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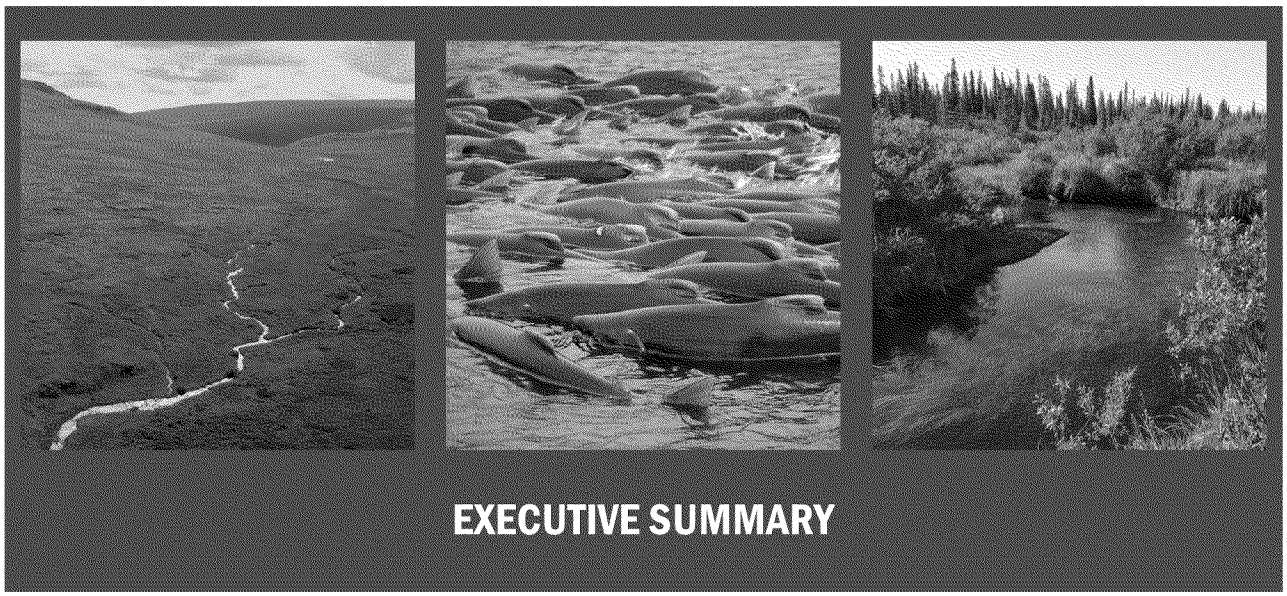
United States Environmental Protection Agency

An Assessment of Potential Mining Impacts on Salmon Ecosystems of Bristol Bay, Alaska

Executive Summary

Region 10, Seattle, WA
www.epa.gov/bristolbay



EXECUTIVE SUMMARY

The Bristol Bay watershed in southwestern Alaska supports the largest sockeye salmon fishery in the world, is home to 25 federally recognized tribal governments, and contains significant mineral resources. The potential for large-scale mining activities in the watershed has raised concerns about the impact of mining on the sustainability of Bristol Bay's world-class commercial, recreational, and subsistence fisheries and the future of Alaska Native tribes in the watershed, who have maintained a salmon-based culture and subsistence-based way of life for at least 4,000 years.

The U.S. Environmental Protection Agency (USEPA) launched this assessment to determine the significance of Bristol Bay's ecological resources and evaluate the potential impacts of large-scale mining on these resources. It uses the well-established methodology of an ecological risk assessment, which is a type of scientific investigation that provides technical information and analyses to foster public understanding and inform future decision making. As a scientific assessment, it does not discuss or recommend policy, legal, or regulatory decisions, nor does it outline or analyze options for future decisions.

This assessment characterizes the biological and mineral resources of the Bristol Bay watershed. It is intended to increase understanding of potential impacts of large-scale mining on the region's fish resources and serve as a technical resource for the public and for federal, state, and tribal governments as they consider how best to address the challenges posed by mining and ecological protection in the Bristol Bay watershed. It will inform ongoing discussions of the risks of mine development to the sustainability of the Bristol Bay salmon fisheries and thus will be of value to the many stakeholders in this debate.

The assessment also will inform the consideration of options for future government action, including, possibly, by USEPA, which has been petitioned by multiple groups to address mining activity in the Bristol Bay watershed using its authority under the Clean Water Act (CWA). Should specific mine projects reach the permitting stage, the assessment will enable state and federal permitting authorities

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to make informed decisions to grant, deny, or condition permits and/or conduct additional research or assessment as a basis for such decisions. USEPA conducted this assessment consistent with its authority under the CWA Section 104(a) and (b).

Scope of the Assessment

This assessment reviews, analyzes, and synthesizes information relevant to potential impacts of large-scale mine development on Bristol Bay fisheries and consequent effects on wildlife and Alaska Native cultures in the region. Given the economic, ecological, and cultural importance of the region's key salmonids (sockeye, Chinook, coho, chum, and pink salmon, as well as rainbow trout and Dolly Varden) and stakeholder and public concern that a mine could affect those species, the primary focus of the assessment is the abundance, productivity, and diversity of these fishes. Because wildlife in Bristol Bay are intimately connected to and dependent on these and other fishes, changes in these fisheries are expected to affect the abundance and health of wildlife populations. Alaska Native cultures have strong nutritional, cultural, social, and spiritual dependence on salmon, so changes in salmon fisheries are expected to affect the health and welfare of Alaska Native populations. Therefore, wildlife and Alaska Native cultures are also considered as assessment endpoints, but only as they are affected by changes in salmonid fisheries.

The assessment considers multiple geographic scales. The largest scale is the Bristol Bay watershed, which is a largely undisturbed region with outstanding natural, cultural, and mineral resources. Within the larger Bristol Bay watershed, the assessment focuses on the Nushagak and Kvichak River watersheds (Figure ES-1). These are the largest of the Bristol Bay watershed's six major river basins, containing about 50% of the total watershed area, and are identified as mineral development areas by the State of Alaska. Given its size and extent of characterization, the Pebble deposit is the most likely site for near-term, large-scale mine development in the region. Because the Pebble deposit is located in the headwaters of tributaries to both the Nushagak and Kvichak Rivers, both of these watersheds are subject to potential risks from mining. The third geographic scale is the watersheds of the three tributaries that originate within the potential footprint of a mine on the Pebble deposit: the South Fork Koktuli River, which drains the Pebble deposit area and converges with the North Fork west of the Pebble deposit; the North Fork Koktuli River, located to the northwest of the Pebble deposit, which flows into the Nushagak River via the Koktuli and Mulchatna Rivers; and Upper Talarik Creek, which drains the eastern portion of the Pebble deposit and flows into the Kvichak River via Iliamna Lake, the largest undeveloped lake in the United States (Figure ES-1). The mine footprints in the three realistic mine scenarios evaluated in the assessment make up the fourth geographic scale. These scenarios—Pebble 0.25, Pebble 2.0, and Pebble 6.5—define three potential mine sizes, representing different stages in the potential mining of the Pebble deposit. The final geographic scale is the combined area of the subwatersheds between the mine footprints and the Kvichak River watershed's eastern boundary that would be crossed by a transportation corridor linking the mine site to Cook Inlet.

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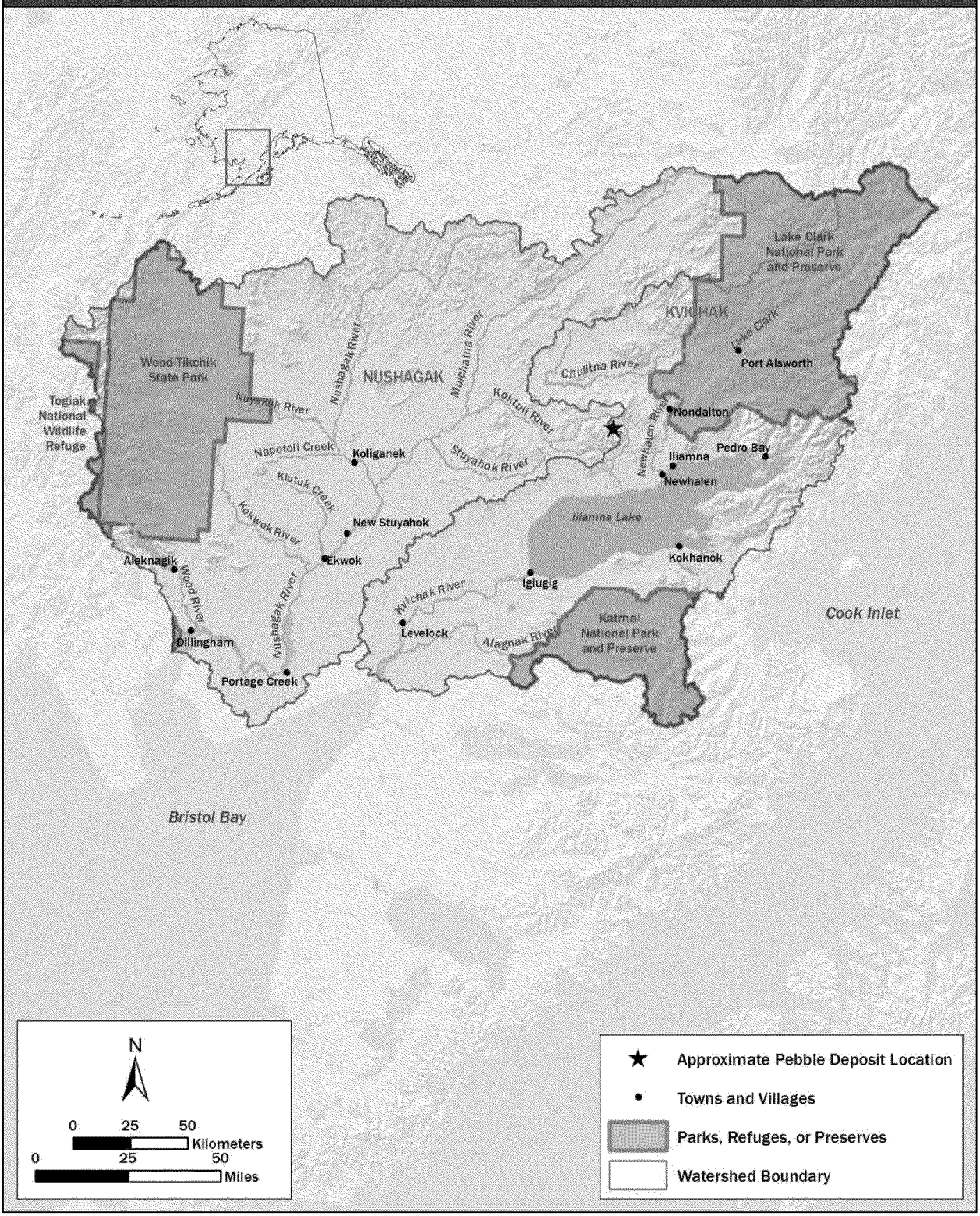
Figure ES-1. The Nushagak and Kvichak River watersheds of Bristol Bay.



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The assessment also addresses two periods for mine activities. The first is the development and operation phase, during which mine infrastructure would be built and the mine would be operated. This phase may last from 20 to 100 years or more. The second is the post-mining phase, during which the site would be monitored and maintained. Water treatment and other waste management activities would continue as necessary and any failures would be remediated. Because mine wastes would be persistent, this period could continue for centuries and potentially in perpetuity.

We began the assessment with a thorough review of what is known about the Bristol Bay watershed, its fisheries and wildlife populations, and its Alaska Native cultures. We also reviewed information about copper mining and publicly available information outlining proposed mine operations for the Pebble deposit. The Pebble deposit has been the focus of much exploratory study and has received significant attention from groups in and outside of Alaska. With the help of regional stakeholders, we developed a set of conceptual models to show potential associations between salmon populations and the environmental stressors that might reasonably result from large-scale mining. Then, following the USEPA's ecological risk assessment framework, we analyzed the sources and exposures that would occur and potential responses to those exposures. Finally, we characterized the risks to fish habitats, salmon, and other fish populations, as well as the implications of those risks for the wildlife and Alaska Native cultures that use them.

This is not an in-depth assessment of a specific mine, but rather an examination of potential impacts of reasonably foreseeable mining activities in the Bristol Bay region, given the nature of the watershed's mineral deposits and the requirements for successful mine development. The assessment analyzes mine scenarios that reflect the expected characteristics of mine operation at the Pebble deposit. It is intended to provide a baseline for understanding potential impacts of mine development, not just at the Pebble deposit but throughout the Nushagak and Kvichak River watersheds. The mining of other existing porphyry copper deposits in the region would be expected to include the same types of activities and facilities evaluated in this assessment for the Pebble deposit (open pit mining and the creation of waste rock piles and tailings storage facilities [TSFs]), and therefore would present potential risks similar to those outlined in this assessment. However, because the region's other ore bodies are believed to be much smaller than the Pebble deposit, those mines would likely be most similar to the smallest mine scenario analyzed in this assessment (Pebble 0.25).

This assessment considers many but not all potential impacts associated with future large-scale mining in the Bristol Bay watershed. Although the mine scenarios assume development of a deep-water port on Cook Inlet to ship product concentrate elsewhere for smelting and refining, impacts of port development and operation are not assessed. The assessment does not evaluate impacts of the one or more large-capacity electricity-generating power plants that would be required to power the mine and the port. We recognize that large-scale mine development would induce the development of additional support services for mine employees and their families, vacation homes and other recreational facilities, and transportation infrastructure beyond the main corridor (i.e., airports, docks, and roads). The assessment describes but does not evaluate the effects of induced development resulting from large-scale mining in the region. Direct effects of mining on Alaska Natives and wildlife are not assessed. The assessment also

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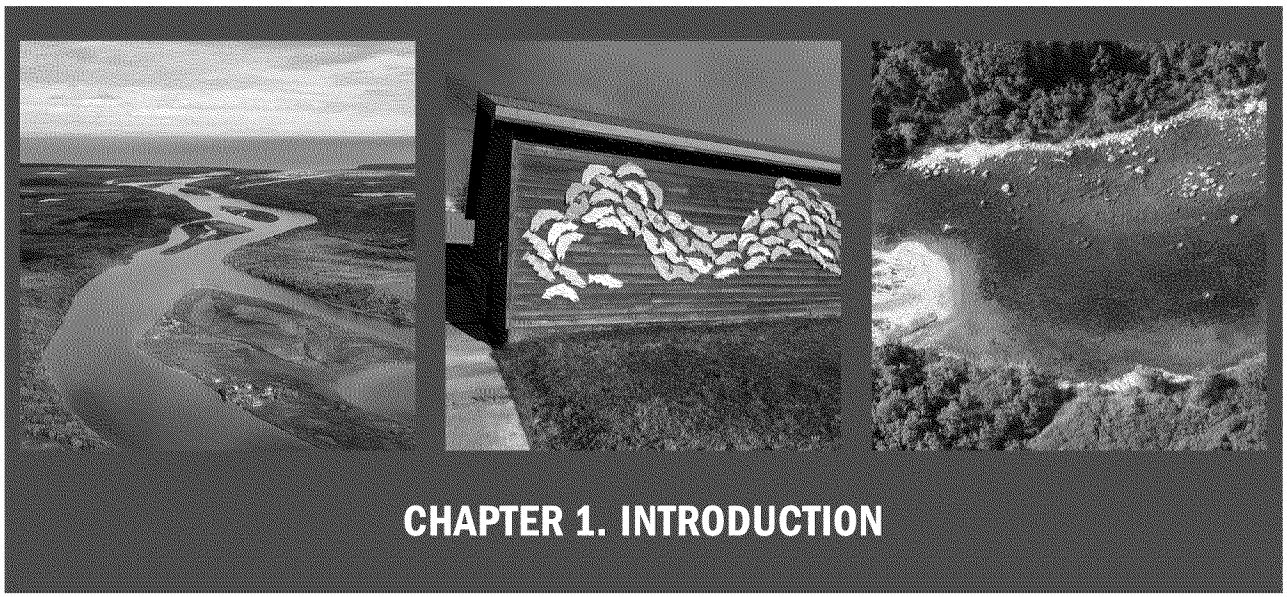

CHAPTER 1. INTRODUCTION

The Bristol Bay watershed in southwestern Alaska supports the largest sockeye salmon fishery in the world, is home to 25 federally recognized tribes, and contains abundant natural resources, including significant mineral reserves. Worldwide attention to this watershed has increased because of widespread mineral exploration activities and the discovery of a large ore deposit in the watershed's northeast-central region. The potential for large-scale mining activities has raised concerns about the quality and sustainability of Bristol Bay's world-class fisheries and the future of Alaska Natives who have maintained a salmon-based culture and a subsistence-based way of life for at least 4,000 years.

Public interest in the Bristol Bay watershed has centered on the ecological goods and services provided by the watershed and on potential mining activity. The watershed is most noted for its abundant fish resources. The Bristol Bay watershed supports production of all five species of Pacific salmon found in North America (sockeye, Chinook, chum, coho, and pink), including almost half of the world's commercial sockeye salmon harvest. In 2009, Bristol Bay's ecosystems, which support the watershed's commercial, recreational, and subsistence fisheries, generated $480 million in direct economic expenditures in the region, and provided employment for over 14,000 full- and part-time workers (Appendix E). This consistently large fish production results from the watershed's high hydrologic diversity and pristine quality, both of which contribute to highly diverse fish populations.

In addition to these biological resources, 16 mine claim blocks have recently been explored in the Bristol Bay's Nushagak and Kvichak River watersheds. Eleven of these claims are associated with porphyry copper deposits, the largest belonging to the Pebble Limited Partnership (PLP). This partnership was created in 2007 by co-owners Northern Dynasty Minerals, Ltd. and Anglo American to design, permit, construct, and operate a long-life mine at the Pebble deposit (PLP 2013) (Anglo American withdrew from the partnership in late 2013). Although PLP has not yet submitted a permit application for a mine, preliminary mine plans have been developed and publicly available information strongly suggests that a

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mine at the Pebble deposit has the potential to become one of the largest mining developments in the world.

The Pebble deposit is a large, low-grade deposit containing copper, gold, and molybdenum-bearing minerals. Extraction is expected to require the creation of a large open pit, the production of large amounts of waste rock and mine tailings, the creation of a transportation corridor connecting the deposit area to Cook Inlet, and the development of a deep-water port. Revenues from such a mine have been estimated at between $300 billion and $500 billion over the mine's life (Chambers et al. 2012), and more than 2,000 and 1,000 jobs could be created during mine construction and operation, respectively (Ghaffari et al. 2011).

