ross Geredien/DC/USEPA/US@EPA, Julia McCarthy/R8/USEPA/US@EPA, Palmer Hough/DC/USEPA/US@EPA
Cc: Marcel Tchaou/DC/USEPA/US@EPA, Matthew Klasen/DC/USEPA/US@EPA, Stefania Shamet/R3/USEPA/US@EPA
Date: 01/12/2011 09:36 AM
Subject: Fw: Instructions and attachments for reviews 30 questions at a time

---

Spruce Team,
here are the batches of responses to comments that need to be checked for references, instructions, and the latest draft of the Reference Appendix. Focus on the references first, then circle back for the cross-references if you have time.

Thanks!

Ross - please take 1-30
Julia - 31-60
Palmer - 61-90

[attachment "Appendix 7 FD Marcel version 1-11-2011Harmonized.doc" deleted by Matthew Klasen/DC/USEPA/US]

Chris Hunter
U.S. Environmental Protection Agency
Office of Wetlands, Oceans, & Watershed
(202) 566-1454
hunter.christopher@epa.gov
----- Forwarded by Christopher Hunter/DC/USEPA/US on 01/12/2011 09:32 AM -----

From: Matthew Klasen/DC/USEPA/US
To: Christopher Hunter/DC/USEPA/US@EPA, Stefania Shamet/R3/USEPA/US@EPA
Cc: Marcel Tchaou/DC/USEPA/US@EPA
Date: 01/12/2011 09:30 AM
Subject: Instructions and attachments for reviews 30 questions at a time

---

Chris / Stef:

Here are instructions and responses, broken up in 30-question increments. Chris: Why don't you assign the first couple groups of these, and let Stef know; she can then farm out the next batch to R3.

Thanks,
Matt

Instructions: Go through and do the following:

- **Go through the document once and check for citations.** Verify that each citation included in the response is included in the reference list. If it isn't, make a note of the reference (e.g., Silva 2010) and a sentence for context (e.g., Silva (2010) found that birds are important).
- **Send citations that are missing and context (in groups of five, or once you're done going through the whole document, to Marcel, and copy Matt.** Make sure you include the questions # so Matt can make a note in the master document.
- **Once you're done going through citations, then go back through and check to make sure references to FD/RD/PD or Appendices or Figures/Tables are correct. If not, keep a running list and email Matt all of the changes (just note in an email, not in Track Changes).**

Call Matt (202-566-0780) or Chris (202-566-1454) with any questions.

For Distributing to Volunteers
[attachment "121A-150A.docx" deleted by Matthew Klasen/DC/USEPA/US] [attachment "1A-30A.docx" deleted by Matthew Klasen/DC/USEPA/US] [attachment "31A-60A.docx" deleted by Matthew Klasen/DC/USEPA/US] [attachment "61A-90A.docx" deleted by Matthew Klasen/DC/USEPA/US] [attachment "91A-120A.docx" deleted by Matthew Klasen/DC/USEPA/US]

Background Material (Chris: Also send folks the FD and appendices, especially the reference list. Probably too big for one email.

Matt Klasen
U.S. Environmental Protection Agency
Office of Water (IO)
202-566-0780
cell (202) 380-7229

Frank Borsuk/R3/USEPA/US
01/12/2011 11:10 AM

To Stefania Shamet
cc Christopher Hunter, David Rider, Michael Dunn
bcc Frank Borsuk
Subject Attached is the DMR data provided by WVDEP on selenium for July 2008 to March 2010 --Re: Disconnect

2 attachments

selenium DMR data for Frank.xls Rider request WV1017021.xls

Stef

Attached is the DMR record for selenium for the time frame - July 2007 to March 2010. This was a part of a download from WVDEP to USEPA.

Frank
p.s. I will search our electronic files for the other DMR parameters.

p.s.s. Also attached is the January 2010 to September 2010 DMR files for all parameters.

Frank Borsuk, Ph.D.
Aquatic/Fisheries Biologist
Freshwater Biology Team
USEPA-Region 3 (Wheeling Office)
Office of Monitoring & Assessment (3EA50)
Environmental Assessment & Innovation Division
1060 Chapline Street, Suite 303
Wheeling, WV 26003-2995
304-234-0241 Phone
304-234-0260 Fax
borsuk.frank@epa.gov

Please visit our website at http://epa.gov/reg3esd1/3ea50.htm

From: Stefania Shamet/R3/USEPA/US
To: Christopher Hunter/DC/USEPA/US@EPA
Cc: Michael Dunn/R3/USEPA/US@EPA, David Rider/R3/USEPA/US@EPA, Frank Borsuk/R3/USEPA/US@EPA

Date: 01/12/2011 10:53 AM
Subject: Re: Disconnect

Ok.

Chris -- get them on to the index. We physically have them in the Region, so it's ok so long as they are on the index.

Mike -- Can you see if they are on Dave's desk.

Dave/Frank -- if you're checking email -- can you send electronically?

From: Christopher Hunter/DC/USEPA/US
To: Stefania Shamet/R3/USEPA/US@EPA
Date: 01/12/2011 10:48 AM
Subject: Re: Disconnect

I don't think we have copies of the December 08-March 10 DMR for the admin file.

Chris Hunter
U.S. Environmental Protection Agency
Office of Wetlands, Oceans, & Watershed
(202) 566-1454
hunter.christopher@epa.gov

From: Stefania Shamet/R3/USEPA/US
To: Christopher Hunter/DC/USEPA/US@EPA
Date: 01/12/2011 07:24 AM
Subject: Disconnect

(b) (5) [redacted]

I propose that:

(b) (5) [redacted]

[redacted]

[redacted]

[redacted]

[redacted]

[redacted]

[redacted]

Table A1.12. Total Recoverable Selenium (µg/L) for Outfalls 015, 017 and 028 for NPDES Permit WV1017021, Mingo Logan Coal Company Spruce No. 1 Mine. Note: Shaded areas indicate selenium concentrations exceeding 5 µg/L.

Site Code	Site Location	Report Date	Min Value	Avg. value	Max value
015	Outlet 015	12/31/2008	0.00	0.00	0.00
017	Outlet 017	12/31/2008	0.00	0.00	0.00
017	Outlet 017	9/30/2009	19.20	19.20	19.20

028	Outlet 028	12/31/2008	5.70	5.70	5.70
028	Outlet 028	1/31/2009	9.80	9.80	9.80
028	Outlet 028	2/28/2009	3.90	3.90	3.90
028	Outlet 028	3/31/2009	0.60	1.00	1.40
028	Outlet 028	4/30/2009	1.70	1.70	1.70
028	Outlet 028	5/31/2009	2.50	2.50	2.50
028	Outlet 028	6/30/2009	3.20	3.30	3.40
028	Outlet 028	8/31/2009	1.25	3.48	5.70
028	Outlet 028	9/30/2009	4.60	6.05	7.50
028	Outlet 028	10/31/2009	3.00	3.00	3.00
028	Outlet 028	11/30/2009	1.40	1.85	2.30
028	Outlet 028	12/31/2009	1.80	1.85	1.90
028	Outlet 028	1/31/2010	3.40	3.80	4.20
028	Outlet 028	2/28/2010	3.80	4.50	5.20
028	Outlet 028	3/31/2010	4.70	6.10	7.50
028	Outlet 028	4/30/2010	3.8	4.40	5.00
028	Outlet 028	5/31/2010	4.70	7.60	10.50
028	Outlet 028	6/30/2010	11.40	11.50	11.60
028	Outlet 028	7/31/2010	6.40	8.50	10.40
028	Outlet 028	8/31/2010	4.80	10.65	14.80
028	Outlet 028	9/30/2010	4.80	9.40	11.00

(b) (5) [redacted]

[redacted]

[redacted]

(b) (5)

[redacted]

[redacted]

[redacted]

[redacted]

[redacted]

(b) (5)

WV1017021	015	HPU	12/31/2008	NORML	LAB	00981	0.00		0.00	
WV1017021	017	HPU	12/31/2008	NORML	LAB	00981	0.00		0.00	
WV1017021	017	HPU	9/30/2009	NORML	LAB	00981	19.20		19.20	
WV1017021	028	HPU	12/31/2008	NORML	LAB	00981	5.70		5.70	
WV1017021	028	HPU	1/31/2009	NORML	LAB	00981	9.80		9.80	
WV1017021	028	HPU	2/28/2009	NORML	LAB	00981	3.90		3.90	
WV1017021	028	HPU	3/31/2009	NORML	LAB	00981	0.60		1.00	
WV1017021	028	HPU	4/30/2009	NORML	LAB	00981	1.70		1.70	
WV1017021	028	HPU	5/31/2009	NORML	LAB	00981	2.50		2.50	
WV1017021	028	HPU	6/30/2009	NORML	LAB	00981	3.20		3.30	
WV1017021	028	HPU	8/31/2009	NORML	LAB	00981	1.25		3.48	
WV1017021	028	HPU	9/30/2009	NORML	LAB	00981	4.60		6.05	
WV1017021	028	HPU	10/31/2009	NORML	LAB	00981	3.00		3.00	
WV1017021	028	HPU	11/30/2009	NORML	LAB	00981	1.40		1.85	
WV1017021	028	HPU	12/31/2009	NORML	LAB	00981	1.80		1.85	
WV1017021	028	HPU	1/31/2010	NORML	LAB	00981	3.40		3.80	
WV1017021	028	HPU	2/28/2010	NORML	LAB	00981	3.80		4.50	
WV1017021	028	HPU	3/31/2010	NORML	LAB	00981	4.70		6.10	
WV1017021	DOB	HPU	7/31/2007	NORML	LAB	00981	0.00		0.00	
WV1017021	DOB	HPU	8/31/2007	NORML	LAB	00981	0.00		0.00	
WV1017021	DOB	HPU	9/30/2007	NORML	LAB	00981	0.00		0.00	
WV1017021	DOB	HPU	10/31/2007	NORML	LAB	00981	0.00		0.00	
WV1017021	DOB	HPU	11/30/2007	NORML	LAB	00981	0.00		0.00	
WV1017021	DOB	HPU	12/31/2007	NORML	LAB	00981	0.00		0.38	
WV1017021	DOB	HPU	1/31/2008	NORML	LAB	00981	0		0	
WV1017021	DOB	HPU	2/29/2008	NORML	LAB	00981	0.00		0.00	
WV1017021	DOB	HPU	3/31/2008	NORML	LAB	00981	0.00		0.37	
WV1017021	DOB	HPU	4/30/2008	NORML	LAB	00981	0.00		0.00	
WV1017021	DOB	HPU	5/31/2008	NORML	LAB	00981	0.00		0.00	
WV1017021	DOB	HPU	6/30/2008	NORML	LAB	00981	0.00		0.33	
WV1017021	DOB	HPU	9/30/2008	NORML	LAB	00981	0.70		1.10	
WV1017021	DOB	HPU	10/31/2008	NORML	LAB	00981	0.00		0.00	
WV1017021	DOB	HPU	11/30/2008	NORML	LAB	00981	0.00		0.00	
WV1017021	DOB	HPU	12/31/2008	NORML	LAB	00981	0.00		0.00	
WV1017021	DOB	HPU	1/31/2009	NORML	LAB	00981	0.60	<	0.60	<
WV1017021	DOB	HPU	2/28/2009	NORML	LAB	00981	0.60	<	0.60	<
WV1017021	DOB	HPU	3/31/2009	NORML	LAB	00981	0.60	<	0.60	<
WV1017021	DOB	HPU	4/30/2009	NORML	LAB	00981	0.60	<	0.60	<
WV1017021	DOB	HPU	5/31/2009	NORML	LAB	00981	0.60	<	0.60	<
WV1017021	DOB	HPU	6/30/2009	NORML	LAB	00981	0.60	<	0.60	<
WV1017021	DOB	HPU	7/31/2009	NORML	LAB	00981	0.60	<	0.60	
WV1017021	DOB	HPU	8/31/2009	NORML	LAB	00981	0.60	<	0.60	<
WV1017021	DOB	HPU	9/30/2009	NORML	LAB	00981	0.60	<	0.60	<
WV1017021	DOB	HPU	10/31/2009	NORML	LAB	00981	0.60	<	0.60	<
WV1017021	DOB	HPU	11/30/2009	NORML	LAB	00981	0.60	<	0.60	<
WV1017021	DOB	HPU	12/31/2009	NORML	LAB	00981	0.60	<	0.60	<
WV1017021	DOB	HPU	1/31/2010	NORML	LAB	00981	0.60	<	0.60	<
WV1017021	DOB	HPU	2/28/2010	NORML	LAB	00981	0.60	<	0.60	<
WV1017021	DOB	HPU	3/31/2010	NORML	LAB	00981	0.60	<	0.60	<
WV1017021	DPB	HPU	7/31/2007	NORML	LAB	00981	0.00		0.00	
WV1017021	DPB	HPU	8/31/2007	NORML	LAB	00981	0.00		0.00	
WV1017021	DPB	HPU	9/30/2007	NORML	LAB	00981	0.00		0.00	
WV1017021	DPB	HPU	10/31/2007	NORML	LAB	00981	0.00		0.00	

WV1017021	DPB	HPU	11/30/2007	NORML	LAB	00981	0.00		0.00	
WV1017021	DPB	HPU	12/31/2007	NORML	LAB	00981	0.00		0.00	
WV1017021	DPB	HPU	1/31/2008	NORML	LAB	00981	0		0	
WV1017021	DPB	HPU	2/29/2008	NORML	LAB	00981	0.62		0.84	
WV1017021	DPB	HPU	3/31/2008	NORML	LAB	00981	0.00		0.39	
WV1017021	DPB	HPU	4/30/2008	NORML	LAB	00981	0.00		0.00	
WV1017021	DPB	HPU	5/31/2008	NORML	LAB	00981	0.00		0.00	
WV1017021	DPB	HPU	6/30/2008	NORML	LAB	00981	0.00		0.00	
WV1017021	DPB	HPU	9/30/2008	NORML	LAB	00981	0.00		0.00	
WV1017021	DPB	HPU	10/31/2008	NORML	LAB	00981	0.00		0.00	
WV1017021	DPB	HPU	11/30/2008	NORML	LAB	00981	0.00		0.00	
WV1017021	DPB	HPU	12/31/2008	NORML	LAB	00981	0.00		0.00	
WV1017021	DPB	HPU	1/31/2009	NORML	LAB	00981	0.60	<	0.60	<
WV1017021	DPB	HPU	2/28/2009	NORML	LAB	00981	0.60	<	0.60	<
WV1017021	DPB	HPU	3/31/2009	NORML	LAB	00981	0.60	<	0.60	<
WV1017021	DPB	HPU	4/30/2009	NORML	LAB	00981	0.60	<	0.60	<
WV1017021	DPB	HPU	5/31/2009	NORML	LAB	00981	0.60	<	0.60	<
WV1017021	DPB	HPU	6/30/2009	NORML	LAB	00981	0.60	<	0.60	<
WV1017021	DPB	HPU	7/31/2009	NORML	LAB	00981	0.60	<	0.60	<
WV1017021	DPB	HPU	8/31/2009	NORML	LAB	00981	0.70		1.30	
WV1017021	DPB	HPU	9/30/2009	NORML	LAB	00981	0.60	<	0.60	<
WV1017021	DPB	HPU	10/31/2009	NORML	LAB	00981	0.60	<	0.60	<
WV1017021	DPB	HPU	11/30/2009	NORML	LAB	00981	0.60	<	0.60	<
WV1017021	DPB	HPU	12/31/2009	NORML	LAB	00981	0.60	<	0.60	<
WV1017021	DPB	HPU	1/31/2010	NORML	LAB	00981	0.60	<	0.60	<
WV1017021	DPB	HPU	2/28/2010	NORML	LAB	00981	0.60	<	0.60	<
WV1017021	DPB	HPU	3/31/2010	NORML	LAB	00981	0.60	<	0.60	<
WV1017021	DSCB	HPU	7/31/2007	NORML	LAB	00981	0.00		2.02	
WV1017021	DSCB	HPU	8/31/2007	NORML	LAB	00981	0.00		1.70	
WV1017021	DSCB	HPU	9/30/2007	NORML	LAB	00981	0.80		4.75	
WV1017021	DSCB	HPU	10/31/2007	NORML	LAB	00981	0.00		0.00	
WV1017021	DSCB	HPU	11/30/2007	NORML	LAB	00981	0.00		1.65	
WV1017021	DSCB	HPU	12/31/2007	NORML	LAB	00981	1.80		2.48	
WV1017021	DSCB	HPU	1/31/2008	NORML	LAB	00981	1.68		2.43	
WV1017021	DSCB	HPU	2/29/2008	NORML	LAB	00981	1.69		3.40	
WV1017021	DSCB	HPU	3/31/2008	NORML	LAB	00981	2.37		3.54	
WV1017021	DSCB	HPU	4/30/2008	NORML	LAB	00981	1.51		1.80	
WV1017021	DSCB	HPU	5/31/2008	NORML	LAB	00981	1.96		2.53	
WV1017021	DSCB	HPU	6/30/2008	NORML	LAB	00981	3.60		3.62	
WV1017021	DSCB	HPU	9/30/2008	NORML	LAB	00981	0.00		0.00	
WV1017021	DSCB	HPU	10/31/2008	NORML	LAB	00981	0.00		0.35	
WV1017021	DSCB	HPU	11/30/2008	NORML	LAB	00981	0.00		0.70	
WV1017021	DSCB	HPU	12/31/2008	NORML	LAB	00981	2.00		3.00	
WV1017021	DSCB	HPU	1/31/2009	NORML	LAB	00981	1.00		1.25	
WV1017021	DSCB	HPU	2/28/2009	NORML	LAB	00981	0.60	<	0.75	
WV1017021	DSCB	HPU	3/31/2009	NORML	LAB	00981	0.60	<	0.60	<
WV1017021	DSCB	HPU	4/30/2009	NORML	LAB	00981	0.60	<	0.60	<
WV1017021	DSCB	HPU	5/31/2009	NORML	LAB	00981	0.60	<	0.65	
WV1017021	DSCB	HPU	6/30/2009	NORML	LAB	00981	1.20		1.40	
WV1017021	DSCB	HPU	7/31/2009	NORML	LAB	00981	0.60	<	0.55	
WV1017021	DSCB	HPU	8/31/2009	NORML	LAB	00981	2.20		2.35	
WV1017021	DSCB	HPU	9/30/2009	NORML	LAB	00981	0.60	<	0.65	
WV1017021	DSCB	HPU	10/31/2009	NORML	LAB	00981	0.60	<	0.70	

WV1017021	DSCB	HPU	11/30/2009	NORML	LAB	00981	0.60	<	0.60	<
WV1017021	DSCB	HPU	12/31/2009	NORML	LAB	00981	0.60	<	0.60	<
WV1017021	DSCB	HPU	1/31/2010	NORML	LAB	00981	0.80		1.10	
WV1017021	DSCB	HPU	2/28/2010	NORML	LAB	00981	0.80		0.80	
WV1017021	DSCB	HPU	3/31/2010	NORML	LAB	00981	0.60		0.90	
WV1017021	DSF	HPU	7/31/2007	NORML	LAB	00981	0.00		0.56	
WV1017021	DSF	HPU	8/31/2007	NORML	LAB	00981	0.00		0.00	
WV1017021	DSF	HPU	9/30/2007	NORML	LAB	00981	0.00		0.48	
WV1017021	DSF	HPU	10/31/2007	NORML	LAB	00981	0.00		0.68	
WV1017021	DSF	HPU	11/30/2007	NORML	LAB	00981	0.00		0.82	
WV1017021	DSF	HPU	12/31/2007	NORML	LAB	00981	1.61		1.74	
WV1017021	DSF	HPU	1/31/2008	NORML	LAB	00981	1.22		1.54	
WV1017021	DSF	HPU	2/29/2008	NORML	LAB	00981	2.30		3.28	
WV1017021	DSF	HPU	3/31/2008	NORML	LAB	00981	1.64		2.23	
WV1017021	DSF	HPU	4/30/2008	NORML	LAB	00981	1.57		1.85	
WV1017021	DSF	HPU	5/31/2008	NORML	LAB	00981	1.69		1.76	
WV1017021	DSF	HPU	6/30/2008	NORML	LAB	00981	1.81		2.16	
WV1017021	DSF	HPU	9/30/2008	NORML	LAB	00981	0.00		0.00	
WV1017021	DSF	HPU	10/31/2008	NORML	LAB	00981	0.00		0.85	
WV1017021	DSF	HPU	11/30/2008	NORML	LAB	00981	0.00		0.00	
WV1017021	DSF	HPU	12/31/2008	NORML	LAB	00981	0.00		1.25	
WV1017021	DSF	HPU	1/31/2009	NORML	LAB	00981	2.00		2.45	
WV1017021	DSF	HPU	2/28/2009	NORML	LAB	00981	1.00		1.70	
WV1017021	DSF	HPU	3/31/2009	NORML	LAB	00981	0.60	<	0.60	<
WV1017021	DSF	HPU	4/30/2009	NORML	LAB	00981	0.90		1.15	
WV1017021	DSF	HPU	5/31/2009	NORML	LAB	00981	0.60	<	1.05	
WV1017021	DSF	HPU	6/30/2009	NORML	LAB	00981	0.60	<	1.10	
WV1017021	DSF	HPU	7/31/2009	NORML	LAB	00981	0.60	<	0.70	
WV1017021	DSF	HPU	8/31/2009	NORML	LAB	00981	1.60		2.05	
WV1017021	DSF	HPU	9/30/2009	NORML	LAB	00981	1.10		1.25	
WV1017021	DSF	HPU	10/31/2009	NORML	LAB	00981	1.00		1.05	
WV1017021	DSF	HPU	11/30/2009	NORML	LAB	00981	0.60	<	0.30	
WV1017021	DSF	HPU	12/31/2009	NORML	LAB	00981	0.60	<	0.60	<
WV1017021	DSF	HPU	1/31/2010	NORML	LAB	00981	1.10		1.10	
WV1017021	DSF	HPU	2/28/2010	NORML	LAB	00981	1.00		1.10	
WV1017021	DSF	HPU	3/31/2010	NORML	LAB	00981	1.00		1.40	
WV1017021	DWOB	HPU	7/31/2007	NORML	LAB	00981	0.00		1.21	
WV1017021	DWOB	HPU	8/31/2007	NORML	LAB	00981	0.00		0.00	
WV1017021	DWOB	HPU	9/30/2007	NORML	LAB	00981	0.00		0.00	
WV1017021	DWOB	HPU	10/31/2007	NORML	LAB	00981	0.00		0.00	
WV1017021	DWOB	HPU	11/30/2007	NORML	LAB	00981	0.00		0.00	
WV1017021	DWOB	HPU	12/31/2007	NORML	LAB	00981	2.63		2.76	
WV1017021	DWOB	HPU	1/31/2008	NORML	LAB	00981	1.94		2.49	
WV1017021	DWOB	HPU	2/29/2008	NORML	LAB	00981	2.33		3.45	
WV1017021	DWOB	HPU	3/31/2008	NORML	LAB	00981	2.34		2.65	
WV1017021	DWOB	HPU	4/30/2008	NORML	LAB	00981	2.00		2.07	
WV1017021	DWOB	HPU	5/31/2008	NORML	LAB	00981	2.03		2.58	
WV1017021	DWOB	HPU	6/30/2008	NORML	LAB	00981	2.35		3.80	
WV1017021	DWOB	HPU	9/30/2008	NORML	LAB	00981	0.80		1.20	
WV1017021	DWOB	HPU	10/31/2008	NORML	LAB	00981	0.00		0.00	
WV1017021	DWOB	HPU	11/30/2008	NORML	LAB	00981	1.40		1.40	
WV1017021	DWOB	HPU	12/31/2008	NORML	LAB	00981	4.00		4.70	
WV1017021	DWOB	HPU	1/31/2009	NORML	LAB	00981	2.70		3.40	

WV1017021	DWOB	HPU	2/28/2009	NORML	LAB	00981	5.40		6.00	
WV1017021	DWOB	HPU	3/31/2009	NORML	LAB	00981	2.00		2.05	
WV1017021	DWOB	HPU	4/30/2009	NORML	LAB	00981	2.30		2.40	
WV1017021	DWOB	HPU	5/31/2009	NORML	LAB	00981	4.40		4.40	
WV1017021	DWOB	HPU	6/30/2009	NORML	LAB	00981	3.20		3.50	
WV1017021	DWOB	HPU	7/31/2009	NORML	LAB	00981	4.60		5.50	
WV1017021	DWOB	HPU	8/31/2009	NORML	LAB	00981	3.90		4.90	
WV1017021	DWOB	HPU	9/30/2009	NORML	LAB	00981	5.20		6.75	
WV1017021	DWOB	HPU	10/31/2009	NORML	LAB	00981	0.60	<	1.90	
WV1017021	DWOB	HPU	11/30/2009	NORML	LAB	00981	3.20		4.55	
WV1017021	DWOB	HPU	12/31/2009	NORML	LAB	00981	2.40		2.70	
WV1017021	DWOB	HPU	1/31/2010	NORML	LAB	00981	2.10		3.90	
WV1017021	DWOB	HPU	2/28/2010	NORML	LAB	00981	3.20		3.75	
WV1017021	DWOB	HPU	3/31/2010	NORML	LAB	00981	4.70		5.20	
WV1017021	USCB	HPU	7/31/2007	NORML	LAB	00981	0.00		0.00	
WV1017021	USCB	HPU	8/31/2007	NORML	LAB	00981	0.00		0.00	
WV1017021	USCB	HPU	9/30/2007	NORML	LAB	00981	0.00		0.00	
WV1017021	USCB	HPU	10/31/2007	NORML	LAB	00981	0.00		0.00	
WV1017021	USCB	HPU	11/30/2007	NORML	LAB	00981	0.00		0.00	
WV1017021	USCB	HPU	12/31/2007	NORML	LAB	00981	0.00		0.45	
WV1017021	USCB	HPU	1/31/2008	NORML	LAB	00981	0		0	
WV1017021	USCB	HPU	2/29/2008	NORML	LAB	00981	1.17		1.22	
WV1017021	USCB	HPU	3/31/2008	NORML	LAB	00981	0.00		0.38	
WV1017021	USCB	HPU	4/30/2008	NORML	LAB	00981	0.00		0.56	
WV1017021	USCB	HPU	5/31/2008	NORML	LAB	00981	0.65		1.90	
WV1017021	USCB	HPU	6/30/2008	NORML	LAB	00981	0.00		0.68	
WV1017021	USCB	HPU	9/30/2008	NORML	LAB	00981	0.80		0.80	
WV1017021	USCB	HPU	11/30/2008	NORML	LAB	00981	0.00		0.00	
WV1017021	USCB	HPU	12/31/2008	NORML	LAB	00981	0.00		0.00	
WV1017021	USCB	HPU	1/31/2009	NORML	LAB	00981	0.60	<	0.60	<
WV1017021	USCB	HPU	2/28/2009	NORML	LAB	00981	0.60	<	0.45	
WV1017021	USCB	HPU	3/31/2009	NORML	LAB	00981	0.60	<	0.60	<
WV1017021	USCB	HPU	4/30/2009	NORML	LAB	00981	0.60	<	0.45	
WV1017021	USCB	HPU	5/31/2009	NORML	LAB	00981	0.60	<	0.50	
WV1017021	USCB	HPU	6/30/2009	NORML	LAB	00981	0.60	<	0.60	<
WV1017021	USCB	HPU	7/31/2009	NORML	LAB	00981	0.60	<	0.55	
WV1017021	USCB	HPU	8/31/2009	NORML	LAB	00981	0.60	<	0.60	<
WV1017021	USCB	HPU	9/30/2009	NORML	LAB	00981	0.60	<	0.60	<
WV1017021	USCB	HPU	10/31/2009	NORML	LAB	00981	0.60	<	0.60	<
WV1017021	USCB	HPU	11/30/2009	NORML	LAB	00981	0.60	<	0.60	<
WV1017021	USCB	HPU	12/31/2009	NORML	LAB	00981	0.60	<	0.60	<
WV1017021	USCB	HPU	1/31/2010	NORML	LAB	00981	0.60	<	0.60	<
WV1017021	USCB	HPU	2/28/2010	NORML	LAB	00981	0.60	<	0.60	<
WV1017021	USCB	HPU	3/31/2010	NORML	LAB	00981	0.60	<	0.30	
WV1017021	USF	HPU	7/31/2007	NORML	LAB	00981	0.00		0.50	
WV1017021	USF	HPU	8/31/2007	NORML	LAB	00981	0.00		0.00	
WV1017021	USF	HPU	9/30/2007	NORML	LAB	00981	0.00		0.00	
WV1017021	USF	HPU	10/31/2007	NORML	LAB	00981	0.00		0.00	
WV1017021	USF	HPU	11/30/2007	NORML	LAB	00981	0.00		0.00	
WV1017021	USF	HPU	12/31/2007	NORML	LAB	00981	1.44		1.50	
WV1017021	USF	HPU	1/31/2008	NORML	LAB	00981	0		0.76	
WV1017021	USF	HPU	2/29/2008	NORML	LAB	00981	2.31		2.45	
WV1017021	USF	HPU	3/31/2008	NORML	LAB	00981	1.70		1.84	

WV1017021	USF	HPU	4/30/2008	NORML	LAB	00981	1.57		2.26	
WV1017021	USF	HPU	5/31/2008	NORML	LAB	00981	2.22		2.28	
WV1017021	USF	HPU	6/30/2008	NORML	LAB	00981	0.00		0.39	
WV1017021	USF	HPU	9/30/2008	NORML	LAB	00981	0.00		0.00	
WV1017021	USF	HPU	10/31/2008	NORML	LAB	00981	0.00		0.00	
WV1017021	USF	HPU	11/30/2008	NORML	LAB	00981	0.00		0.00	
WV1017021	USF	HPU	12/31/2008	NORML	LAB	00981	0.00		0.90	
WV1017021	USF	HPU	1/31/2009	NORML	LAB	00981	3.10		3.85	
WV1017021	USF	HPU	2/28/2009	NORML	LAB	00981	6.10		8.80	
WV1017021	USF	HPU	3/31/2009	NORML	LAB	00981	2.20		2.40	
WV1017021	USF	HPU	4/30/2009	NORML	LAB	00981	2.80		2.85	
WV1017021	USF	HPU	5/31/2009	NORML	LAB	00981	4.90		4.90	
WV1017021	USF	HPU	6/30/2009	NORML	LAB	00981	4.00		4.00	
WV1017021	USF	HPU	7/31/2009	NORML	LAB	00981	4.10		4.75	
WV1017021	USF	HPU	8/31/2009	NORML	LAB	00981	4.10		5.05	
WV1017021	USF	HPU	9/30/2009	NORML	LAB	00981	5.40		6.80	
WV1017021	USF	HPU	10/31/2009	NORML	LAB	00981	0.60	<	3.10	
WV1017021	USF	HPU	11/30/2009	NORML	LAB	00981	3.00		4.75	
WV1017021	USF	HPU	12/31/2009	NORML	LAB	00981	2.60		3.20	
WV1017021	USF	HPU	1/31/2010	NORML	LAB	00981	2.20		4.45	
WV1017021	USF	HPU	2/28/2010	NORML	LAB	00981	3.60		4.20	
WV1017021	USF	HPU	3/31/2010	NORML	LAB	00981	0.60	<	3.10	
WV1017021	UWOB	HPU	12/31/2007	NORML	LAB	00981	0.00		0.43	
WV1017021	UWOB	HPU	1/31/2008	NORML	LAB	00981	0		0	
WV1017021	UWOB	HPU	2/29/2008	NORML	LAB	00981	0.00		0.00	
WV1017021	UWOB	HPU	3/31/2008	NORML	LAB	00981	0.00		0.00	
WV1017021	UWOB	HPU	4/30/2008	NORML	LAB	00981	0.00		0.00	
WV1017021	UWOB	HPU	5/31/2008	NORML	LAB	00981	0.00		0.00	
WV1017021	UWOB	HPU	6/30/2008	NORML	LAB	00981	0.00		0.47	
WV1017021	UWOB	HPU	9/30/2008	NORML	LAB	00981	0.70		1.20	
WV1017021	UWOB	HPU	10/31/2008	NORML	LAB	00981	0.00		0.00	
WV1017021	UWOB	HPU	12/31/2008	NORML	LAB	00981	0.00		0.00	
WV1017021	UWOB	HPU	1/31/2009	NORML	LAB	00981	0.60	<	0.60	<
WV1017021	UWOB	HPU	2/28/2009	NORML	LAB	00981	0.60	<	0.60	<
WV1017021	UWOB	HPU	3/31/2009	NORML	LAB	00981	0.60	<	0.60	<
WV1017021	UWOB	HPU	4/30/2009	NORML	LAB	00981	0.60	<	0.60	<
WV1017021	UWOB	HPU	5/31/2009	NORML	LAB	00981	0.60	<	0.60	<
WV1017021	UWOB	HPU	6/30/2009	NORML	LAB	00981	0.60	<	0.60	<
WV1017021	UWOB	HPU	7/31/2009	NORML	LAB	00981	0.60	<	0.45	
WV1017021	UWOB	HPU	8/31/2009	NORML	LAB	00981	0.60	<	0.60	<
WV1017021	UWOB	HPU	9/30/2009	NORML	LAB	00981	0.60	<	0.60	<
WV1017021	UWOB	HPU	10/31/2009	NORML	LAB	00981	0.60	<	0.60	<
WV1017021	UWOB	HPU	11/30/2009	NORML	LAB	00981	0.60	<	0.60	<
WV1017021	UWOB	HPU	12/31/2009	NORML	LAB	00981	0.60	<	0.60	<
WV1017021	UWOB	HPU	1/31/2010	NORML	LAB	00981	0.60	<	0.60	<
WV1017021	UWOB	HPU	2/28/2010	NORML	LAB	00981	0.60	<	0.60	<
WV1017021	UWOB	HPU	3/31/2010	NORML	LAB	00981	0.60	<	2.80	

0.00		19	S	GR	N/A	N/A		MG/L	Normal	Selenium, ˙Mingo Logan Coal Company
0.00		19	S	GR	N/A	N/A		MG/L	Normal	Selenium, ˙Mingo Logan Coal Company
19.20		28	S	GR	N/A	N/A		UG/L	Normal	Selenium, ˙Mingo Logan Coal Company
5.70		28	S	GR	N/A	N/A		UG/L	Normal	Selenium, ˙Mingo Logan Coal Company
9.80		28	S	GR	N/A	N/A		UG/L	Normal	Selenium, ˙Mingo Logan Coal Company
3.90		28	S	GR	N/A	N/A		UG/L	Normal	Selenium, ˙Mingo Logan Coal Company
1.40		28	S	GR	N/A	N/A		UG/L	Normal	Selenium, ˙Mingo Logan Coal Company
1.70		28	S	GR	N/A	N/A		UG/L	Normal	Selenium, ˙Mingo Logan Coal Company
2.50		28	S	GR	N/A	N/A		UG/L	Normal	Selenium, ˙Mingo Logan Coal Company
3.40		28	S	GR	N/A	N/A		UG/L	Normal	Selenium, ˙Mingo Logan Coal Company
5.70		28	S	GR	N/A	N/A		UG/L	Normal	Selenium, ˙Mingo Logan Coal Company
7.50		28	S	GR	N/A	N/A		UG/L	Normal	Selenium, ˙Mingo Logan Coal Company
3.00		28	S	GR	N/A	N/A		UG/L	Normal	Selenium, ˙Mingo Logan Coal Company
2.30		28	S	GR	N/A	N/A		UG/L	Normal	Selenium, ˙Mingo Logan Coal Company
1.90		28	S	GR	N/A	N/A		UG/L	Normal	Selenium, ˙Mingo Logan Coal Company
4.20		28	S	GR	N/A	N/A		UG/L	Normal	Selenium, ˙Mingo Logan Coal Company
5.20		28	S	GR	N/A	N/A		UG/L	Normal	Selenium, ˙Mingo Logan Coal Company
7.50		28	S	GR	N/A	N/A		UG/L	Normal	Selenium, ˙Mingo Logan Coal Company
0.00		28	S	GR	N/A	N/A		UG/L	Normal	Selenium, ˙Mingo Logan Coal Company
0.00		28	S	GR	N/A	N/A		UG/L	Normal	Selenium, ˙Mingo Logan Coal Company
0.00		28	S	GR	N/A	N/A		UG/L	Normal	Selenium, ˙Mingo Logan Coal Company
0.00		28	S	GR	N/A	N/A		UG/L	Normal	Selenium, ˙Mingo Logan Coal Company
0.00		28	S	GR	N/A	N/A		UG/L	Normal	Selenium, ˙Mingo Logan Coal Company
0.76		28	S	GR	N/A	N/A		UG/L	Normal	Selenium, ˙Mingo Logan Coal Company
0		28	S	GR	N/A	N/A		UG/L	Normal	Selenium, ˙Mingo Logan Coal Company
0.00		28	S	GR	N/A	N/A		UG/L	Normal	Selenium, ˙Mingo Logan Coal Company
0.74		28	S	GR	N/A	N/A		UG/L	Normal	Selenium, ˙Mingo Logan Coal Company
0.00		28	S	GR	N/A	N/A		UG/L	Normal	Selenium, ˙Mingo Logan Coal Company
0.00		28	S	GR	N/A	N/A		UG/L	Normal	Selenium, ˙Mingo Logan Coal Company
0.66		28	S	GR	N/A	N/A		UG/L	Normal	Selenium, ˙Mingo Logan Coal Company
1.50		28	S	GR	N/A	N/A		UG/L	Normal	Selenium, ˙Mingo Logan Coal Company
0.00		28	S	GR	N/A	N/A		UG/L	Normal	Selenium, ˙Mingo Logan Coal Company
0.00		28	S	GR	N/A	N/A		UG/L	Normal	Selenium, ˙Mingo Logan Coal Company
0.00		28	S	GR	N/A	N/A		UG/L	Normal	Selenium, ˙Mingo Logan Coal Company
0.60	<	28	S	GR	N/A	N/A		UG/L	Normal	Selenium, ˙Mingo Logan Coal Company
0.60	<	28	S	GR	N/A	N/A		UG/L	Normal	Selenium, ˙Mingo Logan Coal Company
0.60	<	28	S	GR	N/A	N/A		UG/L	Normal	Selenium, ˙Mingo Logan Coal Company
0.60	<	28	S	GR	N/A	N/A		UG/L	Normal	Selenium, ˙Mingo Logan Coal Company
0.60	<	28	S	GR	N/A	N/A		UG/L	Normal	Selenium, ˙Mingo Logan Coal Company
0.60	<	28	S	GR	N/A	N/A		UG/L	Normal	Selenium, ˙Mingo Logan Coal Company
0.90		28	S	GR	N/A	N/A		UG/L	Normal	Selenium, ˙Mingo Logan Coal Company
0.60	<	28	S	GR	N/A	N/A		UG/L	Normal	Selenium, ˙Mingo Logan Coal Company
0.60	<	28	S	GR	N/A	N/A		UG/L	Normal	Selenium, ˙Mingo Logan Coal Company
0.60	<	28	S	GR	N/A	N/A		UG/L	Normal	Selenium, ˙Mingo Logan Coal Company
0.60	<	28	S	GR	N/A	N/A		UG/L	Normal	Selenium, ˙Mingo Logan Coal Company
0.60	<	28	S	GR	N/A	N/A		UG/L	Normal	Selenium, ˙Mingo Logan Coal Company
0.60	<	28	S	GR	N/A	N/A		UG/L	Normal	Selenium, ˙Mingo Logan Coal Company
0.60	<	28	S	GR	N/A	N/A		UG/L	Normal	Selenium, ˙Mingo Logan Coal Company
0.00		28	S	GR	N/A	N/A		UG/L	Normal	Selenium, ˙Mingo Logan Coal Company
0.00		28	S	GR	N/A	N/A		UG/L	Normal	Selenium, ˙Mingo Logan Coal Company
0.00		28	S	GR	N/A	N/A		UG/L	Normal	Selenium, ˙Mingo Logan Coal Company
0.00		28	S	GR	N/A	N/A		UG/L	Normal	Selenium, ˙Mingo Logan Coal Company

0.00		28	S	GR	N/A	N/A	UG/L	Normal	Selenium, ˙Mingo Logan Coal Company
0.00		28	S	GR	N/A	N/A	UG/L	Normal	Selenium, ˙Mingo Logan Coal Company
0		28	S	GR	N/A	N/A	UG/L	Normal	Selenium, ˙Mingo Logan Coal Company
1.06		28	S	GR	N/A	N/A	UG/L	Normal	Selenium, ˙Mingo Logan Coal Company
0.78		28	S	GR	N/A	N/A	UG/L	Normal	Selenium, ˙Mingo Logan Coal Company
0.00		28	S	GR	N/A	N/A	UG/L	Normal	Selenium, ˙Mingo Logan Coal Company
0.00		28	S	GR	N/A	N/A	UG/L	Normal	Selenium, ˙Mingo Logan Coal Company
0.00		28	S	GR	N/A	N/A	UG/L	Normal	Selenium, ˙Mingo Logan Coal Company
0.00		28	S	GR	N/A	N/A	UG/L	Normal	Selenium, ˙Mingo Logan Coal Company
0.00		28	S	GR	N/A	N/A	UG/L	Normal	Selenium, ˙Mingo Logan Coal Company
0.00		28	S	GR	N/A	N/A	UG/L	Normal	Selenium, ˙Mingo Logan Coal Company
0.60	<	28	S	GR	N/A	N/A	UG/L	Normal	Selenium, ˙Mingo Logan Coal Company
0.60	<	28	S	GR	N/A	N/A	UG/L	Normal	Selenium, ˙Mingo Logan Coal Company
0.60	<	28	S	GR	N/A	N/A	UG/L	Normal	Selenium, ˙Mingo Logan Coal Company
0.60	<	28	S	GR	N/A	N/A	UG/L	Normal	Selenium, ˙Mingo Logan Coal Company
0.60	<	28	S	GR	N/A	N/A	UG/L	Normal	Selenium, ˙Mingo Logan Coal Company
0.60	<	28	S	GR	N/A	N/A	UG/L	Normal	Selenium, ˙Mingo Logan Coal Company
0.60	<	28	S	GR	N/A	N/A	UG/L	Normal	Selenium, ˙Mingo Logan Coal Company
1.90		28	S	GR	N/A	N/A	UG/L	Normal	Selenium, ˙Mingo Logan Coal Company
0.60	<	28	S	GR	N/A	N/A	UG/L	Normal	Selenium, ˙Mingo Logan Coal Company
0.60	<	28	S	GR	N/A	N/A	UG/L	Normal	Selenium, ˙Mingo Logan Coal Company
0.60	<	28	S	GR	N/A	N/A	UG/L	Normal	Selenium, ˙Mingo Logan Coal Company
0.60	<	28	S	GR	N/A	N/A	UG/L	Normal	Selenium, ˙Mingo Logan Coal Company
0.60	<	28	S	GR	N/A	N/A	UG/L	Normal	Selenium, ˙Mingo Logan Coal Company
0.60	<	28	S	GR	N/A	N/A	UG/L	Normal	Selenium, ˙Mingo Logan Coal Company
0.60	<	28	S	GR	N/A	N/A	UG/L	Normal	Selenium, ˙Mingo Logan Coal Company
4.03		28	S	GR	N/A	N/A	UG/L	Normal	Selenium, ˙Mingo Logan Coal Company
3.40		28	S	GR	N/A	N/A	UG/L	Normal	Selenium, ˙Mingo Logan Coal Company
8.70		28	S	GR	N/A	N/A	UG/L	Normal	Selenium, ˙Mingo Logan Coal Company
0.00		28	S	GR	N/A	N/A	UG/L	Normal	Selenium, ˙Mingo Logan Coal Company
3.30		28	S	GR	N/A	N/A	UG/L	Normal	Selenium, ˙Mingo Logan Coal Company
3.16		28	S	GR	N/A	N/A	UG/L	Normal	Selenium, ˙Mingo Logan Coal Company
3.74		28	S	GR	N/A	N/A	UG/L	Normal	Selenium, ˙Mingo Logan Coal Company
5.10		28	S	GR	N/A	N/A	UG/L	Normal	Selenium, ˙Mingo Logan Coal Company
4.70		28	S	GR	N/A	N/A	UG/L	Normal	Selenium, ˙Mingo Logan Coal Company
2.09		28	S	GR	N/A	N/A	UG/L	Normal	Selenium, ˙Mingo Logan Coal Company
3.09		28	S	GR	N/A	N/A	UG/L	Normal	Selenium, ˙Mingo Logan Coal Company
3.64		28	S	GR	N/A	N/A	UG/L	Normal	Selenium, ˙Mingo Logan Coal Company
0.00		28	S	GR	N/A	N/A	UG/L	Normal	Selenium, ˙Mingo Logan Coal Company
0.70		28	S	GR	N/A	N/A	UG/L	Normal	Selenium, ˙Mingo Logan Coal Company
1.40		28	S	GR	N/A	N/A	UG/L	Normal	Selenium, ˙Mingo Logan Coal Company
4.00		28	S	GR	N/A	N/A	UG/L	Normal	Selenium, ˙Mingo Logan Coal Company
1.50		28	S	GR	N/A	N/A	UG/L	Normal	Selenium, ˙Mingo Logan Coal Company
1.20		28	S	GR	N/A	N/A	UG/L	Normal	Selenium, ˙Mingo Logan Coal Company
0.60	<	28	S	GR	N/A	N/A	UG/L	Normal	Selenium, ˙Mingo Logan Coal Company
0.60	<	28	S	GR	N/A	N/A	UG/L	Normal	Selenium, ˙Mingo Logan Coal Company
1.00		28	S	GR	N/A	N/A	UG/L	Normal	Selenium, ˙Mingo Logan Coal Company
1.60		28	S	GR	N/A	N/A	UG/L	Normal	Selenium, ˙Mingo Logan Coal Company
0.80		28	S	GR	N/A	N/A	UG/L	Normal	Selenium, ˙Mingo Logan Coal Company
2.50		28	S	GR	N/A	N/A	UG/L	Normal	Selenium, ˙Mingo Logan Coal Company
1.00		28	S	GR	N/A	N/A	UG/L	Normal	Selenium, ˙Mingo Logan Coal Company
1.40		28	S	GR	N/A	N/A	UG/L	Normal	Selenium, ˙Mingo Logan Coal Company

0.60	<	28	S	GR	N/A	N/A	UG/L	Normal	Selenium, ˙Mingo Logan Coal Company
0.60	<	28	S	GR	N/A	N/A	UG/L	Normal	Selenium, ˙Mingo Logan Coal Company
1.40		28	S	GR	N/A	N/A	UG/L	Normal	Selenium, ˙Mingo Logan Coal Company
0.80		28	S	GR	N/A	N/A	UG/L	Normal	Selenium, ˙Mingo Logan Coal Company
1.20		28	S	GR	N/A	N/A	UG/L	Normal	Selenium, ˙Mingo Logan Coal Company
1.12		28	S	GR	N/A	N/A	UG/L	Normal	Selenium, ˙Mingo Logan Coal Company
0.00		28	S	GR	N/A	N/A	UG/L	Normal	Selenium, ˙Mingo Logan Coal Company
0.95		28	S	GR	N/A	N/A	UG/L	Normal	Selenium, ˙Mingo Logan Coal Company
1.35		28	S	GR	N/A	N/A	UG/L	Normal	Selenium, ˙Mingo Logan Coal Company
1.64		28	S	GR	N/A	N/A	UG/L	Normal	Selenium, ˙Mingo Logan Coal Company
1.86		28	S	GR	N/A	N/A	UG/L	Normal	Selenium, ˙Mingo Logan Coal Company
2		28	S	GR	N/A	N/A	UG/L	Normal	Selenium, ˙Mingo Logan Coal Company
4.26		28	S	GR	N/A	N/A	UG/L	Normal	Selenium, ˙Mingo Logan Coal Company
2.81		28	S	GR	N/A	N/A	UG/L	Normal	Selenium, ˙Mingo Logan Coal Company
2.12		28	S	GR	N/A	N/A	UG/L	Normal	Selenium, ˙Mingo Logan Coal Company
1.83		28	S	GR	N/A	N/A	UG/L	Normal	Selenium, ˙Mingo Logan Coal Company
2.51		28	S	GR	N/A	N/A	UG/L	Normal	Selenium, ˙Mingo Logan Coal Company
0.00		28	S	GR	N/A	N/A	UG/L	Normal	Selenium, ˙Mingo Logan Coal Company
1.70		28	S	GR	N/A	N/A	UG/L	Normal	Selenium, ˙Mingo Logan Coal Company
0.00		28	S	GR	N/A	N/A	UG/L	Normal	Selenium, ˙Mingo Logan Coal Company
2.50		28	S	GR	N/A	N/A	UG/L	Normal	Selenium, ˙Mingo Logan Coal Company
2.90		28	S	GR	N/A	N/A	UG/L	Normal	Selenium, ˙Mingo Logan Coal Company
2.40		28	S	GR	N/A	N/A	UG/L	Normal	Selenium, ˙Mingo Logan Coal Company
0.60	<	28	S	GR	N/A	N/A	UG/L	Normal	Selenium, ˙Mingo Logan Coal Company
1.40		28	S	GR	N/A	N/A	UG/L	Normal	Selenium, ˙Mingo Logan Coal Company
1.80		28	S	GR	N/A	N/A	UG/L	Normal	Selenium, ˙Mingo Logan Coal Company
1.90		28	S	GR	N/A	N/A	UG/L	Normal	Selenium, ˙Mingo Logan Coal Company
1.10		28	S	GR	N/A	N/A	UG/L	Normal	Selenium, ˙Mingo Logan Coal Company
2.50		28	S	GR	N/A	N/A	UG/L	Normal	Selenium, ˙Mingo Logan Coal Company
1.40		28	S	GR	N/A	N/A	UG/L	Normal	Selenium, ˙Mingo Logan Coal Company
1.10		28	S	GR	N/A	N/A	UG/L	Normal	Selenium, ˙Mingo Logan Coal Company
0.60		28	S	GR	N/A	N/A	UG/L	Normal	Selenium, ˙Mingo Logan Coal Company
0.60	<	28	S	GR	N/A	N/A	UG/L	Normal	Selenium, ˙Mingo Logan Coal Company
1.10		28	S	GR	N/A	N/A	UG/L	Normal	Selenium, ˙Mingo Logan Coal Company
1.20		28	S	GR	N/A	N/A	UG/L	Normal	Selenium, ˙Mingo Logan Coal Company
1.80		28	S	GR	N/A	N/A	UG/L	Normal	Selenium, ˙Mingo Logan Coal Company
2.41		28	S	GR	N/A	N/A	UG/L	Normal	Selenium, ˙Mingo Logan Coal Company
0.00		28	S	GR	N/A	N/A	UG/L	Normal	Selenium, ˙Mingo Logan Coal Company
0.00		28	S	GR	N/A	N/A	UG/L	Normal	Selenium, ˙Mingo Logan Coal Company
0.00		28	S	GR	N/A	N/A	UG/L	Normal	Selenium, ˙Mingo Logan Coal Company
0.00		28	S	GR	N/A	N/A	UG/L	Normal	Selenium, ˙Mingo Logan Coal Company
2.89		28	S	GR	N/A	N/A	UG/L	Normal	Selenium, ˙Mingo Logan Coal Company
3.04		28	S	GR	N/A	N/A	UG/L	Normal	Selenium, ˙Mingo Logan Coal Company
4.57		28	S	GR	N/A	N/A	UG/L	Normal	Selenium, ˙Mingo Logan Coal Company
2.96		28	S	GR	N/A	N/A	UG/L	Normal	Selenium, ˙Mingo Logan Coal Company
2.13		28	S	GR	N/A	N/A	UG/L	Normal	Selenium, ˙Mingo Logan Coal Company
3.12		28	S	GR	N/A	N/A	UG/L	Normal	Selenium, ˙Mingo Logan Coal Company
5.25		28	S	GR	N/A	N/A	UG/L	Normal	Selenium, ˙Mingo Logan Coal Company
1.60		28	S	GR	N/A	N/A	UG/L	Normal	Selenium, ˙Mingo Logan Coal Company
0.00		28	S	GR	N/A	N/A	UG/L	Normal	Selenium, ˙Mingo Logan Coal Company
1.40		28	S	GR	N/A	N/A	UG/L	Normal	Selenium, ˙Mingo Logan Coal Company
5.40		28	S	GR	N/A	N/A	UG/L	Normal	Selenium, ˙Mingo Logan Coal Company
4.10		28	S	GR	N/A	N/A	UG/L	Normal	Selenium, ˙Mingo Logan Coal Company