In light of these factors, nine Bristol Bay federally recognized tribes, the Bristol Bay Native Association, the Bristol Bay Native Corporation, other tribal organizations, and many groups and individuals petitioned the U.S. Environmental Protection Agency (USEPA) to use its authorities under Clean Water Act (CWA) Section 404(c) to restrict or prohibit the disposal of dredged or fill material associated with large-scale mining activities in the Bristol Bay watershed. These groups are concerned that large-scale mining could adversely affect the region's valuable natural resources, particularly its fisheries. Four Bristol Bay federally recognized tribes, other tribal organizations, the governor of Alaska, and other groups and individuals, including PLP, have asked USEPA to wait until formal mine permit applications have been submitted and an environmental impact statement has been developed.

USEPA initiated this assessment in response to these competing requests. The assessment's purpose is to characterize the biological and mineral resources of the Bristol Bay watershed, increase understanding of the potential impacts of large-scale mining, in terms of both day-to-day operations and potential accidents and failures, on the region's fish resources, and inform future decisions, by government agencies and others, related to protecting and maintaining the chemical, physical, and biological integrity of the watershed. The assessment represents a review and synthesis of available information to identify and evaluate potential risks of future large-scale mining development on the Bristol Bay watershed's fish habitats and populations and consequent indirect effects on the region's wildlife and Alaska Native cultures.

1.1 Assessment Approach

This assessment was conducted as an ecological risk assessment (ERA). ERA is a scientific process used to determine whether exposure to one or more stressors may result in adverse ecological effects, the findings of which are used to inform environmental decision making. USEPA routinely uses ERA methods to evaluate the potential impacts of current and future actions when considering management decisions (USEPA 2002a, 2002b, 2002c, 2008, 2011). USEPA is conducting this assessment consistent with its authority under CWA Section 104. CWA Sections 104(a) and (b) provide USEPA with the authority to study the resources of the Bristol Bay watershed, evaluate the effect of pollution from large-scale mining development on those resources, and make such an assessment available to the public. This

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assessment is not an environmental impact assessment, an economic or social cost-benefit analysis, or an assessment of any one specific mine proposal.

Risk assessors, decision makers, and community stakeholders determine the topical, spatial, and temporal scope needed to effectively address the decisions the ERA is informing. Within this scope, risk assessments consider the potential effects of an activity and use one or more scenarios, or sets of assumptions, to identify how resources of interest (in this case, fish habitat and populations) could be exposed to stressors generated by some activity (in this case, porphyry copper mining).

Assessment endpoints are explicit expressions of the environmental resources of interest to the risk assessors, decision makers, and stakeholders. We selected fish, and specifically salmon and other salmonids, as our primary assessment endpoint because of their critical importance to stakeholders and future decision making in the watershed. The sustainability of the Bristol Bay fisheries is a concern shared by all Bristol Bay stakeholders—including those who support mining—and the ecological, economic, and cultural importance of the region's commercial, sport and subsistence fisheries has been emphasized consistently by all stakeholders throughout the process. Our preliminary technical consultations with federal, state, and tribal representatives indicated that evaluating the potential risks of large-scale mining on the region's fishery resources was a top priority. During our public engagement efforts, stakeholders consistently emphasized that fish are the crucial resource of concern.

We also considered two key secondary endpoints: wildlife and Alaska Native cultures. Fish-mediated effects on wildlife were considered because fish, particularly salmon, are an important food resource for wildlife, via both direct consumption and as a source of marine-derived nutrients that contribute to the watershed's overall productivity. Fish-mediated effects on Alaska Natives were considered because sustainability of the region's fish populations is critical to the future of Alaska Natives in the Bristol Bay region, and because concern about the region's fishery resources prompted the original requests from Alaska Natives that USEPA examine potential mine development in the Bristol Bay watershed.

Multiple geographic scales are considered in the assessment. Background and characterization information is presented for the entire Bristol Bay watershed. The evaluation of potential large-scale mining impacts focuses on the Nushagak and Kvichak River watersheds. These two watersheds are the most likely to be affected by large-scale mining development, given the location of current mine claims and current federal and state restrictions on development in other portions of the Bristol Bay watershed. These two watersheds are responsible for approximately half of the Bristol Bay sockeye salmon production, and are also home to approximately half of the region's Alaska Native communities and federally recognized tribes. There are 31 federally recognized tribes in the larger Bristol Bay region, and 25 of these tribal communities are within the Bristol Bay watershed boundary defined in this assessment. Fourteen of these communities (13 of which have federally recognized tribes) are within the Nushagak and Kvichak River watersheds.

The assessment also considers smaller geographic scales for risk analysis and characterization. Because the Pebble deposit is the largest known and most explored deposit in the region, we use it as a case study for potential risks. Because none of the parties holding mine claims in the Bristol Bay watershed

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has submitted a formal application and mine plan, we developed a set of realistic mine scenarios for the assessment. The foundations for these scenarios are industry documents outlining approaches for mining porphyry copper deposits, as well as specific documents from the PLP outlining a basic, preliminary mine plan for the Pebble deposit. The mine scenarios were used to complete the risk analyses and characterizations in the assessment. Although these mine scenarios were developed for the Pebble deposit, the potential risks evaluated are expected to be qualitatively similar to potential risks associated with any mine of the same resource type (porphyry copper) anywhere in the Nushagak and Kvichak River watersheds.

Risk assessments are inherently uncertain, because they must predict the occurrence and consequences of future actions. In this assessment, expressions of uncertainty are treated differently for accidents and failures and for routine operations. Risks of accidents and failures are based on empirical frequencies (summarized in Table 14-1), but we acknowledge the possibility of lower risks due to advances in technology or practices. For example, data concerning risks of culvert failure provide frequencies of 0.3 to 0.6 per culvert. However, risks during operation are simply described as low, because our scenario specifies daily inspections and there are no data quantifying failure rates under such intensive maintenance programs. Risks that effects would occur due to routine operations are not described probabilistically, because they are unintended results of planned actions. However, these risks are uncertain due to lack of knowledge about the receiving environment and its response to mining activities. Those uncertainties are described based on the professional judgment of the authors using ordinary language such as "likely" and, when the evidence allows, in terms of possible deviations from expectations (e.g., thresholds for effects could be at least a factor of 2 lower). The term "likely" is used commonly as an abbreviation for "more likely than not" (>0.5 probability). The risk of a tailings storage facility (TSF) spillway release is different in that it is a hybrid between a failure (TSFs should not overflow during mine operation) and routine operations (spillways are installed to spill excess water, because overflows are a reasonable expectation). No statistics are available on overflow frequencies, but they are judged to be likely over the life of a mine and inevitable afterwards, if water treatment is not continued in perpetuity.

Throughout the assessment, we have reached out to interested parties to ensure transparency of the assessment process (Box 1-1). Through public comment opportunities and by engaging an Intergovernmental Technical Team (IGTT) of federal, state, and tribal representatives, we were able to identify additional information helpful for characterizing the biological and mineral resources of the watershed. These interactions with community members were also helpful in narrowing the scope of the assessment to issues that were most important to stakeholders.

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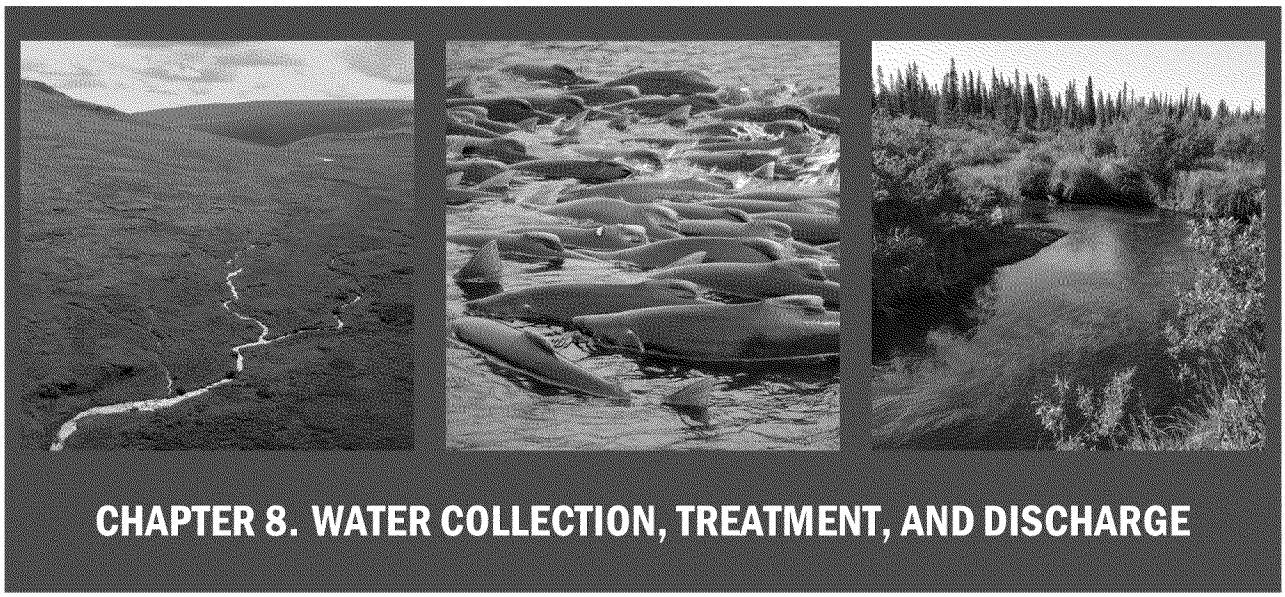

CHAPTER 8. WATER COLLECTION, TREATMENT, AND DISCHARGE

The water collection, treatment, and discharge scenarios presume that, under routine operations, runoff water, leachate, and wastewater would be collected and properly treated before release to meet state standards, federal criteria, and permit requirements. However, some leachate would escape collection, supernatant water may be spilled from tailings storage facilities (TSFs), and some treatment failures would be expected to occur. This chapter begins with a description of potential sources of contaminants (Section 8.1). It then describes potential routes and magnitudes of exposure to contaminated water and the exposure-response relationships used to screen leachate constituents (Section 8.2), with particular focus on the major contaminant of concern, copper. This section ends with a characterization of the potential risks from aqueous effluents and a discussion of potential additional remediation and uncertainties. Potential effects of water temperature changes associated with water collection, treatment, and discharge are discussed in Section 8.3. Figure 8-1 illustrates potential linkages between sources, stressors, and responses associated with water treatment, discharge, fate, and effects that are considered in this chapter.

8.1 Water Discharge Sources

Discharges were calculated for routine operations and wastewater treatment plant (WWTP) failure in the Pebble 0.25, 2.0, and 6.5 scenarios; post-closure discharges are discussed qualitatively. Sources of water discharge under routine operations associated with each mine scenario include effluents discharged from the WWTP, uncollected leachates from the TSFs and waste rock piles, and spillway releases from the TSFs. Other routine sources, including domestic wastewater, are outside the scope of this assessment and thus not analyzed here. In addition, we evaluate a WWTP failure scenario in which the system releases untreated wastewater. This failure represents one potential failure among many accidents and failures that could occur. We specify that under routine operations, the WWTP would meet permit limits. In the event of a complete treatment failure, flows would pass through the WWTP at

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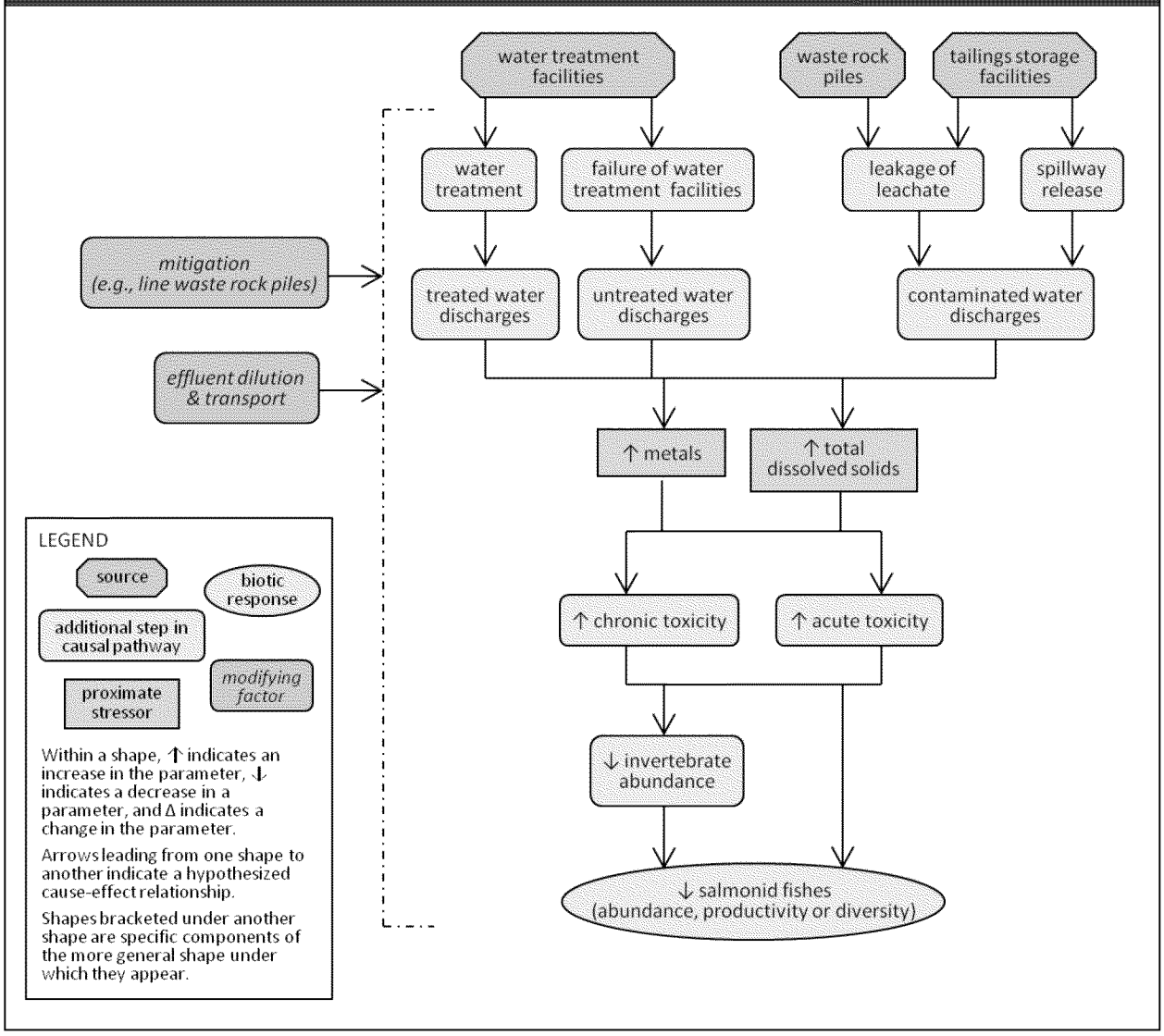
the estimated influent concentrations. These two water collection, treatment, and discharge scenarios bound the likely range of water treatment operation, but do not encompass the worst case. For example, treatment might fail when wastewater composition is worse than average, or an extreme accident like dumping reverse-osmosis brine could occur.

Figure 8-1. Conceptual model illustrating the pathways linking water treatment, discharge, fate, and effects.



In addition to the discharge of treated water, water treatment generates wastes that are likely to be hazardous due primarily to the copper and other metals removed from the wastewaters. The treatment process is unspecified and it is unclear whether treatment wastes would be transported off site or deposited in the TSFs or another on-site facility. Therefore, this assessment does not include risks of water pollution resulting from spills of those waste materials and does not include them when estimating chemical concentrations in the TSF leakage or spillage.

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Following the termination of mine operations, it is expected that water collection and treatment would continue for waste rock and tailings leachates. If the water is nontoxic, in compliance with all criteria and standards, and its composition is stable or improving, the collection and treatment system may be shut down under permit. Otherwise, treatment would continue in perpetuity—that is, until untreated water quality was acceptable or institutional failures ultimately resulted in abandonment of the system. If the mine operator abandons the site, the State of Alaska should assume operation of the treatment system; if both the mine operator and the State of Alaska abandon the site, untreated leachates would flow to streams draining the site.

The promulgated state water quality standards are enforceable numeric limits on the concentrations and durations of exposure for ambient waters, biotic communities, and associated designated uses. They would be applied to permits for the discharges discussed here. National ambient water quality criteria are contaminant limits that are recommended to the states. However, states such as Alaska may lag in adopting the latest criteria. In particular, the U.S. Environmental Protection Agency (USEPA) (2007) has published copper criteria based on the biotic ligand model (BLM), but Alaska still uses the hardness-based criteria for copper. We use the current USEPA copper criteria in this assessment based on the assumption that, before permitting a copper mine in the Bristol Bay watershed, Alaska would adopt those criteria at the state level or would apply them on a site-specific basis to any discharge permits.

8.1.1 Routine Operations

Under the mine scenarios, water in contact with tailings, waste rock, ore, product concentrate, or mine walls would leach minerals from those materials (Section 6.1.2.5). In addition, chemicals would be added to the water used in ore processing (Box 4-5). Most of the water used to transport tailings or concentrate or used in ore processing would be reused. Leachates collected from TSFs or waste rock piles would be stored in the TSF or treated for use or discharge, but leachate that escaped collection would flow to streams (Figure 6-5). Waste rock used in the construction of berms, roads and other mine structures would be leached by rain and snowmelt, but that source is assumed to be small relative to the waste rock piles and dams. Waste rock leachates are assumed to have the mean concentrations of reported humidity cell tests (Appendix H and PLP 2011). Mine pit water would also be used or treated for disposal. Surplus water on the site would be treated to meet applicable standards and other permit limits and discharged. Based on Alaskan Water Quality Standards defined in the Alaska Administrative Code, Title 18, Section 70, no mixing zones would be authorized for anadromous streams or spawning habitat for most game or subsistence fish species. Thus, it is expected that effluents would be required to meet state standards that are equivalent to national criteria and other permit limits (i.e., no exemptions would be granted).

During mine operations, water available on the site would exceed operational needs, and approximately 11 to 51 million m^3 of treated water would be discharged per year (Table 6-3). The mine scenarios specify that effluent would be discharged to the South and North Fork Koktuli Rivers as proposed by Ghaffari et al. (2011) (Tables 8-1 through 8-3). The effluent could contain treated tailings leachate,

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waste rock leachate, mine pit water, runoff, and excess transport or process waters. Tailings leachate would come from the TSFs as either excess water in the impoundment or leakage captured below the dams. The primary concern during routine operations would be waste rock leachate. Captured waste rock leachate would become more voluminous as the waste rock piles increased during operation. After mine closure, that leachate would be a major component of routinely generated wastewater, along with water pumped from the TSFs and the pit (after it has filled). In addition, because the waste rock piles and TSFs would not be lined, some leachates from both would not be captured and would flow to the three receiving streams.