6.60		28	S	GR	N/A	N/A	UG/L	Normal	Selenium, ˙Mingo Logan Coal Company
2.10		28	S	GR	N/A	N/A	UG/L	Normal	Selenium, ˙Mingo Logan Coal Company
2.50		28	S	GR	N/A	N/A	UG/L	Normal	Selenium, ˙Mingo Logan Coal Company
4.40		28	S	GR	N/A	N/A	UG/L	Normal	Selenium, ˙Mingo Logan Coal Company
3.80		28	S	GR	N/A	N/A	UG/L	Normal	Selenium, ˙Mingo Logan Coal Company
6.40		28	S	GR	N/A	N/A	UG/L	Normal	Selenium, ˙Mingo Logan Coal Company
5.90		28	S	GR	N/A	N/A	UG/L	Normal	Selenium, ˙Mingo Logan Coal Company
8.30		28	S	GR	N/A	N/A	UG/L	Normal	Selenium, ˙Mingo Logan Coal Company
3.80		28	S	GR	N/A	N/A	UG/L	Normal	Selenium, ˙Mingo Logan Coal Company
5.90		28	S	GR	N/A	N/A	UG/L	Normal	Selenium, ˙Mingo Logan Coal Company
3.00		28	S	GR	N/A	N/A	UG/L	Normal	Selenium, ˙Mingo Logan Coal Company
5.70		28	S	GR	N/A	N/A	UG/L	Normal	Selenium, ˙Mingo Logan Coal Company
4.30		28	S	GR	N/A	N/A	UG/L	Normal	Selenium, ˙Mingo Logan Coal Company
5.70		28	S	GR	N/A	N/A	UG/L	Normal	Selenium, ˙Mingo Logan Coal Company
0.00		28	S	GR	N/A	N/A	UG/L	Normal	Selenium, ˙Mingo Logan Coal Company
0.00		28	S	GR	N/A	N/A	UG/L	Normal	Selenium, ˙Mingo Logan Coal Company
0.00		28	S	GR	N/A	N/A	UG/L	Normal	Selenium, ˙Mingo Logan Coal Company
0.00		28	S	GR	N/A	N/A	UG/L	Normal	Selenium, ˙Mingo Logan Coal Company
0.00		28	S	GR	N/A	N/A	UG/L	Normal	Selenium, ˙Mingo Logan Coal Company
0.90		28	S	GR	N/A	N/A	UG/L	Normal	Selenium, ˙Mingo Logan Coal Company
0		28	S	GR	N/A	N/A	UG/L	Normal	Selenium, ˙Mingo Logan Coal Company
1.26		28	S	GR	N/A	N/A	UG/L	Normal	Selenium, ˙Mingo Logan Coal Company
0.75		28	S	GR	N/A	N/A	UG/L	Normal	Selenium, ˙Mingo Logan Coal Company
1.11		28	S	GR	N/A	N/A	UG/L	Normal	Selenium, ˙Mingo Logan Coal Company
3.15		28	S	GR	N/A	N/A	UG/L	Normal	Selenium, ˙Mingo Logan Coal Company
1.35		28	S	GR	N/A	N/A	UG/L	Normal	Selenium, ˙Mingo Logan Coal Company
0.80		28	S	GR	N/A	N/A	UG/L	Normal	Selenium, ˙Mingo Logan Coal Company
0.00		28	S	GR	N/A	N/A	UG/L	Normal	Selenium, ˙Mingo Logan Coal Company
0.00		28	S	GR	N/A	N/A	UG/L	Normal	Selenium, ˙Mingo Logan Coal Company
0.60	<	28	S	GR	N/A	N/A	UG/L	Normal	Selenium, ˙Mingo Logan Coal Company
0.60		28	S	GR	N/A	N/A	UG/L	Normal	Selenium, ˙Mingo Logan Coal Company
0.60	<	28	S	GR	N/A	N/A	UG/L	Normal	Selenium, ˙Mingo Logan Coal Company
0.60		28	S	GR	N/A	N/A	UG/L	Normal	Selenium, ˙Mingo Logan Coal Company
0.70		28	S	GR	N/A	N/A	UG/L	Normal	Selenium, ˙Mingo Logan Coal Company
0.60	<	28	S	GR	N/A	N/A	UG/L	Normal	Selenium, ˙Mingo Logan Coal Company
0.80		28	S	GR	N/A	N/A	UG/L	Normal	Selenium, ˙Mingo Logan Coal Company
0.60	<	28	S	GR	N/A	N/A	UG/L	Normal	Selenium, ˙Mingo Logan Coal Company
0.60	<	28	S	GR	N/A	N/A	UG/L	Normal	Selenium, ˙Mingo Logan Coal Company
0.60	<	28	S	GR	N/A	N/A	UG/L	Normal	Selenium, ˙Mingo Logan Coal Company
0.60	<	28	S	GR	N/A	N/A	UG/L	Normal	Selenium, ˙Mingo Logan Coal Company
0.60	<	28	S	GR	N/A	N/A	UG/L	Normal	Selenium, ˙Mingo Logan Coal Company
0.60	<	28	S	GR	N/A	N/A	UG/L	Normal	Selenium, ˙Mingo Logan Coal Company
0.60	<	28	S	GR	N/A	N/A	UG/L	Normal	Selenium, ˙Mingo Logan Coal Company
0.60		28	S	GR	N/A	N/A	UG/L	Normal	Selenium, ˙Mingo Logan Coal Company
1.00		28	S	GR	N/A	N/A	UG/L	Normal	Selenium, ˙Mingo Logan Coal Company
0.00		28	S	GR	N/A	N/A	UG/L	Normal	Selenium, ˙Mingo Logan Coal Company
0.00		28	S	GR	N/A	N/A	UG/L	Normal	Selenium, ˙Mingo Logan Coal Company
0.00		28	S	GR	N/A	N/A	UG/L	Normal	Selenium, ˙Mingo Logan Coal Company
0.00		28	S	GR	N/A	N/A	UG/L	Normal	Selenium, ˙Mingo Logan Coal Company
1.55		28	S	GR	N/A	N/A	UG/L	Normal	Selenium, ˙Mingo Logan Coal Company
1.52		28	S	GR	N/A	N/A	UG/L	Normal	Selenium, ˙Mingo Logan Coal Company
2.58		28	S	GR	N/A	N/A	UG/L	Normal	Selenium, ˙Mingo Logan Coal Company
1.97		28	S	GR	N/A	N/A	UG/L	Normal	Selenium, ˙Mingo Logan Coal Company

2.95		28	S	GR	N/A	N/A	UG/L	Normal	Selenium, ˙Mingo Logan Coal Company
2.33		28	S	GR	N/A	N/A	UG/L	Normal	Selenium, ˙Mingo Logan Coal Company
0.78		28	S	GR	N/A	N/A	UG/L	Normal	Selenium, ˙Mingo Logan Coal Company
0.00		28	S	GR	N/A	N/A	UG/L	Normal	Selenium, ˙Mingo Logan Coal Company
0.00		28	S	GR	N/A	N/A	UG/L	Normal	Selenium, ˙Mingo Logan Coal Company
0.00		28	S	GR	N/A	N/A	UG/L	Normal	Selenium, ˙Mingo Logan Coal Company
1.80		28	S	GR	N/A	N/A	UG/L	Normal	Selenium, ˙Mingo Logan Coal Company
4.60		28	S	GR	N/A	N/A	UG/L	Normal	Selenium, ˙Mingo Logan Coal Company
11.50		28	S	GR	N/A	N/A	UG/L	Normal	Selenium, ˙Mingo Logan Coal Company
2.60		28	S	GR	N/A	N/A	UG/L	Normal	Selenium, ˙Mingo Logan Coal Company
2.90		28	S	GR	N/A	N/A	UG/L	Normal	Selenium, ˙Mingo Logan Coal Company
4.90		28	S	GR	N/A	N/A	UG/L	Normal	Selenium, ˙Mingo Logan Coal Company
4.00		28	S	GR	N/A	N/A	UG/L	Normal	Selenium, ˙Mingo Logan Coal Company
5.40		28	S	GR	N/A	N/A	UG/L	Normal	Selenium, ˙Mingo Logan Coal Company
6.00		28	S	GR	N/A	N/A	UG/L	Normal	Selenium, ˙Mingo Logan Coal Company
8.20		28	S	GR	N/A	N/A	UG/L	Normal	Selenium, ˙Mingo Logan Coal Company
6.20		28	S	GR	N/A	N/A	UG/L	Normal	Selenium, ˙Mingo Logan Coal Company
6.50		28	S	GR	N/A	N/A	UG/L	Normal	Selenium, ˙Mingo Logan Coal Company
3.80		28	S	GR	N/A	N/A	UG/L	Normal	Selenium, ˙Mingo Logan Coal Company
6.70		28	S	GR	N/A	N/A	UG/L	Normal	Selenium, ˙Mingo Logan Coal Company
4.80		28	S	GR	N/A	N/A	UG/L	Normal	Selenium, ˙Mingo Logan Coal Company
6.20		28	S	GR	N/A	N/A	UG/L	Normal	Selenium, ˙Mingo Logan Coal Company
0.86		28	S	GR	N/A	N/A	UG/L	Normal	Selenium, ˙Mingo Logan Coal Company
0		28	S	GR	N/A	N/A	UG/L	Normal	Selenium, ˙Mingo Logan Coal Company
0.00		28	S	GR	N/A	N/A	UG/L	Normal	Selenium, ˙Mingo Logan Coal Company
0.00		28	S	GR	N/A	N/A	UG/L	Normal	Selenium, ˙Mingo Logan Coal Company
0.00		28	S	GR	N/A	N/A	UG/L	Normal	Selenium, ˙Mingo Logan Coal Company
0.00		28	S	GR	N/A	N/A	UG/L	Normal	Selenium, ˙Mingo Logan Coal Company
0.93		28	S	GR	N/A	N/A	UG/L	Normal	Selenium, ˙Mingo Logan Coal Company
1.70		28	S	GR	N/A	N/A	UG/L	Normal	Selenium, ˙Mingo Logan Coal Company
0.00		28	S	GR	N/A	N/A	UG/L	Normal	Selenium, ˙Mingo Logan Coal Company
0.00		28	S	GR	N/A	N/A	UG/L	Normal	Selenium, ˙Mingo Logan Coal Company
0.60	<	28	S	GR	N/A	N/A	UG/L	Normal	Selenium, ˙Mingo Logan Coal Company
0.60	<	28	S	GR	N/A	N/A	UG/L	Normal	Selenium, ˙Mingo Logan Coal Company
0.60	<	28	S	GR	N/A	N/A	UG/L	Normal	Selenium, ˙Mingo Logan Coal Company
0.60	<	28	S	GR	N/A	N/A	UG/L	Normal	Selenium, ˙Mingo Logan Coal Company
0.60	<	28	S	GR	N/A	N/A	UG/L	Normal	Selenium, ˙Mingo Logan Coal Company
0.60	<	28	S	GR	N/A	N/A	UG/L	Normal	Selenium, ˙Mingo Logan Coal Company
0.60		28	S	GR	N/A	N/A	UG/L	Normal	Selenium, ˙Mingo Logan Coal Company
0.60	<	28	S	GR	N/A	N/A	UG/L	Normal	Selenium, ˙Mingo Logan Coal Company
0.60	<	28	S	GR	N/A	N/A	UG/L	Normal	Selenium, ˙Mingo Logan Coal Company
0.60	<	28	S	GR	N/A	N/A	UG/L	Normal	Selenium, ˙Mingo Logan Coal Company
0.60	<	28	S	GR	N/A	N/A	UG/L	Normal	Selenium, ˙Mingo Logan Coal Company
0.60	<	28	S	GR	N/A	N/A	UG/L	Normal	Selenium, ˙Mingo Logan Coal Company
0.60	<	28	S	GR	N/A	N/A	UG/L	Normal	Selenium, ˙Mingo Logan Coal Company
0.60	<	28	S	GR	N/A	N/A	UG/L	Normal	Selenium, ˙Mingo Logan Coal Company
5.60		28	S	GR	N/A	N/A	UG/L	Normal	Selenium, ˙Mingo Logan Coal Company

permit no.	outlet	date	dmr type ind	parameter	quantity minimum	quantity minimum mdl	quantity average	quantity average mdl	quantity maximum	quantity maximum md
WV1017021	001	1/31/2010 00:00:00	NCONS							
WV1017021	001	2/28/2010 00:00:00	NCONS							
WV1017021	001	3/31/2010 00:00:00	NCONS							
WV1017021	001	4/30/2010 00:00:00	NCONS							
WV1017021	001	5/31/2010 00:00:00	NCONS							
WV1017021	001	6/30/2010 00:00:00	NCONS							
WV1017021	001	7/31/2010 00:00:00	NCONS							
WV1017021	001	8/31/2010 00:00:00	NCONS							
WV1017021	001	9/30/2010 00:00:00	NCONS							
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WV1017021	002	2/28/2010 00:00:00	NCONS							
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WV1017021	002	8/31/2010 00:00:00	NCONS							
WV1017021	002	9/30/2010 00:00:00	NCONS							
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WV1017021	003	9/30/2010 00:00:00	NCONS							
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WV1017021	004	2/28/2010 00:00:00	NCONS							
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WV1017021	004	4/30/2010 00:00:00	NCONS							
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WV1017021	025	3/31/2010 00:00:00	NCONS
WV1017021	025	4/30/2010 00:00:00	NCONS
WV1017021	025	5/31/2010 00:00:00	NCONS
WV1017021	025	6/30/2010 00:00:00	NCONS
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WV1017021	025	8/31/2010 00:00:00	NCONS
WV1017021	025	9/30/2010 00:00:00	NCONS
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WV1017021	026	3/31/2010 00:00:00	NCONS
WV1017021	026	4/30/2010 00:00:00	NCONS

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WV1017021	026	6/30/2010 00:00:00	NCONS				
WV1017021	026	7/31/2010 00:00:00	NCONS				
WV1017021	026	8/31/2010 00:00:00	NCONS				
WV1017021	026	9/30/2010 00:00:00	NCONS				
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WV1017021	027	2/28/2010 00:00:00	NCONS				
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WV1017021	027	4/30/2010 00:00:00	NCONS				
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WV1017021	027	6/30/2010 00:00:00	NCONS				
WV1017021	027	7/31/2010 00:00:00	NCONS				
WV1017021	027	8/31/2010 00:00:00	NCONS				
WV1017021	027	9/30/2010 00:00:00	NCONS				
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WV1017021	028	2/28/2010 00:00:00	NORML	00058	575.000	662.500	750.000
WV1017021	028	3/31/2010 00:00:00	NORML	00058	665.000	713.500	762.000
WV1017021	028	4/30/2010 00:00:00	NORML	00058	277.000	408.500	540.000
WV1017021	028	5/31/2010 00:00:00	NORML	00058	195.000	644.500	1094.000
WV1017021	028	6/30/2010 00:00:00	NORML	00058	150.000	210.500	271.000
WV1017021	028	7/31/2010 00:00:00	NORML	00058		350	927
WV1017021	028	8/31/2010 00:00:00	NORML	00058		233.25	468
WV1017021	028	9/30/2010 00:00:00	NORML	00058		32 29	88
WV1017021	028	1/31/2010 00:00:00	NORML	00400			
WV1017021	028	2/28/2010 00:00:00	NORML	00400			
WV1017021	028	3/31/2010 00:00:00	NORML	00400			
WV1017021	028	4/30/2010 00:00:00	NORML	00400			
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WV1017021	028	6/30/2010 00:00:00	NORML	00400			
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WV1017021	028	8/31/2010 00:00:00	NORML	00400			
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WV1017021	028	9/30/2010 00:00:00	NORML	01106
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WV1017021	029	2/28/2010 00:00:00	NCONS	
WV1017021	029	3/31/2010 00:00:00	NCONS	
WV1017021	029	4/30/2010 00:00:00	NCONS	
WV1017021	029	5/31/2010 00:00:00	NCONS	
WV1017021	029	6/30/2010 00:00:00	NCONS	
WV1017021	029	7/31/2010 00:00:00	NCONS	
WV1017021	029	9/30/2010 00:00:00	NCONS	
WV1017021	031	1/31/2010 00:00:00	NCONS	
WV1017021	031	2/28/2010 00:00:00	NCONS	
WV1017021	031	3/31/2010 00:00:00	NCONS	

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WV1017021	031	5/31/2010 00:00:00	NFLOW				
WV1017021	031	6/30/2010 00:00:00	NFLOW				
WV1017021	031	7/31/2010 00:00:00	NFLOW				
WV1017021	031	8/31/2010 00:00:00	NFLOW				
WV1017021	031	9/30/2010 00:00:00	NFLOW				
WV1017021	032	1/31/2010 00:00:00	NCONS				
WV1017021	032	2/28/2010 00:00:00	NCONS				
WV1017021	032	3/31/2010 00:00:00	NCONS				
WV1017021	032	4/30/2010 00:00:00	NCONS				
WV1017021	032	5/31/2010 00:00:00	NCONS				
WV1017021	032	6/30/2010 00:00:00	NCONS				
WV1017021	032	7/31/2010 00:00:00	NCONS				
WV1017021	032	9/30/2010 00:00:00	NCONS				
WV1017021	033	1/31/2010 00:00:00	NCONS				
WV1017021	033	2/28/2010 00:00:00	NCONS				
WV1017021	033	3/31/2010 00:00:00	NCONS				
WV1017021	033	4/30/2010 00:00:00	NCONS				
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WV1017021	033	6/30/2010 00:00:00	NCONS				
WV1017021	033	7/31/2010 00:00:00	NCONS				
WV1017021	033	8/31/2010 00:00:00	NCONS				
WV1017021	033	9/30/2010 00:00:00	NCONS				
WV1017021	DOB	1/31/2010 00:00:00	NORML	00061	0.880	1.739	2.598
WV1017021	DOB	2/28/2010 00:00:00	NORML	00061	1.913	2.133	2.352
WV1017021	DOB	3/31/2010 00:00:00	NORML	00061	0.614	1.323	2.032
WV1017021	DOB	4/30/2010 00:00:00	NORML	00061	0.401	0.775	1.149
WV1017021	DOB	5/31/2010 00:00:00	NORML	00061	0.407	0.610	0.813
WV1017021	DOB	6/30/2010 00:00:00	NORML	00061	0.352	0.481	0.610
WV1017021	DOB	7/31/2010 00:00:00	NORML	00061		0.149	0.213
WV1017021	DOB	8/31/2010 00:00:00	NORML	00061		0.252	0.256
WV1017021	DOB	9/30/2010 00:00:00	NORML	00061		0.092	0.153
WV1017021	DOB	1/31/2010 00:00:00	NORML	00400			
WV1017021	DOB	2/28/2010 00:00:00	NORML	00400			
WV1017021	DOB	3/31/2010 00:00:00	NORML	00400			
WV1017021	DOB	4/30/2010 00:00:00	NORML	00400			
WV1017021	DOB	5/31/2010 00:00:00	NORML	00400			
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WV1017021	DPB	2/28/2010 00:00:00	NORML	00061	1.664	1.760	1.856
WV1017021	DPB	3/31/2010 00:00:00	NORML	00061	0.848	1.524	2.199
WV1017021	DPB	4/30/2010 00:00:00	NORML	00061	1.154	1.372	1.590
WV1017021	DPB	5/31/2010 00:00:00	NORML	00061	1.073	1.344	1.615
WV1017021	DPB	6/30/2010 00:00:00	NORML	00061	0.612	1.472	2.332
WV1017021	DPB	7/31/2010 00:00:00	NORML	00061		0.812	0.931
WV1017021	DPB	8/31/2010 00:00:00	NORML	00061		0.554	0.811
WV1017021	DPB	9/30/2010 00:00:00	NORML	00061		0.365	0.539
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WV1017021	DSCB	3/31/2010 00:00:00	NORML	00061	3.449	4.603	5.757
WV1017021	DSCB	4/30/2010 00:00:00	NORML	00061	0.512	2.322	4.131
WV1017021	DSCB	5/31/2010 00:00:00	NORML	00061	2.627	5.110	7.593
WV1017021	DSCB	6/30/2010 00:00:00	NORML	00061	1.176	3.393	5.610
WV1017021	DSCB	7/31/2010 00:00:00	NORML	00061		2.434	2.896
WV1017021	DSCB	8/31/2010 00:00:00	NORML	00061		1.651	1.762
WV1017021	DSCB	9/30/2010 00:00:00	NORML	00061		0.344	0.358
WV1017021	DSCB	1/31/2010 00:00:00	NORML	00400			
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WV1017021	DSF	2/28/2010 00:00:00	NORML	00061	17.807	20 916	24.024
WV1017021	DSF	3/31/2010 00:00:00	NORML	00061	19.191	29 841	40.490
WV1017021	DSF	4/30/2010 00:00:00	NORML	00061	16.334	21 681	27.027
WV1017021	DSF	5/31/2010 00:00:00	NORML	00061	18.959	21 660	24.360
WV1017021	DSF	6/30/2010 00:00:00	NORML	00061	6.143	16 320	26.497
WV1017021	DSF	7/31/2010 00:00:00	NORML	00061		18 9045	21.392
WV1017021	DSF	8/31/2010 00:00:00	NORML	00061		5.4065	5.586
WV1017021	DSF	9/30/2010 00:00:00	NORML	00061		3.748	3.959
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WV1017021	DWOB	2/28/2010 00:00:00	NORML	00061	10.846	13.183	15.519
WV1017021	DWOB	3/31/2010 00:00:00	NORML	00061	11.934	12 337	12.740
WV1017021	DWOB	4/30/2010 00:00:00	NORML	00061	6.082	8.809	11.535
WV1017021	DWOB	5/31/2010 00:00:00	NORML	00061	12.782	15.526	18.270
WV1017021	DWOB	6/30/2010 00:00:00	NORML	00061	4.768	5.854	6.940
WV1017021	DWOB	7/31/2010 00:00:00	NORML	00061		7.915	7.954
WV1017021	DWOB	8/31/2010 00:00:00	NORML	00061		5.170	6.272
WV1017021	DWOB	9/30/2010 00:00:00	NORML	00061		2.213	2.339
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WV1017021	DWOB	5/31/2010 00:00:00	NORML	01105			
WV1017021	DWOB	6/30/2010 00:00:00	NORML	01105			
WV1017021	DWOB	7/31/2010 00:00:00	NORML	01105			
WV1017021	DWOB	8/31/2010 00:00:00	NORML	01105			
WV1017021	DWOB	9/30/2010 00:00:00	NORML	01105			
WV1017021	DWOB	1/31/2010 00:00:00	NORML	01106			
WV1017021	DWOB	2/28/2010 00:00:00	NORML	01106			
WV1017021	DWOB	3/31/2010 00:00:00	NORML	01106			
WV1017021	DWOB	4/30/2010 00:00:00	NORML	01106			
WV1017021	DWOB	5/31/2010 00:00:00	NORML	01106			
WV1017021	DWOB	6/30/2010 00:00:00	NORML	01106			
WV1017021	DWOB	7/31/2010 00:00:00	NORML	01106			
WV1017021	DWOB	8/31/2010 00:00:00	NORML	01106			
WV1017021	DWOB	9/30/2010 00:00:00	NORML	01106			
WV1017021	USCB	1/31/2010 00:00:00	NORML	00061	5.416	5.648	5.880
WV1017021	USCB	2/28/2010 00:00:00	NORML	00061	0.929	3.333	5.737
WV1017021	USCB	3/31/2010 00:00:00	NORML	00061	1.069	1.704	2.339
WV1017021	USCB	4/30/2010 00:00:00	NORML	00061	0.670	1.383	2.096
WV1017021	USCB	5/31/2010 00:00:00	NORML	00061	2.883	3.889	4.895
WV1017021	USCB	6/30/2010 00:00:00	NORML	00061	0.893	1.164	1.434
WV1017021	USCB	7/31/2010 00:00:00	NORML	00061		0.973	1.343
WV1017021	USCB	8/31/2010 00:00:00	NORML	00061		0.515	0.548
WV1017021	USCB	9/30/2010 00:00:00	NORML	00061		0.247	0.365
WV1017021	USCB	1/31/2010 00:00:00	NORML	00400			
WV1017021	USCB	2/28/2010 00:00:00	NORML	00400			
WV1017021	USCB	3/31/2010 00:00:00	NORML	00400			

WV1017021	USCB	4/30/2010 00:00:00	NORML	00400
WV1017021	USCB	5/31/2010 00:00:00	NORML	00400
WV1017021	USCB	6/30/2010 00:00:00	NORML	00400
WV1017021	USCB	7/31/2010 00:00:00	NORML	00400
WV1017021	USCB	8/31/2010 00:00:00	NORML	00400
WV1017021	USCB	9/30/2010 00:00:00	NORML	00400
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WV1017021	USCB	2/28/2010 00:00:00	NORML	00981
WV1017021	USCB	3/31/2010 00:00:00	NORML	00981
WV1017021	USCB	4/30/2010 00:00:00	NORML	00981
WV1017021	USCB	5/31/2010 00:00:00	NORML	00981
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WV1017021	USCB	7/31/2010 00:00:00	NORML	00981
WV1017021	USCB	8/31/2010 00:00:00	NORML	00981
WV1017021	USCB	9/30/2010 00:00:00	NORML	00981
WV1017021	USCB	1/31/2010 00:00:00	NORML	01045
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WV1017021	USCB	8/31/2010 00:00:00	NORML	01045
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WV1017021	USCB	7/31/2010 00:00:00	NORML	01105
WV1017021	USCB	8/31/2010 00:00:00	NORML	01105
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WV1017021	USCB	1/31/2010 00:00:00	NORML	01106
WV1017021	USCB	2/28/2010 00:00:00	NORML	01106
WV1017021	USCB	3/31/2010 00:00:00	NORML	01106
WV1017021	USCB	4/30/2010 00:00:00	NORML	01106
WV1017021	USCB	5/31/2010 00:00:00	NORML	01106
WV1017021	USCB	6/30/2010 00:00:00	NORML	01106
WV1017021	USCB	7/31/2010 00:00:00	NORML	01106
WV1017021	USCB	8/31/2010 00:00:00	NORML	01106

WV1017021	USCB	9/30/2010 00:00:00	NORML	01106			
WV1017021	USF	1/31/2010 00:00:00	NORML	00061	1.127	10 364	19.601
WV1017021	USF	2/28/2010 00:00:00	NORML	00061	7.473	10.401	13.328
WV1017021	USF	3/31/2010 00:00:00	NORML	00061	6.270	7.410	8.549
WV1017021	USF	4/30/2010 00:00:00	NORML	00061	2.687	3.833	4.979
WV1017021	USF	5/31/2010 00:00:00	NORML	00061	4.913	5.107	5.300
WV1017021	USF	6/30/2010 00:00:00	NORML	00061	2.130	3.610	5.089
WV1017021	USF	7/31/2010 00:00:00	NORML	00061		4.5815	5.565
WV1017021	USF	8/31/2010 00:00:00	NORML	00061		2.554	2.914
WV1017021	USF	9/30/2010 00:00:00	NORML	00061		1.708	1.735
WV1017021	USF	1/31/2010 00:00:00	NORML	00400			
WV1017021	USF	2/28/2010 00:00:00	NORML	00400			
WV1017021	USF	3/31/2010 00:00:00	NORML	00400			
WV1017021	USF	4/30/2010 00:00:00	NORML	00400			
WV1017021	USF	5/31/2010 00:00:00	NORML	00400			
WV1017021	USF	6/30/2010 00:00:00	NORML	00400			
WV1017021	USF	7/31/2010 00:00:00	NORML	00400			
WV1017021	USF	8/31/2010 00:00:00	NORML	00400			
WV1017021	USF	9/30/2010 00:00:00	NORML	00400			
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WV1017021	USF	2/28/2010 00:00:00	NORML	00981			
WV1017021	USF	3/31/2010 00:00:00	NORML	00981			
WV1017021	USF	4/30/2010 00:00:00	NORML	00981			
WV1017021	USF	5/31/2010 00:00:00	NORML	00981			
WV1017021	USF	6/30/2010 00:00:00	NORML	00981			
WV1017021	USF	7/31/2010 00:00:00	NORML	00981			
WV1017021	USF	8/31/2010 00:00:00	NORML	00981			
WV1017021	USF	9/30/2010 00:00:00	NORML	00981			
WV1017021	USF	1/31/2010 00:00:00	NORML	01045			
WV1017021	USF	2/28/2010 00:00:00	NORML	01045			
WV1017021	USF	3/31/2010 00:00:00	NORML	01045			
WV1017021	USF	4/30/2010 00:00:00	NORML	01045			
WV1017021	USF	5/31/2010 00:00:00	NORML	01045			
WV1017021	USF	6/30/2010 00:00:00	NORML	01045			
WV1017021	USF	7/31/2010 00:00:00	NORML	01045			
WV1017021	USF	8/31/2010 00:00:00	NORML	01045			
WV1017021	USF	9/30/2010 00:00:00	NORML	01045			
WV1017021	USF	1/31/2010 00:00:00	NORML	01055			
WV1017021	USF	2/28/2010 00:00:00	NORML	01055			
WV1017021	USF	3/31/2010 00:00:00	NORML	01055			
WV1017021	USF	4/30/2010 00:00:00	NORML	01055			
WV1017021	USF	5/31/2010 00:00:00	NORML	01055			
WV1017021	USF	6/30/2010 00:00:00	NORML	01055			
WV1017021	USF	7/31/2010 00:00:00	NORML	01055			
WV1017021	USF	8/31/2010 00:00:00	NORML	01055			
WV1017021	USF	9/30/2010 00:00:00	NORML	01055			
WV1017021	USF	1/31/2010 00:00:00	NORML	01105			
WV1017021	USF	2/28/2010 00:00:00	NORML	01105			
WV1017021	USF	3/31/2010 00:00:00	NORML	01105			
WV1017021	USF	4/30/2010 00:00:00	NORML	01105			

WV1017021	USF	5/31/2010 00:00:00	NORML	01105			
WV1017021	USF	6/30/2010 00:00:00	NORML	01105			
WV1017021	USF	7/31/2010 00:00:00	NORML	01105			
WV1017021	USF	8/31/2010 00:00:00	NORML	01105			
WV1017021	USF	9/30/2010 00:00:00	NORML	01105			
WV1017021	USF	1/31/2010 00:00:00	NORML	01106			
WV1017021	USF	2/28/2010 00:00:00	NORML	01106			
WV1017021	USF	3/31/2010 00:00:00	NORML	01106			
WV1017021	USF	4/30/2010 00:00:00	NORML	01106			
WV1017021	USF	5/31/2010 00:00:00	NORML	01106			
WV1017021	USF	6/30/2010 00:00:00	NORML	01106			
WV1017021	USF	7/31/2010 00:00:00	NORML	01106			
WV1017021	USF	8/31/2010 00:00:00	NORML	01106			
WV1017021	USF	9/30/2010 00:00:00	NORML	01106			
WV1017021	UWOB	9/30/2010 00:00:00	NFLOW				
WV1017021	UWOB	1/31/2010 00:00:00	NORML	00061	0.487	1.478	2.468
WV1017021	UWOB	2/28/2010 00:00:00	NORML	00061	1.172	1.972	2.771
WV1017021	UWOB	3/31/2010 00:00:00	NORML	00061	0.699	0.961	1.223
WV1017021	UWOB	4/30/2010 00:00:00	NORML	00061	0.436	0.880	1.323
WV1017021	UWOB	5/31/2010 00:00:00	NORML	00061	0.659	1.715	2.771
WV1017021	UWOB	6/30/2010 00:00:00	NORML	00061	0.249	0.428	0.606
WV1017021	UWOB	7/31/2010 00:00:00	NORML	00061		0.679	0.891
WV1017021	UWOB	8/31/2010 00:00:00	NORML	00061		0.3885	0.539
WV1017021	UWOB	1/31/2010 00:00:00	NORML	00400			
WV1017021	UWOB	2/28/2010 00:00:00	NORML	00400			
WV1017021	UWOB	3/31/2010 00:00:00	NORML	00400			
WV1017021	UWOB	4/30/2010 00:00:00	NORML	00400			
WV1017021	UWOB	5/31/2010 00:00:00	NORML	00400			
WV1017021	UWOB	6/30/2010 00:00:00	NORML	00400			
WV1017021	UWOB	7/31/2010 00:00:00	NORML	00400			
WV1017021	UWOB	8/31/2010 00:00:00	NORML	00400			
WV1017021	UWOB	1/31/2010 00:00:00	NORML	00981			
WV1017021	UWOB	2/28/2010 00:00:00	NORML	00981			
WV1017021	UWOB	3/31/2010 00:00:00	NORML	00981			
WV1017021	UWOB	4/30/2010 00:00:00	NORML	00981			
WV1017021	UWOB	5/31/2010 00:00:00	NORML	00981			
WV1017021	UWOB	6/30/2010 00:00:00	NORML	00981			
WV1017021	UWOB	7/31/2010 00:00:00	NORML	00981			
WV1017021	UWOB	8/31/2010 00:00:00	NORML	00981			
WV1017021	UWOB	1/31/2010 00:00:00	NORML	01045			
WV1017021	UWOB	2/28/2010 00:00:00	NORML	01045			
WV1017021	UWOB	3/31/2010 00:00:00	NORML	01045			
WV1017021	UWOB	4/30/2010 00:00:00	NORML	01045			
WV1017021	UWOB	5/31/2010 00:00:00	NORML	01045			
WV1017021	UWOB	6/30/2010 00:00:00	NORML	01045			
WV1017021	UWOB	7/31/2010 00:00:00	NORML	01045			
WV1017021	UWOB	8/31/2010 00:00:00	NORML	01045			
WV1017021	UWOB	1/31/2010 00:00:00	NORML	01055			
WV1017021	UWOB	2/28/2010 00:00:00	NORML	01055			
WV1017021	UWOB	3/31/2010 00:00:00	NORML	01055			

WV1017021	UWOB	4/30/2010 00:00:00	NORML	01055
WV1017021	UWOB	5/31/2010 00:00:00	NORML	01055
WV1017021	UWOB	6/30/2010 00:00:00	NORML	01055
WV1017021	UWOB	7/31/2010 00:00:00	NORML	01055
WV1017021	UWOB	8/31/2010 00:00:00	NORML	01055
WV1017021	UWOB	1/31/2010 00:00:00	NORML	01105
WV1017021	UWOB	2/28/2010 00:00:00	NORML	01105
WV1017021	UWOB	3/31/2010 00:00:00	NORML	01105
WV1017021	UWOB	4/30/2010 00:00:00	NORML	01105
WV1017021	UWOB	5/31/2010 00:00:00	NORML	01105
WV1017021	UWOB	6/30/2010 00:00:00	NORML	01105
WV1017021	UWOB	7/31/2010 00:00:00	NORML	01105
WV1017021	UWOB	8/31/2010 00:00:00	NORML	01105
WV1017021	UWOB	1/31/2010 00:00:00	NORML	01106
WV1017021	UWOB	2/28/2010 00:00:00	NORML	01106
WV1017021	UWOB	3/31/2010 00:00:00	NORML	01106
WV1017021	UWOB	4/30/2010 00:00:00	NORML	01106
WV1017021	UWOB	5/31/2010 00:00:00	NORML	01106
WV1017021	UWOB	6/30/2010 00:00:00	NORML	01106
WV1017021	UWOB	7/31/2010 00:00:00	NORML	01106
WV1017021	UWOB	8/31/2010 00:00:00	NORML	01106

quantity code	concentration minimum	concentration minimum mdl	concentration average	concentration average mdl	concentration maximum	concentration maximum md	concentration code	sampling frequency code

78								S
78								S
78								S
78								S
78								S
78								S
78								S
78								S
78								S
	7.70		7.85		8.00		12	S
	8.40		8.45		8.50		12	S
	7.40		7.90		8.40		12	S
	7.10		7.65		8.20		12	S
	8.30		8.30		8.30		12	S
	7.80		8.00		8.20		12	S
	8.3		8.4		8.7		12	S
	7.8		8.2		8.4		12	S
	8.1		8.3		8.5		12	S
	2		12		21		19	S
	2		4		6		19	S
	3		8		13		19	S
	2	<	1.5		3		19	S
	13		17		20		19	S
	4		10		15		19	S
	4		4		5		19	S
	4		11		19		19	S
	2		4		6		19	S
	0.1	<	0.1	<	0.1	<	25	S
	0.2	<	0.2	<	0.2	<	25	S
	0.2	<	0.2	<	0.2	<	25	S
	3.40		3.80		4.20		28	S
	3.80		4.50		5.20		28	S
	4.70		6.10		7.50		28	S
	3.80		4.40		5.00		28	S
	4.70		7.60		10.50		28	S
	11.40		11.50		11 60		28	S

6.4		8.5		10.4		28	S
4.8		10.65		14 8		28	S
4.8		9.4		11.0		28	S
0.36		0.38		0.39		19	S
0.25		0.27		0.29		19	S
0.27		0.36		0.45		19	S
0.21		0.26		0.30		19	S
0.27		0.27		0.27		19	S
0.20		0.26		0.31		19	S
0.14		0.20		0.24		19	S
0.19		0.20		0.22		19	S
0.18		0.21		0.24		19	S
0.36		0.36		0.36		19	S
0.49		0.54		0.58		19	S
0.40		0.55		0.69		19	S
0.41		0.52		0.63		19	S
0.32		0.33		0.33		19	S
0.53		0.56		0.59		19	S
0.38		0.48		0.60		19	S
0.26		0.49		0.59		19	S
0.52		0.56		0.60		19	S
0.14		0.15		0.15		19	S
0.06		0.07		0.07		19	S
0.07		0.12		0.17		19	S
0.05		0.05		0.05		19	S
0.09		0.11		0.12		19	S
0.05		0.07		0.08		19	S
0.13		0.23		0.40		19	S
0.05		0.16		0.33		19	S
0.05		0.07		0.08		19	S
0.05	<	0.05	<	0.05	<	19	S
0.05	<	0.05	<	0.05	<	19	S
0.05	<	0.05	<	0.05	<	19	S
0.05	<	0.05	<	0.05	<	19	S
0.05	<	0.05	<	0.05	<	19	S
0.05	<	0.05	<	0.05	<	19	S
0.05	<	0.02		0.06		19	S
0.05	<	0.04		0.09		19	S
0.05	<	0.05	<	0.05	<	19	S

08								S
08								S
08								S
08								S
08								S
08								S
08								S
08								S
08								S
	7.00		7.50		8.00		12	S
	6.40		7.55		8.70		12	S
	6.30		7.35		8.40		12	S
	7.50		7.55		7.60		12	S
	7.70		7.90		8.10		12	S
	6.30		7.30		8.30		12	S
	8.2		8.2		8.2		12	S
	7.9		8.0		8.1		12	S
	7.7		7.8		7.9		12	S
	0.60	<	0.60	<	0.60	<	28	S
	0.60	<	0.60	<	0.60	<	28	S
	0.60	<	0.60	<	0.60	<	28	S
	0.60	<	0.60	<	0.60	<	28	S
	0.60	<	0.60	<	0.60	<	28	S
	0.60	<	0.60	<	0.60	<	28	S
	.6	<	.6	<	.6	<	28	S
	.6	<	.6	<	.6	<	28	S
	.6	<	.6	<	.6	<	28	S

	0.10		0.16		0.21	19	S
	0.15		0.17		0.18	19	S
	0.13		0.22		0.30	19	S
	0.09		0.13		0.16	19	S
	0.07		0.08		0.09	19	S
	0.12		0.18		0.23	19	S
	0.12		0.16		0.20	19	S
	0.10		0.14		0.18	19	S
	0.05		0.08		0.10	19	S
	0.01	<	0.01	<	0.01 <	19	S
	0.01	<	0.01	<	0.01 <	19	S
	0.01		0.01		0.01	19	S
	0.01	<	0.01	<	0.01 <	19	S
	0.01	<	0.01	<	0.01 <	19	S
	0.01	<	0.01	<	0.01 <	19	S
	0.01	<	0.01	<	0.01 <	19	S
	0.01	<	0.01	<	0.01 <	19	S
	0.01	<	0.01	<	0.01 <	19	S
	0.10		0.16		0.21	19	S
	0.15		0.16		0.17	19	S
	0.25		0.42		0.59	19	S
	0.05		0.09		0.12	19	S
	0.05	<	0.05	<	0.05 <	19	S
	0.05	<	0.07		0.13	19	S
	0.05	<	0.06		0.11	19	S
	0.05		0.07		0.09	19	S
	0.05	<	0.03		0.05	19	S
	0.05	<	0.05	<	0.05 <	19	S
	0.05	<	0.05	<	0.05 <	19	S
	0.05	<	0.05	<	0.05 <	19	S
	0.05	<	0.05	<	0.05 <	19	S
	0.05	<	0.05	<	0.05 <	19	S
	0.05	<	0.05	<	0.05 <	19	S
	0.05	<	0.05	<	0.05 <	19	S
	0.05	<	0.05	<	0.05 <	19	S
08							S
08							S
08							S
08							S
08							S
08							S
08							S
08							S
08							S
	7.90		7.90		7.90	12	S
	7.10		7.90		8.70	12	S
	7.30		7.70		8.10	12	S
	7.00		7.55		8.10	12	S
	7.60		7.95		8.30	12	S

7.30		7.75		8.20		12	S
7.4		7.7		8.0		12	S
7.7		7.9		8.1		12	S
7.8		7.8		7.8		12	S
0.60	<	0.60	<	0.60	<	28	S
0.60	<	0.60	<	0.60	<	28	S
0.60	<	0.60	<	0.60	<	28	S
0.60	<	0.60	<	0.60	<	28	S
0.60	<	0.60	<	0.60	<	28	S
0.60	<	0.60	<	0.60	<	28	S
.8		2.7		4.6		28	S
1.2		2.6		4.0		28	S
1.0		1.4		1.7		28	S
0.14		0.21		0.28		19	S
0.06		0.08		0.09		19	S
0.06		0.17		0.28		19	S
0.09		0.14		0.18		19	S
0.06		0.08		0.09		19	S
0.12		0.42		0.71		19	S
0.14		0.18		0.21		19	S
0.11		0.12		0.13		19	S
0.05	<	0.44		0.88		19	S
0.01	<	0.01	<	0.01	<	19	S
0.01	<	0.01	<	0.01	<	19	S
0.01	<	0.01		0.01		19	S
0.01	<	0.01	<	0.01	<	19	S
0.01	<	0.01	<	0.01	<	19	S
0.01	<	0.02		0.03		19	S
0.01	<	0.01		0.01		19	S
0.01		0.01		0.01		19	S
0.01	<	0.01		0.02		19	S
0.14		0.23		0.31		19	S
0.07		0.10		0.12		19	S
0.05		0.14		0.22		19	S
0.05	<	0.07		0.13		19	S
0.05	<	0.05	<	0.05	<	19	S
0.05	<	0.23		0.46		19	S
0.06		0.10		0.13		19	S
0.06		0.11		0.15		19	S
0.05	<	0.03		0.05		19	S
0.05	<	0.05	<	0.05	<	19	S
0.05	<	0.05	<	0.05	<	19	S
0.05	<	0.05	<	0.05	<	19	S
0.05	<	0.05	<	0.05	<	19	S
0.05	<	0.05	<	0.05	<	19	S
0.05	<	0.05	<	0.05	<	19	S
0.05	<	0.05	<	0.05	<	19	S
0.05	<	0.05	<	0.05	<	19	S
08							S

08							S
08							S
08							S
08							S
08							S
08							S
08							S
08							S
	7.80		7.90		8.00	12	S
	7.40		7.40		7.40	12	S
	7.10		7.35		7.60	12	S
	7.30		7.55		7.80	12	S
	7.90		8.30		8.70	12	S
	7.00		7.60		8.20	12	S
	8.0		8.1		8.1	12	S
	8.0		8.0		8.0	12	S
	7.7		7.8		7.8	12	S
	0.80		1.10		1.40	28	S
	0.80		0.80		0.80	28	S
	0.60		0.90		1.20	28	S
	0.70		1.05		1.40	28	S
	2.30		2.85		3.40	28	S
	0.60	<	1.50		3.00	28	S
	2.1		2.2		2.2	28	S
	2.2		2.7		3.2	28	S
	.6	<	.6		1.2	28	S
	0.22		0.25		0.28	19	S
	0.14		0.14		0.14	19	S
	0.15		0.21		0.26	19	S
	0.17		0.17		0.17	19	S
	0.12		0.14		0.16	19	S
	0.16		0.35		0.54	19	S
	0.18		0.19		0.19	19	S
	0.20		0.20		0.20	19	S
	0.15		0.25		0.35	19	S
	0.09		0.14		0.18	19	S
	0.14		0.14		0.14	19	S
	0.13		0.14		0.15	19	S
	0.14		0.15		0.16	19	S
	0.11		0.13		0.14	19	S
	0.17		0.17		0.17	19	S
	0.17		0.18		0.18	19	S
	0.22		0.23		0.23	19	S
	0.30		0.34		0.38	19	S
	0.17		0.17		0.17	19	S
	0.05	<	0.05	<	0.05 <	19	S
	0.05	<	0.05		0.09	19	S
	0.05	<	0.05	<	0.05 <	19	S
	0.05	<	0.05		0.10	19	S
	0.05	<	0.06		0.11	19	S

	0.05	<	0.05	<	0.05	<	19	S
	0.05	<	0.04		0.07		19	S
	0.05	<	0.07		0.13		19	S
	0.05	<	0.05	<	0.05	<	19	S
	0.05	<	0.05	<	0.05	<	19	S
	0.05	<	0.05	<	0.05	<	19	S
	0.05	<	0.05	<	0.05	<	<	S
	0.05	<	0.03		0.05		19	S
	0.05	<	0.05	<	0.05	<	19	S
	0.05	<	0.05	<	0.05	<	19	S
	0.05	<	0.05	<	0.05	<	19	S
	0.05	<	0.05	<	0.05	<	19	S
08								S
08								S
08								S
08								S
08								S
08								S
08								S
08								S
08								S
	7.80		8.10		8.40		12	S
	7.50		8.10		8.70		12	S
	7.40		7.85		8.30		12	S
	7.40		7.70		8.00		12	S
	8.00		8.30		8.60		12	S
	7.90		8.10		8.30		12	S
	8.3		8.4		8.5		12	S
	8.2		8.3		8.3		12	S
	8.2		8.3		8.3		12	S
	1.10		1.10		1.10		28	S
	1.00		1.10		1.20		28	S
	1.00		1.40		1.80		28	S
	0.60		0.90		1.20		28	S
	2.00		2.50		3.00		28	S
	0.60	<	1.40		2.80		28	S
	2.0		2.1		2.1		28	S
	1.4		2.1		2.7		28	S
	.6	<	.6	<	.6	<	28	S
	0.24		0.28		0.32		19	S
	0.12		0.14		0.15		19	S
	0.15		0.16		0.17		19	S
	0.16		0.17		0.17		19	S
	0.13		0.14		0.15		19	S
	0.21		0.33		0.45		19	S
	0.17		0.18		0.18		19	S
	0.15		0.33		0.51		19	S
	0.10		0.11		0.12		19	S
	0.07		0.09		0.10		19	S
	0.10		0.12		0.13		19	S

	0.01		0.08		0.15	19	S
	0.12		0.13		0.13	19	S
	0.09		0.10		0.10	19	S
	0.11		0.11		0.11	19	S
	0.09		0.10		0.10	19	S
	0.10		0.10		0.10	19	S
	0.07		0.08		0.09	19	S
	0.19		0.21		0.22	19	S
	0.05		0.06		0.07	19	S
	0.08		0.16		0.24	19	S
	0.05	<	0.05	<	0.05	< 19	S
	0.05	<	0.04		0.08	19	S
	0.05	<	0.06		0.12	19	S
	0.05	<	0.05		0.09	19	S
	0.05	<	0.03		0.05	19	S
	0.05	<	0.05	<	0.05	< 19	S
	0.05	<	0.05	<	0.05	< 19	S
	0.05	<	0.05	<	0.05	< 19	S
	0.05	<	0.05	<	0.05	< 19	S
	0.05	<	0.05	<	0.05	< 19	S
	0.05	<	0.03		0.05	19	S
	0.05	<	0.05	<	0.05	< 19	S
	0.05	<	0.05	<	0.05	< 19	S
	0.05	<	0.05	<	0.05	< 19	S
	0.05	<	0.05	<	0.05	< 19	S
08							S
08							S
08							S
08							S
08							S
08							S
08							S
08							S
08							S
	7.00		7.45		7.90	12	S
	7.30		7.80		8.30	12	S
	7.20		7.55		7.90	12	S
	7.80		7.80		7.80	12	S
	7.30		7.65		8.00	12	S
	8.10		8.10		8.10	12	S
	8.0		8.2		8.3	12	S
	7.9		7.9		7.9	12	S
	7.0		7.3		7.6	12	S
	2.10		3.90		5.70	28	S
	3.20		3.75		4.30	28	S
	4.70		5.20		5.70	28	S
	4.20		5.50		6.80	28	S
	5.20		5.20		5.20	28	S
	8.40		9.70		11.00	28	S
	6.2		9.5		12.7	28	S

	6.8		10.1		13.4		28	S
	6.1		6.3		6.4		28	S
	0.35		0.60		0.85		19	S
	0.39		0.42		0.45		19	S
	0.42		0.52		0.61		19	S
	0.38		0.51		0.64		19	S
	0.43		0.45		0.46		19	S
	0.51		0.52		0.53		19	S
	0.26		0.51		0.76		19	S
	0.32		0.35		0.37		19	S
	0.35		0.39		0.42		19	S
	0.05		0.06		0.07		19	S
	0.04		0.04		0.04		19	S
	0.05		0.05		0.05		19	S
	0.05		0.07		0.08		19	S
	0.05		0.05		0.05		19	S
	0.07		0.08		0.09		19	S
	0.06		0.07		0.07		19	S
	0.06		0.08		0.09		19	S
	0.12		0.16		0.20		19	S
	0.30		0.58		0.86		19	S
	0.33		0.38		0.42		19	S
	0.31		0.43		0.54		19	S
	0.28		0.59		0.90		19	S
	0.34		0.36		0.38		19	S
	0.21		0.24		0.26		19	S
	0.19		0.28		0.37		19	S
	0.15		0.18		0.20		19	S
	0.13		0.14		0.14		19	S
	0.05	<	0.05	<	0.05	<	19	S
	0.05	<	0.05	<	0.05	<	19	S
	0.05	<	0.03		0.06		19	S
	0.05	<	0.04		0.07		19	S
	0.05	<	0.04		0.05		19	S
	0.05	<	0.04		0.08		19	S
	0.05	<	0.03		0.06		19	S
	0.05	<	0.03		0.05		19	S
	0.05	<	0.05	<	0.05	<	19	S
08								S
08								S
08								S
08								S
08								S
08								S
08								S
08								S
08								S
	8.00		8.15		8.30		12	S
	8.00		8.20		8.40		12	S
	7.40		7.90		8.40		12	S

6.90		7.40		7.90		12	S
8.10		8.10		8.10		12	S
7.70		7.85		8.00		12	S
8.1		8.1		8.1		12	S
7.8		8.0		8.2		12	S
6.5		7.4		8.2		12	S
0.60	<	0.60	<	0.60	<	28	S
0.60	<	0.60	<	0.60	<	28	S
0.60	<	0.30		0.60		28	S
0.70		0.80		0.90		28	S
0.60	<	0.60	<	0.60	<	28	S
0.60	<	0.60	<	0.60	<	28	S
.6	<	.6	<	.6	<	28	S
.6	<	.6	<	.6	<	28	S
.6	<	.6	<	.6	<	28	S
0.09		0.15		0.20		19	S
0.05	<	0.05		0.10		19	S
0.07		0.62		1.16		19	S
0.05	<	0.05		0.10		19	S
0.09		0.11		0.12		19	S
0.05		0.06		0.06		19	S
0.05		0.12		0.18		19	S
0.05	<	0.05	<	0.05	<	19	S
0.05	<	0.05	<	0.05	<	19	S
0.01	<	0.01	<	0.01	<	19	S
0.01	<	0.01	<	0.01	<	19	S
0.01		0.10		0.18		19	S
0.01	<	0.01	<	0.01	<	19	S
0.01	<	0.01		0.01		19	S
0.01	<	0.01	<	0.01	<	19	S
0.01	<	0.01		0.01		19	S
0.01	<	0.01	<	0.01	<	19	S
0.01	<	0.01	<	0.01	<	19	S
0.08		0.13		0.18		19	S
0.05	<	0.05		0.09		19	S
0.05	<	0.03		0.05		19	S
0.05	<	0.04		0.07		19	S
0.05		0.06		0.07		19	S
0.05	<	0.05	<	0.05	<	19	S
0.05	<	0.08		0.15		19	S
0.05	<	0.05	<	0.05	<	19	S
0.05	<	0.05	<	0.05	<	19	S
0.05	<	0.05	<	0.05	<	19	S
0.05	<	0.05	<	0.05	<	19	S
0.05	<	0.05	<	0.05	<	19	S
0.05	<	0.05	<	0.05	<	19	S
0.05	<	0.05	<	0.05	<	19	S
0.05	<	0.05	<	0.05	<	19	S
0.05	<	0.05	<	0.05	<	19	S
0.05	<	0.05	<	0.05	<	19	S