Risk quotients are used to determine whether the leachates are potentially toxic and, if so, which constituents are most responsible (Tables 8-4 through 8-8). A risk quotient equals the exposure level divided by an ecotoxicological benchmark. For screening, the undiluted leachate concentration is treated as an exposure level. The benchmarks are national ambient water quality criteria or equivalent values (Section 6.4.2.3). These benchmarks are for either acute (the criterion maximum concentration, or CMC) or chronic (the criterion continuous concentration, or CCC) exposures—that is, CMCs are intended to be thresholds for significant lethality in short-term exposures, whereas CCCs are intended to be thresholds for significant lethal or nonlethal effects in long-term exposures. If the quotient is less than 1, the leachate or constituent can be eliminated as a chemical of potential concern because instream concentrations would not exceed the undiluted concentrations.

8.1.1.1 Tailings Leachate

Estimation of potential flow through the substrate located under and around proposed TSFs requires estimation of hydraulic conductivity. The hydraulic conductivity of the substrate material located near possible dam sites varies greatly with depth and location. Ghaffari et al. (2011) report a range from 10^{-6} to 10^{-5} m/s in the upper bedrock, with a general decrease with depth and a range on the order of 10^{-7} to 10^{-9} m/s in the lower portions of bedrock with some zones of higher hydraulic conductivity (Figure 6-7). In addition, the presence of fractured bedrock allows for localized discontinuities in the rate of groundwater movement that can greatly influence overall groundwater conveyance (Ghaffari et al. 2011).

We estimated leachate flow from the TSFs using a hydraulic conductivity of 10^{-6} m/s in the upper 100 m of overburden and bedrock, with no flow below that depth. We allowed vertical downward flow in the tailings and radial flow outward in all directions from the TSF, with the excess head dissipating over a horizontal distance of 1,200 m, comparable to the distance of the mine pit drawdown beyond the pit rim. The interior surface area of TSF 1 would be 6.5 km^2 for the Pebble 0.25 scenario and 14.2 km^2 for the Pebble 2.0 and 6.5 scenarios (Table 6-2). The Pebble 6.5 scenario would include two additional impoundments, with interior surface areas of 20.1 km^2 (TSF 2) and 8.2 km^2 (TSF 3) (Table 6-2).

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An Assessment of Potential Mining Impacts on Salmon Ecosystems of Bristol Bay, Alaska

Volume 3—Appendices E-J

Appendix J: Compensatory Mitigation and Large-Scale Hardrock Mining in the Bristol Bay Watershed

December 2013

Appendix J
Compensatory Mitigation and Large-Scale Hardrock Mining in the Bristol Bay Watershed

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This appendix provides an overview of Clean Water Act Section 404 compensatory mitigation requirements for unavoidable impacts to aquatic resources, and discusses an array of measures that various entities have proposed as having the potential to compensate for the unavoidable impacts to wetlands, streams, and fish identified in the Bristol Bay Assessment. Please note that any formal determinations regarding compensatory mitigation can only take place in the context of a regulatory action. The Bristol Bay Assessment is not a regulatory action, and thus a complete evaluation of compensatory mitigation is outside the scope of the assessment.

1. Overview of Clean Water Act Section 404 Compensatory Mitigation Requirements

The overall objective of the Clean Water Act is to restore and maintain the chemical, physical and biological integrity of the nation's waters. To help achieve that objective, Section 404 of the Clean Water Act establishes a program to regulate the discharge of dredged or fill material into waters of the United States, including wetlands. Section 404 requires a permit before dredged or fill material may be discharged into waters of the United States, unless the activity is exempt from Section 404 regulation (e.g. certain farming and forestry activities).

The U.S. Environmental Protection Agency (EPA) and the Department of the Army, operating through the Army Corps of Engineers (ACOE), share responsibilities for implementing the Section 404 program. Section 404(a) authorizes the ACOE to issue permits for the discharge of dredged or fill material into waters of the U.S. at specified disposal sites. Section 404(b) directs the ACOE to apply environmental criteria developed by EPA in making its permit decisions (these criteria are binding regulations known as the "Section 404(b)(1) Guidelines" (40 CFR Part 230)). Under EPA's Section 404(b)(1) Guidelines, no discharge of dredged or fill material may be permitted by the ACOE if: (1) a practicable alternative exists that is less damaging to the aquatic environment so long as that alternative does not have other significant adverse environmental consequences or (2) the nation's waters would be significantly degraded. Under the Guidelines, a project must incorporate all appropriate and practicable measures to first avoid impacts to wetlands, streams, and other aquatic resources and then minimize unavoidable impacts; after avoidance and minimization measures have been applied, the project must include appropriate and practicable compensatory mitigation for the remaining unavoidable impacts.

Compensatory mitigation refers to the restoration, establishment, enhancement, and/or preservation of wetlands, streams, or other aquatic resources conducted specifically for the purpose of offsetting authorized impacts to these resources (Hough and Robertson 2009). Compensatory mitigation regulations jointly promulgated by EPA and the ACOE (40 CFR §§ 230.91 - 230.98 and 33 CFR §§ 332.1 - 332.8) state that "the fundamental

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objective of compensatory mitigation is to offset environmental losses resulting from unavoidable impacts to waters of the United States authorized by [Clean Water Act Section 404 permits issued by the ACOE]" (40 CFR Part 230.93(a)(1)). Compensatory mitigation enters the analysis only after a proposed project has incorporated all appropriate and practicable means to avoid and minimize adverse impacts to aquatic resources (40 CFR Part 230.91(c)).

Section 404 permitting requirements for compensatory mitigation are based on what is "practicable and capable of compensating for the aquatic resource functions that will be lost as a result of the permitted activity" (40 CFR Part 230.93(a)(1)). In determining what type of compensatory mitigation will be "environmentally preferable," the ACOE "must assess the likelihood for ecological success and sustainability, the location of the compensation site relative to the impact site and their significance within the watershed, and the costs of the compensatory mitigation project"(40 CFR Part 230.93(a)(1)). Furthermore, compensatory mitigation requirements must be commensurate with the amount and type of impact associated with a particular Section 404 permit (40 CFR Part 230.93(a)(1)). The regulations recognize that there may be instances when the ACOE cannot issue a permit "because of the lack of appropriate and practicable compensatory mitigation options" (40 CFR Part 230.91(c)(3)).

1.1 Compensatory Mitigation Methods

Compensatory mitigation can occur through four methods: aquatic resource **restoration**, **establishment**, **enhancement**, or in certain circumstances, **preservation** (40 CFR Part 230.93(a)(2)).

- Restoration is the reestablishment or rehabilitation of a wetland, stream, or other aquatic resource with the goal of returning natural or historic functions and characteristics to a former or degraded aquatic resource. When it is an option, restoration is generally the preferred method, due in part to its higher likelihood of success as measured by gain in aquatic resource function, area, or both.
- Establishment, or creation, is the development of a wetland or other aquatic resource where one did not exist previously, with success measured as a net gain in both area and function of the aquatic resource.
- Enhancement includes activities conducted within existing aquatic resources that heighten, intensify, or improve one or more aquatic resource functions, without increasing the area of the aquatic resource. Examples include improved floodwater retention or wildlife habitat.
- Preservation is the permanent protection of aquatic resources and/or upland buffers or riparian areas through legal and physical mechanisms, such as conservation easements and title transfers. Because preservation does not replace lost aquatic resource area or functions, regulations limit its use to situations in which the resources to be preserved provide important functions for and contribute significantly to the ecological sustainability of the watershed,

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and those resources are under threat of destruction or adverse modification (40 CFR Part 230.93(h)).

1.2 Compensatory Mitigation Mechanisms

There are three general mechanisms for achieving the four methods of compensatory mitigation (listed in order of preference as established in 40 CFR 230.93(b)): **mitigation banks**, **in-lieu fee programs**, and **permittee-responsible mitigation**.

- A mitigation bank is a site with restored, established, enhanced, or preserved aquatic resources, riparian areas and/or upland buffers that the ACOE has approved for use to compensate for losses from future permitted activities. The bank approval process establishes the number of available compensation credits, which permittees may purchase upon ACOE approval that the bank represents appropriate compensation. The bank sponsor is responsible for the success of these mitigation sites.
- For in-lieu fee mitigation, a permittee provides funds to an in-lieu fee program sponsor who conducts compensatory mitigation projects according to the compensation planning framework approved by ACOE. Typically specific compensatory mitigation projects are started only after pooling funds from multiple permittees. The in-lieu fee program sponsor is responsible for the success of these mitigation sites.
- In permittee-responsible mitigation, the permittee undertakes and bears full responsibility for the implementation and success of the mitigation. Mitigation may occur either at the site where the regulated activity caused the loss of aquatic resources (on-site) or at a different location (off-site), preferably within the same watershed.

Although it is the permit applicant's responsibility to propose an appropriate compensatory mitigation option, mitigation banks and in-lieu fee programs are the federal government's preferred forms of compensatory mitigation as they "usually involve consolidating compensatory mitigation projects where ecologically appropriate, consolidating resources, providing financial planning and scientific expertise (which often is not practical for permittee-responsible compensatory mitigation projects), reducing temporal losses of functions, and reducing uncertainty over project success" (40 CFR 230.93(a)(1); *see also* 40 CFR 230.93(b)).

1.3 Location, Type, and Amount of Compensation

Regulations regarding compensatory mitigation require the use of a watershed approach to "establish compensatory mitigation requirements in [Department of the Army] permits to the extent appropriate and practicable" (40 CFR 230.93(c)(1)). Under these regulations, the watershed approach to compensatory mitigation site selection and planning is an analytical process for making compensatory mitigation decisions that support the sustainability or improvement of aquatic resources in a watershed. It

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involves consideration of watershed needs and how locations and types of compensatory mitigation projects address those needs (40 CFR 230.92). The regulations specifically state that compensatory mitigation generally should occur within the same watershed as the impact site and in a location where it is most likely to successfully replace lost functions and services (40 CFR 230.93(b)(1)). The goal of this watershed approach is to "maintain and improve the quality and quantity of aquatic resources within watersheds through strategic selection of compensatory mitigation sites" (40 CFR 230.93(c)(1)).

The regulations emphasize using existing watershed plans to inform compensatory mitigation decisions, when such plans are determined to be appropriate for use in this context (40 CFR 230.93(c)(1)). Watershed plans that could support compensatory mitigation decision-making are typically:

> "…developed by federal, tribal, state, and/or local government agencies or appropriate non-governmental organizations, in consultation with relevant stakeholders, for the specific goal of aquatic resource restoration, establishment, enhancement and preservation. A watershed plan addresses aquatic resource conditions in the watershed, multiple stakeholder interests, and land uses. Watershed plans may also identify priority sites for aquatic resource restoration and protection" (40 CFR 230.92).

Where appropriate plans do not exist, the regulations describe the types of considerations and information that should be used to support a watershed approach to compensation decision-making. Central to the watershed approach is consideration of how the types and locations of potential compensatory mitigation projects would sustain aquatic resource functions in the watershed. To achieve that goal, the regulations emphasize that mitigation projects should, where practicable, replace the suite of functions typically provided by the affected aquatic resource, rather than focus on specific individual functions (40 CFR 230.93(c)(2)). For this purpose, "watershed" means an "area that drains to a common waterway, such as a stream, lake, estuary, wetland, or ultimately the ocean" (40 CFR 230.92). Although there is flexibility in defining geographic scale, the watershed "should not be larger than is appropriate to ensure that the aquatic resources provided through compensation activities will effectively compensate for adverse environmental impacts resulting from [permitted] activities" (40 CFR 230.93(c)(4)).

With regard to type, in-kind mitigation (i.e., involving resources similar to those being impacted) is generally preferable to out-of-kind mitigation, because it is most likely to compensate for functions lost at the impact site (40 CFR 230.93(e)(1)). Furthermore, the regulations recognize that, for difficult-to-replace resources such as bogs, fens, springs, and streams, in-kind "rehabilitation, enhancement, or preservation" should be the compensation of choice, given the greater likelihood of success of those types of mitigation (40 CFR 230.93(e)(3)).

The amount of compensatory mitigation required must be, to the extent practicable, "sufficient to replace lost aquatic resource functions" (40 CFR 230.93(f)(1)), as determined through the use of a functional or condition assessment. If an applicable assessment methodology is not available, the regulations require a minimum one-to-one acreage or linear foot compensation ratio (40 CFR 230.93(f)(1)). Certain circumstances require higher ratios, even in the absence of an assessment methodology (e.g., use of preservation, lower likelihood of success, differences in functionality between the impact site and compensation project, difficulty of restoring lost functions, and the distance between the impact and compensation sites) (40 CFR 230.93(f)(2)).

1.4 Compensatory Mitigation Guidance for Alaska

In addition to the federal regulations regarding compensatory mitigation, the agencies have also developed compensatory mitigation guidance applicable specifically to Alaska. In their 1994 Alaska Wetlands Initiative Summary Report, EPA and the Department of the Army concluded that it was not necessary to provide "broad exemptions" from mitigation sequencing in Alaska, given the "inherent flexibility provided by" the regulations and associated guidance. The agencies also recognized that "it may not always be practicable to provide compensatory mitigation through wetlands restoration or creation in areas where there is a high proportion of land which is wetlands. In cases where potential compensatory mitigation sites are not available due to the abundance of wetlands in a region and lack of enhancement or restoration sites, compensatory mitigation is not required under the [Section 404(b)(1)] Guidelines" (EPA et al., 1994). In promulgating the compensatory mitigation regulations in 2008, EPA and the ACOE specifically referenced the 1994 policy and reiterated the flexibility and discretion available to decision-makers (e.g., 40 CFR 230.91(a)(1), 40 CFR 230.93(a)(1)).

Although opportunities for wetland restoration and creation continue to be rather limited in Alaska, a number of other wetland compensatory mitigation options (e.g., mitigation banks, in-lieu fee programs) have become available since 1994. Moreover, it is important to note that the 1994 policy applies only to compensatory mitigation for impacts to wetlands and does not address compensatory mitigation for impacts to Alaska streams. Furthermore, subsequent guidance issued by the ACOE Alaska District in 2009 clarifies that fill placed in streams or in wetlands adjacent to anadromous fish streams in Alaska will require compensatory mitigation (ACOE 2009). A 2011 supplement to the Alaska District's 2009 guidance further recommends that projects in "difficult to replace" wetlands, fish-bearing waters, or wetlands within 500 feet of such waters will also likely require compensatory mitigation, as will "large scale projects with significant aquatic resource impacts," such as "mining development" (ACOE 2011).

The ACOE's 2009 Alaska guidance also provides sample compensatory mitigation ratios based on the type of mitigation and the ecological value of the impacted resource (high, moderate, or low). These guidelines include streams in the high quality category,

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indicating compensation ratios of 2:1 for restoration and/or enhancement and 3:1 for preservation (ACOE 2009).

2. Compensatory Mitigation Considerations for the Bristol Bay Assessment

2.1 Important Ecological Functions and Services Provided by Affected Streams and Wetlands

Bristol Bay's stream and wetland resources support a world-class commercial and sport fishery for Pacific salmon and other important fish. They have also supported a salmon-based culture and subsistence-based lifestyle for Alaska Natives in the watershed for at least 4,000 years. Bristol Bay's streams and wetlands support production of 35 species of fish including all five species of Pacific salmon found in North America: sockeye (*Oncorhynchus nerka*), coho (*O. kisutch*), Chinook or king (*O. tshawytscha*), chum (*O. keta*), and pink (*O. gorbuscha*). Because no hatchery fish are raised or released in the watershed, Bristol Bay's salmon populations are entirely wild. These fish are anadromous, hatching and rearing in freshwater systems, migrating to the sea to grow to adult size, and returning to freshwater systems to spawn and die.

In the Bristol Bay region, hydrologically-diverse riverine and wetland landscapes provide a variety of salmon spawning and rearing habitats. Environmental conditions can be very different among habitats in close proximity, with ponds, lakes and streams expressing very different flow, temperature, and physical habitat characteristics at very fine spatial scales (see Chapter 7 of the assessment for additional discussion). Recent research has highlighted the potential for local adaptations and fine-scale population structuring in Bristol Bay and neighboring watersheds associated with this environmental template (Quinn et al. 2001, Olsen et al. 2003, Ramstad et al. 2010, Quinn et al. 2012). For example, sockeye salmon that use spring-fed ponds and streams located approximately 1 km apart exhibit differences in traits such as spawn timing, spawn site fidelity, and productivity consistent with discrete populations (Quinn et al. 2012). Bristol Bay's streams and wetlands support a diverse array of salmon populations that are unique to specific drainages within the Bay and this population diversity is key to the stability of the overall Bristol Bay salmon fishery (i.e., the portfolio effect) (Schindler et al. 2010).

As discussed in detail in the Bristol Bay Assessment (see Chapter 7), streams and wetlands that would be lost as a result of the mine footprints described in the assessment's scenarios provide important ecological functions. These headwater streams provide spawning habitat for coho and sockeye salmon and likely spawning habitat for anadromous and resident forms of Dolly Varden. Headwater streams and associated wetlands also provide rearing habitat for chum salmon, sockeye salmon, Chinook salmon, coho salmon, Dolly Varden, rainbow trout, Arctic grayling, slimy

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sculpin, northern pike, and ninespine stickleback (Johnson and Blanche 2012, ADFG 2012a). Headwater streams and associated wetlands are often exploited by fish for spawning and rearing because they can provide refuge from predators and competitors that are more abundant downstream (Quinn 2005). Off-channel wetlands with their unique low-velocity, depositional environments and variable thermal conditions provide additional options for juvenile salmon feeding and rearing. For example, ephemeral swamps provided important thermal and hydraulic refuge for coho salmon in a coastal British Columbia stream (Brown and Hartman 1988). Off-channel ponds provided highly productive foraging environments and enhanced overwinter growth of coho salmon in an interior British Columbia stream (Swales and Levings 1989).

It has long been recognized that in addition to providing habitat for stream fishes, headwater streams and wetlands serve an important role in the stream network by contributing nutrients, water, organic material, algae, bacteria and macroinvertebrates downstream, to higher order streams in the watershed (Vannote et al. 1980, Meyer et al. 2007). But only recently have specific subsidies from headwater systems been extensively quantified (Wipfli and Baxter 2010). The contributions of headwaters to downstream systems results from their high density in the dendritic stream network. Headwater streams also have high rates of instream nutrient processing and storage, thereby determining downstream water chemistry due to relatively large organic matter inputs, high retention capacity, high primary productively, bacteria-induced decomposition, and extensive hyporheic zone interactions (Richardson et al. 2005, Alexander et al. 2007, Meyer et al. 2007). Because of their crucial influence on downstream water flow, chemistry, and biota, impacts to headwaters reverberate throughout entire watersheds downstream (Freeman et al. 2007, Meyer et al. 2007).

The majority of streams directly in the footprint of the mine scenarios are classified as small headwater streams (less than 0.15 m^3/s mean annual streamflow) (see assessment Table 7-6). Because of their narrow width, headwater streams receive proportionally larger inputs of organic material than do larger stream channels (Vannote et al. 1980). This material is either used in the headwater environment (Tank et al. 2010) or transported downstream as a subsidy to larger streams in the network (Wipfli et al. 2007). Consumers in headwater stream food webs, such as invertebrates, juvenile salmon, and other fishes rely heavily on the terrestrial inputs that enter the stream (Doucett et al. 1996, Eberle and Stanford 2010, Dekar et al. 2012). Headwater streams also encompass the upper limits of anadromous fish distribution, and may receive none, or lower quantities of marine-derived nutrients (MDN) from spawning salmon relative to downstream portions of the river network, making terrestrial nutrient sources relatively more important (Wipfli and Baxter 2010).

Both invertebrates and detritus are exported from headwaters to downstream reaches and provide an important energy subsidy for juvenile salmonids (Wipfli and Gregovich 2002, Meyer et al. 2007). Headwater wetlands and associated wetland vegetation can also be important sources of dissolved and particulate organic matter, and

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macroinvertebrate diversity (King et al. 2012), contributing to the chemical, physical, and biological condition of downstream waters (Shaftel et al. 2011a, Shaftel et al. 2011b, Dekar et al. 2012, Walker et al. 2012). Thus, losses of headwater streams and wetlands due to the mine scenario footprints would not only eliminate important fish habitat but also reduce inputs of organic material, nutrients, water, primary producers, bacteria, and macroinvertebrates to reaches downstream of the mine scenario footprints.

2.2 Identifying the Appropriate Watershed Scale for Compensatory Mitigation

As previously noted, the regulations regarding compensatory mitigation specifically state that compensatory mitigation generally should occur within the same watershed as the impact site and in a location where it is most likely to successfully replace lost functions and services (40 CFR 230.93(b)(1)).

For the mine scenarios evaluated in the Bristol Bay Assessment, the lost functions and services occur in the watersheds that drain to the North Fork Koktuli (NFK) and South Fork Koktuli (SFK) Rivers and Upper Talarik Creek (UTC) (see Figure 1). Accordingly, the most appropriate geographic scale at which to compensate for any unavoidable impacts resulting from such a project would be within these same watersheds, as this location would offer the greatest likelihood that compensation measures would replace the "suite of functions typically provided by the affected aquatic resource" (40 CFR 230.93(c)(2), Yocom and Bernard 2013). An important consideration is that salmon populations in these watersheds may possess unique adaptations to local environmental conditions, as suggested by recent research in the region (Quinn et al. 2001, Olsen et al. 2003, Ramstad et al. 2010, Quinn et al. 2012). Accordingly, maintenance of local biocomplexity (i.e., salmon genetic, behavioral, and phenotypic variation) and the environmental template upon which biocomplexity develops will be important for sustaining resilience of these populations (Hilborn et al. 2003, Schindler et al. 2010). Thus, the most appropriate spatial scale and context for compensation would be within the local watersheds where impacts to salmon populations occur.

If there are no practicable or appropriate opportunities to provide compensation in these watersheds, it may be appropriate to explore options in adjoining watersheds. However, defining the watershed scale too broadly would likely fail to ensure that wetland, stream, and associated fish losses under the mine scenarios would be effectively offset, because compensation in a different watershed(s) would not address impacts to the portfolio effect from losses in the impacted watersheds. Similarly, compensation in different watersheds would not address impacts to the subsistence fishery where users depend on a specific temporal and spatial distribution of fish to ensure nutritional needs and cultural values are maintained (see Bristol Bay Assessment Chapter 12).

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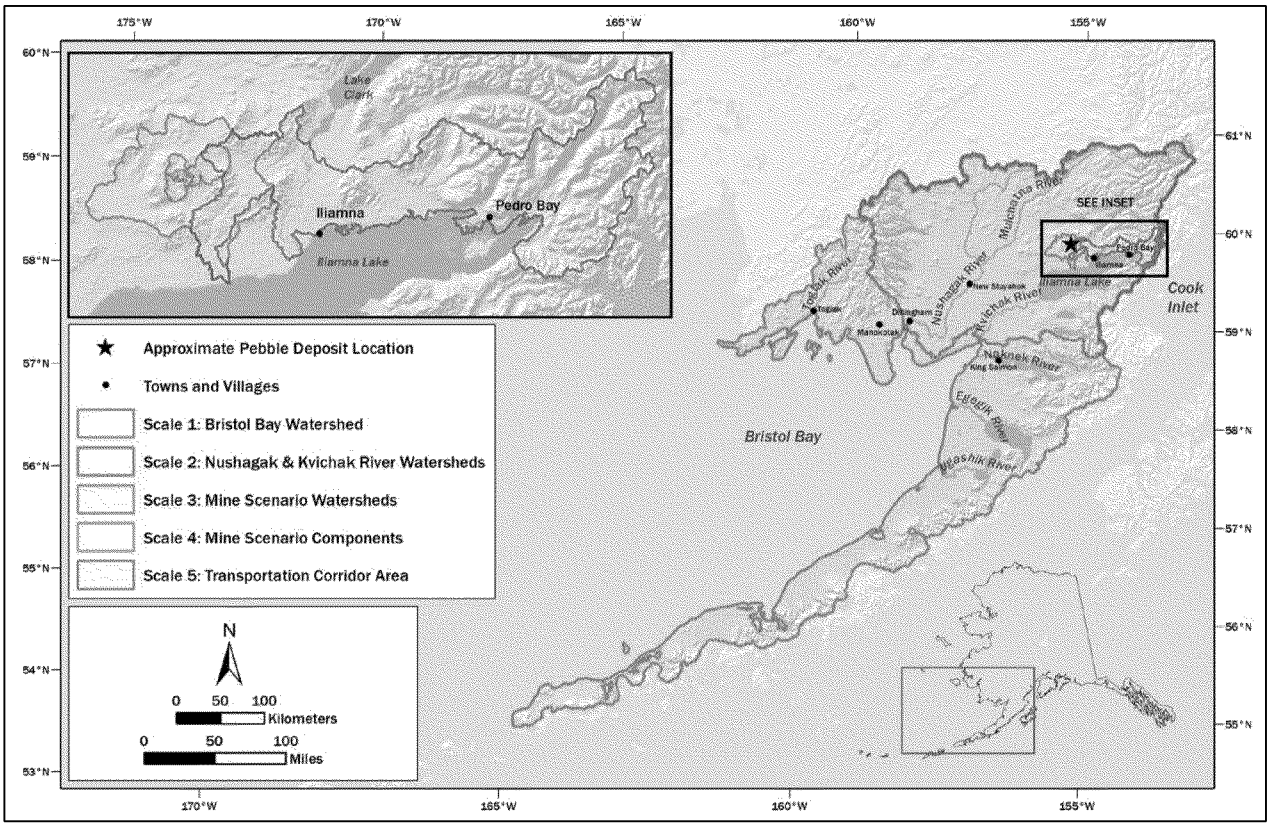

Figure 1. The boundaries of the Bristol Bay watershed (brown), the Nushagak and Kvichak River watersheds (green) and the North Fork Koktuli, South Fork Koktuli, and Upper Talarik Creek watersheds (blue).

3. Potential Compensatory Mitigation Measures in Bristol Bay

As discussed in Chapter 7 of the Bristol Bay Assessment, impact avoidance and minimization measures do not eliminate all of the footprint impacts associated with the mining scenarios. Reasons impact avoidance and minimization measures fail to eliminate these kinds of impacts include: the large extent and wide distribution of wetlands and streams in the watersheds, the fact that substantial infrastructure would need to be built to support porphyry copper mining in this largely undeveloped area and the fact that ore body location constrains siting options. The mine scenarios evaluated in the assessment identify that the mine footprints alone would result in the unavoidable loss (i.e., filling, blocking or otherwise eliminating) of hundreds to thousands of acres of high-functioning wetlands and tens of miles of salmon-supporting streams (see Figure 2).

The public and peer review comments on the draft Bristol Bay Assessment identified an array of compensation measures that some commenters believed could potentially offset these impacts to wetlands, streams, and fish. The following discussion considers the likely efficacy of the complete array of compensation measures proposed by commenters at offsetting potential adverse effects, organized in the order that the regulations prescribe for considering compensation mechanisms:

1) Mitigation bank credits;
2) In-lieu fee program credits; and
3) Variations of permittee-responsible mitigation.

3.1 Mitigation Bank Credits

There are currently no approved mitigation banks with service areas[1] that cover the impact site for the mine scenarios; thus, no mitigation bank credits are available. Should one or more bank sponsors pursue the establishment of mitigation bank sites to address the impacts associated with the mine scenarios, they would likely encounter the same challenges described below (Section 3.3).

[1] The service area is the watershed, ecoregion, physiographic province, and/or other geographic area within which the mitigation bank or in-lieu fee program is authorized to provide compensatory mitigation (40 CFR 230.98(d)(6)(ii)(A)).

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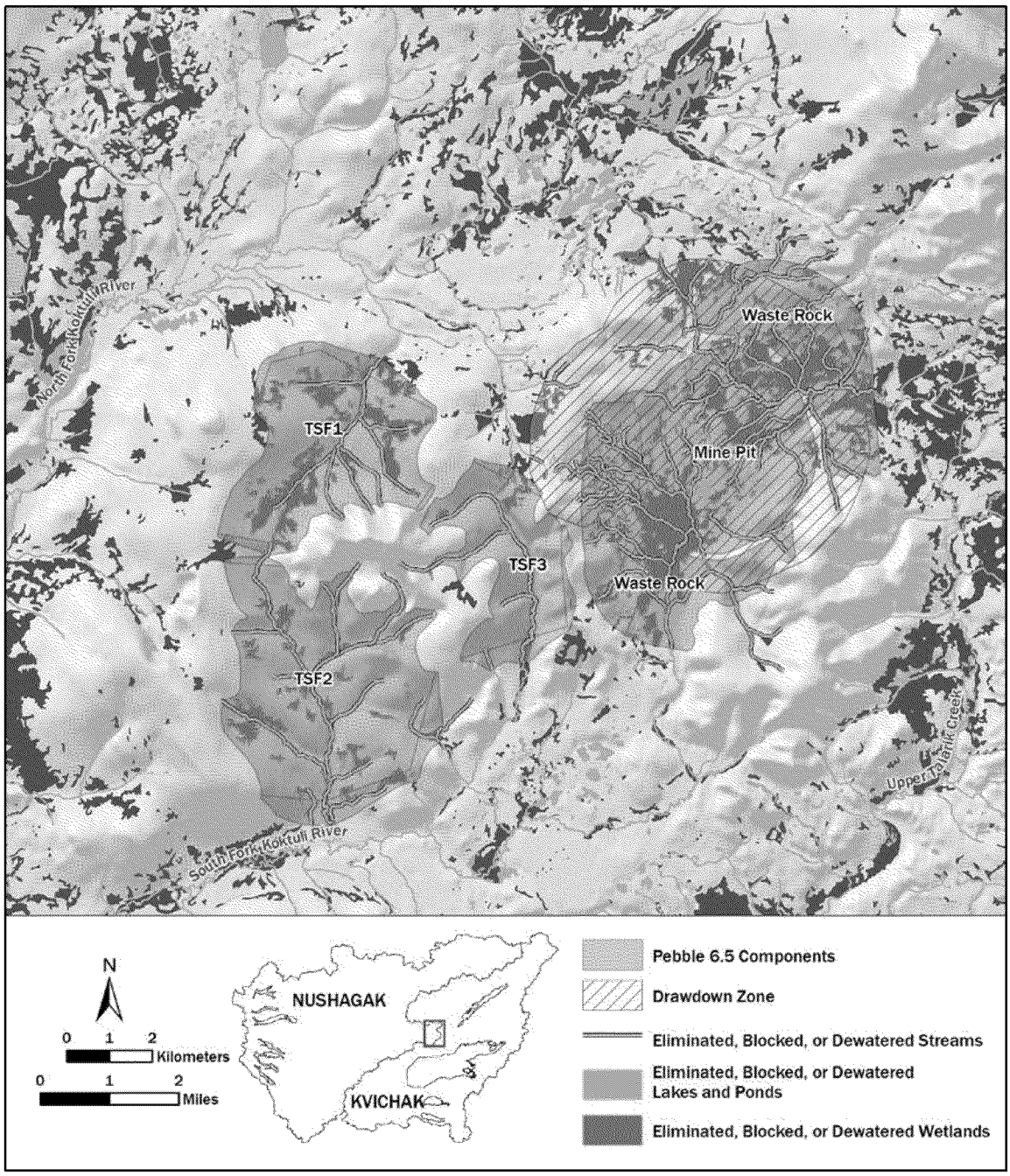

Figure 2. Streams, wetlands and other waters lost (eliminated, blocked, or dewatered) in the Pebble 6.5 scenario evaluated in the Bristol Bay Assessment.

3.2 In-Lieu Fee Program Credits

There is currently one in-lieu fee program approved to operate in the Bristol Bay watershed, which has been administered by The Conservation Fund (TCF) since 1994. The TCF program operates statewide, and the Bristol Bay watershed falls within one of its service areas. According to TCF, its compensation projects consist almost entirely of wetland preservation. To date, TCF has completed four wetland preservation projects in the Bristol Bay watershed, financed in part with in-lieu fee funds. Although the majority of in-lieu fees collected by the TCF program have been for relatively small impacts to aquatic resources, TCF has accepted in-lieu fees to compensate for a few projects with over 50 acres of impacts statewide. To date, the largest impact represented in the TCF program is the loss of 267 acres of wetlands associated with the development of the Point Thomson natural gas production/processing facilities on Alaska's Beaufort Sea coast. It is not clear if this program could effectively provide the magnitude of compensation necessary to address the loss of hundreds to thousands of acres of high functioning wetlands and tens of miles of salmon-supporting streams associated with the mine scenarios. In addition, it is likely that any in-lieu fee sponsor seeking to address the impacts associated with the mine scenarios would encounter the same challenges described below (Section 3.3).

3.3 Permittee-Responsible Compensatory Mitigation

Currently, there is no watershed plan for the NFK, SFK, or UTC, or other components of the Nushagak or Kvichak River drainages that could serve as a guide to permittee-responsible compensatory mitigation. In the absence of such a plan, the regulations call for the use of a watershed approach that considers information on watershed conditions and needs, including potential sites and priorities for restoration and preservation (40 CFR 230.93(c)). When a watershed approach is not practicable, the next option is to consider on-site (i.e., on the same site as the impacts or on adjoining land) and in-kind compensatory mitigation for project impacts, taking into account both practicability and compatibility with the proposed project (40 CFR 230.93(b)(5)). When such measures would be impracticable, incompatible, or inadequate, the last resort would be off-site and/or out-of-kind mitigation opportunities (40 CFR 230.93(b)(6)).

3.3.1 Opportunities within the NFK, SFK, and UTC Watersheds

In the context of the mine scenarios, the primary challenge to both a watershed approach and on-site compensatory mitigation is the absence of existing degraded resources within the NFK, SFK and UTC watersheds. Specifically, these three watersheds are largely unaltered by human activities; thus, opportunities for restoration or enhancement are very limited, and, as discussed below, likelihood of success appears to be very low.

Here we discuss specific suggestions for potential compensation measures within the NFK, SFK and UTC watersheds that were provided in the public and peer review comments on the Bristol Bay Assessment.

3.3.1.1 Increase Habitat Connectivity

Connectivity among aquatic habitats within stream networks is an important attribute influencing the ability of mobile aquatic taxa to utilize the diversity and extent of habitats within those networks. Within riverine floodplain systems, a complex array of habitats can develop that express varying degrees of surface and sub-surface water connectivity to main channels (Stanford and Ward 1993). In the study area, off-channel floodplain habitats can include side channels (both inlet and outlet connections to main channel), various types of single-connection habitats including alcoves and percolation channels, and pools and ponds with no surface connection to the main channel during certain flow conditions (PLP 2011 Appendix 15.1D). Beaver can be very important modifiers and creators of habitat in these off-channel systems (Pollock et al. 2003, Rosell et al. 2005). As a result of their morphology and variable hydrology, the degree of surface-water connectivity and the ability of fish to move among floodplain habitats changes with surface water levels. Connectivity for fish movement at larger spatial scales within watersheds is influenced by barriers to longitudinal movements and migrations. Examples include dams and waterfalls.

Efforts to manage or enhance connectivity within aquatic systems have primarily focused on watersheds altered by human activities, where land uses and water utilization have lead to aquatic habitat fragmentation. Specific activities to increase habitat connectivity within human-dominated stream-wetland systems may include: 1) improving access around real or perceived barriers to migration (including dams constructed by humans or beaver); 2) removing or retrofitting of road culverts; and 3) excavating and engineering of channels to connect isolated wetlands and ponds to main channels. Within watersheds minimally impacted by human activity, efforts may include creation of passage around barrier waterfalls to expand the availability of habitat for species like Pacific salmon. Human-created dams do not offer any opportunities for habitat improvement or expansion in the Nushagak or Kvichak River watersheds because they are absent, so they are not discussed further. Since road stream crossing retrofits presently offer no opportunities for habitat improvement or expansion within the NFK, SFK, and UTC watersheds, but exist elsewhere in the larger Nushagak and Kvichak River watersheds, they are discussed in Section 3.3.2.3. Here, we focus on beaver dam removal and engineered connections to variably-connected floodplain habitats, and habitats upstream of barrier waterfalls. For each of these measures, the potential applicability, suitability, and effectiveness as mitigation tools within the study area watersheds are addressed.

3.3.1.1.1 Remove Beaver Dams

Two commenters suggested the removal of beaver dams as a potential compensation measure. Presumably, the rationale for this recommendation is that beaver dams can block fish passage, limiting fish access to otherwise suitable habitat, thus, the removal of beaver dams could increase the amount of available fish habitat. This rationale is based upon early research that led to the common fish management practice of removing beaver dams to protect certain fish populations like trout (Sayler 1934, Reid 1952, *in* Pollock et al. 2004). However, more recent research has documented numerous benefits of beaver ponds to fish populations and habitat (Murphy et al. 1989, Pollock et al. 2003). For example, Bustard and Narver (1975) found that a series of beaver ponds on Vancouver Island had a survival rate for overwintering juvenile coho salmon that was twice as high as the 35% estimated for the entire stream. Pollock et al. (2004) estimated a 61% reduction in summer habitat capacity relative to historical levels, for coho salmon in one Washington watershed, largely due to loss of beaver ponds.