	0.05	<	0.05	<	0.05	<	19	S
08								S
08								S
08								S
08								S
08								S
08								S
08								S
08								S
08								S
	7.00		7.85		8.70		12	S
	7.60		8.00		8.40		12	S
	7.80		7.95		8.10		12	S
	7.80		7.95		8.10		12	S
	7.50		7.75		8.00		12	S
	8.00		8.05		8.10		12	S
	7.8		8.0		8.2		12	S
	7.8		7.9		7.9		12	S
	7.1		7.2		7.3		12	S
	2.20		4.45		6.70		28	S
	3.60		4.20		4.80		28	S
	0.60	<	3.10		6.20		28	S
	7.20		10.60		14.00		28	S
	5.50		5.75		6.00		28	S
	8.40		9.85		11 30		28	S
	.6	<	6.5		12 9		28	S
	6.7		10.9		15.1		28	S
	6.8		7.1		7.4		28	S
	0.33		0.46		0.58		19	S
	0.46		0.52		0.57		19	S
	0.10		0.35		0.60		19	S
	0.43		0.63		0.83		19	S
	0.49		0.53		0.57		19	S
	0.66		0.68		0.69		19	S
	0.30		0.58		0.86		19	S
	0.37		0.42		0.47		19	S
	0.57		0.81		1.04		19	S
	0.04		0.05		0.05		19	S
	0.04		0.04		0.04		19	S
	0.01		0.04		0.06		19	S
	0.05		0.06		0.07		19	S
	0.04		0.05		0.05		19	S
	0.06		0.07		0.08		19	S
	0.06		0.06		0.06		19	S
	0.06		0.08		0.09		19	S
	0.13		0.19		0.24		19	S
	0.30		0.44		0.57		19	S
	0.40		0.42		0.43		19	S
	0.10		0.26		0.42		19	S
	0.29		0.32		0.34		19	S

	0.32		0.35		0.37		19	S
	0.27		0.30		0.32		19	S
	0.27		0.36		0.45		19	S
	0.16		0.22		0.27		19	S
	0.18		0.20		0.22		19	S
	0.05	<	0.05	<	0.05	<	19	S
	0.05	<	0.05	<	0.05	<	19	S
	0.05	<	0.04		0.07		19	S
	0.05	<	0.04		0.07		19	S
	0.05	<	0.03		0.06		19	S
	0.06		0.08		0.09		19	S
	0.05	<	0.05	<	0.05	<	19	S
	0.05		0.06		0.06		19	S
	0.05	<	0.05	<	0.05	<	19	S
08								S
08								S
08								S
08								S
08								S
08								S
08								S
08								S
	7.10		7.90		8.70		12	S
	7.70		8.15		8.60		12	S
	7.90		8.05		8.20		12	S
	8.00		8.20		8.40		12	S
	7.80		7.95		8.10		12	S
	7.50		7.90		8.30		12	S
	8.1		8.2		8.3		12	S
	7.9		8.1		8.3		12	S
	0.60	<	0.60	<	0.60	<	28	S
	0.60	<	0.60	<	0.60	<	28	S
	0.60	<	2.80		5.60		28	S
	0.60	<	0.30		0.60		28	S
	0.60	<	0.60	<	0.60	<	28	S
	0.60	<	0.60	<	0.60	<	28	S
	.6	<	3.4		6.8		28	S
	.6	<	.6	<	.6	<	28	S
	0.05	<	0.07		0.13		19	S
	0.07		0.09		0.11		19	S
	0.08		0.31		0.53		19	S
	0.05	<	0.24		0.47		19	S
	0.27		0.39		0.50		19	S
	0.07		0.09		0.10		19	S
	0.13		0.22		0.30		19	S
	0.09		0.19		0.28		19	S
	0.01	<	0.01	<	0.01	<	19	S
	0.01	<	0.01	<	0.01	<	19	S
	0.01		0.04		0.06		19	S

0.01	<	0.03		0.05		19	S
0.04		0.05		0.06		19	S
0.02		0.03		0.03		19	S
0.04		0.05		0.05		19	S
0.02		0.03		0.04		19	S
0.05	<	0.08		0.15		19	S
0.06		0.08		0.09		19	S
0.25		0.30		0.35		19	S
0.05	<	3.04		6.08		19	S
0.41		0.61		0.80		19	S
0.05	<	0.03		0.05		19	S
0.05		0.14		0.23		19	S
0.07		0.13		0.19		19	S
0.05	<	0.05	<	0.05	<	19	S
0.05	<	0.05	<	0.05	<	19	S
0.05	<	0.05	<	0.05	<	19	S
0.05	<	0.05	<	0.05	<	19	S
0.05	<	0.05		0.10		19	S
0.05	<	0.05	<	0.05	<	19	S
0.05	<	0.04		0.07		19	S
0.05	<	0.05	<	0.05	<	19	S

sample type code	monitoring location code	reporting frequency code	quantity description	concentration description

EST	N/A	N/A	GPM	
EST	N/A	N/A	GPM	
EST	N/A	N/A	GPM	
EST	N/A	N/A	GPM	
EST	N/A	N/A	GPM	
EST	N/A	N/A	GPM	
EST	N/A	N/A	GPM	
EST	N/A	N/A	GPM	
EST	N/A	N/A	GPM	
GR	N/A	N/A		Std Units
GR	N/A	N/A		Std Units
GR	N/A	N/A		Std Units
GR	N/A	N/A		Std Units
GR	N/A	N/A		Std Units
GR	N/A	N/A		Std Units
GR	N/A	N/A		Std Units
GR	N/A	N/A		Std Units
GR	N/A	N/A		Std Units
GR	N/A	N/A		MG/L
GR	N/A	N/A		MG/L
GR	N/A	N/A		MG/L
GR	N/A	N/A		MG/L
GR	N/A	N/A		MG/L
GR	N/A	N/A		MG/L
GR	N/A	N/A		MG/L
GR	N/A	N/A		MG/L
GR	N/A	N/A		MG/L
GR	N/A	N/A		ML/L
GR	N/A	N/A		ML/L
GR	N/A	N/A		ML/L
GR	N/A	N/A		UG/L
GR	N/A	N/A		UG/L
GR	N/A	N/A		UG/L
GR	N/A	N/A		UG/L
GR	N/A	N/A		UG/L
GR	N/A	N/A		UG/L

GR	N/A	N/A	UG/L
GR	N/A	N/A	UG/L
GR	N/A	N/A	UG/L
GR	N/A	N/A	MG/L
GR	N/A	N/A	MG/L
GR	N/A	N/A	MG/L
GR	N/A	N/A	MG/L
GR	N/A	N/A	MG/L
GR	N/A	N/A	MG/L
GR	N/A	N/A	MG/L
GR	N/A	N/A	MG/L
GR	N/A	N/A	MG/L
GR	N/A	N/A	MG/L
GR	N/A	N/A	MG/L
GR	N/A	N/A	MG/L
GR	N/A	N/A	MG/L
GR	N/A	N/A	MG/L
GR	N/A	N/A	MG/L
GR	N/A	N/A	MG/L
GR	N/A	N/A	MG/L
GR	N/A	N/A	MG/L
GR	N/A	N/A	MG/L
GR	N/A	N/A	MG/L
GR	N/A	N/A	MG/L
GR	N/A	N/A	MG/L
GR	N/A	N/A	MG/L
GR	N/A	N/A	MG/L
GR	N/A	N/A	MG/L
GR	N/A	N/A	MG/L
GR	N/A	N/A	MG/L
GR	N/A	N/A	MG/L
GR	N/A	N/A	MG/L
GR	N/A	N/A	MG/L
GR	N/A	N/A	MG/L
GR	N/A	N/A	MG/L
GR	N/A	N/A	MG/L
GR	N/A	N/A	MG/L
GR	N/A	N/A	MG/L
GR	N/A	N/A	MG/L

EST	N/A	N/A	CFS	
EST	N/A	N/A	CFS	
EST	N/A	N/A	CFS	
EST	N/A	N/A	CFS	
EST	N/A	N/A	CFS	
EST	N/A	N/A	CFS	
EST	N/A	N/A	CFS	
EST	N/A	N/A	CFS	
EST	N/A	N/A	CFS	
GR	N/A	N/A		Std Units
GR	N/A	N/A		Std Units
GR	N/A	N/A		Std Units
GR	N/A	N/A		Std Units
GR	N/A	N/A		Std Units
GR	N/A	N/A		Std Units
GR	N/A	N/A		Std Units
GR	N/A	N/A		Std Units
GR	N/A	N/A		Std Units
GR	N/A	N/A		UG/L
GR	N/A	N/A		UG/L
GR	N/A	N/A		UG/L
GR	N/A	N/A		UG/L
GR	N/A	N/A		UG/L
GR	N/A	N/A		UG/L
GR	N/A	N/A		UG/L
GR	N/A	N/A		UG/L
GR	N/A	N/A		UG/L

GR	N/A	N/A		MG/L
GR	N/A	N/A		MG/L
GR	N/A	N/A		MG/L
GR	N/A	N/A		MG/L
GR	N/A	N/A		MG/L
GR	N/A	N/A		MG/L
GR	N/A	N/A		MG/L
GR	N/A	N/A		MG/L
GR	N/A	N/A		MG/L
GR	N/A	N/A		MG/L
GR	N/A	N/A		MG/L
GR	N/A	N/A		MG/L
GR	N/A	N/A		MG/L
GR	N/A	N/A		MG/L
GR	N/A	N/A		MG/L
GR	N/A	N/A		MG/L
GR	N/A	N/A		MG/L
GR	N/A	N/A		MG/L
GR	N/A	N/A		MG/L
GR	N/A	N/A		MG/L
GR	N/A	N/A		MG/L
GR	N/A	N/A		MG/L
GR	N/A	N/A		MG/L
GR	N/A	N/A		MG/L
GR	N/A	N/A		MG/L
GR	N/A	N/A		MG/L
GR	N/A	N/A		MG/L
GR	N/A	N/A		MG/L
GR	N/A	N/A		MG/L
GR	N/A	N/A		MG/L
GR	N/A	N/A		MG/L
EST	N/A	N/A	CFS	
EST	N/A	N/A	CFS	
EST	N/A	N/A	CFS	
EST	N/A	N/A	CFS	
EST	N/A	N/A	CFS	
EST	N/A	N/A	CFS	
EST	N/A	N/A	CFS	
EST	N/A	N/A	CFS	
EST	N/A	N/A	CFS	
GR	N/A	N/A		Std Units
GR	N/A	N/A		Std Units
GR	N/A	N/A		Std Units
GR	N/A	N/A		Std Units
GR	N/A	N/A		Std Units

GR	N/A	N/A		Std Units
GR	N/A	N/A		Std Units
GR	N/A	N/A		Std Units
GR	N/A	N/A		Std Units
GR	N/A	N/A		UG/L
GR	N/A	N/A		UG/L
GR	N/A	N/A		UG/L
GR	N/A	N/A		UG/L
GR	N/A	N/A		UG/L
GR	N/A	N/A		UG/L
GR	N/A	N/A		UG/L
GR	N/A	N/A		UG/L
GR	N/A	N/A		UG/L
GR	N/A	N/A		MG/L
GR	N/A	N/A		MG/L
GR	N/A	N/A		MG/L
GR	N/A	N/A		MG/L
GR	N/A	N/A		MG/L
GR	N/A	N/A		MG/L
GR	N/A	N/A		MG/L
GR	N/A	N/A		MG/L
GR	N/A	N/A		MG/L
GR	N/A	N/A		MG/L
GR	N/A	N/A		MG/L
GR	N/A	N/A		MG/L
GR	N/A	N/A		MG/L
GR	N/A	N/A		MG/L
GR	N/A	N/A		MG/L
GR	N/A	N/A		MG/L
GR	N/A	N/A		MG/L
GR	N/A	N/A		MG/L
GR	N/A	N/A		MG/L
GR	N/A	N/A		MG/L
GR	N/A	N/A		MG/L
GR	N/A	N/A		MG/L
GR	N/A	N/A		MG/L
GR	N/A	N/A		MG/L
GR	N/A	N/A		MG/L
GR	N/A	N/A		MG/L
GR	N/A	N/A		MG/L
GR	N/A	N/A		MG/L
GR	N/A	N/A		MG/L
GR	N/A	N/A		MG/L
GR	N/A	N/A		MG/L
GR	N/A	N/A		MG/L
EST	N/A	N/A	CFS	

EST	N/A	N/A	CFS	
EST	N/A	N/A	CFS	
EST	N/A	N/A	CFS	
EST	N/A	N/A	CFS	
EST	N/A	N/A	CFS	
EST	N/A	N/A	CFS	
EST	N/A	N/A	CFS	
EST	N/A	N/A	CFS	
GR	N/A	N/A		Std Units
GR	N/A	N/A		Std Units
GR	N/A	N/A		Std Units
GR	N/A	N/A		Std Units
GR	N/A	N/A		Std Units
GR	N/A	N/A		Std Units
GR	N/A	N/A		Std Units
GR	N/A	N/A		Std Units
GR	N/A	N/A		Std Units
GR	N/A	N/A		UG/L
GR	N/A	N/A		UG/L
GR	N/A	N/A		UG/L
GR	N/A	N/A		UG/L
GR	N/A	N/A		UG/L
GR	N/A	N/A		UG/L
GR	N/A	N/A		UG/L
GR	N/A	N/A		UG/L
GR	N/A	N/A		UG/L
GR	N/A	N/A		MG/L
GR	N/A	N/A		MG/L
GR	N/A	N/A		MG/L
GR	N/A	N/A		MG/L
GR	N/A	N/A		MG/L
GR	N/A	N/A		MG/L
GR	N/A	N/A		MG/L
GR	N/A	N/A		MG/L
GR	N/A	N/A		MG/L
GR	N/A	N/A		MG/L
GR	N/A	N/A		MG/L
GR	N/A	N/A		MG/L
GR	N/A	N/A		MG/L
GR	N/A	N/A		MG/L
GR	N/A	N/A		MG/L
GR	N/A	N/A		MG/L
GR	N/A	N/A		MG/L
GR	N/A	N/A		MG/L
GR	N/A	N/A		MG/L
GR	N/A	N/A		MG/L
GR	N/A	N/A		MG/L
GR	N/A	N/A		MG/L
GR	N/A	N/A		MG/L
GR	N/A	N/A		MG/L

GR	N/A	N/A		MG/L
GR	N/A	N/A		MG/L
GR	N/A	N/A		MG/L
GR	N/A	N/A		MG/L
GR	N/A	N/A		MG/L
GR	N/A	N/A		MG/L
GR	N/A	N/A		MG/L
GR	N/A	N/A		MG/L
GR	N/A	N/A		MG/L
GR	N/A	N/A		MG/L
GR	N/A	N/A		MG/L
GR	N/A	N/A		MG/L
EST	N/A	N/A	CFS	
EST	N/A	N/A	CFS	
EST	N/A	N/A	CFS	
EST	N/A	N/A	CFS	
EST	N/A	N/A	CFS	
EST	N/A	N/A	CFS	
EST	N/A	N/A	CFS	
EST	N/A	N/A	CFS	
EST	N/A	N/A	CFS	
GR	N/A	N/A		Std Units
GR	N/A	N/A		Std Units
GR	N/A	N/A		Std Units
GR	N/A	N/A		Std Units
GR	N/A	N/A		Std Units
GR	N/A	N/A		Std Units
GR	N/A	N/A		Std Units
GR	N/A	N/A		Std Units
GR	N/A	N/A		Std Units
GR	N/A	N/A		UG/L
GR	N/A	N/A		UG/L
GR	N/A	N/A		UG/L
GR	N/A	N/A		UG/L
GR	N/A	N/A		UG/L
GR	N/A	N/A		UG/L
GR	N/A	N/A		UG/L
GR	N/A	N/A		UG/L
GR	N/A	N/A		UG/L
GR	N/A	N/A		MG/L
GR	N/A	N/A		MG/L
GR	N/A	N/A		MG/L
GR	N/A	N/A		MG/L
GR	N/A	N/A		MG/L
GR	N/A	N/A		MG/L
GR	N/A	N/A		MG/L
GR	N/A	N/A		MG/L
GR	N/A	N/A		MG/L
GR	N/A	N/A		MG/L
GR	N/A	N/A		MG/L

GR	N/A	N/A		MG/L
GR	N/A	N/A		MG/L
GR	N/A	N/A		MG/L
GR	N/A	N/A		MG/L
GR	N/A	N/A		MG/L
GR	N/A	N/A		MG/L
GR	N/A	N/A		MG/L
GR	N/A	N/A		MG/L
GR	N/A	N/A		MG/L
GR	N/A	N/A		MG/L
GR	N/A	N/A		MG/L
GR	N/A	N/A		MG/L
GR	N/A	N/A		MG/L
GR	N/A	N/A		MG/L
GR	N/A	N/A		MG/L
GR	N/A	N/A		MG/L
GR	N/A	N/A		MG/L
GR	N/A	N/A		MG/L
GR	N/A	N/A		MG/L
GR	N/A	N/A		MG/L
GR	N/A	N/A		MG/L
GR	N/A	N/A		MG/L
GR	N/A	N/A		MG/L
EST	N/A	N/A	CFS	
EST	N/A	N/A	CFS	
EST	N/A	N/A	CFS	
EST	N/A	N/A	CFS	
EST	N/A	N/A	CFS	
EST	N/A	N/A	CFS	
EST	N/A	N/A	CFS	
EST	N/A	N/A	CFS	
EST	N/A	N/A	CFS	
GR	N/A	N/A		Std Units
GR	N/A	N/A		Std Units
GR	N/A	N/A		Std Units
GR	N/A	N/A		Std Units
GR	N/A	N/A		Std Units
GR	N/A	N/A		Std Units
GR	N/A	N/A		Std Units
GR	N/A	N/A		Std Units
GR	N/A	N/A		Std Units
GR	N/A	N/A		UG/L
GR	N/A	N/A		UG/L
GR	N/A	N/A		UG/L
GR	N/A	N/A		UG/L
GR	N/A	N/A		UG/L
GR	N/A	N/A		UG/L
GR	N/A	N/A		UG/L

GR	N/A	N/A		UG/L
GR	N/A	N/A		UG/L
GR	N/A	N/A		MG/L
GR	N/A	N/A		MG/L
GR	N/A	N/A		MG/L
GR	N/A	N/A		MG/L
GR	N/A	N/A		MG/L
GR	N/A	N/A		MG/L
GR	N/A	N/A		MG/L
GR	N/A	N/A		MG/L
GR	N/A	N/A		MG/L
GR	N/A	N/A		MG/L
GR	N/A	N/A		MG/L
GR	N/A	N/A		MG/L
GR	N/A	N/A		MG/L
GR	N/A	N/A		MG/L
GR	N/A	N/A		MG/L
GR	N/A	N/A		MG/L
GR	N/A	N/A		MG/L
GR	N/A	N/A		MG/L
GR	N/A	N/A		MG/L
GR	N/A	N/A		MG/L
GR	N/A	N/A		MG/L
GR	N/A	N/A		MG/L
GR	N/A	N/A		MG/L
GR	N/A	N/A		MG/L
GR	N/A	N/A		MG/L
GR	N/A	N/A		MG/L
GR	N/A	N/A		MG/L
GR	N/A	N/A		MG/L
GR	N/A	N/A		MG/L
GR	N/A	N/A		MG/L
GR	N/A	N/A		MG/L
EST	N/A	N/A	CFS	
EST	N/A	N/A	CFS	
EST	N/A	N/A	CFS	
EST	N/A	N/A	CFS	
EST	N/A	N/A	CFS	
EST	N/A	N/A	CFS	
EST	N/A	N/A	CFS	
EST	N/A	N/A	CFS	
EST	N/A	N/A	CFS	
GR	N/A	N/A		Std Units
GR	N/A	N/A		Std Units
GR	N/A	N/A		Std Units

GR	N/A	N/A	Std Units
GR	N/A	N/A	Std Units
GR	N/A	N/A	Std Units
GR	N/A	N/A	Std Units
GR	N/A	N/A	Std Units
GR	N/A	N/A	Std Units
GR	N/A	N/A	UG/L
GR	N/A	N/A	UG/L
GR	N/A	N/A	UG/L
GR	N/A	N/A	UG/L
GR	N/A	N/A	UG/L
GR	N/A	N/A	UG/L
GR	N/A	N/A	UG/L
GR	N/A	N/A	UG/L
GR	N/A	N/A	UG/L
GR	N/A	N/A	MG/L
GR	N/A	N/A	MG/L
GR	N/A	N/A	MG/L
GR	N/A	N/A	MG/L
GR	N/A	N/A	MG/L
GR	N/A	N/A	MG/L
GR	N/A	N/A	MG/L
GR	N/A	N/A	MG/L
GR	N/A	N/A	MG/L
GR	N/A	N/A	MG/L
GR	N/A	N/A	MG/L
GR	N/A	N/A	MG/L
GR	N/A	N/A	MG/L
GR	N/A	N/A	MG/L
GR	N/A	N/A	MG/L
GR	N/A	N/A	MG/L
GR	N/A	N/A	MG/L
GR	N/A	N/A	MG/L
GR	N/A	N/A	MG/L
GR	N/A	N/A	MG/L
GR	N/A	N/A	MG/L
GR	N/A	N/A	MG/L
GR	N/A	N/A	MG/L
GR	N/A	N/A	MG/L
GR	N/A	N/A	MG/L
GR	N/A	N/A	MG/L
GR	N/A	N/A	MG/L
GR	N/A	N/A	MG/L
GR	N/A	N/A	MG/L
GR	N/A	N/A	MG/L
GR	N/A	N/A	MG/L
GR	N/A	N/A	MG/L
GR	N/A	N/A	MG/L
GR	N/A	N/A	MG/L
GR	N/A	N/A	MG/L

GR	N/A	N/A		MG/L
EST	N/A	N/A	CFS	
EST	N/A	N/A	CFS	
EST	N/A	N/A	CFS	
EST	N/A	N/A	CFS	
EST	N/A	N/A	CFS	
EST	N/A	N/A	CFS	
EST	N/A	N/A	CFS	
EST	N/A	N/A	CFS	
EST	N/A	N/A	CFS	
GR	N/A	N/A		Std Units
GR	N/A	N/A		Std Units
GR	N/A	N/A		Std Units
GR	N/A	N/A		Std Units
GR	N/A	N/A		Std Units
GR	N/A	N/A		Std Units
GR	N/A	N/A		Std Units
GR	N/A	N/A		Std Units
GR	N/A	N/A		Std Units
GR	N/A	N/A		UG/L
GR	N/A	N/A		UG/L
GR	N/A	N/A		UG/L
GR	N/A	N/A		UG/L
GR	N/A	N/A		UG/L
GR	N/A	N/A		UG/L
GR	N/A	N/A		UG/L
GR	N/A	N/A		UG/L
GR	N/A	N/A		UG/L
GR	N/A	N/A		MG/L
GR	N/A	N/A		MG/L
GR	N/A	N/A		MG/L
GR	N/A	N/A		MG/L
GR	N/A	N/A		MG/L
GR	N/A	N/A		MG/L
GR	N/A	N/A		MG/L
GR	N/A	N/A		MG/L
GR	N/A	N/A		MG/L
GR	N/A	N/A		MG/L
GR	N/A	N/A		MG/L
GR	N/A	N/A		MG/L
GR	N/A	N/A		MG/L
GR	N/A	N/A		MG/L
GR	N/A	N/A		MG/L
GR	N/A	N/A		MG/L
GR	N/A	N/A		MG/L
GR	N/A	N/A		MG/L
GR	N/A	N/A		MG/L
GR	N/A	N/A		MG/L
GR	N/A	N/A		MG/L
GR	N/A	N/A		MG/L
GR	N/A	N/A		MG/L
GR	N/A	N/A		MG/L
GR	N/A	N/A		MG/L
GR	N/A	N/A		MG/L