Kemp et al. (2012) recently published a definitive review of the effects of beaver in stream systems, indicating that they have a positive impact on sockeye, coho, and Chinook salmon as well as Dolly Varden, rainbow trout, and steelhead. Using meta-analysis and weight-of-evidence methodology, the review showed that most (71.4%) negative effects cited, such as low dissolved oxygen and impediment to fish movement, lack supportive data and are speculative in nature, whereas the majority (51.1%) of positive impacts cited are quantitative in nature and well-supported by data (Kemp et al. 2012). In addition to increased invertebrate (i.e., food) production and habitat heterogeneity, the study cited the importance of beaver ponds as rearing habitat due to the increased cover and protection that higher levels of woody material and overall structural diversity provide. Other studies have identified beaver ponds as excellent salmon rearing habitat because they have high macrophyte cover, low flow velocity, and increased temperatures, and they trap organic materials and nutrients (Nickelson et al. 1992, Collen and Gibson 2001, Lang et al. 2006). DeVries et al (2012) describe a stream restoration approach that attempts to mimic and facilitate beaver dam creation and the numerous positive benefits for stream habitat and riparian enhancement. Studies in Oregon have shown that salmon abundance is positively related to pool size, especially during low flow conditions (Reeves et al. 2011), and beaver ponds provide particularly large pools. During winter, beaver ponds typically retain liquid water below the frozen surface, providing refugia for species that overwinter in streams and off-channel habitats (Nickelson et al. 1992, Cunjak 1996).

Beaver dams generally do not constitute significant barriers to salmonid migration even though their semi-permeability may temporarily limit fish movement during periods of low stream flow (Rupp 1954, Gard 1961, Bryant 1984, Pollock et al. 2003). Even when beaver dams impede fish movements, the effects are typically temporary, with higher flows from storm events ultimately overtopping them or blowing them out (Leidholt-Bruner et al. 1992, Kemp et al. 2012). Even the temporary effect may be limited, when

seasonal rainfall is at least average (Snodgrass and Meffe 1998, Kemp et al. 2012). Adding to the body of evidence, Pacific salmon and other migratory fish species commonly occur above beaver dams, including above beaver dams in the study area (PLP 2011; Appendix 15.1D). One study in southeast Alaska documented coho salmon upstream of all surveyed beaver dams, including one that was two meters high; in fact, the survey recorded highest coho densities in streams with beaver (Bryant 1984). Other surveys have documented both adult and juvenile sockeye salmon, steelhead, cutthroat, and char upstream of beaver dams (Bryant 1984, Swales et al. 1988, Murphy et al. 1989, Pollock et al. 2003).

Beavers preferentially colonize headwater streams, such as those found near the Pebble deposit, because of their shallow depths and narrow widths (Collen and Gibson 2001, Pollock et al. 2003). An October 2005 aerial survey of active beaver dams in the mine scenarios area mapped a total of 113 active beaver colonies (PLP 2011). The Pebble Limited Partnership's (PLP) Environmental Baseline Document (EBD) highlights the significant role that beaver ponds are currently providing for Pacific salmon in this area when it states:

> "[W]hile beaver ponds were relatively scarce in the mainstem UT [UTC], the off-channel habitat study revealed a preponderance of beaver ponds in the off-channel habitats. As in the SFK watershed, beaver ponds accounted for more than 90 percent of the off-channel habitat surveyed. Beaver ponds in the UT provided habitat for adult spawning and juvenile overwintering for Pacific salmon. The water temperature in beaver ponds in the UT was slightly warmer than in other habitat types and thus, beaver ponds may represent a more productive habitat as compared to other mainstem channel habitat types" (PLP 2011).

The current body of literature describing the effects of beaver dams on salmonid species reports more positive associations between beaver dam activity and salmonids than negative associations (Kemp et al. 2012). Hence, removal of beaver dams as a means of compensatory mitigation could lead to a net negative impact on salmonid abundance, growth, and productivity. Moreover, since the mine scenario would eliminate or block several streams with active beaver colonies in the headwaters of the SFK and UTC, the benefits provided by those habitats would be part of the suite of functions that compensatory mitigation should aim to offset.

3.3.1.1.2 Connect Off-channel Habitats and Habitat Above Impassible Waterfalls

Off-channel habitats can provide important low-velocity rearing habitats for juvenile salmon and other native fishes. Floodplain-complex habitats including beaver ponds, side channels, oxbow channels, and alcoves can contribute significantly to juvenile salmonid rearing capacity (e.g., Beechie et al. 1994). Such habitats are a common

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feature of unmodified alluvial river corridors. These habitats may express varying degrees of surface-water connectivity to main channels that in unmodified rivers is dependent upon streamflow stage and natural channel dynamics. Off-channel habitats may become isolated from the main channel during certain streamflow conditions due to channel migration or avulsion, and in highly dynamic channels, connectivity may change frequently during bed-mobilizing events (Stanford and Ward 1993). This shifting mosaic of depositional and erosional habitats within the floodplain creates a diverse hydraulic and geomorphic setting, contributing to biocomplexity (Amoros and Bornette 2002). In river systems modified by human activity, isolation or elimination of off-channel habitats has had severe impacts on salmon productivity (e.g., Beechie et al. 1994), and re-connection and re-creation of off-channel habitats are now common tools for increasing juvenile salmonid habitat capacity in those systems (Morley et al. 2005, Roni et al. 2006).

Waterfalls or high-gradient stream reaches can prevent mobile fish species from accessing upstream habitats, due to velocity barriers or drops that exceed passage capabilities of fish (Reiser et al. 2006). Waters upstream of barriers may be devoid of all fish life, or may contain resident fish species including genetically-distinct populations (e.g., Whiteley et al. 2010). Engineered passageways for fish around waterfalls have been used to create access to upstream lakes or stream systems for fish such as salmon. However, the response of resident fish species to barrier removal and the colonization success of species from downstream habitats may be difficult to predict (Kiffney et al. 2009). Salmon population responses to a fishway in southeast Alaska depended on the species, and the ecological effects of fish passage on the upstream lake system and watershed are not fully understood (Bryant et al. 1999). Burger et al. (2000) provide a well-documented history of colonization of sockeye salmon in Frazer Lake, Alaska above a historically-impassible waterfall following passage installation and planting of salmon eggs, fry, and adults above the barrier. Their study documents how differing donor populations, each with different life-history characteristics, contributed differently toward the establishment of populations in the newly accessible habitats (Burger et al. 2000). This study highlights the importance of genetics and life history adaptations of source populations to colonization success.

Creating connectivity between parts of the river network that are naturally disconnected can have adverse ecological effects, including impacts to resident vertebrate and invertebrate communities, as well as disruptions to ecosystem processes. Introduction of fish to fish-less areas can lead to altered predator-prey interactions, food web changes, changes in algal production, nutrient cycling and meta-population dynamics of other vertebrate species (see Section 3.3.2.5). For example, previous studies on the introduction of trout species to montane, wilderness lakes have shown that introducing fish to fish-less lakes can have substantial impacts to nutrient cycles (Knapp et al. 2001). The risk of disruption to the functions of naturally fish-less aquatic ecosystems should be fully evaluated before these approaches are used for the sole purpose of creating new fish habitat area.

Rosenfeld and co-authors (Rosenfeld et al. 2008, Rosenfeld et al. 2009) conducted a variety of experiments and monitoring activities within a re-connected river meander in coastal British Columbia to explore the relationship of salmon productivity to habitat features. Their work highlights the importance of habitat configuration. In their study, spacing of pools (foraging habitats for fish) and riffles (source areas for invertebrate prey) was an important factor influencing growth rates of juvenile coho salmon. Given the high diversity of channel conditions within floodplain habitats in the project area (PLP 2011), it is likely that fish responses to increased connectivity would be highly variable.

Rosenfeld et al. (2008) point out the importance of considering the full suite of factors that influence habitat capacity and productivity when designing restoration or enhancement projects. For instance, 'optimising' habitat structure for one species may adversely impact species with differing habitat preferences, as demonstrated by Morley et al. (2005) who found differential responses of juvenile steelhead and juvenile coho salmon to conditions in constructed and natural off-channel habitats. Predator-prey relationships also need to be considered. Increased connectivity of off-channel habitats has been proposed as a strategy for enhancing northern pike production in northern Canada (Cott, 2004). How increased connectivity in the project area would influence trophic relationships among northern pike and salmon, trout and char is unknown, although introduced northern pike in other areas of Alaska have the potential to reduce local abundances of salmonids via predation (Sepulveda et al. 2013). Bryant et al. (1999) in their study of the effects of improved passage at a waterfall concluded that the effects on food webs, trophic relationships, and genetics among resident and newly-colonizing species were largely unknown. Rosenfeld and co-authors (2009) emphasize the high degree of uncertainty associated with channel design for enhanced fish productivity, stating:

> "…despite the enormous quantity of research on stream rearing salmonids and their habitat associations, stream ecologists still lack a definitive understanding of the relationship between channel structure, prey production and habitat capacity for drift-feeding fishes" (Rosenfeld et al. 2009, page 581).

Several commenters proposed that enhanced or increased connectivity of off-channel habitats or habitats above waterfalls could provide fish access to habitat currently underutilized or inaccessible. This comment presumes that currently disconnected habitats would provide suitable mitigation sites. Based on the above, there are multiple criteria that would have to be met, and numerous assumptions that would have to be validated in order for these sites to qualify as valid mitigation sites. For such measures to succeed, the following conditions would need to be considered:

a. Are currently inaccessible habitats suitable for salmon and other target fish species?

b. Does improved access to habitat address a currently limiting factor or condition?

c. Can the habitat be effectively connected in a way that enhances productivity?

d. Will enhanced connectivity be sustainable over the long term (e.g., be maintained despite sediment dynamics or channel adjustments)?

e. If enhanced connectivity is not self-sustainable, can a feasible monitoring and maintenance plan ensure continued connectivity and effectiveness?

f. What is the risk that changes to the hydrology, chemistry, temperature and morphology of the habitat complex associated with the construction of hydrologic connectivity will fundamentally alter the habitat suitability of the site such that it is no longer addressing a habitat need?

g. Would predators/competitors present within the existing disconnected habitat overwhelm the benefit to target species?

h. Are fish populations present in isolated habitats (e.g., above impassible waterfalls) genetically distinct or otherwise of special value, and potentially lost if connections to downstream fish populations are enabled?

i. How would potential adverse ecosystem changes in fish-less isolated habitats (e.g., above impassible waterfalls) due to fish introductions be evaluated and addressed?

Given the above considerations and examples of the challenges of connectivity management, use of fishways at waterfalls and engineered connections to off-channel habitats have many unanswered questions for the project area streams and wetlands. Such approaches would be effectively an "adaptive management experiment" (Rosenfeld et al. 2008); requiring careful monitoring and evaluation of alterations within an experimental context.

3.3.1.2 Increase Habitat Quality

Addition of large structural elements such as wood and boulders to streams has been a common stream habitat rehabilitation approach in locations where stream habitats have been extensively simplified by mining, logging and associated timber transportation, or other disturbances (Roni et al. 2008). The goals of large structure additions are typically to create increased hydraulic and structural complexity and improve local-scale habitat conditions for fish in streams that are otherwise lacking in rearing or spawning microhabitats. Properly engineered structural additions to channels can increase hydraulic diversity, habitat complexity, and retention of

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substrates and organic materials in channels, but benefits for aquatic life have been difficult to quantify (see review by Palmer et al. 2010). The paucity of demonstrated beneficial biotic responses to stream structural enhancements is at odds with perceptions by managers whose evaluations tend to be overtly positive – but usually based on qualitative opinion rather than scientific observation (Jähnig et al. 2011). In addition, improperly sited or engineered structural additions can fail to achieve desired effects or have adverse, unanticipated consequences (e.g., via structural failure or scour and fill of sensitive non-target habitats (Frissell and Nawa 1992)), highlighting the need for appropriate design.

Commenters proposed that quality of stream habitats in the project area could be enhanced by increasing habitat complexity through the addition of boulders or large wood to existing off-channel habitats. Off-channel habitats can provide important low-velocity rearing habitats for juvenile salmon and other native fishes. Floodplain-complex habitats including beaver ponds, side channels, oxbow channels, and alcoves provide hydraulic diversity that can be important for fish in variable flows (Amoros and Bornette 2002, Rosenfeld et al. 2008). Beaver are a major player in the creation and maintenance of these habitats in the study area (PLP 2011, Appendix 15.1D), as has been noted elsewhere (Pollock et al. 2003, Rosell et al. 2005). Off-channel habitats also provide important foraging environments, and can be thermally-diverse, offering opportunities for thermoregulation or enhanced bioenergetic efficiency (Giannico and Hinch 2003). Off-channel habitats are relatively frequent and locally-abundant in area streams and rivers, particularly in lower-gradient, unconstrained valley settings and at tributary confluences (e.g., PLP 2011 Figure 15.1-15, cover photo of this assessment). PLP's EBD, Appendix 15.1D (PLP 2011) contains an assessment of the natural fluvial processes creating and maintaining off-channel habitats, and their quality and quantity and function in the study area, including mechanisms of connectivity to the mainstem channels. This background information provides very useful information for evaluating the potential effectiveness of off-channel habitat modification.

Commenters proposed that off-channel habitats could also be improved by engineered modifications to the depth, shoreline development ratio, and configuration of off-channel habitats to create better overwintering habitat for juvenile salmon. The degree to which existing habitats could be enhanced to improve survival of juvenile salmon as proposed by commenters will be dependent upon several considerations, including an evaluation of factors known to influence the utilization, survival, and growth within these habitats. These considerations are discussed below.

Off-channel habitats surveyed by PLP and other investigators reveal that patterns of occupancy and density are high but variable among off-channel habitats (PLP 2011, Appendix 15.1D). Some of the highest densities observed were within off-channel habitats such as side channels and alcoves, but even some 'isolated' pools held fish (PLP 2011, Appendix 15.1D). This variability could reflect variation in suitability, access, or other characteristics of individual off-channel habitats. Juvenile salmonids require a

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diverse suite of resources to meet habitat requirements – cover and visual isolation provided by habitat complexity is one such resource, but other critical resources include food, space, and suitable temperatures and water chemistry (Quinn 2005). Habitat configuration within constructed side-channel habitats can also strongly influence density, size and growth of juvenile salmonids (Rosenfeld and Raeburn 2009). Giannico and Hinch (2003) in experimental treatments in side channels in British Columbia, found that wood additions were beneficial to coho salmon growth and survival in surface-water fed side channels, but not in groundwater-fed channels. They attributed this effect to differences in foraging strategy and bioenergetics of the juvenile coho salmon overwintering in the channels. Additions of wood had no effect, or even possibly a detrimental effect, on coho salmon survival in groundwater-fed side channels. These findings highlight the importance of understanding the ecology, bioenergetics, and behavior of the species and life histories present within habitats that may be quite diverse with regard to hydrology and geomorphology.

It is not clear from current data that adding complexity would address any limiting factor within existing off-channel habitats, or that additions of boulders and wood would enhance salmonid abundance or survival. Placement of structures (e.g., boulders, large wood) within stream channels should also be guided by careful consideration of potential adverse consequences, including unanticipated shifts in hydraulic conditions that lead to bank erosion or loss of other desirable habitat features. Sustainability of off-channel habitat modifications is also in question. As stated in the EBD, off-channel habitats are a product of a dynamic floodplain environment and "..are continually being created and destroyed" (PLP 2011; Appendix 15.1D; page 2). Maintenance of engineered structures or altered morphologies of such habitats over the long term would be a challenging task. Observations from the EBD suggest that beaver are already providing desired complexity; to quote, "..habitat mapping from this off-channel study shows that the beaver ponds contain extensive and diverse habitats and dominate the active valley floor." And, "…these off-channel habitats provide a critical habitat component of freshwater rearing of coho salmon, and to a lesser extent, other anadromous and resident species." (PLP 2011, Appendix 15.1D page 14).

3.3.1.3 Increase Habitat Quantity

The creation of spawning channels and off-channel habitats has been proposed as a means to compensate for lost salmon spawning and rearing areas. The intent of a constructed spawning channel is to simulate a natural salmon stream by regulating flow, gravel size, and spawner density (Hilborn 1992). Off-channel habitats may be enlarged or modified to alter habitat conditions and capacities for rearing juvenile salmonids. Examples include the many spawning channels (Bonnell 1991) and off-channel habitats (Cooperman 2006) enhanced or created in British Columbia and off-channel ponds rehabilitated by the City of Seattle (Hall and Wissmar 2004).

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Off-channel spawning and rearing habitats can be advantageous to salmon populations by providing diverse hydraulic and habitat characteristics. Redds constructed in these habitats may be less susceptible to scour compared to main channel habitats due to flow stability provided by their hyporheic or groundwater sources (Hall and Wissmar 2004). Moderated thermal regimes can provide benefits for growth and survival for overwintering juveniles (Giannico and Hinch 2003). Morley et al. (2005) compared 11 constructed off-channel habitats to naturally-occurring paired reference side channels and found that both natural and constructed off-channel habitats supported high densities of juvenile salmonids in both winter and summer. Although numerous studies have documented short-term or localized benefits of constructed off-channel habitats, ascertaining population-level effects is much more difficult. Any additional fry produced by spawning channels (if successful) would require additional suitable habitat for juvenile rearing and subsequent life stages in order to have a net positive effect on populations. Hilborn (1992) indicates that success, measured by increased production of adult fish from such channels, is unpredictable and generally unmonitored. A notable exception is the study by Sheng et al. (1990), which documented 2- to 8-fold increases in recruitment of coho spawner production from groundwater-fed off-channel habitats. Sheng et al. (1990) stated that effectiveness would be greatest in systems which currently lack adequate overwinter refuges. As with any rehabilitation strategy, population responses will be dependent upon whether factors actually limiting production are addressed. As stated elsewhere in this assessment, additional research and monitoring is required to quantify factors currently limiting production within project area watersheds.

Replacing destroyed salmon habitats with new constructed channels is not a simple task. Factors for consideration in designing and implementing off-channel habitat development are outlined in Lister and Finnigan (1997), and include evaluation of species and life stages present, current habitat conditions, and factors limiting capacity or productivity (Roni et al. 2008). Research indicates that channels fed by hyporheic flow or groundwater may be most effective for creating suitable spawning and rearing habitats (Lister and Finnigan 1997). Near-stream excavation and compaction associated with channel construction can alter groundwater flowpaths, so designing projects to protect current function and groundwater connectivity is very important.

Numerous researchers have emphasized that replacing lost habitats is not merely a process of providing habitat structure (Lake et al. 2007). Effective replacement of function also requires establishment of appropriate food web structure and productivity to support the food supply for fish – in essence, an entire ecosystem, including all full suite of organisms such as bacteria, algae, and invertebrates – needs to be in place in order for a constructed channel to begin to perform some of the same functions of a destroyed stream (Palmer et al. 2010). Quigley and Harper (2006b), in a review of stream rehabilitation projects, concluded "the ability to replicate ecosystem function is clearly limited."

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There is some history of using constructed spawning channels to mitigate for the impacts of various development projects on fish, based on the premise that they would provide additional spawning habitat and produce more fry, which would presumably result in more adult fish returning (Hilborn 1992). Off-channel rearing habitats have also been used to create additional overwintering habitats in Pacific Northwest rivers (Roni et al. 2006), and spawning channels have also been shown to provide suitable overwintering habitats for juvenile coho salmon (Sheng et al. 1990). However, there are very few studies regarding the efficacy of such channels at enhancing adult salmon recruitment in the published literature. Constructed spawning channels, particularly those dependent upon surface flow, may also require annual maintenance and cleaning (Hilborn 1992), and salmon using them can be prone to disease outbreaks (Mulcahy et al. 1982). The need for frequent maintenance would be contrary to the regulations' intent that compensatory mitigation projects be self-sustaining (40 CFR 230.97(b)). Off-channel habitats to mainstems are also extremely difficult to engineer in a way that can self-sustain in the face of a dynamic fluvial environment. Alluvial channels frequently shift (Amoros and Bornette 2002), and beaver are highly effective ecosystem engineers whose activities are constantly re-arranging floodplain channels and creating new dams (Pollock et al. 2003) - including within engineered channels and culverts (Cooperman 2006).

In light of their uncertain track record, it does not appear that constructed spawning channels and engineered connections of off-channel habitats would provide reliable and sustainable fish habitat in the Bristol Bay region.

3.3.1.4 Manage Water Quantity

Two commenters suggested a variety of techniques to manipulate water quantities within the NFK, SFK and UTC watersheds to improve fish productivity. Possible techniques for accomplishing this include: flow management, flow augmentation, and flow pump-back.

3.3.1.4.1 Direct Excess On-site Water

Commenters suggested that fish habitat productivity could be improved through careful water management at the mine scenario site, including the storage and strategic delivery of excess water to streams and aquifers to maintain or enhance flow and/or thermal regimes in the receiving streams. Delivering such flows via groundwater (i.e., by using wastewater treatment plant (WWTP) discharges to "recharge and surcharge groundwater aquifers") was identified as a preferred approach; commenters argued doing so would both render the measure less prone to operational anomalies at the WWTP and better mimic current natural flow patterns, thereby attenuating potential adverse effects related to discharge volume and temperature. Ideally, flow, temperature, and habitat modeling would inform the design and operation of flow

management to optimize species and habitat benefits by, for example providing water at specific times to locations where low flow currently limits fish productivity.

Manipulation of surface flows at another mine in Alaska—Red Dog, in the northwest part of the state—has resulted in an increase in fish (Arctic grayling and Dolly Varden) use of the downstream creek (Scannell 2005, Ott 2004). The circumstances at Red Dog, however, differ from those in the NFK, SFK, and UTC area. As described in Scannell (2005), the near complete absence of fish in Red Dog Creek prior to implementation of the water management techniques was the direct result of water quality, not quantity, as the stream periodically experienced toxic levels of metals that occurred naturally as it flowed through and downslope of the exposed ore body. Furthermore, the Red Dog water management system primarily involves point-to-point diversion or transfer of surface, rather than groundwater, both around the ore body and from tributaries upstream of the mine. We have been unable to locate any documentation of successful attempts to manage flow volume or temperature from mine sites (or other industrial developments), via groundwater, for the benefit of fish and/or fish habitat.

Given that most streams in the area support multiple salmonid species and life stages, with differing habitat needs at different times, designing and managing a water delivery system to overcome limiting factors for one or more species without adversely impacting others would be a significant challenge. Given the complexity of the surface-groundwater connectivity in the area, ensuring that discharges to groundwater actually reached the target habitat at the intended time would, perhaps, be the most difficult task. Quigley and Harper (2006b), in a review of stream rehabilitation projects, concluded "the ability to replicate ecosystem function is clearly limited."

This challenge could potentially be easier to overcome where habitat limitations occurred only as a result of mine development, assuming pre-project modeling and verification accurately identified groundwater flow paths to those areas. It is important to note, however, that even if such actions appeared to be feasible, they likely would be required to avoid or minimize the adverse impacts of flow reduction due to mine development, rather than to compensate for unavoidable habitat losses.

If it were an overall enhancement to pre-existing habitat, using WWTP discharges to groundwater to address natural limitation factors could be a form of compensatory mitigation. For example, PLP (2011) points out that productivity may be limited by the existence of "losing" reaches along the SFK mainstem and intermittent or ephemeral tributaries to both the SFK and NFK. Altering the natural flow regimes at such sites, however, could have unintended consequences on the local ecosystem and species assemblages (Poff et al. 1997). Moreover, "enhancing" these habitats through a WWTP-sourced groundwater flow delivery system would be even more challenging than managing flow to avoid or minimize impacts to already productive habitat, because it would require "improving" the natural flow delivery system that currently results in the periodic drying/low flows. We have not located any documented successful application

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of this technique, making it a highly experimental approach to enhancing fish productivity, particularly in a natural stream system. Highly experimental and unpredictable activities are generally discouraged as compensatory mitigation (40 CFR 230.93(a)(1); *see also* 73 FR 19633). The regulations also strongly discourage compensatory mitigation projects that require the long-term use of active engineering features (40 CFR 230.97(b)).

3.3.1.4.2 Augment Flows

Another means suggested for maintaining or increasing habitat productivity downstream of the mine site is to increase flow volume into certain streams by creating new sources of surface flow and/or groundwater recharge, specifically, from impoundments and/or ice fields. We are unaware of any documented successful efforts to create impoundments or ice fields for the benefit of salmonids. As described in the previous section, actions to maintain or reestablish pre-mine flow in streams likely would be required as avoidance or minimization measures, and would not constitute compensatory mitigation for unavoidable impacts.

Only if it were an overall enhancement to existing habitat would creating impoundments and/or ice fields have the potential for offsetting unavoidable adverse impacts. Thus, the objective would be to target stream reaches where flow-habitat modeling indicated opportunities for enhancement.

PLP's EBD notes that a portion of the SFK mainstem, as well as some Koktuli River tributaries, exhibit either intermittent or ephemeral flow that appears to be a limiting factor for salmonid productivity (PLP 2011). However, two of the tributaries are in the uppermost reaches of the SFK and would be eliminated by the mine scenarios.

Although there are potential locations for impoundments to manage flow in the stream reaches identified as having "sub-optimal" flow, logistical and environmental issues decrease the likely efficacy and sustainability of such an approach. Manipulating streamflows in particular watersheds would require diverting water from other basins or capturing water during peak flows for subsequent release at other times, with the concomitant engineering, construction, and maintenance challenges. Doing so would create additional adverse impacts from the construction of infrastructure and would be subject to modeling and perpetual management sufficient to ensure that water withdrawals from the "donor" watershed or from other times of the year would not adversely impact fish habitat and populations in its downstream waters. These concerns are in addition to those commonly associated with impoundments, such as alteration of flow, thermal, and sediment transport regimes.

Creating ice fields to increase the total volume of water available to a stream would also require water diversion, with the same challenges and concerns related to building and maintaining system infrastructure and reducing water volumes in the source watershed.

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Using ice fields to change the timing of water availability would encounter issues related to managing the melt to produce stream flow at the intended time (i.e., late summer or late winter low-flow periods). Moreover, since aquatic organisms supported by a particular water body typically have evolved specific life history, behavioral, and morphological traits consistent with the characteristics of that water body's natural flow regime, local populations are inherently vulnerable to flow modification (Lytle and Poff 2004). Any use of ice fields would face the potentially substantial challenges of the effects of climate change on ice production and preservation. Besides requiring active management in perpetuity, ice field creation for flow augmentation would be decidedly experimental, with high uncertainty regarding the likelihood of success. Flow augmentation techniques would also be inconsistent with the regulation's provision that "[c]ompensatory mitigation projects shall be designed, to the maximum extent practicable, to be self-sustaining once performance standards have been achieved. This includes minimization of active engineering features…" (40 CFR 230.97(b)).

3.3.1.4.3 Pump Water Upstream

Another option suggested for making flow in some stream reaches more persistent is to pump groundwater or surface water from a down-gradient site upstream to either a direct release point or a recharge area. This technique has been used for fish habitat restoration at sites in the continental U.S. (e.g., the Umatilla River, OR (Bronson and Duke 2005), the Lower Owens River, CA (LADWP 2013), and Muddy Creek, CO (AECOM et al. 2010 and GrandRiver Consulting 2008)), although we are unaware of any documentation addressing its efficacy in increasing salmonid productivity. As with flow management and augmentation, using this technique to offset flow reductions from mine operations would not be compensatory mitigation, limiting its potential use as such to reaches that already have sub-optimal flow. One such stream is NFK 1.190.10, a tributary that enters NFK 1.190 downstream of the tailings storage facility location. Flow modeling, however, indicates that mine development would diminish flow in that stream even further (see Figures 7-15 through 7-17 of the assessment).

For the periodically intermittent or ephemeral reaches identified in the EBD, potential source sites presumably would be in or along the lower reaches of the NFK or SFK, downstream of the mine, waste rock, and tailings storage facilities. Flow modeling indicates that the NFK would experience a decrease in flow under the Pebble 6.5 scenario (see Figure 7-17 of the assessment), increasing the possibility that withdrawing additional water from the system to pump back upstream either would not be possible or would have adverse downstream impacts. Extensive modeling would be necessary to assess downstream effects in either watershed.

Even with sufficient downstream water, this technique would require substantial disturbance associated with the construction of tens of kilometers of water pipeline, power infrastructure, and access, along with maintenance of those facilities in perpetuity. It would also entail active management to ensure that releases occur at

appropriate times, to increase the persistence of flow in target streams without otherwise adversely impacting their hydrographs or habitat. Such management would be another aspect of the approach that would be perpetual. In total, this technique would involve a great deal of uncertainty with regard to both efficacy and sustainability, making it a questionable mechanism for providing compensatory mitigation. This technique would also be inconsistent with the regulation's provision that "[c]ompensatory mitigation projects shall be designed, to the maximum extent practicable, to be self-sustaining once performance standards have been achieved. This includes minimization of active engineering features (e.g., pumps) and appropriate siting to ensure that natural hydrology and landscape context will support long-term sustainability" (40 CFR 230.97(b)).

3.3.1.5 Manipulate Water Quality

Two commenters suggested that alteration of stream water chemistry would improve fish production in the NFK, SFK and UTC. They suggest increasing two groups of water chemistry parameters: basic parameters such as alkalinity, hardness, and total dissolved solids, and nutrients such as nitrogen (N) and phosphorous (P). This argument suggests that low concentrations of basic parameters and/or nutrients limit the production of algae, which limits aquatic macroinvertebrate production and habitat complexity. This in turn can reduce overall fish production, reduce individual fish growth rates, or result in fish movements away from low production areas.

3.3.1.5.1 Increase Levels of Alkalinity, Hardness, and Total Dissolved Solids

Commenters propose that altering stream water chemistry to increase levels of alkalinity, hardness, and total dissolved solids would improve the buffering capacity, primary productivity, secondary productivity, and reduce the potential toxicity of metals at waters downstream of these altered locations. Commenters suggest two mechanisms to achieve these improvements: 1) the addition of limestone in some form at "appropriate" locations or 2) the discharge of higher alkalinity water into fish-producing streams through a water management program. Commenters argue that current levels of alkalinity, hardness, and total dissolved solids in the NFK, SFK and UTC are suboptimal for fish production and could be manipulated to improve fish production. However, the majority of the literature relating to alkalinity and limestone management, including every published study cited by commenters, evaluates these approaches in streams and lakes in northern Europe, eastern U.S., or eastern Canada whose fisheries have been heavily impacted by acid mine drainage, acid deposition or other mechanisms of acidification and even in these degraded water bodies, alkalinity/limestone treatment results were variable (Gunn and Keller 1984, Hasselrot and Hultberg 1984, Rosseland and Skogheim 1984, Zurbuch 1984, Gagen et al. 1989, Lacroix 1992, Clayton et al. 1998, McClurg et al. 2007). It is not clear from any of the published studies cited by commenters what effect the addition of limestome or higher

alkalinity water would have on the kinds of unaltered stream systems and fishery resources found in the Bristol Bay region of Alaska.

Alkalinity has two potential roles. First, it is a measure of the ability of water to neutralize acids. If the intent is to neutralize acid rock drainage from the potential mine, that use constitutes impact minimization or remediation, not compensation. Second, alkalinity is primarily due to carbonate and bicarbonate, which is the source of carbon used by aquatic algae so increasing alkalinity is potentially fertilization. However, given that the streams at the site are relatively shallow and rapidly flowing, it is very unlikely that they are carbon limited. Therefore, it is unlikely that increasing alkalinity would increase algal production unless it is neutralizing acids from a mine.

Similar considerations apply to increasing hardness. Aqueous hardness is due to calcium and magnesium, which reduce the toxicity of divalent metals such as copper by competing for uptake sites. Increasing hardness would be a potential means of remediating the effects of high metal levels drainage from mine waste leachate into streams. Alternatively, calcium and magnesium are nutrient elements and hypothetically could be limiting production. However, the commenters produce no evidence that such limitations are occurring, and it is less credible than the potential N and P limitations discussed in the next section.

Manipulating water chemistry could have a deleterious effect on salmon populations. A key characteristic of Pacific salmon is their homing migrations from oceanic feeding grounds, through diverse habitats, to their natal river to spawn. Homing is generally precise and has resulted in reproductively isolated spawning populations with specialized adaptations for their natal habitat. (Wisby and Hasler 1954, Hasler and Scholz 1983, Quinn and Dittman 1992, Dittman et al. 1995, Dittman and Quinn 1996). Olfactory systems of salmon are acutely sensitive to changes in water chemistry (McIntyre et al. 2012). Physiological and behavioral experiments demonstrate that calcium is an important odorant enabling salmon to recognize individual waters and that sockeye salmon olfactory systems are acutely sensitive to calcium ions (Bodznik 1978). This would suggest that manipulating stream chemistry through the addition of limestone or higher alkalinity water could impede salmon from recognizing and homing to their natal streams. Some commenters who raised concerns about manipulating stream chemistry through these approaches point out that homing failure could reduce productivity if salmon die without spawning or stray to non-natal habitats to which they are poorly adapted and experience higher mortality.

We are not aware of any published studies describing projects where the chemistry of unaltered/un-degraded salmon streams in Alaska or elsewhere has been manipulated through the addition of limestone or higher alkalinity water to achieve improvements in buffering capacity against natural acidity, increase primary or secondary productivity, or reduce toxicity to naturally occurring metals. Rather, the scientific literature suggests that such chemical alterations could result in deleterious effects on salmon in

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unaltered/un-degraded stream systems. Manipulating stream chemistry in the NFK, SFK and UTC through the addition of limestone or higher alkalinity water would be a challenging and difficult experiment with an unknown outcome.

3.3.1.5.2 Increase Levels of Nitrogen and/or Phosphorus

The same two commenters suggest altering stream water chemistry to increase levels of N and P where they are individually or co-limiting. They provide four categories of considerations for determining how to increase stream or lake nutrients:

1) The spatial and temporal distribution of the limiting nutrients,
2) The timing and duration of nutrient application(s),
3) The desired concentrations of each nutrient and the ratio between N and P for each application location, and
4) The need for detailed pre-project information including the biological species composition of the waterbody and a low level nutrient analysis.

The commenters make a few general recommendations about how to consider these factors when developing mitigation in the NFK, SFK and UTC. They suggest that the spatial distribution could focus on existing or newly created side channels, sloughs, beaver ponds, alcoves, or, if necessary, the main channels at 10 km intervals. They suggest several possible temporal distribution options; of adding the nutrients only during the growing season, potentially earlier, or all winter in open water locations where biological production continues year round. They further indicate that the key considerations are access cost and maintenance requirements. The commenters note several types of nutrient delivery methods: liquid fertilizer, slow-release fertilizer, and nutrient analogs (which are essentially slow-release pellets of processed fish).

As support for their conclusion that lake and stream fertilization represent "demonstrably successful mitigation techniques" for the NFK, SFK and UTC, the commenters cite a number of papers summarizing experiments and case studies, as well as references to several management programs in the U.S., Canada, and northern Europe. These studies have examined the use of increased levels of N and P, or fish carcasses, to improve ecosystem productivity and/or fish production.

The two commenters argue that current levels of N and P in the NFK, SFK and UTC are suboptimal for fish production stating that benefits of fertilizing oligotrophic waters to stimulate fish production have been demonstrated in many venues. Although numerous studies show an effect at one or more trophic levels in response to fertilization, these studies are insufficient for drawing conclusions regarding the long-term effectiveness of nutrient application to streams in the NFK, SFK and UTC watersheds because they lack scientific controls or have not been replicated, do not account for potential confounding factors, were conducted in very different ecosystems, and/or only evaluated short-term effects. These differences are pointed out in the following paragraphs.

Commenters provided examples of experiments and studies aimed at increasing primary productivity and theoretically salmon productivity. These studies assume that nutrients are the limiting factor preventing increased salmon productivity, but that is not necessarily the case. Paleolimnetic studies in Alaska indicate nutrient inputs are not always tied to higher primary productivity or salmon productivity (Chen et al 2011). Wipfli and Baxter (2010) found that most fish consume food from external or very distant sources, including from marine systems borne by adult salmon, from fishless headwaters that transport prey to downstream fish, and from riparian vegetation and associated habitats. An increase in food via nutrients may not overcome other limiting factors such as habitat availability or interspecies competition.

Most studies on stream and lake fertilization to increase productivity are short-term in duration and conducted in ecosystems with important differences from Bristol Bay (e.g. Perrin et al. 1987, Raastad et al. 1993, Wipfli et al. 1998, Slaney et al. 2003). For example, studies conducted at the Keogh and Salmon Rivers (Ward et al. 2003, Slaney et al. 2003) examined the effect of nutrient supplement in the form of salmon carcasses and inorganic N and P, respectively, in two coastal river systems for a period of three years. A spike in productivity has been seen in a number of these studies, but long term studies call into question whether the trend will be sustained over longer periods as is described in the following two long-term studies.