GR	N/A	N/A		MG/L
GR	N/A	N/A		MG/L
GR	N/A	N/A		MG/L
GR	N/A	N/A		MG/L
GR	N/A	N/A		MG/L
GR	N/A	N/A		MG/L
GR	N/A	N/A		MG/L
GR	N/A	N/A		MG/L
GR	N/A	N/A		MG/L
GR	N/A	N/A		MG/L
GR	N/A	N/A		MG/L
GR	N/A	N/A		MG/L
GR	N/A	N/A		MG/L
GR	N/A	N/A		MG/L
EST	N/A	N/A	CFS	
EST	N/A	N/A	CFS	
EST	N/A	N/A	CFS	
EST	N/A	N/A	CFS	
EST	N/A	N/A	CFS	
EST	N/A	N/A	CFS	
EST	N/A	N/A	CFS	
EST	N/A	N/A	CFS	
GR	N/A	N/A		Std Units
GR	N/A	N/A		Std Units
GR	N/A	N/A		Std Units
GR	N/A	N/A		Std Units
GR	N/A	N/A		Std Units
GR	N/A	N/A		Std Units
GR	N/A	N/A		Std Units
GR	N/A	N/A		Std Units
GR	N/A	N/A		UG/L
GR	N/A	N/A		UG/L
GR	N/A	N/A		UG/L
GR	N/A	N/A		UG/L
GR	N/A	N/A		UG/L
GR	N/A	N/A		UG/L
GR	N/A	N/A		UG/L
GR	N/A	N/A		UG/L
GR	N/A	N/A		MG/L
GR	N/A	N/A		MG/L
GR	N/A	N/A		MG/L
GR	N/A	N/A		MG/L
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GR	N/A	N/A	MG/L

dmr_type_description	parameter_desc	responsible_party_name
Not Constructed		Mingo Logan Coal Company
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Normal	Total Suspended Solids	Mingo Logan Coal Company
Normal	Total Suspended Solids	Mingo Logan Coal Company
Normal	Total Suspended Solids	Mingo Logan Coal Company
Normal	Total Suspended Solids	Mingo Logan Coal Company
Normal	Total Suspended Solids	Mingo Logan Coal Company
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Normal	Total Suspended Solids	Mingo Logan Coal Company
Normal	Total Suspended Solids	Mingo Logan Coal Company
Normal	Settleable Solids	Mingo Logan Coal Company
Normal	Settleable Solids	Mingo Logan Coal Company
Normal	Settleable Solids	Mingo Logan Coal Company
Normal	Selenium, Total Recoverable	Mingo Logan Coal Company
Normal	Selenium, Total Recoverable	Mingo Logan Coal Company
Normal	Selenium, Total Recoverable	Mingo Logan Coal Company
Normal	Selenium, Total Recoverable	Mingo Logan Coal Company
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Normal	Selenium, Total Recoverable	Mingo Logan Coal Company
Normal	Selenium, Total Recoverable	Mingo Logan Coal Company
Normal	Selenium, Total Recoverable	Mingo Logan Coal Company
Normal	Iron, Total (as Fe)	Mingo Logan Coal Company
Normal	Iron, Total (as Fe)	Mingo Logan Coal Company
Normal	Iron, Total (as Fe)	Mingo Logan Coal Company
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Normal	Iron, Total (as Fe)	Mingo Logan Coal Company
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Normal	Iron, Total (as Fe)	Mingo Logan Coal Company
Normal	Iron, Total (as Fe)	Mingo Logan Coal Company
Normal	Manganese, Total (as Mn)	Mingo Logan Coal Company
Normal	Manganese, Total (as Mn)	Mingo Logan Coal Company
Normal	Manganese, Total (as Mn)	Mingo Logan Coal Company
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Normal	Manganese, Total (as Mn)	Mingo Logan Coal Company
Normal	Manganese, Total (as Mn)	Mingo Logan Coal Company
Normal	Aluminum, Total (as Al)	Mingo Logan Coal Company
Normal	Aluminum, Total (as Al)	Mingo Logan Coal Company
Normal	Aluminum, Total (as Al)	Mingo Logan Coal Company
Normal	Aluminum, Total (as Al)	Mingo Logan Coal Company
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Normal	Aluminum, Total (as Al)	Mingo Logan Coal Company
Normal	Aluminum, Diss. (as Al)	Mingo Logan Coal Company
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Normal	Aluminum, Diss. (as Al)	Mingo Logan Coal Company
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Normal	Aluminum, Diss. (as Al)	Mingo Logan Coal Company
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Normal	Stream Flow cfs	Mingo Logan Coal Company
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Normal	Selenium, Total Recoverable	Mingo Logan Coal Company
Normal	Selenium, Total Recoverable	Mingo Logan Coal Company
Normal	Selenium, Total Recoverable	Mingo Logan Coal Company
Normal	Selenium, Total Recoverable	Mingo Logan Coal Company
Normal	Selenium, Total Recoverable	Mingo Logan Coal Company
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Normal	Selenium, Total Recoverable	Mingo Logan Coal Company
Normal	Selenium, Total Recoverable	Mingo Logan Coal Company
Normal	Selenium, Total Recoverable	Mingo Logan Coal Company

Normal	Iron, Total (as Fe)	Mingo Logan Coal Company
Normal	Iron, Total (as Fe)	Mingo Logan Coal Company
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Normal	Iron, Total (as Fe)	Mingo Logan Coal Company
Normal	Iron, Total (as Fe)	Mingo Logan Coal Company
Normal	Manganese, Total (as Mn)	Mingo Logan Coal Company
Normal	Manganese, Total (as Mn)	Mingo Logan Coal Company
Normal	Manganese, Total (as Mn)	Mingo Logan Coal Company
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Normal	Manganese, Total (as Mn)	Mingo Logan Coal Company
Normal	Aluminum, Total (as Al)	Mingo Logan Coal Company
Normal	Aluminum, Total (as Al)	Mingo Logan Coal Company
Normal	Aluminum, Total (as Al)	Mingo Logan Coal Company
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Normal	Aluminum, Diss. (as Al)	Mingo Logan Coal Company
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Normal	Aluminum, Diss. (as Al)	Mingo Logan Coal Company
Normal	Stream Flow cfs	Mingo Logan Coal Company
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Normal	Selenium, Total Recoverable	Mingo Logan Coal Company
Normal	Selenium, Total Recoverable	Mingo Logan Coal Company
Normal	Selenium, Total Recoverable	Mingo Logan Coal Company
Normal	Selenium, Total Recoverable	Mingo Logan Coal Company
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Normal	Selenium, Total Recoverable	Mingo Logan Coal Company
Normal	Selenium, Total Recoverable	Mingo Logan Coal Company
Normal	Iron, Total (as Fe)	Mingo Logan Coal Company
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Normal	Iron, Total (as Fe)	Mingo Logan Coal Company
Normal	Manganese, Total (as Mn)	Mingo Logan Coal Company
Normal	Manganese, Total (as Mn)	Mingo Logan Coal Company
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Normal	Aluminum, Total (as Al)	Mingo Logan Coal Company
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Normal	Stream Flow cfs	Mingo Logan Coal Company

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Normal	Selenium, Total Recoverable	Mingo Logan Coal Company
Normal	Selenium, Total Recoverable	Mingo Logan Coal Company
Normal	Selenium, Total Recoverable	Mingo Logan Coal Company
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Normal	Iron, Total (as Fe)	Mingo Logan Coal Company
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Normal	Manganese, Total (as Mn)	Mingo Logan Coal Company
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Normal	Aluminum, Total (as Al)	Mingo Logan Coal Company
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Normal	Stream Flow cfs	Mingo Logan Coal Company
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Normal	pH	Mingo Logan Coal Company
Normal	Selenium, Total Recoverable	Mingo Logan Coal Company
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Normal	Aluminum, Diss. (as Al)	Mingo Logan Coal Company

Christopher Hunter/DC/USEPA/US
01/12/2011 11:11 AM

To Frank Borsuk
cc
bcc
Subject Re: Attached is the DMR data provided by WVDEP on selenium for July 2008 to March 2010 --Re: Disconnect

Thank you very much Frank!

Chris Hunter
U.S. Environmental Protection Agency
Office of Wetlands, Oceans, & Watershed
(202) 566-1454
hunter.christopher@epa.gov

Frank Borsuk | Stef Attached is the DMR record for selenium for... | 01/12/2011 11:10:57 AM

From: Frank Borsuk/R3/USEPA/US
To: Stefania Shamet/R3/USEPA/US@EPA
Cc: Christopher Hunter/DC/USEPA/US@EPA, David Rider/R3/USEPA/US@EPA, Michael Dunn/R3/USEPA/US@EPA
Date: 01/12/2011 11:10 AM
Subject: Attached is the DMR data provided by WVDEP on selenium for July 2008 to March 2010 --Re: Disconnect

---

Stef

Attached is the DMR record for selenium for the time frame - July 2007 to March 2010. This was a part of a download from WVDEP to USEPA.

Frank
p.s. I will search our electronic files for the other DMR parameters.

p.s.s. Also attached is the January 2010 to September 2010 DMR files for all parameters.

[attachment "selenium DMR data for Frank.xls" deleted by Christopher Hunter/DC/USEPA/US]

[attachment "Rider request WV1017021.xls" deleted by Christopher Hunter/DC/USEPA/US]

Frank Borsuk, Ph.D.
Aquatic/Fisheries Biologist
Freshwater Biology Team
USEPA-Region 3 (Wheeling Office)
Office of Monitoring & Assessment (3EA50)
Environmental Assessment & Innovation Division
1060 Chapline Street, Suite 303
Wheeling, WV 26003-2995
304-234-0241 Phone
304-234-0260 Fax
borsuk.frank@epa.gov

Please visit our website at http://epa.gov/reg3esd1/3ea50.htm

Stefania Shamet Ok. Chris -- get them on to the index. We physi... 01/12/2011 10:53:12 AM

From: Stefania Shamet/R3/USEPA/US
To: Christopher Hunter/DC/USEPA/US@EPA
Cc: Michael Dunn/R3/USEPA/US@EPA, David Rider/R3/USEPA/US@EPA, Frank Borsuk/R3/USEPA/US@EPA
Date: 01/12/2011 10:53 AM
Subject: Re: Disconnect

Ok.

Chris -- get them on to the index. We physically have them in the Region, so it's ok so long as they are on the index.

Mike -- Can you see if they are on Dave's desk.

Dave/Frank -- if you're checking email -- can you send electronically?

Christopher Hunter I don't think we have copies of the December 08... 01/12/2011 10:48:19 AM

From: Christopher Hunter/DC/USEPA/US
To: Stefania Shamet/R3/USEPA/US@EPA
Date: 01/12/2011 10:48 AM
Subject: Re: Disconnect

I don't think we have copies of the December 08-March 10 DMR for the admin file.

Chris Hunter
U.S. Environmental Protection Agency
Office of Wetlands, Oceans, & Watershed
(202) 566-1454
hunter.christopher@epa.gov

Stefania Shamet (b) (5) [redacted] .. 01/12/2011 07:24:34 AM

From: Stefania Shamet/R3/USEPA/US
To: Christopher Hunter/DC/USEPA/US@EPA
Date: 01/12/2011 07:24 AM
Subject: Disconnect

(b) (5) [redacted]

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(b) (5)

Frank Borsuk/R3/USEPA/US
01/12/2011 11:15 AM

To Christopher Hunter
cc Stefania Shamet, David Rider, borsuk.frank, Michael Dunn
bcc
Subject The remaining DMR Data for July 2007 to March 2010 is attached - originally sent to Borsuk from Rider

Chris/Stef:

I found the whole DMR electronic file for July 2007 to March 2010 dataset. It is attached.

Frank

ATTACHMENT REDACTED - DELIBERATIVE

Franks_WV1017021 - Spruce DMRs.xls

Frank Borsuk, Ph.D.
Aquatic/Fisheries Biologist
Freshwater Biology Team
USEPA-Region 3 (Wheeling Office)
Office of Monitoring & Assessment (3EA50)
Environmental Assessment & Innovation Division
1060 Chapline Street, Suite 303
Wheeling, WV 26003-2995
304-234-0241 Phone
304-234-0260 Fax
borsuk.frank@epa.gov

Please visit our website at http://epa.gov/reg3esd1/3ea50.htm

Christopher Hunter	Thank you very much Frank! Chris Hunter	01/12/2011 11:11:46 AM

From: Christopher Hunter/DC/USEPA/US
To: Frank Borsuk/R3/USEPA/US@EPA
Date: 01/12/2011 11:11 AM
Subject: Re: Attached is the DMR data provided by WVDEP on selenium for July 2008 to March 2010 --Re: Disconnect

---

Thank you very much Frank!

Chris Hunter
U.S. Environmental Protection Agency
Office of Wetlands, Oceans, & Watershed
(202) 566-1454
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Frank Borsuk	Stef Attached is the DMR record for selenium for...	01/12/2011 11:10:57 AM
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Christopher Hunter	I don't think we have copies of the December 08...	01/12/2011 10:48:19 AM
Stefania Shamet	Chris -- This am I revised PD 29 to include the u...	01/12/2011 07:24:34 AM

Frank Borsuk/R3/USEPA/US
01/12/2011 11:15 AM

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Stefania Shamet | Ok. Chris -- get them on to the index. We physi... | 01/12/2011 10:53:12 AM

From: Stefania Shamet/R3/USEPA/US
To: Christopher Hunter/DC/USEPA/US@EPA
Cc: Michael Dunn/R3/USEPA/US@EPA, David Rider/R3/USEPA/US@EPA, Frank Borsuk/R3/USEPA/US@EPA
Date: 01/12/2011 10:53 AM
Subject: Re: Disconnect

Ok.

Chris -- get them on to the index. We physically have them in the Region, so it's ok so long as they are on the index.

Mike -- Can you see if they are on Dave's desk.

Dave/Frank -- if you're checking email -- can you send electronically?

Christopher Hunter | I don't think we have copies of the December 08... | 01/12/2011 10:48:19 AM

From: Christopher Hunter/DC/USEPA/US
To: Stefania Shamet/R3/USEPA/US@EPA

Date: 01/12/2011 10:48 AM
Subject: Re: Disconnect

I don't think we have copies of the December 08-March 10 DMR for the admin file.

Chris Hunter
U.S. Environmental Protection Agency
Office of Wetlands, Oceans, & Watershed
(202) 566-1454
hunter.christopher@epa.gov

Stefania Shamet (b) (5) [redacted] 01/12/2011 07:24:34 AM

From: Stefania Shamet/R3/USEPA/US
To: Christopher Hunter/DC/USEPA/US@EPA
Date: 01/12/2011 07:24 AM
Subject: Disconnect

(b) (5) [redacted]

(b) (5) [redacted]

[redacted]

Table A1.12. Total Recoverable Selenium (µg/L) for Outfalls 015, 017 and 028 for NPDES Permit WV1017021, Mingo Logan Coal Company Spruce No. 1 Mine. Note: Shaded areas indicate selenium concentrations exceeding 5 µg/L.

Site Code	Site Location	Report Date	Min Value	Avg. value	Max value
015	Outlet 015	12/31/2008	0.00	0.00	0.00
017	Outlet 017	12/31/2008	0.00	0.00	0.00
017	Outlet 017	9/30/2009	19.20	19.20	19.20
028	Outlet 028	12/31/2008	5.70	5.70	5.70
028	Outlet 028	1/31/2009	9.80	9.80	9.80
028	Outlet 028	2/28/2009	3.90	3.90	3.90
028	Outlet 028	3/31/2009	0.60	1.00	1.40
028	Outlet 028	4/30/2009	1.70	1.70	1.70
028	Outlet 028	5/31/2009	2.50	2.50	2.50
028	Outlet 028	6/30/2009	3.20	3.30	3.40
028	Outlet 028	8/31/2009	1.25	3.48	5.70
028	Outlet 028	9/30/2009	4.60	6.05	7.50
028	Outlet 028	10/31/2009	3.00	3.00	3.00
028	Outlet 028	11/30/2009	1.40	1.85	2.30
028	Outlet 028	12/31/2009	1.80	1.85	1.90
028	Outlet 028	1/31/2010	3.40	3.80	4.20
028	Outlet 028	2/28/2010	3.80	4.50	5.20
028	Outlet 028	3/31/2010	4.70	6.10	7.50
028	Outlet 028	4/30/2010	3.8	4.40	5.00
028	Outlet 028	5/31/2010	4.70	7.60	10.50
028	Outlet 028	6/30/2010	11.40	11.50	11.60
028	Outlet 028	7/31/2010	6.40	8.50	10.40
028	Outlet 028	8/31/2010	4.80	10.65	14.80
028	Outlet 028	9/30/2010	4.80	9.40	11.00

(b) (5) [redacted]

[redacted]

(b) (5)

[redacted]

[redacted]

[redacted]

[redacted]

(b) (5)

[redacted]

[redacted]

[redacted]

Matthew Klasen/DC/USEPA/US
01/12/2011 11:19 AM

To Kevin Minoli
cc
bcc
Subject Re: 49A

Done

Matt Klasen
U.S. Environmental Protection Agency
Office of Water (IO)
202-566-0780
cell (202) 380-7229

Kevin Minoli (b) (5) [redacted] 01/12/2011 11:17:28 AM

From: Kevin Minoli/DC/USEPA/US
To: Matthew Klasen/DC/USEPA/US@EPA
Date: 01/12/2011 11:17 AM
Subject: 49A

(b) (5) [redacted]

[redacted]

Matthew Klasen/DC/USEPA/US

01/12/2011 11:24 AM

To Kevin Minoli, Stefania Shamet, Christopher Hunter, Karyn Wendelowski, Gregory Peck

cc

bcc

Subject OST response to 67A re: fish tissue

I've plugged this in. Let me know if you have any concerns (b) (5) [redacted]

Thanks.
Matt

(b) (5) [redacted]

(b) (5)

[redacted]

[redacted]

Matt Klasen
U.S. Environmental Protection Agency
Office of Water (IO)
202-566-0780
cell (202) 380-7229

Betsy Behl/DC/USEPA/US
01/12/2011 11:27 AM

To Matthew Klasen, zipf.lynn, Joe Beaman, Gregory Peck, Joe Beaman
cc
bcc
Subject Fw: Add'l Spruce OST reviews (in addition to fish tissue)

Matt: some minor changes to the first conductivity comment. looks good.

spruce mine conductivity.docx

----- Forwarded by Betsy Behl/DC/USEPA/US on 01/12/2011 11:25 AM -----

From: Matthew Klasen/DC/USEPA/US
To: Lynn Zipf/DC/USEPA/US@EPA
Cc: Gregory Peck/DC/USEPA/US@EPA, Joe Beaman/DC/USEPA/US@EPA, Betsy Behl/DC/USEPA/US@EPA
Date: 01/10/2011 01:55 PM
Subject: Add'l Spruce OST reviews (in addition to fish tissue)

Hi Lynn,

We had a good discussion this morning with Betsy and Joe on the fish tissue Se issues, and we're well on our way to getting that resolved.

There are three other Spruce responses that we'd like OST review of to make sure there aren't any problematic programmatic or policy statements.

Responses are attached, and they address the following:
(b) (5) [redacted]

I'm guessing Joe or Betsy is the right person to review the first group, but not sure who is right for the second one. Can you let me know whether these looks OK after forwarding to the appropriate folks? COB today would be great, and again, the goal is just to ensure we're not overstepping policy- or program-wise with our specific responses on Spruce.

Happy to help explain more by phone if that would help.

Thanks,
Matt

[attachment "2011-01-10 99A, 100A, 147A for OST.docx" deleted by Betsy Behl/DC/USEPA/US]

Matt Klasen
U.S. Environmental Protection Agency
Office of Water (IO)
202-566-0780
cell (202) 380-7229

Gregory Peck/DC/USEPA/US
01/12/2011 11:52 AM

To Kevin Minoli
cc
bcc
Subject Revised press release

Can you take a quick look at this before I send back to the 3rd floor. Thanks

ATTACHMENT REDACTED - DELIBERATIVE

Spruce press release gep edits.docx

Travis Loop
<tloop@chesapeakebay.net>
01/12/2011 11:55 AM

To Betsaida Alcantara
cc Gregory Peck, Matthew Klasen, Nancy Stoner
bcc
Subject spruce Q & A

2 attachments

ATTACHMENTS REDACTED - DELIBERATIVE

INTERNAL Q&A Spruce Mine.doc EXTERNAL Q&A Spruce Mine.doc

I took a cut at dividing the Spruce Q&A into external and internal docs.(b) (5) [redacted]

Travis Loop
Office of Water
U.S. Environmental Protection Agency
office: 202.564.0183
cell: 443.510.1571

Kevin Minoli/DC/USEPA/US
01/12/2011 12:08 AM

To Matthew Klasen
cc Christopher Hunter, Gregory Peck, Karyn Wendelowski, Stefania Shamet
bcc
Subject Re: Last batch of responses for your review (only one response left)

Here are my comments on these. There are a couple questions we could probably follow up on at 9:30 tomorrow.

Thanks, Kevin

ATTACHMENT REDACTED - DELIBERATIVE

2011-01-11 Kevin follow-ups.ksm.docx

Last batch of responses for your review (only one response left)

Last batch of responses for your review (only one response left)

Matthew Klasen to: Kevin Minoli 01/11/2011 02:16 PM

Cc: Stefania Shamet, Christopher Hunter, Karyn Wendelowski, Gregory Peck

---

Hey Kevin,

Attached is the last batch of responses for your review. With one exception, this should include all responses that you haven't seen, as well as all responses you wanted to see again. (b) (5) [redacted]

Thanks,
Matt

[attachment "2011-01-11 Kevin follow-ups.docx" deleted by Kevin Minoli/DC/USEPA/US]

Matt Klasen
U.S. Environmental Protection Agency
Office of Water (IO)
202-566-0780
cell (202) 380-7229

Christopher Hunter/DC/USEPA/US
01/12/2011 12:16 PM

To Stefania Shamet, Matthew Klasen
cc Julia McCarthy
bcc
Subject Fw: Instructions and attachments for reviews 30 questions at a time

Julia is starting on her 3rd batch, 211 - 240

Chris Hunter
U.S. Environmental Protection Agency
Office of Wetlands, Oceans, & Watershed
(202) 566-1454
hunter.christopher@epa.gov
----- Forwarded by Christopher Hunter/DC/USEPA/US on 01/12/2011 12:15 PM -----

From: Matthew Klasen/DC/USEPA/US
To: Christopher Hunter/DC/USEPA/US@EPA, Stefania Shamet/R3/USEPA/US@EPA
Date: 01/12/2011 10:57 AM
Subject: Re: Fw: Instructions and attachments for reviews 30 questions at a time

Chris and Stef:

Here are the other chunks of RD comments for when people are ready.

mk

211A-240A.docx

ATTACHMENT REDACTED - DELIBERATIVE

Matt Klasen
U.S. Environmental Protection Agency
Office of Water (IO)
202-566-0780
cell (202) 380-7229

Christopher Hunter | Spruce Team, here are the batches of response... | 01/12/2011 09:36:55 AM

From: Christopher Hunter/DC/USEPA/US
To: Ross Geredien/DC/USEPA/US@EPA, Julia McCarthy/R8/USEPA/US@EPA, Palmer Hough/DC/USEPA/US@EPA
Cc: Marcel Tchaou/DC/USEPA/US@EPA, Matthew Klasen/DC/USEPA/US@EPA, Stefania Shamet/R3/USEPA/US@EPA
Date: 01/12/2011 09:36 AM
Subject: Fw: Instructions and attachments for reviews 30 questions at a time

Spruce Team,
here are the batches of responses to comments that need to be checked for references, instructions, and the latest draft of the Reference Appendix. Focus on the references first, then circle back for the cross-references if you have time.

Thanks!

Ross - please take 1-30
Julia - 31-60

Palmer - 61-90

[attachment "Appendix 7 FD Marcel version 1-11-2011Harmonized.doc" deleted by Matthew Klasen/DC/USEPA/US]

Chris Hunter
U.S. Environmental Protection Agency
Office of Wetlands, Oceans, & Watershed
(202) 566-1454
hunter.christopher@epa.gov
----- Forwarded by Christopher Hunter/DC/USEPA/US on 01/12/2011 09:32 AM -----

From:	Matthew Klasen/DC/USEPA/US
To:	Christopher Hunter/DC/USEPA/US@EPA, Stefania Shamet/R3/USEPA/US@EPA
Cc:	Marcel Tchaou/DC/USEPA/US@EPA
Date:	01/12/2011 09:30 AM
Subject:	Instructions and attachments for reviews 30 questions at a time

Chris / Stef:

Here are instructions and responses, broken up in 30-question increments. Chris: Why don't you assign the first couple groups of these, and let Stef know; she can then farm out the next batch to R3.

Thanks,
Matt

Instructions: Go through and do the following:

- **Go through the document once and check for citations.** Verify that each citation included in the response is included in the reference list. If it isn't, make a note of the reference (e.g., Silva 2010) and a sentence for context (e.g., Silva (2010) found that birds are important).
- **Send citations that are missing and context (in groups of five, or once you're done going through the whole document, to Marcel, and copy Matt.** Make sure you include the questions # so Matt can make a note in the master document.
- **Once you're done going through citations, then go back through and check to make sure references to FD/RD/PD or Appendices or Figures/Tables are correct. If not, keep a running list and email Matt all of the changes (just note in an email, not in Track Changes).**

Call Matt (202-566-0780) or Chris (202-566-1454) with any questions.

For Distributing to Volunteers
[attachment "121A-150A.docx" deleted by Matthew Klasen/DC/USEPA/US] [attachment "1A-30A.docx" deleted by Matthew Klasen/DC/USEPA/US] [attachment "31A-60A.docx" deleted by Matthew Klasen/DC/USEPA/US] [attachment "61A-90A.docx" deleted by Matthew Klasen/DC/USEPA/US] [attachment "91A-120A.docx" deleted by Matthew Klasen/DC/USEPA/US]

Background Material (Chris: Also <u>send folks the FD and appendices</u>, especially the reference list. Probably too big for one email.

Matt Klasen
U.S. Environmental Protection Agency
Office of Water (IO)

202-566-0780
cell (202) 380-7229

Christopher Hunter/DC/USEPA/US

01/12/2011 12:35 PM

To Matthew Klasen, Kevin Minoli, Karyn Wendelowski, Stefania Shamet, Gregory Peck

cc

bcc

Subject Clean Appendices

Appendix 1 Water Qualiy & Widlife 011211.doc Appendix 2 macroinvertebrates 011211.doc Appendix 3 Mitigation 011211.doc

Appendix 4 Selenium 011111.doc Appendix 5 Cumulative Effects 011211.doc

Chris Hunter
U.S. Environmental Protection Agency
Office of Wetlands, Oceans, & Watershed
(202) 566-1454
hunter.christopher@epa.gov

ATTACHMENTS REDACTED - DELIBERATIVE

Christopher Hunter/DC/USEPA/US

01/12/2011 12:37 PM

To Stefania Shamet

cc Gregory Peck, Karyn Wendelowski, Kevin Minoli, Matthew Klasen

bcc

Subject Re: Revised fish/selenium section

Thanks Stef. I'll add this in to the next version of final.

Stefania Shamet (b) (5) [redacted] 01/12/2011 12:33:58 PM

From: Stefania Shamet/R3/USEPA/US
To: Christopher Hunter/DC/USEPA/US@EPA
Cc: Gregory Peck/DC/USEPA/US@EPA, Karyn Wendelowski/DC/USEPA/US@EPA, Kevin Minoli/DC/USEPA/US@EPA, Matthew Klasen/DC/USEPA/US@EPA
Date: 01/12/2011 12:33 PM
Subject: Re: Revised fish/selenium section

(b) (5) [redacted]

Christopher Hunter (b) (5) [redacted] 01/12/2011 11:58:21 AM

From: Christopher Hunter/DC/USEPA/US
To: Matthew Klasen/DC/USEPA/US@EPA, Gregory Peck/DC/USEPA/US@EPA, Stefania Shamet/R3/USEPA/US@EPA, Kevin Minoli/DC/USEPA/US@EPA, Karyn Wendelowski/DC/USEPA/US@EPA
Date: 01/12/2011 11:58 AM
Subject: Revised fish/selenium section

(b) (5) [redacted]

[redacted]

[redacted]

[redacted]

(b) (5)

[redacted]

Chris Hunter
U.S. Environmental Protection Agency
Office of Wetlands, Oceans, & Watershed
(202) 566-1454
hunter.christopher@epa.gov

Mark Douglas/R3/USEPA/US
01/12/2011 12:39 PM

To Michael Dunn
cc
bcc
Subject Fw: Guidance Memorandum No. 32 - 10

Mark Douglas
Environmental Assessment and Innovation Division
US EPA Region 3
3EA30
1650 Arch St
Philadelphia, PA 19103
215-814-2767

----- Forwarded by Mark Douglas/R3/USEPA/US on 01/12/2011 12:39 PM -----

From: Bette Conway/R3/USEPA/US
To: Mark Douglas/R3/USEPA/US@EPA
Date: 09/28/2010 01:27 PM
Subject: Fw: Guidance Memorandum No. 32 - 10

Bette Conway
EPA Region III
Water Protection Division
NPDES Permits Branch
1650 Arch Street, (3WP41)
Philadelphia PA 19103
Ph: 215-814-5744
Fax: 215-814-2301
conway.bette@epa.gov

----- Forwarded by Bette Conway/R3/USEPA/US on 09/28/2010 01:27 PM -----

From: Evelyn MacKnight/R3/USEPA/US
To: Francisco Cruz/R3/USEPA/US@EPA, Stefania Shamet/R3/USEPA/US@EPA, Jaclyn Mcilwain/R3/USEPA/US@EPA, Bette Conway/R3/USEPA/US@EPA
Cc: David McGuigan/R3/USEPA/US@EPA, Marcus Zobrist/DC/USEPA/US@EPA, Sharmin Syed/DC/USEPA/US, David Hair/DC/USEPA/US@EPA, Mark Nuhfer/R4/USEPA/US@EPA, Chris Thomas/R4/USEPA/US@EPA
Date: 09/27/2010 04:39 PM
Subject: Fw: Guidance Memorandum No. 32 - 10

FYI. A copy of VA's Narrative Guidance FYI in case you haven't seen it. I sent this out from my Blackberry last week, but am not sure if it went thru.