Results from the longest running study on stream fertilization raise concerns about using fertilization other than as an interim restorative measure. Slavik et al (2004) found that persistent increased levels of N and P can result in dramatic ecosystem shifts. This long term ecological research on the North Slope of Alaska examined the effect of P input into P-limited streams, finding an increase in production for some species at all trophic levels over the first few years. However, starting at seven or eight years, nutrient enrichment caused a dramatic rise in moss (photos A and B) that changed ecosystem structure. Despite higher insect biomass in the fertilized area during this period, the growth of fish was no longer significantly greater than in the reference area (Slavik et al. 2004). The resulting decrease in fish productivity was thought to result from the effects of moss on preferred insect prey. Following cessation of nutrient enrichment, it took eight years of recovery to approach reference levels, after storms had scoured most remnant moss in the recovering reach. These results demonstrate that even at low concentrations, sustained nutrient enrichment can have "dramatic and persistent consequences" (Benstead et al. 2007).

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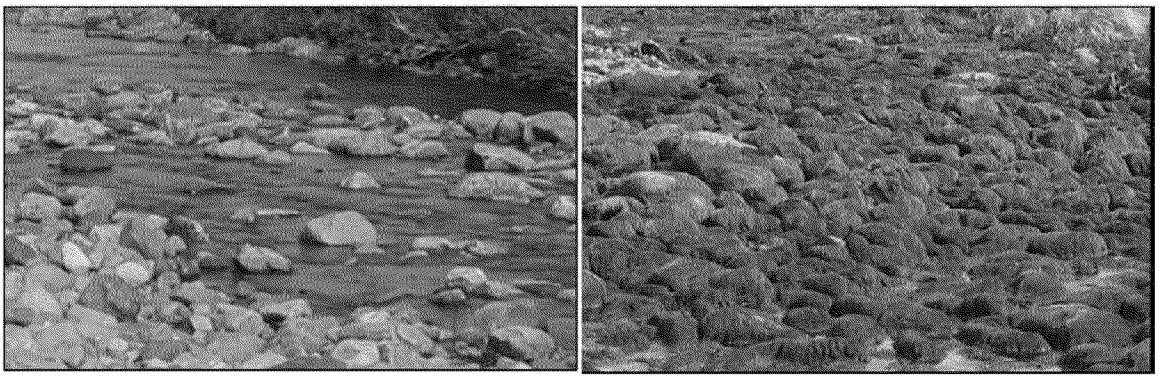

Photos showing the difference in bottom coverage between the diatom state (Photo A, left) and the fertilized moss state (Photo B, right). Used with permission (Slavik et al.).

In another study, long-term nutrient enrichment produced an unanticipated trophic decoupling whereby enrichment continued to stimulate primary consumer production without a similar increase in predator fish. The majority of the increased ecosystem productivity was confined to lower trophic levels because the long-term enrichment primarily stimulated primary consumers that were relatively resistant to predation. Based on these results, the authors concluded that "even in ecosystems where energy flow is predicted to be relatively efficient, nutrient enrichment may still increase the production of non-target taxa (e.g. predator or grazer resistant prey), decrease the production of higher trophic levels, or lead to unintended consequences that may compromise the productivity of freshwater ecosystems" (Davis et al. 2010 p 124).

These unanticipated results raise important questions about the potential consequences of long-term nutrient supplementations. They also underscore the unpredictability of nutrient additions on the food web, and the greater likelihood of unintended consequences as the effects ripple through complex interactions between species. These implications are especially relevant considerations for potential long-term mitigation that would be necessary in the NFK, SFK and UTC. If long-term nutrient addition were to cause an ecosystem shift at lower trophic levels in the NFK, SFK and UTC, effects on higher trophic levels including the productivity of salmon and other target fish species are unknown.

Studies examining the relationship between salmon carcasses and productivity at various trophic levels are another active area of investigation. Some research provides evidence that carcasses are superior to inorganic nutrient amendments for sustaining and restoring stream productivity, including fish production, potentially because inorganic nutrients lack biochemicals and macromolecules that are utilized directly by consumers (Wipfli et al. 2010, Martin et al. 2010, Heintz et al. 2010). Others have found the effects of carcasses can be transient, localized, and variable with no increase in fish growth (Cram et al. 2011). Few studies have documented the long-term impacts of carcass addition, and there are many remaining gaps in understanding the efficacy of this method of potentially improving salmon productivity. In addition, a number of

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authors express concern about the potential for the spread of toxins and pathogens when carcasses are used as the supplemental nutrient source (Compton et al. 2006).

Setting aside questions of scientific efficacy and applicability, there are numerous practical challenges inherent in nutrient addition as a potential mitigation method. Conducting a long-term management protocol in remote waterways subject to extreme weather changes necessarily requires careful monitoring of water chemistry and precise application of nutrients, which calls into question the sustainability of altering stream water chemistry to improve the fish production.

Authors of many of these studies state that the application of their results are relevant and appropriate for salmonid restoration in streams or lakes with depressed numbers (Larkin and Slaney 2011). The authors do not describe their results as informing methods to manipulate existing unaltered wild systems to further augment salmon production. Although the commenters draw heavily from Ashley and Stockner (2003), the authors of that study actually state:

> "The goal of stream and lake enrichment is to rebuild salmonid escapement to historical levels via temporary supplementations of limiting nutrients using organic and/or inorganic formulations. Stream and lake enrichment should not be used as a 'techno-fix' to perpetuate the existing mismanagement of salmonids when there is any possibility of re-establishing self-sustaining wild populations through harvest reductions and restoration of salmonid habitat. Therefore, fertilization should be viewed as an interim restorative measure that is most effective if all components of ecosystem recovery and key external factors (e.g. overfishing) are cooperatively achieved and coordinated. This paper reviews some of the technical and more applied aspects of stream, river, and lake enrichment as currently practiced in British Columbia and elsewhere. As a caveat, the discussion assumes that salmonid stock status of candidate lakes and streams has been quantified and classified as significantly depressed and that additional limiting factors (e.g. habitat/water quality and quantity) have been addressed and/or incorporated into an integrated basin or lake restoration plan." (Ashley and Stockner 2003 p. 246)

There are still many gaps in understanding the role of nutrients in fish productivity, so there is a great deal we do not know about whether nutrient addition can be a successful method to increase fish productivity. At this time there are no scientific studies showing how an increase in nutrients resulting in increase salmon productivity can be reliably achieved on a long-term basis in the NFK, SFK and UTC watersheds or the larger Bristol Bay ecosystem without risk to the region's existing robust populations. Just as for the addition of non-nutrients such as limestone, manipulating stream chemistry in this largely unaltered ecosystem through the addition of N and P would be a challenging and difficult experiment with many negative outcomes possible.

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3.3.1.6 Preserve Aquatic Resources

As described above, preservation as compensatory mitigation for the mine scenarios would require a site that is very large, performs similarly important aquatic functions, and is under threat of destruction or adverse modification. No commenters identified specific potential preservation sites, either within these watersheds or elsewhere in Bristol Bay. One challenge in identifying appropriate preservation sites is the high percentage of state and federal land ownership in the area. Public lands can provide mitigation, but only if the mitigating measure—in this case, preservation—is "over and above [that] provided by public programs already planned or in place" (40 CFR 230.93(a)(3)). Further, the aquatic functions of any preservation site downstream from the proposed mine scenarios would be subject to degradation from the direct, secondary, and cumulative effects of the mine itself. These factors could limit most properties of adequate area and similar aquatic function from serving as acceptable mitigation sites. Moreover, there is no precedent for such a preservation-dominated compensation approach in the context of this type and magnitude of ecological loss.

3.3.2 Other Opportunities within the Nushagak and Kvichak River Watersheds

As noted above, if practicable or appropriate opportunities to provide compensation within the NFK, SFK or UTC watersheds are non-existent or limited, it may be appropriate to explore options in adjoining watersheds. For example, there are a few scattered degraded sites in more distant portions of the Nushagak and Kvichak River watersheds that could potentially benefit from restoration or enhancement.

Here we discuss specific suggestions for other potential compensation measures within the Nushagak and Kvichak River watersheds that were provided in the public and peer review comments on the Bristol Bay Assessment.

3.3.2.1 Remediate Old Mine Sites

The U.S. Geologic Survey (USGS) identifies four small mine sites within the Nushagak and Kvichak River watersheds: Red Top (in the Wood River drainage), Bonanza Creek (a Mulchatna River tributary), Synneva or Scynneva Creek (a Bonanza Creek tributary), and Portage Creek (in the Lake Clark drainage) (USGS 2008, 2012). These sites could provide opportunities for performing ecological restoration or enhancement. However, due to their relatively small size and distant location, it is unlikely that these sites could provide sufficient restored or enhanced acreage or ecological function to offset what would be lost under the assessment mine scenarios. Further, some mitigation measures have already occurred at these mines; for example, there have been some remediation activities at Red Top mine, although traces of mercury and diesel-range organics remain in soils (BLM 2000). Resolution of liability and contamination issues at these old mines

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would be necessary before they could serve as compensatory mitigation sites for other projects.

3.3.2.2 Remove Roads

Another potential type of restoration within the Nushagak and Kvichak River watersheds is the removal of existing or abandoned roads. As described in detail in Appendix G of the assessment, roads have persistent, multifaceted impacts on ecosystems and can strongly affect water quality and fish habitat. Common long-term impacts from roads include: 1) permanent loss of natural habitat; 2) increased surface runoff and reduced groundwater flow; 3) channelization or structural simplification of streams and hydrologic connectivity; 4) persistent changes in the chemical composition of water and soil 5) disruption of movements of animals, including fishes and other freshwater species; 6) aerial transport of pollutants via road dust; and 7) disruption of near-surface groundwater processes, including interception or re-routing of hyporheic flows, and conversion of subsurface slope groundwater to surface flows (Darnell et al. 1976, Trombulak and Frissell 2000, Forman 2004). Road removal, thus, could facilitate not only the reestablishment of former wetlands and stream channels, but also the enhancement of nearby aquatic resources currently degraded by the road(s).

Commenters did not offer specific suggestions for potential road removal sites. As Appendix G of the assessment highlights, the Nushagak and Kvichak River watersheds are almost entirely roadless areas (see Figure 1 of Appendix G). Further, it is unlikely that local communities would support removal of any segments of the few existing roads in the watersheds. Thus, it would appear there are very few, if any, viable opportunities to provide environmental benefits through road removal.

3.3.2.3 Retrofit Road Stream Crossings

Another potential type of enhancement within the Nushagak and Kvichak River watersheds is to retrofit existing road stream crossings to improve fish passage through these man-made features. Stream crossings can adversely impact spawning, rearing (Sheer and Steel 2006, Davis and Davis 2011), and refuge habitats (Price et al. 2010), as well as reduce genetic diversity (Wofford et al. 2005, Neville et al. 2009). These changes can in turn reduce long-term sustainability of salmon populations (Hilborn et al. 2003, Schindler et al. 2010). Blockage or inhibition of fish passage is a well-documented problem commonly associated with declines in salmon and other fish populations in many regions of the U.S. (Nehlsen et al. 1991, Bates et al. 2003), including Alaska (ADFG 2012b).

Removing and replacing crossings that serve as barriers to fishes could improve fish passage and re-open currently inaccessible habitat. However, as noted in Section 3.3.2.2, the Nushagak and Kvichak River watersheds are almost entirely roadless areas, and thus offer few, if any, viable opportunities to provide the extent of environmental

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benefits necessary to offset the magnitude of impacts associated with the mine scenarios and associated development. Further, prior to concluding that any effort to retrofit existing stream crossings would be appropriate compensatory mitigation, it would first be necessary to determine that no other party has responsibility for the maintenance of fish passage at those stream crossings (e.g., through the terms or conditions of a Section 404 permit that authorized the crossing).

3.3.2.4 Construct Hatcheries

One commenter referenced the potential use of hatcheries as a compensation measure. Such a proposal could be very problematic, particularly in the context of Bristol Bay, where the current salmon population is entirely wild. There are several concerns over the introduction of hatchery-produced salmon to the Bristol Bay watershed, best expressed by the National Oceanic and Atmospheric Administration's Northwest Fisheries Science Center:

> "Over the past several decades, wild salmon populations have declined dramatically, despite, and perhaps sometimes because of, the contribution of hatcheries. Many salmon stocks in Washington and Oregon are now listed as either threatened or endangered under the U.S. Endangered Species Act. With this decline has come an increased focus on the preservation of indigenous wild salmon stocks.
>
> Hatcheries have the potential to assist in the conservation of wild stocks, but they also pose some risks. At this time, scientists still have many questions about the extent to which hatchery programs enhance or threaten the survival of wild populations. Additional research and investigation is needed." (NOAA 2012)

Many of the potential risks associated with fish hatcheries concern reductions in fitness, growth, health, and productivity that result from decreases in genetic diversity when hatchery-reared stocks hybridize with wild salmon populations. Hatchery-raised salmon have lower genetic diversity than wild salmon (Christie et al. 2011, Yu et al. 2012). Consequently, when hatchery-raised salmon hybridize with wild salmon, the result can be a more genetically homogenous population, leading to decreases in genetic fitness (Waples 1991). In some cases, wild populations can become genetically swamped by hatchery stocks. Zhivitovsky et al. (2012) found evidence of such swamping in a wild chum salmon population in Kurilskiy Bay, Russia during a two-year period of high rates of escaped hatchery fish. This genetic homogenization is of concern because hatchery-raised fish stocks are considered less genetically "fit" and therefore could increase the risk of collapse of salmon fisheries. This concern is supported by Araki et al. (2008), a review of 14 studies which suggests that nonlocal hatchery stocks reproduce very poorly in the wild. The authors of this review also found that wild stocks reproduce better than both hatchery stocks and wild, local fish spawned and reared in hatcheries.

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Hatchery fish can also compete directly for food and resources with wild salmon populations in both freshwater and marine environments (Rand et al. 2012a). Ruggerone et al. (2012) examined the effect that Asian hatchery chum salmon have had on wild chum salmon in Norton Sound, Alaska since the early 1980s. They found that an increase in adult hatchery chum salmon abundance from 10 million to 80 million adult fish led to a 72% reduction in the abundance of the wild chum salmon population. They also found smaller adult length-at-age, delayed age-at-maturation, and reduced productivity were all associated with greater production of Asian hatchery chum since 1965 (Ruggerone et al. 2012). In addition to this competition for resources, hatchery-raised subyearling salmon can also prey upon wild subyearling salmon, which tend to be smaller in size (Naman and Sharpe 2012).

Despite extensive efforts to restore federally listed Pacific Northwest salmon populations, they remain imperiled, and hatchery fish stocks may be a contributing stressor (Kostow 2009). Given the exceptional productivity of the wild Bristol Bay salmon population, hatcheries would appear to pose greater ecological risks than benefits to this unique and valuable wild salmon population.

3.3.2.5 Stock Fish

Since many of the fish used in fish stocking originate in hatcheries, fish stocking raises many of the same concerns as hatcheries and thus would also be a problematic form of compensatory mitigation for the Bristol Bay region. Although stocking has been a common practice in other regions, even in previously fishless habitats (e.g., Red Dog Mine, Alaska), a large body of literature describes widespread adverse impacts of such management decisions. Fish stocking throughout western North America and worldwide has impacted other fish (Knapp et al. 2001, Townsend 2003), nutrient cycling (Schindler et al. 2001, Eby et al. 2006, Johnson et al. 2010), primary production (Townsend 2003, Cucherousset and Olden 2011), aquatic macroinvertebrates (Dunham et al. 2004, Pope et al. 2009 Cucherousset and Olden 2011), amphibians (Pilliod and Peterson 2001, Finlay and Vredenberg 2007), and terrestrial species (Epanchin et al. 2010). Although fish stocking has provided limited benefits in certain circumstances, it would appear from the growing body of literature that the ecological costs of fish stocking far outweigh any potential benefits.

3.4 Other Suggested Compensation Measures

Comments also included suggestions that compensatory mitigation for impacts to fish and other aquatic resources could take the form of making payments to organizations that support salmon sustainability or investing in various public education, outreach, or research activities designed to promote salmon sustainability. Although these kinds of initiatives can provide benefits in other contexts, compensatory mitigation for impacts authorized under Section 404 of the Clean Water Act can only be provided through purchasing credits from an approved mitigation bank or in-lieu fee program or

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conducting permittee-responsible compensatory mitigation projects (40 CFR 230.92). One commenter also suggested reducing commercial fishery harvests to compensate for fish losses due to large-scale mining; however, such a measure would also be inconsistent with the definition of compensatory mitigation (40 CFR 230.92).

4. Effectiveness of Compensation Measures at Offsetting Impacts to Salmonids

In North America, 73% of fish extinctions are linked to habitat alterations (Miller et al. 1989). Although extensive efforts have been undertaken to create or improve salmon habitat and prevent losses to fisheries, the current status of U.S. salmon is a sobering testament to the billions spent on mitigation efforts given that all U.S. Atlantic salmon populations are endangered (NOAA 2013), 40% of Pacific salmon in the Lower 48 are extirpated from historic habitats (NRC 1996), and one third of remaining populations are threatened or endangered with extinction (Nehlsen et al. 1991, Slaney et al. 1996, Gustafson et al. 2007). Approximately one third of sockeye salmon population diversity is considered endangered or extinct (Rand et al. 2012b), and Bristol Bay sockeye salmon likely represent the most abundant diverse sockeye salmon populations left in the U.S.

Since 1990, a billion dollars has been spent annually in the U.S. on stream and watershed restoration (Bernhardt et al. 2005) and more than 60% of the projects completed during this period were associated with salmon and trout habitat restoration efforts in the Pacific Northwest and California (Katz et al. 2007). Despite the proliferation of projects and the significant funds being expended on these efforts, debate continues over the effectiveness of various fish habitat restoration techniques and the cumulative impact of multiple, poorly coordinated restoration actions at a watershed or regional scale (Reeves et al. 1991, Chapman 1996, Roni et al. 2002, Kondolf et al. 2008). Further, independent evaluations of the effectiveness of fish habitat compensation projects are rare (Harper and Quigley 2005b, Quigley and Harper 2006a, Quigley and Harper 2006b), and consequently the long-term success rates and efficacy of such projects are not well known (DFO 1997, Lister and Bengeyfield 1998, Lange et al. 2001, Quigley and Harper 2006a). A recent study by Roni et al. (2010) clearly questions the efficacy of mitigation to specifically offset salmon losses.