From: "Davis, Jackie (DMME)" <Jackie.Davis@dmme.virginia.gov>
To: Evelyn MacKnight/R3/USEPA/US@EPA
Date: 09/21/2010 03:42 PM
Subject: Guidance Memorandum No. 32 - 10

ATTACHMENT REDACTED - DELIBERATIVE

Guidance Memorandum No. 32 - 10.doc

DEPARTMENT OF MINES, MINERALS AND ENERGY
DIVISION OF MINED LAND RECLAMATION

GUIDANCE MEMORANDUM[1] No. 32-10
Issue Date: September 2, 2010
Subject: Permitting Guidance for Surface Coal Mining Operations to Protect Virginia's Narrative Water Quality Standards

This Guidance Memorandum supersedes the **Permitting Guidance for Surface Coal Mining Operations to Protect Virginia's Narrative Water Quality Standards** (Permit Guidance) issued by the Virginia Department of Mines, Minerals and Energy, Division of Mined Land Reclamation (DMLR) on August 30, 2010. The following Permit Guidance corrects minor typographical errors and makes some editorial changes in the August 30th version. It also provides guidance to applicants and DMLR staff to develop site-specific National Pollutant Discharge Elimination System permit conditions for surface coal mining operations using a holistic watershed management approach. This holistic approach includes the use of Total Maximum Daily Loads reports, biological, chemical monitoring, representative data (if available) and where necessary, whole effluent toxicity testing.

Applicants and consultants are encouraged to meet with the appropriate DMLR Technical staff prior to selection of monitoring/sampling points to ensure the monitoring/sampling locations will be acceptable for any proposed permit application.

Should you have questions regarding this Guidance Memorandum, please contact the DMLR Technical Services Manager at 276/523-8156.

---

[1] This Memorandum is to be considered a guideline issued under the authority of § 45.1-230.A1 of the Code of Virginia which reads:

"In addition to the adoption of regulations under this chapter, the Director may at his discretion issue or distribute to the public interpretative, advisory or procedural bulletins or guidelines pertaining to permit applications or to matters reasonably related thereto without following any of the procedures set forth in the Administrative Process Act (§ 2.2-4000 et seq.). The materials shall be clearly designated as to their nature, shall be solely for purposes of public information and education, and shall not have the force of regulations under this chapter or under any other provision of this Code."

Permitting Guidance for Surface Coal Mining Operations to Protect Virginia's Narrative Water Quality Standards

INTRODUCTION

The purpose of this Permitting Guidance (Guidance) is to assist applicants in collecting the data necessary for the Virginia Department of Mines, Minerals and Energy (DMME), Division of Mined Land Reclamation (DMLR) staff to develop site-specific National Pollutant Discharge Elimination System (NPDES) permit conditions for surface coal mining operations. The Department will use a holistic watershed management approach including use of Total Maximum Daily Loads (TMDL) reports, biological, chemical monitoring, and whole effluent toxicity ("WET") testing. This Guidance also explains how the Department will address requirements for compliance with narrative water quality standards.

Virginia's narrative water quality standards are found in Virginia's *Administrative Code*, which states, in the Virginia Department of Environmental Quality (DEQ) regulations at 9VAC25-260-20. General criteria.

> *"A. State waters, including wetlands, shall be free from substances attributable to sewage, industrial waste, or other waste in concentrations, amounts, or combinations which contravene established standards or interfere directly or indirectly with designated uses of such water or which are inimical or harmful to human, animal, plant, or aquatic life. Specific substances to be controlled include, but are not limited to: floating debris, oil, scum, and other floating materials; toxic substances (including those which bioaccumulate); substances that produce color, tastes, turbidity, odors, or settle to form sludge deposits; and substances which nourish undesirable or nuisance aquatic plant life. Effluents which tend to raise the temperature of the receiving water will also be controlled. Conditions within mixing zones established according to 9VAC25-260-20 B do not violate the provisions of this subsection.*
> *B. The board may use mixing zone concepts in evaluating limitations for Virginia Pollutant Discharge Elimination System permits."*

DMLR will use the process outlined in this guidance[2] in its review of NPDES permit applications. It has been drafted to apply to all outfalls associated with surface coal mining operations.

Approximately half of Virginia's permitted coal mining discharges never discharge and many remaining discharges are intermittent, primarily discharging in response to precipitation. Intermittent discharges have limited potential for environmental impacts as they discharge only in response to precipitation events and not during critical low flow conditions. Intermittent

[2] In light of the changing nature of the policy concerns addressed herein, this document is intended to be dynamic and will likely be modified in the future as technology and best management practices develop and improve.

discharges will not be considered to have a reasonable potential (RP) to cause or contribute to an exceedance of water quality standards.

DMLR will complete a RP analysis of the remaining continuous discharges. As part of the RP analysis for these continuous discharges, DMLR will review biological surveys, toxic and chemical instream monitoring, as well as WET analyses and chemical effluent screening at representative outfalls. The representative outfalls should be within the same HUC 12 watershed or TMDL watershed, whichever is smaller in area. Representative data, including data used to develop TMDLs, data in DMLR possession or data submitted by the applicant, may be utilized. DMLR will make the final determination as to whether data and outfalls are representative of the discharges addressed in the permit.

The applicant may utilize existing data in place of screening analyses or testing required by this guidance upon DMLR's determination that the data is representative. Applicants are encouraged to contact DMLR during development of the permit application to determine whether representative data is available for the proposed discharges.

TMDL WATERSHEDS

REASONABLE POTENTIAL ANALYSIS

In deciding which permit conditions are needed for a new or expanded discharge permit within TMDL watersheds, DMLR must perform a RP analysis. DMLR will also perform a RP analysis at permit mid-term and renewal. DMLR will consider whether the discharge will comply with the TMDL as a portion of the RP analysis. This analysis will be based primarily on the potential for the permit's individual sediment control structures to discharge, and upon the nature of the discharge, mining practices, including the geology, drainage area, etc.

Effluent Screening WET Analyses and/or WET Limits

When necessary due to the nature of a discharge, DMLR will assign WET screening requirements at representative outfalls within the watershed to begin within six months of mining disturbance for new or expanded discharges. These will be required when no representative WET screening data is available (Table 1). If representative data is available, DMLR will not require additional screening. At permit reissuance and mid-term, DMLR will use actual and representative WET and biological assessment data to determine, on a case-by-case basis, whether an existing discharge causes, has the RP to cause, or contributes to an excursion from the numeric or narrative water quality standards.

The collected WET assays will be utilized as a screening tool to conduct a RP analysis for effluent toxicity. Acute or chronic bioassays, as appropriate, will need to be utilized to measure WET in discharge samples for four consecutive quarters. Effluents demonstrating toxicity will receive appropriate WET limits for the discharge. Discharges not exhibiting toxicity will not receive WET limits. DMLR will review the need for WET analyses at mid-term and renewal.

Characterization will need to be conducted by a qualified laboratory per DEQ protocol. WET assays will utilize standard WET testing organisms and toxicity will be determined utilizing the results from such testing.

Table 1
Effluent Screening Program

(new coal mine permit/modification or at permit mid-term/renewal)

Method	Initial Permit	Outfall construction	Mid-term and Renewal	Qualifier
WET	Representative discharge(s) identified in NPDES permit for each type of mining Ex. Bench basin, hollow fill, prep plant, dewatering	WET test of discharge for four consecutive quarters, to begin within 6 months of commencement of active mining operations relative to selected representative outfall (representative data may be used)	One test for each selected representative outfall (representative data may be used)	Continuous discharges (outfalls that have continuous discharge duration >5 days will require Chronic Outfall discharge duration ≤5 consecutive days will require Acute tests only.) WET limits will be applied to discharge if appropriate based on test results Continuous discharges for the purposes of this guidance are those that discharge 50% or more of the time and 5 consecutive days based on the submitted Discharge Monitoring Report (DMR).
Outfall Chemical	Selected representative discharges (representative data may be used) Ex. Bench basin, hollow fill, prep plant, dewatering	Sample collected from discharge, within 6 months of commencement of active mining operations relative to outfall	Selected representative outfall (representative data may be used)	Numeric effluent limits will be applied to discharge, if appropriate, based on analytical results after reopening permit
In-Stream Chemical	Receiving Streams Minimum monthly for six months for standard instream baseline parameters and once prior to start of operations for Table 2 parameters.	N/A	Receiving Streams	Can be coordinated with biological monitoring stations if appropriate

For both new and expanded discharge permits and existing permits at midterm and renewal, DMLR will document its RP assessment in the fact sheet for the permit. Where DMLR concludes that an existing outfall has a RP, the permit will be reopened to add WET limits in

accordance with 40 CFR § 122.44(d) (1) (v). In cases where insufficient data is available to make a determination of RP upon permit reissuance, the DMLR will place WET screening requirements and triggers in the permit.

WET Screening

When the DMLR assigns screening as described above, the permit writer will establish WET screening triggers using all applicable rules and guidance, including the EPA's 1991 *Technical Support Document for Water Quality-based Toxics Control* ("TSD").[3] In developing the WET trigger, the DMLR will consider the instream waste concentration of the effluent in the immediate receiving stream and calculate it so as to result in no greater than 1.0 chronic toxicity unit (TU_c) and 0.3 acute toxicity unit (TU_a) at the edge of the appropriate mixing zones, where applicable.

When needed, the permittee will need to perform WET screening for four consecutive quarters for representative outfalls. The TSD requires use of the most sensitive available surrogate organism (*Ceriodaphnia dubia*) for chronic toxicity testing of effluents in addition to *Pimephales promelas*. DMLR requires temperature, pH, dissolved oxygen, hardness, Total Dissolved Solids (TDS), conductivity, sulfate, and bicarbonate alkalinity analyses for each aliquot used in WET screening.

If WET screening shows an exceedance of the specified triggers prescribed in the permit, the permittee will need to resample and test the effluent within 30 days. If that test shows compliance, the permittee will need to continue WET screening in accordance with the permit requirements. However, if that test shows an exceedance, the permittee will need to, within 60 days, submit a toxicity reduction plan, as referenced in the Aquatic Protection Plan section, identifying actions it will take to achieve compliance with the WET triggers. If, after four additional consecutive quarters, the permittee is still exceeding WET triggers, the permittee will also need to submit a permit modification to place WET limits in the permit.

WET Limits

If the WET and biological assessment screening described above shows a RP, the DMLR will establish WET limits using all applicable rules and guidance, including the EPA's TSD.[4] To develop the WET limits, the DMLR will consider the instream waste concentration of the effluent in the immediate receiving stream and calculate it so as to result in no greater than 1.0 chronic toxicity unit (TU_c) and 0.3 acute toxicity unit (TU_a) at the edge of the appropriate mixing zones, where applicable.

The permittee will be required to perform WET testing at the assigned frequency identified in the permit. The TSD requires use of the most sensitive available surrogate organism (*Ceriodaphnia dubia*) for chronic toxicity testing of effluents in addition to *Pimephales promelas*. DMLR requires temperature, pH, dissolved oxygen, hardness, TDS, conductivity, sulfate, and bicarbonate alkalinity analyses for each aliquot used in WET testing.

---

[3] EPA/505/2-90-001 PB91-127415
[4] Id.

If WET testing shows noncompliance with the specified limitations prescribed in the permit, the permittee will need to resample and test the effluent within 30 days. If the second test shows compliance, the permittee will need to continue WET testing in accordance with the permit requirements. However, if the second test shows noncompliance, the permittee will need to, within 60 days, conduct a Toxicity Reduction Evaluation (TRE)/Toxicity Identification Evaluation (TIE) analysis identifying actions it will take to achieve compliance with the WET discharge limitations.

Chemical Effluent Screening and Instream Chemical Analyses

In addition to what is currently required by technology based standards and identified TMDL stressors, the permit will require sampling for the parameters in Table 2 within 6 months of commencing the permitted activity, at mid-term, and at renewal for each representative outfall, and in receiving streams. The same sampling suite will be required for all established biological assessment stations ("BAS") semi-annually concurrently with aquatic surveys, as described below. All analyses and sample collection for representative discharges are to be conducted in accordance with requirements of 40 CFR 136. Metal analyses for these discharges will be required for total metals. Instream water quality standards are based on dissolved metal concentrations. If metal analyses concentrations exceed instream standards, the permittee will be asked to collect dissolved metal samples for those specific metals exceeding instream standards to confirm whether or not the standard has been met.

TABLE 2 - Parameters

Parameter
Flow (gpm)
Temperature (ºC)
pH (std units)
TSS (mg/L)
Specific Conductance (uS/cm)
TDS (mg/L)
Sulfates (mg/L)
Chlorides (mg/L)
Aluminum (mg/L)
Iron (mg/L)
Manganese (mg/L)
Magnesium (mg/L)
Total Acidity (mg/L)
Total Alkalinity (mg/L CaCO3)
Bicarbonate Alkalinity (mg/L)
Carbonate Alkalinity (mg/L)
Hardness (mg/L CaCO3)
Total Zinc (ug/L)
Total Antimony (ug/L)
Total Arsenic (ug/L)
Total Beryllium (ug/L)
Total Cadmium (ug/L)
Total Chromium (ug/L)
Total Copper (ug/L)
Total Lead (ug/L

TABLE 2 – Parameters (Continued)

Total Mercury (ug/L)
Total Nickel (ug/L)
Total Selenium (ug/L)
Total Silver (ug/L)
Total Thallium (ug/L)
Total Barium (µg/L)
Total Boron (µg/L)
Total Cobalt (µg/L)
Total Cyanide (µg/L)
Total Phenols (µg/L)
Nitrate (mg/L)
Nitrite (mg/L)
Dissolved Organic Carbon (mg/L)
Hydrogen Sulfide (mg/L)[5]

Instream Biological Surveys

The DMLR will assign semi-annual biological monitoring downstream of the representative outfall, with initial sampling done prior to commencement of any permitted activity for new and expanded permits (Table 3). To ensure data quality/consistency and to minimize duplication of sampling efforts, the biological monitoring protocols defined in the DMLR Aquatic Species Specific Protection Measures (SSPM) should be followed for all instream surveys in areas covered by the SSPM. For other areas, the Virginia Stream Condition Index (VASCI) protocol may be used. In addition, all biologic sampling shall be done in accordance with the Virginia Department of Game and Inland Fisheries scientific collection permit requirements.

SSPM analysis will need to be adjusted to produce a VASCI score. In order to reconcile Kentucky protocols required in the SSPM, the DEQ has developed the following procedure:

- Conduct benthic sampling using Virginia benthic protocols including time of year restrictions for sample collection.
- Collect organisms, laboratory subsample to 300 organisms in a gridded pan.
- Identify organisms to genus level, excluding chironomids (midges).
- Collapse data to family level.
- Statistically rarify data to 100 organisms; computer subsampling programs available.
- Calculate the VASCI score.
- Provide raw 300 count genus-level data in electronic spreadsheet format.

The applicant is strongly encouraged to have a VADEQ approved Level III Quality Assurance Project Plan as well as laboratory and field standard operating procedures per the Virginia Citizen Water Quality Monitoring Program.

The permit will require the maintenance of acceptable ecosystem health in waters of the state. An applicant must submit a monitoring plan for agency approval that proposes instream BAS

[5] This parameter need only be analyzed for underground mine discharges.

that allow a holistic assessment of the aquatic ecosystem and a determination of the impacts of the permitted activity.

Table 3.
Instream Biological Monitoring Program
(new coal mine permit/modification or at permit mid-term/renewal)

Monitoring target	Years/ Frequency/ Seasonal window(s)[1]	Method(s)	Location(s)
Invertebrates	0 – 5 / semi-annually / March 1 – May 31 and Sep. 1 – Nov. 30. With 2-week seasonal windows.	VASCI KYMBI[2] EKSAP[2]	One sample upstream of uppermost discharge site plus one site below the downstream-most NPDES outfall in each affected watershed. Applies to intermittent and perennial streams.
Fish	0,2, 4/ once per year / July 15 – November 15	TVA IBI KIBI for Big Sandy Basin	Below point where all drainage from the permit area passes. Perennial streams only.
Habitat	0 – 5/ concurrent with biomonitoring	EPA RBP	At each Aquatic Biological Station. Adjacent ephemeral reaches should also be included.
In-stream surface water chemistry	Years 0 – 5/ once per year/ concurrent with biomonitoring	EPA Table 2 parameters	Fish and Invertebrate Sites

1. Year 0 is baseline, pre-project. If no adverse impacts to streams are detected during the initial 5 year monitoring period and the permit is renewed, fish, invertebrate, and instream surface and sediment chemistry monitoring should be repeated at the appropriate frequency only during the year of the midterm review.
2. If other indices are used, VASCI score must also be included.

The applicant should work with the DMLR staff to establish a monitoring strategy with the most appropriate monitoring locations for a holistic evaluation of the aquatic ecosystem. The applicant will need to submit to DMLR for approval, a monitoring plan that is consistent with Virginia regulatory requirements.

- An instream BAS should be located at the first appropriate riffle/run habitat downstream of each new outfall in a perennial stream segment. Ideally, the BAS will be located such that future impacts to the stream are attributable solely to the permitted activity.
- Additional stations should be situated on a site-specific basis, but generally should be located upstream and downstream of the confluence of the immediate receiving stream and the stream into which it drains, which allows the aquatic ecosystem's health to be assessed in its entirety.
- If the first available location for a BAS is potentially influenced by other watershed activities and stressors, then a clear linkage between the permit controls and biological condition at the station may not be possible. Those scenarios will require baseline

documentation of the other potential stressors and tracking of watershed activities over time. The applicant will also have to submit a monitoring plan in accordance with the provisions set forth in "Chemical Monitoring" above.

- Additional monitoring stations may be designated further upstream or downstream at points that are useful in determining the entire aquatic ecosystem's health. Such stations may be beneficial in identifying actions the applicant can take to improve the overall health of the aquatic ecosystem.
- Based on benthic data from the central Appalachian region, headwater catchments of over 75 acres should be able to yield at least 300 organisms in riffle habitats. Permit writers will consider whether use of fewer than 300 organisms is appropriate for headwater catchments draining less than 75 acres.
- The plan should include chemical and biological monitoring at the BAS prior to the start of the permitted activity.

If the aquatic ecosystem at the assessment stations, prior to initiation of the permitted activity, is not impaired based on the VASCI score, then the acceptable future biological condition will be a VASCI score greater than or equal to 60. In determining whether a lower VASCI score represents an unacceptable condition, the DMLR will utilize best professional judgment, including a holistic examination of the health of the aquatic ecosystem.

If the aquatic ecosystem at the assessment stations, prior to initiation of the permitted activity, is impaired based on the VASCI score, then the applicant will need to identify existing conditions within the watershed that may be contributing to the problem. A VASCI score greater than or equal to the baseline value or compliance with TMDL requirements would represent an acceptable future condition.

Aquatic Protection Plan

DMLR issues a combined SMCRA and NPDES permit. For all mining permit applications proposing new and expanded discharges, an Aquatic Protection Plan (APP) for DMLR review and approval will need to be included in the combined permit. The plan is a preventative and predictive plan intended to reduce impacts. An APP describes the potential control measures the applicant would implement to minimize adverse biological impacts to the aquatic ecosystem surrounding the permitted activity. The plan should also include controls designed to lower the magnitude of pollutant loading associated with mining activities. If the agency cannot conclude that the proposed measures are reasonably expected to result in compliance, then the permit will not be issued.

The applicant should consider all appropriate options when selecting and implementing control measures. If WET limits are imposed as a result of effluent screening and those limits are not met, the applicant will need to amend its APP to include additional measures that enable it to comply with WET limits. This amended plan will need to include, at a minimum, a Toxicity Reduction Evaluation (TRE)/Toxicity Identification Evaluation (TIE) plan and schedule to obtain compliance with final effluent limits or triggers for chronic toxicity. For guidance in conducting a TRE/TIE study, the permittee should reference EPA's TSD. The TRE/TIE may

identify toxic parameters associated with the effluent, and appropriate effluent limitations may need to be developed in accordance with 9VAC25-31-220(D) (1).

The applicant can implement any of a number of controls in an attempt to protect the aquatic ecosystem and to reduce or minimize the ionic strength in the stream. Some examples of control measures that may be included in the APP include, but are not limited to, the following:

- Test overburden to determine the material that contains sulfur or other ionic strength-bearing material, so it can be isolated through material handling;
- Minimize the amount of area disturbed at one time;
- Minimize stormwater contact with pulverized material;
- Increase stream buffer zones;
- Minimize fill areas;
- Cap fills and spoil so as to minimize pass-through of rain water;
- Revegetate any disturbed areas to minimize runoff;
- Develop a plan to reduce or prevent ionic stress;
- If necessary, conduct TRE/TIE pursuant to EPA's TSD;
- Weathered rock segregation and return to surface;
- Expedited reclamation;
- Enhanced riparian plantings;
- Natural stream restoration.

Reopener Clause

The permit will contain a reopener clause allowing DMLR to modify or revoke the permit if prescribed controls do not attain and maintain applicable water quality standards. The permit may also be reopened if, after a sufficient amount of data has been collected, the agency determines that reasonable potential does not exist and the permittee can relax its monitoring activities.

NON-TMDL WATERSHEDS

REASONABLE POTENTIAL ANALYSIS

In deciding which permit conditions are needed for a new or expanded discharge permit within non-TMDL watersheds, DMLR must perform a RP analysis. DMLR will also perform a RP analysis at permit mid-term and renewal for existing permits. This analysis will be based primarily on the potential for the permit's sediment control structures to discharge and upon the nature of the discharge, mining practices, including the geology, drainage area, etc.

Effluent Screening WET Analyses and/or WET Limits

When necessary due to the nature of a discharge, DMLR will assign WET effluent screening requirements, at representative outfalls within the respective watershed, to begin within six months of mining disturbance for new or expanded discharges (Table 4). At permit reissuance and mid-term, DMLR will require WET and biological assessment data from the representative

outfalls identified in the NPDES permit to determine, on a case-by-case basis, whether an existing discharge causes, has the RP to cause, or contributes to an excursion from the narrative water quality criteria. The collected WET assays will be utilized as a screening tool to conduct a RP analysis for effluent toxicity. Acute or chronic bioassays, as appropriate, will be utilized to measure whole effluent toxicity in discharge samples for four consecutive quarters when possible. Effluents demonstrating toxicity will receive appropriate WET limits for the discharge. Discharges not exhibiting toxicity will not receive WET limits and will only be required to submit additional WET analyses at mid-term and renewal. Characterization will be conducted by a qualified laboratory per DEQ protocol. WET assays will utilize standard WET testing organisms and toxicity will be determined utilizing the results from such testing.

Table 4
Effluent Screening Program

(new coal mine permit/modification or at permit mid-term/renewal)

Method	Initial Permit	Outfall construction	Mid-term and Renewal	Qualifier
WET	Representative discharge(s) identified in NPDES permit for each type of mining Ex. Bench basin, hollow fill, prep plant, dewatering	WET test of discharge for four consecutive quarters, to begin within 6 months of commencement of active mining operations relative to outfall	One test for each selected representative outfall	Continuous discharges (outfalls that have continuous discharge duration >5 days will require Chronic Outfall discharge duration <5 consecutive days will require Acute tests only.) WET limits will be applied to discharge if appropriate based on test results Continuous discharges for the purposes of this guidance are those that discharge approximately 50% of the time or more and 5 consecutive days based on the submitted DMRs.
Outfall Chemical	Representative discharge(s) identified in NPDES permit for each type of mining Ex. Bench basin, hollow fill, prep plant, dewatering	Sample collected from discharge, within 6 months of commencement of active mining operations relative to outfall	Selected representative outfall	Numeric effluent limits will be applied to discharge if appropriate based on analytical results after reopening permit.
In-Stream Chemical	Receiving Streams Minimum monthly for six months for standard instream baseline parameters and once prior to start of operations for Table 2 parameters.	N/A	Receiving Streams	Can be coordinated with biological monitoring stations if appropriate

For both new and expanded discharge permits and existing permits at midterm and renewal, DMLR will document its RP assessment in the fact sheet for the permit. Where DMLR concludes that an existing outfall has a RP, the permit will be reopened to add WET limits in accordance with 40 C.F.R. § 122.44(d) (1) (v). In cases where insufficient data is available to make a determination of RP upon permit reissuance, the DMLR will place WET screening requirements and triggers in the permit.

WET Screening

When the DMLR assigns screening as described above, the permit writer will establish WET screening triggers using all applicable rules and guidance, including the EPA's 1991 *Technical Support Document for Water Quality-based Toxics Control* ("TSD").[6] In developing the WET trigger, the DMLR will consider the instream waste concentration of the effluent in the immediate receiving stream and calculate it so as to result in no greater than 1.0 chronic toxicity unit (TU_c) and 0.3 acute toxicity unit (TU_a) at the edge of the appropriate mixing zones, where applicable.

When needed, the permittee will need to perform WET screening for four consecutive quarters for representative outfalls. The TSD requires use of the most sensitive available surrogate organism (*Ceriodaphnia dubia*) for chronic toxicity testing of effluents in addition to *Pimephales promelas*. DMLR requires temperature, pH, dissolved oxygen, hardness, TDS, conductivity, sulfate, and bicarbonate alkalinity analyses for each aliquot used in WET screening.

If WET screening shows an exceedance of the specified triggers prescribed in the permit, the permittee will need to resample and test the effluent within 30 days. If that test shows compliance, the permittee will need to continue WET screening in accordance with the permit requirements. However, if that test shows an exceedance, the permittee will need to, within 60 days, conduct a toxicity reduction plan, as referenced in the Aquatic Protection Plan section, identifying actions it will take to achieve compliance with the WET triggers. If, after four additional consecutive quarters, the permittee is still exceeding WET triggers, the permittee will also need to submit a permit modification to place WET limits in the permit.

WET Limits

If the WET and biological assessment screening described above shows a RP, the DMLR will establish WET limits using all applicable rules and guidance, including the EPA's TSD.[7] To develop the WET limits, the DMLR will consider the in-stream waste concentration of the effluent in the immediate receiving stream and calculate it so as to result in no greater than 1.0 chronic toxicity unit (TU_c) and 0.3 acute toxicity unit (TU_a) at the edge of the appropriate mixing zones, where applicable.

The permittee will be required to perform WET testing at the assigned frequency identified in the permit. The TSD requires use of the most sensitive available surrogate organism (*Ceriodaphnia dubia*) for chronic toxicity testing of effluents in addition to *Pimephales promelas*. DMLR

[6] EPA/505/2-90-001 PB91-127415
[7] Id.

requires temperature, pH, dissolved oxygen, hardness, TDS, conductivity, sulfate, and bicarbonate alkalinity analyses for each aliquot used in WET testing.

If WET testing shows noncompliance with the specified limitations prescribed in the permit, the permittee will need to resample and test the effluent within 30 days. If the second test shows compliance, the permittee will need to continue WET testing in accordance with the permit requirements. However, if the second test shows noncompliance, the permittee will need to, within 60 days, conduct a TRE/TRI identifying actions it will take to achieve compliance with the WET discharge limitations.

Chemical Effluent Screening and Instream Chemical Analyses

In addition to what is currently required by technology based standards, the permit will require sampling for the parameters in Table 5 within 6 months of commencing the permitted activity at mid-term and renewal for each representative outfall and in receiving streams. The same sampling suite will be required for all established biological assessment stations ("BAS") semi-annually concurrently with aquatic surveys, as described below. All analyses and sample collection for representative discharges are to be conducted in accordance with requirements of 40 CFR 136. Metal analyses for these discharges will be required for total metals. Instream water quality standards are based on dissolved metal concentrations. If total metal analyses concentrations exceed instream standards, the permittee will be asked to collect dissolved metal samples for those specific metals exceeding instream standards to confirm whether or not the instream standard has been met. Otherwise the total metals concentration will be used to determine compliance with the instream standard.

TABLE 5 - Parameters

Flow (gpm)
Temperature (^{o}C)
pH (std units)
TSS (mg/L)
Specific Conductance (uS/cm)
TDS (mg/L)
Sulfates (mg/L)
Chlorides (mg/L)
Aluminum (mg/L)
Iron (mg/L)
Manganese (mg/L)
Magnesium (mg/L)
Total Acidity (mg/L)
Total Alkalinity (mg/L CaCO3)
Bicarbonate Alkalinity (mg/L)
Carbonate Alkalinity (mg/L)
Hardness (mg/L CaCO3)
Total Zinc (ug/L)
Total Antimony (ug/L)
Total Arsenic (ug/L)
Total Beryllium (ug/L)
Total Cadmium (ug/L)
Total Chromium (ug/L)

TABLE 5 – Parameters (Continued)

Total Copper (ug/L)
Total Lead (ug/L)
Total Mercury (ug/L)
Total Nickel (ug/L)
Total Selenium (ug/L)
Total Silver (ug/L)
Total Thallium (ug/L)
Total Barium (µg/L)
Total Boron (µg/L)
Total Cobalt (µg/L)
Total Cyanide (µg/L)
Total Phenols (µg/L)
Nitrate (mg/L)
Nitrite (mg/L)
Dissolved Organic Carbon (mg/L)
Hydrogen Sulfide (mg/L)

Instream Biological Surveys

The DMLR will assign semi-annual biological monitoring downstream of the outfall, with initial sampling done prior to commencement of any permitted activity for new and expanded permits (Table 3). To ensure data quality/consistency and to minimize duplication of sampling efforts, the biological monitoring protocols defined in the DMLR Aquatic Species Specific Protection Measures (SSPM) should be followed for all instream surveys in areas covered by the SSPM. For other areas, the Virginia Stream Condition Index (VASCI) protocol may be used. In addition, all biologic sampling shall be done in accordance with the Virginia Department of Game and Inland Fisheries scientific collection permit and DEQ's Virginia Stream Condition Index ("VASCI") protocol. SSPM analysis will need to be adjusted to produce a VASCI score. In order to reconcile Kentucky protocols required in the SSPM, the DEQ has developed the following procedure:

- Conduct benthic sampling using Virginia benthic protocols including time of year restrictions for sample collection.
- Collect organisms, laboratory subsample to 300 organisms in a gridded pan.
- Identify organisms to genus level, excluding chironomids (midges).
- Collapse data to family level.
- Statistically rarify data to 100 organisms; computer subsampling programs available.
- Calculate the VASCI score.
- Provide raw 300 count genus-level data in electronic spreadsheet format.

The applicant is strongly encouraged to have a VADEQ approved Level III Quality Assurance Project Plan, as well as laboratory and/or field standard operating procedures, per the Virginia Citizen Water Quality Monitoring Program. The permit will require the maintenance of acceptable ecosystem health in waters of the state. An applicant must submit a monitoring plan for agency approval that proposes instream BAS that allow a holistic assessment of the aquatic ecosystem and a determination of the impacts of the permitted activity.

Table 3.
Instream Biological Monitoring Program
(new coal mine permit/modification or at permit mid-term/renewal)

Monitoring target	Years/ Frequency/ Seasonal window(s)[1]	Method(s)	Location(s)
Invertebrates	0 – 5 / semi-annually / March 1 – May 31 and Sep. 1 – Nov. 30. With 2-week seasonal windows.	VASCI KYMBI[2] EKSAP[2]	One sample upstream of uppermost discharge site plus one site below the downstream-most NPDES outfall in each affected watershed. Applies to intermittent and perennial streams.
Fish	0,2, 4/ once per year / July 15 – November 15	TVA IBI KIBI for Big Sandy Basin	Below point where all drainage from the permit area passes. Perennial streams only.
Habitat	0 – 5/ concurrent with biomonitoring	EPA RBP	At each Aquatic Biological Station. Adjacent ephemeral reaches should also be included.
In-stream surface water chemistry	Years 0 – 5/ once per year/ concurrent with biomonitoring	EPA Table 2 parameters	Fish and Invertebrate Sites

1 Year 0 is baseline, pre-project. If no adverse impacts to streams are detected during the initial 5 year monitoring period and the permit is renewed, fish, invertebrate, and instream surface and sediment chemistry monitoring should be repeated at the appropriate frequency only during the year of the midterm review.
2 If other indices are used, VASCI score must also be included.

The applicant should work with the DMLR staff to establish a monitoring strategy with the most appropriate monitoring locations for a holistic evaluation of the aquatic ecosystem. The applicant will need to submit to DMLR, for approval, a monitoring plan that is consistent with Virginia regulatory requirements.

- An instream BAS should be located at the first appropriate riffle/run habitat downstream of each new outfall in a perennial stream segment. Ideally, the BAS will be located such that future impacts to the stream are attributable solely to the permitted activity.
- Additional stations should be situated on a site-specific basis, but generally should be located upstream and downstream of the confluence of the immediate receiving stream and the stream into which it drains, which allows the aquatic ecosystem's health to be assessed in its entirety.
- If the first available location for a BAS is potentially influenced by other watershed activities and stressors, then a clear linkage between the permit controls and biological condition at the station may not be possible. Those scenarios will require baseline documentation of the other potential stressors and tracking of watershed activities over time. The applicant will also have to submit a monitoring plan in accordance with the provisions set forth in "Chemical Monitoring" above.

- Additional monitoring stations may be designated further upstream or downstream at points that are useful in determining the entire aquatic ecosystem's health. Such stations may be beneficial in identifying actions the applicant can take to improve the overall health of the aquatic ecosystem.
- Based on benthic data from the central Appalachian region, headwater catchments of over 75 acres should be able to yield at least 300 organisms in riffle habitats. Permit writers will consider whether use of fewer than 300 organisms is appropriate for headwater catchments draining less than 75 acres.
- The plan should include chemical and biological monitoring at the BAS prior to the start of the permitted activity.

If the aquatic ecosystem at the assessment stations prior to initiation of the permitted activity is not impaired based on the VASCI score, then the acceptable future biological condition is a VASCI score greater than or equal to 60. In determining whether a lower VASCI score represents an unacceptable condition, the DMLR will utilize best professional judgment, including a holistic examination of the health of the aquatic ecosystem.

If the aquatic ecosystem at the assessment stations prior to initiation of the permitted activity is impaired based on the VASCI score, then the applicant will need to identify existing conditions within the watershed that may be contributing to the problem. A VASCI score greater than or equal to the baseline value would represent an acceptable future condition.

Aquatic Protection Plan

DMLR issues a combined SMCRA and NPDES permit. For all mining permit applications proposing new and expanded discharges, an Aquatic Protection Plan (APP) for DMLR review and approval will need to be included in the combined permit. The plan is a preventative and predictive plan intended to reduce impacts. An APP describes the potential control measures the applicant would implement to minimize adverse biological impacts to the aquatic ecosystem surrounding the permitted activity. The plan will need to include controls designed to lower the magnitude of pollutant loading associated with mining activities. If the agency cannot conclude that the proposed measures are reasonably expected to result in compliance, then the permit will not be issued. The applicant should consider all appropriate options when selecting and implementing control measures. If WET limits are imposed as a result of effluent screening and those limits are not met, the applicant must amend its APP to include additional measures that enable it to comply with WET limits. This amended plan will need to include at a minimum, a Toxicity Reduction Evaluation (TRE)/Toxicity Identification Evaluation (TIE) plan and schedule to obtain compliance with final effluent limits or triggers for chronic toxicity. For guidance in conducting a TRE/TIE study, the permittee shall reference EPA's TSD. The TRE/TIE may identify toxic parameters associated with the effluent and appropriate effluent limitations may need to be developed in accordance with 9VAC25-31-220(D) (1).

The applicant can implement any of a number of controls in an attempt to protect the aquatic ecosystem and to reduce or minimize the ionic strength in the stream. Some examples of control measures that may be included in the APP include, but are not limited to, the following:

- Test overburden to determine the material that contains sulfur or other ionic strength-bearing material, so it can be isolated through material handling;
- Minimize the amount of area disturbed at one time;
- Minimize stormwater contact with pulverized material;
- Increase stream buffer zones;
- Minimize fill areas;
- Cap fills and spoil so as to minimize pass-through of rain water;
- Revegetate any disturbed areas to minimize runoff;
- Develop a plan to reduce or prevent ionic stress;
- If necessary, conduct TRE/TIE pursuant to EPA's TSD;
- Weathered rock segregation and return to surface;
- Expedited reclamation;
- Enhanced riparian plantings;
- Natural stream restoration.

Reopener Clause

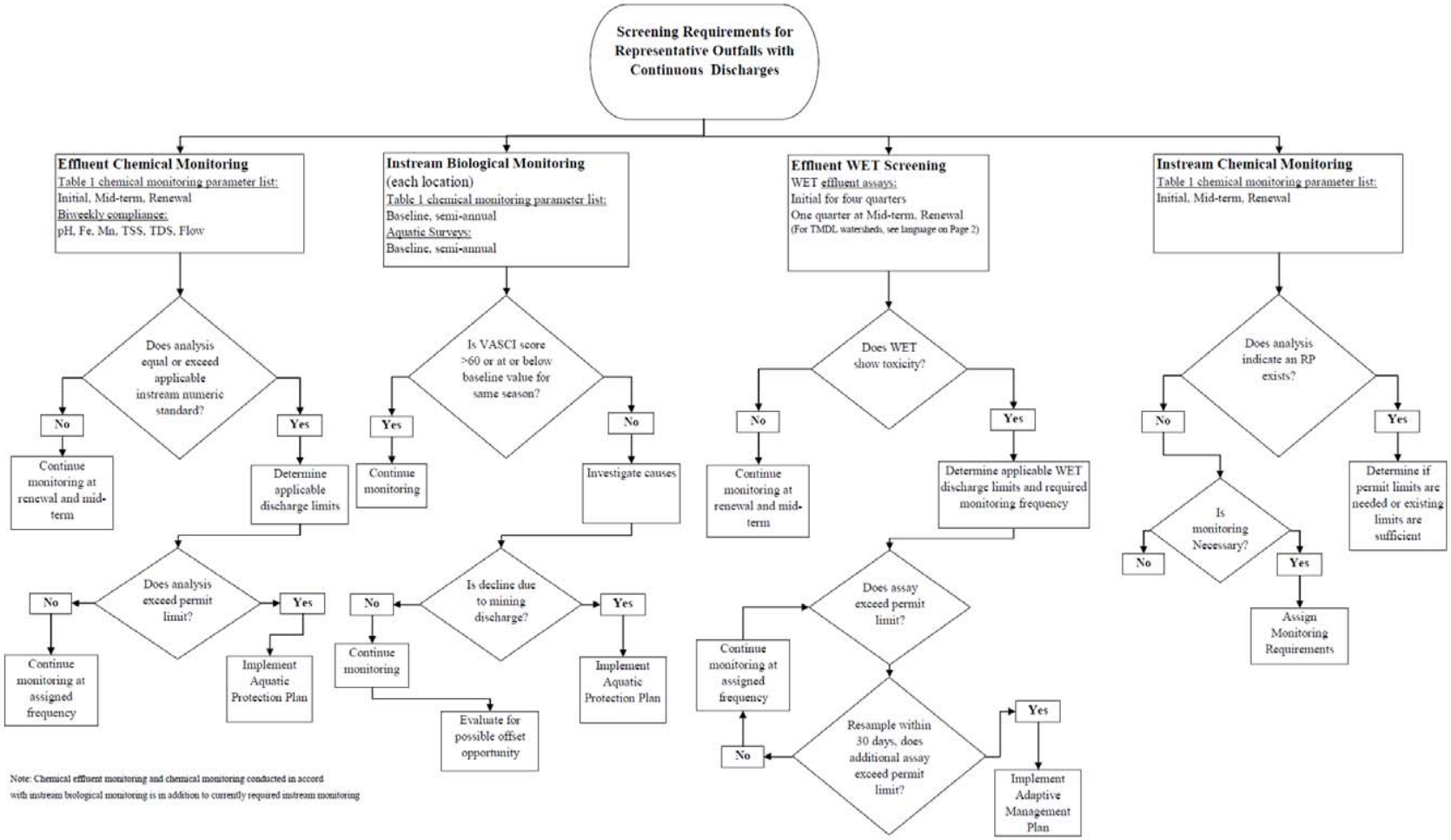
The permit will contain a reopener clause allowing DMLR to modify or revoke the permit if prescribed controls do not attain and maintain applicable water quality standards. The permit may also be reopened if, after a sufficient amount of data has been collected, the agency determines that a RP does not exist and the permittee can relax its monitoring activities.

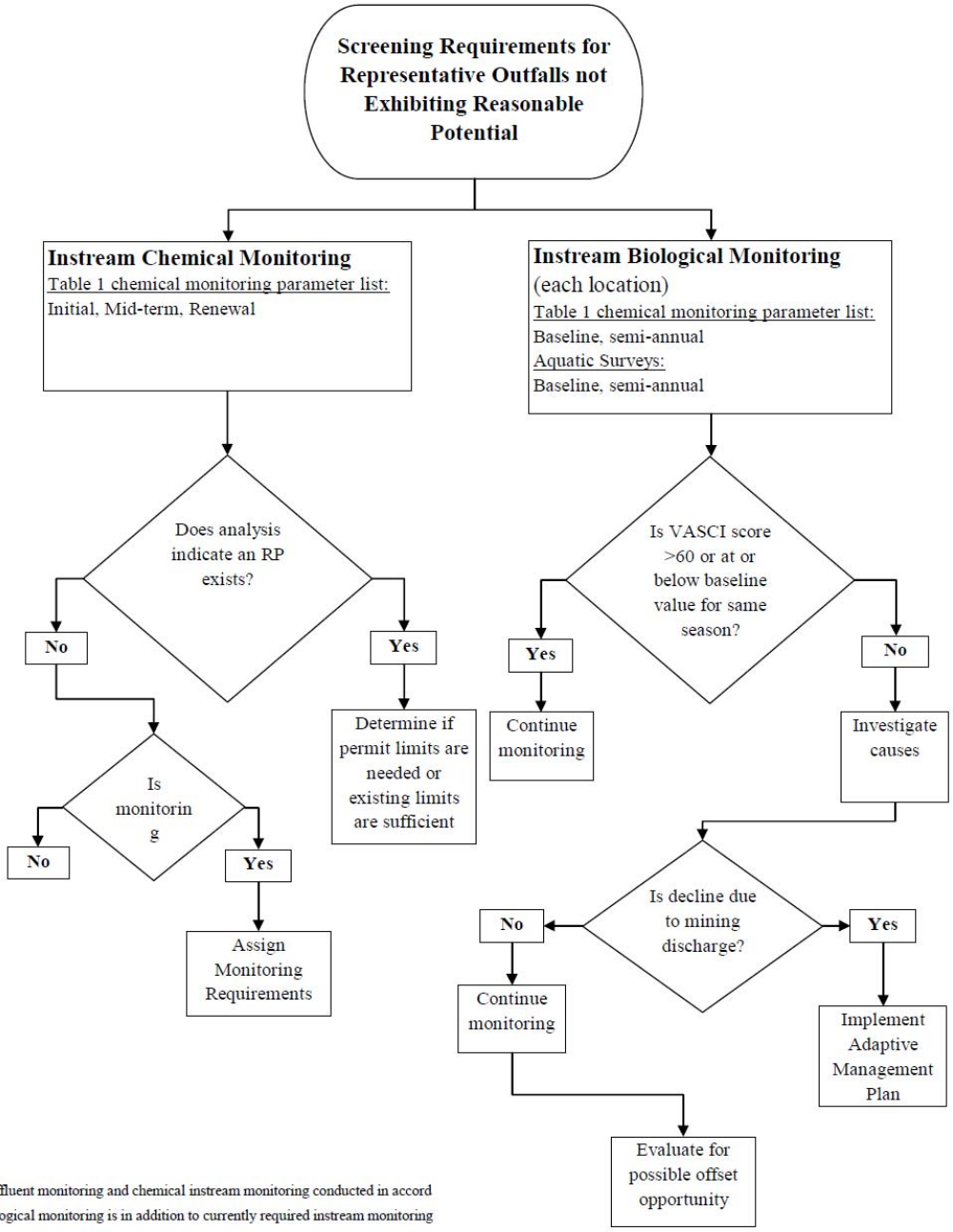
REFERENCES

EPA's *Policy on the Use of Biological Assessments and Criteria in the Water Quality Program* (May 1991)

EPA's *Technical Support Document for Water Quality-based Toxics Control*, EPA/505/2-90-001 (March 1991)

EPA's *NPDES Permit Writers' Manual*, EPA-833-B-96-003


Screening Requirements for Representative Outfalls with Continuous Discharges
Effluent Chemical Monitoring
Table 1 chemical monitoring parameter list:
Initial, Mid-term, Renewal
Biweekly compliance:
pH, Fe, Mn, TSS, TDS, Flow
Does analysis equal or exceed applicable instream numeric standard?
No
Continue monitoring at renewal and mid-term
Yes
Determine applicable discharge limits
Does analysis exceed permit limit?
No
Continue monitoring at assigned frequency
Yes
Implement Aquatic Protection Plan
Instream Biological Monitoring
(each location)
Table 1 chemical monitoring parameter list:
Baseline, semi-annual
Aquatic Surveys:
Baseline, semi-annual
Is VASCI score >60 or at or below baseline value for same season?
Yes
Continue monitoring
No
Investigate causes
Is decline due to mining discharge?
No
Continue monitoring
Evaluate for possible offset opportunity
Yes
Implement Aquatic Protection Plan
Effluent WET Screening
WET effluent assays:
Initial for four quarters
One quarter at Mid-term, Renewal
(For TMDL watersheds, see language on Page 2)
Does WET show toxicity?
No
Continue monitoring at renewal and mid-term
Yes
Determine applicable WET discharge limits and required monitoring frequency
Does assay exceed permit limit?
Continue monitoring at assigned frequency
Resample within 30 days, does additional assay exceed permit limit?
No
Yes
Implement Adaptive Management Plan
Instream Chemical Monitoring
Table 1 chemical monitoring parameter list:
Initial, Mid-term, Renewal
Does analysis indicate an RP exists?
No
Is monitoring Necessary?
No
Yes
Assign Monitoring Requirements
Yes
Determine if permit limits are needed or existing limits are sufficient
Note: Chemical effluent monitoring and chemical monitoring conducted in accord with instream biological monitoring is in addition to currently required instream monitoring



Note: Chemical effluent monitoring and chemical instream monitoring conducted in accord with instream biological monitoring is in addition to currently required instream monitoring

Gregory Peck/DC/USEPA/US
01/12/2011 12:44 PM

To Betsaida Alcantara
cc Arvin Ganesan, Bob Sussman, Jordan Dorfman, Nancy Stoner, "Travis Loop"
bcc Kevin Minoli
Subject Re: Spruce press release

Betsaida

Here are some suggested edits to your draft of the PR.

Thanks,
Greg

Document Withheld-FOIA (b)(5)

Spruce press release gep edits.docx

Betsaida Alcantara | Bob I've been waiting for your edits on what I se... | 01/12/2011 11:26:26 AM

From: Betsaida Alcantara/DC/USEPA/US
To: Bob Sussman/DC/USEPA/US@EPA, Nancy Stoner/DC/USEPA/US@EPA
Cc: Arvin Ganesan/DC/USEPA/US@EPA, Gregory Peck/DC/USEPA/US@EPA, Jordan Dorfman/DC/USEPA/US@EPA, "Travis Loop" <tloop@chesapeakebay.net>
Date: 01/12/2011 11:26 AM
Subject: Re: Spruce press release

Bob I've been waiting for your edits on what I sent last night, then I'll incorporate some of the points from greg

Bob Sussman

----- Original Message -----
From: Bob Sussman
Sent: 01/12/2011 11:25 AM EST
To: Nancy Stoner
Cc: Arvin Ganesan; Betsaida Alcantara; Gregory Peck; Jordan Dorfman; "Travis Loop" <tloop@chesapeakebay.net>
Subject: Re: Spruce press release

All good points. Is someone revising?

Robert M. Sussman
Senior Policy Counsel to the Administrator
Office of the Administrator
(202)-564-7397
US Environmental Protection Agency

Nancy Stoner | Good thoughts ----- Original Message ----- | 01/12/2011 11:05:23 AM

From: Nancy Stoner/DC/USEPA/US
To: Gregory Peck/DC/USEPA/US@EPA, Betsaida Alcantara/DC/USEPA/US@EPA
Cc: Arvin Ganesan/DC/USEPA/US@EPA, Bob Sussman/DC/USEPA/US@EPA, Jordan Dorfman/DC/USEPA/US@EPA, "Travis Loop" <tloop@chesapeakebay.net>
Date: 01/12/2011 11:05 AM
Subject: Re: Spruce press release

Good thoughts

Gregory Peck

----- Original Message -----
From: Gregory Peck
Sent: 01/12/2011 10:34 AM EST
To: Betsaida Alcantara
Cc: Arvin Ganesan; Bob Sussman; Jordan Dorfman; Nancy Stoner; Travis Loop
(b) (6) [redacted]
Subject: Re: Spruce press release

Betsaida

Not sure if you looked at the latest version of the OW draft release? I've attached. (b) (5) [redacted]

Thanks,
Greg

[attachment "Mining Spruce DRAFT Press Release JAN 10 11.docx" deleted by Nancy Stoner/DC/USEPA/US]

Betsaida Alcantara | Here;s the press release with my edits and the f... | 01/11/2011 06:11:26 PM

From: Betsaida Alcantara/DC/USEPA/US
To: Arvin Ganesan/DC/USEPA/US@EPA, Bob Sussman/DC/USEPA/US@EPA, Gregory Peck/DC/USEPA/US@EPA, Nancy Stoner/DC/USEPA/US@EPA
Cc: Jordan Dorfman/DC/USEPA/US@EPA, Travis Loop(b) (6) [redacted]
Date: 01/11/2011 06:11 PM
Subject: Spruce press release

Here;s the press release with my edits and the factsheet. Bob, if you can take a look, that'd be great. I'll send over the internal qs and as and external qs and as tomorrow.

[attachment "factsheet.doc" deleted by Gregory Peck/DC/USEPA/US] [attachment "press release.docx" deleted by Gregory Peck/DC/USEPA/US]

Marcel Tchaou/DC/USEPA/US
01/12/2011 12:55 PM

To Matthew Klasen
cc
bcc
Subject Re: Fw: Where I am now

Matt, I am not sure which version of App. & Stef is using, but I have some of the things already updated. Anyway this is the latest version.

ATTACHMENT REDACTED - DELIBERATIVE

Appendix 7 FD Marcel version 1-11-2011Harmonized.doc

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Marcel K. Tchaou, Ph.D., P.E., P.H.
Environmental Engineer
Wetlands & Aquatic Resources Regulatory Branch
Office of Wetlands, Oceans and Watersheds
U.S. EPA
1200 Pennsylvania Avenue, NW (MC 4502T)
Washington, DC 20460
202-566-1904

Matthew Klasen | Marcel: Can you add the references in Stef's att... | 01/12/2011 12:08:22 PM

From: Matthew Klasen/DC/USEPA/US
To: Marcel Tchaou/DC/USEPA/US@EPA
Date: 01/12/2011 12:08 PM
Subject: Fw: Where I am now

Marcel: Can you add the references in Stef's attachment below?

Thanks,
Matt

Matt Klasen
U.S. Environmental Protection Agency
Office of Water (IO)
202-566-0780
cell (202) 380-7229
----- Forwarded by Matthew Klasen/DC/USEPA/US on 01/12/2011 12:07 PM -----

From: Stefania Shamet/R3/USEPA/US
To: Matthew Klasen/DC/USEPA/US@EPA
Date: 01/12/2011 11:57 AM
Subject: Where I am now

Per our conversation

Here's the App 6 with my comments through 63; here's my running list

[attachment "running list of references.doc" deleted by Marcel Tchaou/DC/USEPA/US]