The most comprehensive investigation, to date, of the efficacy of fish habitat mitigation measures was conducted by the Department of Fisheries and Oceans, Environment Canada (Harper and Quigley 2005a, Harper and Quigley 2005b, Quigley and Harper 2006a, Quigley and Harper 2006b). Quigley and Harper (2006a) showed that 67% of compensation projects resulted in net losses to fish habitat and only 2% resulted in no net loss, whereas only 31% achieved a net gain in habitat area. Quigley and Harper (2006a) concluded that habitat compensation in Canada was, at best, only slowing the rate of fish habitat loss. Quigley and Harper (2006b) showed that 63% of projects resulted in net losses to aquatic habitat productivity and only 25% achieved no net loss,

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whereas only 12% provided net gains in aquatic habitat productivity. Quigley and Harper (2006b) concluded "the ability to replicate ecosystem function is clearly limited."

Quigley and Harper (2006b) highlight the need for improvements in compensation science as well as institutional approaches such as better project planning, monitoring, and maintenance. However, they also recognize that, based on decades of experience in wetland replacement projects, simply achieving compliance with all regulatory requirements does not ensure that ecological functions are replaced (NRC 2001, Sudol and Ambrose 2002, Ambrose and Lee 2006, Kihslinger 2008). Although there are clearly opportunities to improve the performance of fish habitat compensation projects, Quigley and Harper (2006b) caution:

> "it is important to acknowledge that it is simply not possible to compensate for some habitats. Therefore, the option to compensate for HADDs [*harmful alteration, disruption or destruction to fish habitat*] may not be viable for some development proposals demanding careful exploration of alternative options including redesign, relocation, or rejection."

5. Conclusions

There are significant challenges regarding the potential efficacy, applicability and sustainability of compensation measures proposed by commenters for use in the Bristol Bay region, raising questions as to whether sufficient compensation measures exist that could address impacts of the type and magnitude described in the Bristol Bay Assessment. The mine scenarios evaluated in the assessment show that the mine footprint alone would result in the loss (i.e., filling, blocking or otherwise eliminating) of hundreds to thousands of acres of high-functioning wetlands and tens of miles of salmon-supporting streams. In addition to these direct losses, these mine scenarios would also result in extensive adverse secondary and cumulative impacts to wetlands, streams, and fish that would have to be addressed. Such extensive habitat losses and degradation could also result in the loss of unique salmon populations, eroding the genetic diversity essential to the stability of the overall Bristol Bay salmon fishery.

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About Bristol Bay

The Bristol Bay watershed in southwestern Alaska supports the largest sockeye salmon fishery in the world, is home to 25 federally recognized tribal governments, and contains large mineral resources.

The Nushagak River and Kvichak River watersheds are the largest of Bristol Bay's six major river basins and compose about 50% of the total watershed area.

Ecological resources

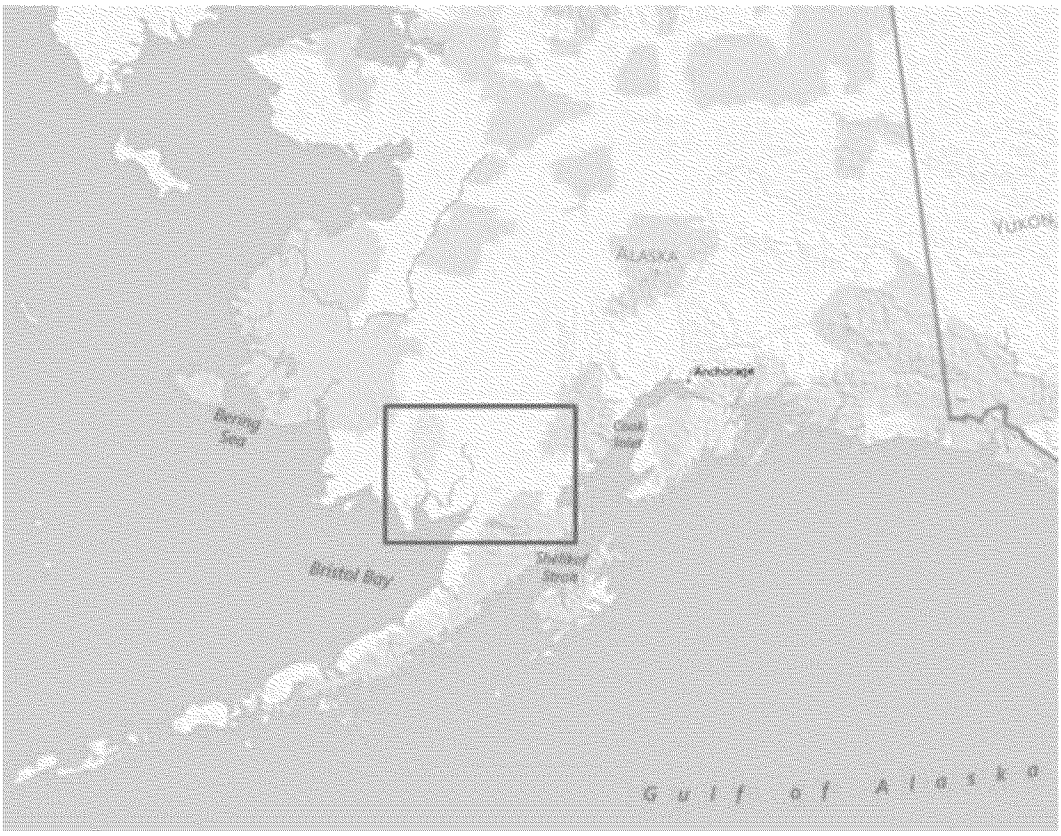
The Bristol Bay watershed provides habitat for numerous animal species, including 29 fishes, more than 190 birds, and more than 40 terrestrial mammals. Chief among these resources is a world-class commercial and sport fishery for Pacific salmon and other important resident fishes. The watershed supports production of all five species of Pacific salmon found in North America: sockeye, coho, Chinook, chum, and pink.

Because no hatchery fish are raised or released in the watershed, Bristol Bay's salmon populations are entirely wild. These fish are anadromous - hatching and rearing in freshwater systems, migrating to the sea to grow to adult size, and returning to freshwater systems to spawn and die.

The most abundant salmon species in the watershed is sockeye salmon. The Bristol Bay watershed supports the largest sockeye salmon fishery in the world, with approximately 46% of the average global abundance of wild sockeye salmon. Between 1990 and 2010, the annual average inshore run of sockeye salmon in Bristol Bay was approximately 37.5 million fish. Annual commercial harvest of sockeye over this same period averaged 27.5 million. Approximately half of the Bristol Bay sockeye salmon production is from the Nushagak River and Kvichak River watersheds.

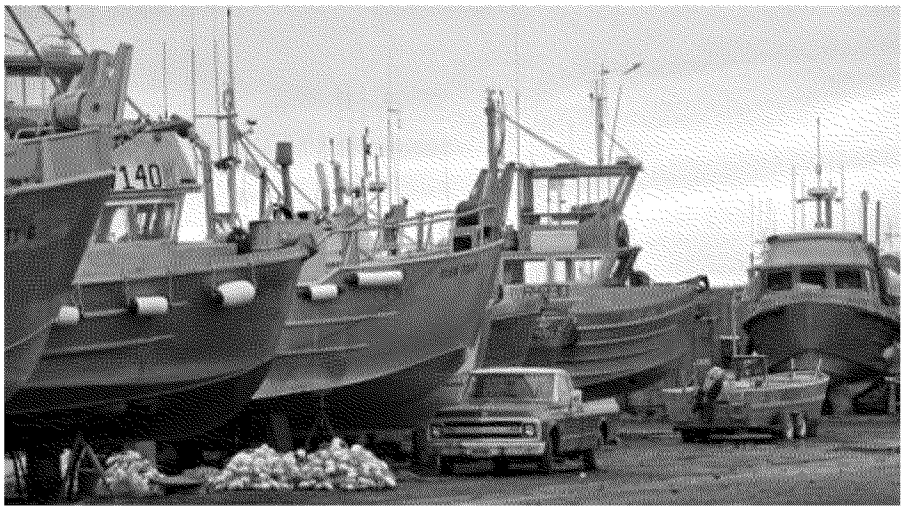
Indigenous cultures

The Alaska Native cultures present in the Nushagak River and Kvichak River watersheds - the Yup'ik and Dena'ina - are two of the last intact, sustainable salmon-based cultures in the world. Salmon are integral to the entire way of life in these cultures as subsistence food and as the foundation for their language, spirituality, and social structure.

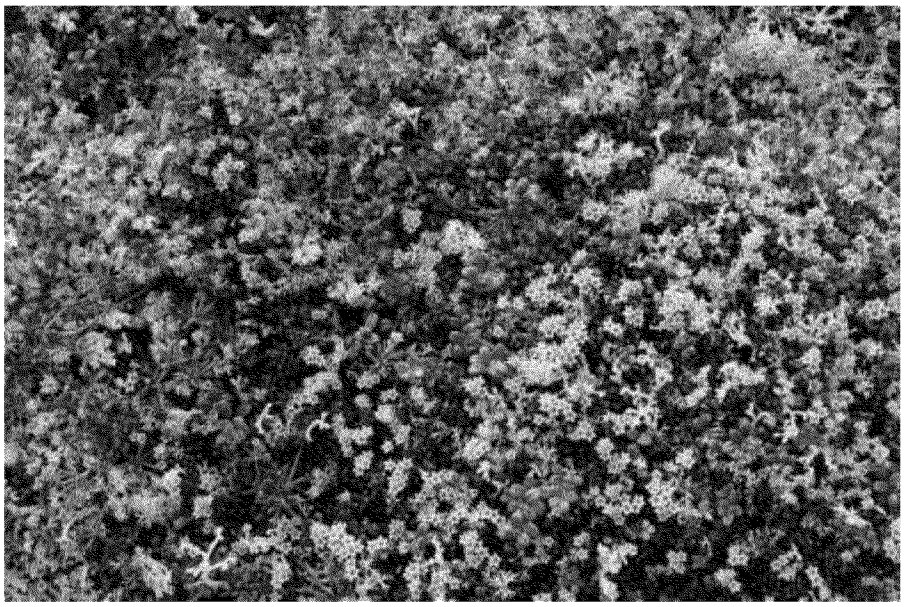


Bristol Bay is located at the northeastern end of the Alaskan peninsula. Click on map for larger view.

A view of Upper Talarik Creek which flows into Lake Iliamna in the Kvichak River watershed. Click on image for larger view.



Commercial fishing boats stand ready. Click image for larger view.



Tundra wildflowers bloom along the Koktuli River. Click image for larger view.

Fourteen of Bristol Bay's 25 Alaska Native villages and communities are within the Nushagak River and Kvichak River watersheds, with a total population of 4,337 in 2010.

In the Bristol Bay region, salmon constitute approximately 52% of the subsistence harvest. Subsistence from all sources (fish, moose, and other wildlife) accounts for an average of 80% of protein consumed by area residents.

These cultures have a strong connection to the landscape and its resources. In the Bristol Bay watershed, this connection has been maintained for at least the past 4,000 years and is in part due to and responsible for the continued pristine condition of the region's landscape and biological resources.

Economy of ecological resources

The Bristol Bay watershed supports several economic sectors that are wilderness-compatible and sustainable:

- commercial, sport and subsistence fishing
- sport and subsistence hunting
- non-consumptive recreation (e.g. wildlife viewing and tourism)

Considering all these sectors, the ecological resources of the Bristol Bay watershed generated nearly $480 million in direct economic expenditures and sales in 2009, and provided employment for over 14,000 full- and part-time workers.

The Bristol Bay commercial salmon fishery generates the largest component of economic activity and was valued at approximately $300 million in 2009 (first wholesale value) and provided employment for over 11,500 full- and part-time workers at the peak of the season.

Geological resources

The Nushagak River and Kvichak River watersheds contain considerable mineral resources. The potential for large-scale mining development within the region is greatest for copper deposits and, to a lesser extent, for intrusion-related gold deposits. Because these deposits are low-grade - meaning that they contain relatively small amounts of metals relative to the amount of ore - mining will be economic only if conducted over a large area, and a large amount of waste material will be produced as a result of mining and processing.

The largest known deposit and the deposit most explored to assess future mining potential is the Pebble deposit. If fully mined, the Pebble deposit could produce more than 11 billion metric tons (1 metric ton = 1,000 kg, approximately 2,200 pounds) of ore, which would make it the largest mine of its type in North America.

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Water Quality Standards Handbook

Chapter 4: Antidegradation

The WQS Handbook does not impose legally binding requirements on the EPA, states, tribes or the regulated community, nor does it confer legal rights or impose legal obligations upon any member of the public. The Clean Water Act (CWA) provisions and the EPA regulations described in this document contain legally binding requirements. This document does not constitute a regulation, nor does it change or substitute for any CWA provision or the EPA regulations.

Water Quality Standards Handbook
CHAPTER 4: ANTIDEGRADATION

(40 CFR 131.12)

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CHAPTER 4 ANTIDEGRADATION

This chapter provides guidance on the antidegradation component of water quality standards, its application in conjunction with the other parts of the water quality standards regulation, and its implementation by the States. Antidegradation implementation by the States is based on a set of procedures to be followed when evaluating activities that may impact the quality of the waters of the United States. Antidegradation implementation is an integral component of a comprehensive approach to protecting and enhancing water quality.

4.1 History of Antidegradation

The first antidegradation policy statement was released on February 8, 1968, by the Secretary of the U.S. Department of the Interior. It was included in EPA's first Water Quality Standards Regulation (40 CFR 130.17, 40 F.R. 55340-41, November 28, 1975), and was slightly refined and re-promulgated as part of the current program regulation published on November 8, 1983 (48 F.R. 51400, 40 CFR 131.12). Antidegradation requirements and methods for implementing those requirements are minimum conditions to be included in a State's water quality standards. Antidegradation was originally based on the spirit, intent, and goals of the Act, especially the clause ". . . restore and maintain the chemical, physical and biological integrity of the Nation's waters" (101(a)) and the provision of 303(a) that made water quality standards under prior law the "starting point" for CWA water quality requirements. Antidegradation was explicitly incorporated in the CWA through:

- a 1987 amendment codified in section 303(d)(4)(B) requiring satisfaction of antidegradation requirements before making certain changes in NPDES permits; and
- the 1990 Great Lakes Critical Programs Act codified in CWA section 118(c)(2) requiring EPA to publish Great Lakes water quality guidance including antidegradation policies and implementation procedures.

4.2 Summary of the Antidegradation Policy

Section 131.12(a)(l), or "Tier 1," protecting "existing uses," provides the absolute floor of water quality in all waters of the United States. This paragraph applies a minimum level of protection to all waters.

Section 131.12(a)(2), or "Tier 2," applies to waters whose quality exceeds that necessary to protect the section 101(a)(2) goals of the Act. In this case, water quality may not be lowered to less than the level necessary to fully protect the "fishable/swimmable" uses and other existing uses and may be lowered even to those levels only after following all the provisions described in section 131.12(a)(2).

Section 131.12(a)(3), or "Tier 3," applies to Outstanding National Resource Waters (ONRW) where the ordinary use classifications and supporting criteria may not be sufficient or appropriate. As described in the preamble to the Water Quality Standards Regulation, "States may allow some limited activities which result in temporary and short-term changes in water quality," but such changes in

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water quality should not impact existing uses or alter the essential character or special use that makes the water an ONRW.

The requirement for potential water quality impairment associated with thermal discharges contained in section 131.12 (a)(4) of the regulation is intended to coordinate the requirements and procedures of the antidegradation policy with those established in the Act for setting thermal discharge limitations. Regulations implementing section 316 may be found at 40 CFR 124.66. The statutory scheme and legislative history indicate that limitations developed under section 316 take precedence over other requirements of the Act.

As the States began to focus more attention on implementing their antidegradation policies, an additional concept was developed by the States, which EPA has accepted even though not directly mentioned in previous EPA guidance or in the regulation. This concept, commonly known as "Tier 2½," is an application of the antidegradation policy that has implementation requirements that are more stringent than for "Tier 2" (high-quality waters), but somewhat less stringent than the prohibition against any lowering of water quality in "Tier 3" (ONRWs). EPA accepts this additional tier in State antidegradation policies because it is clearly a more stringent application of the Tier 2 provisions of the antidegradation policy and, therefore, permissible under section 510 of the CWA.

The supporting rationale that led to the development of the Tier 2½ concept was a concern by the States that the Tier 3 ONRW provision was so stringent that its application would likely prevent States from taking actions in the future that were consistent with important social and economic development on, or upstream of, ONRWs. This concern is a major reason that relatively few water bodies are designated as ONRWs. The Tier 2½ approach allows States to provide a very high level of water quality protection without precluding unforeseen future economic and social development considerations.

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4.3 State Antidegradation Requirements

UPDATED INFORMATION

State-Specific Water Quality Standards Effective Under the Clean Water Act- This website provides access to state, authorized tribal and territorial water quality standards, including antidegradation policies, that EPA has approved or are otherwise in effect for Clean Water Act purposes.

Federal Rules Involving Antidegradation

Water Quality Standards for Puerto Rico: Final Rule (2007) - This federal register notice promulgated methods to implement Puerto Rico's existing antidegradation policy.

Advanced Notice of Proposed Rulemaking for Water Quality Standards (1998) See pages 36779 to 36787 for an overview of antidegradation policy and EPA's thinking on program development in 1998.

Final Water Quality Guidance for the Great Lakes System: Final Rule (1995) See Appendix E for Antidegradation Provisions.

Each State must develop, adopt, and retain a statewide antidegradation policy regarding water quality standards and establish procedures for its implementation through the water quality management process. The State antidegradation policy and implementation procedures must be consistent with the components detailed in 40 CFR 131.12. If not included in the standards regulation of a State, the policy must be specifically referenced in the water quality standards so that the functional relationship between the policy and the standards is clear. Regardless of the location of the policy, it must meet all applicable requirements. States may adopt antidegradation statements more protective than the Federal requirement. The antidegradation implementation procedures specify how the State will determine on a case-by-case basis whether, and to what extent, water quality may be lowered.

State antidegradation polices and implementation procedures are subject to review by the Regional Administrator. EPA has clear authority to review and approve or disapprove and promulgate an antidegradation policy for a State. EPA's review of the implementation procedures is limited to ensuring that procedures are included that describe how the State will implement the required elements of the antidegradation review. EPA may disapprove and federally promulgate all or part of an implementation process for antidegradation if, in the judgment of the Administrator, the State's process (or certain provisions thereof) can be implemented in such a way as to circumvent the intent and purpose of the antidegradation policy. EPA encourages submittal of any amendments to the statement and implementing procedures to the Regional Administrator for pre-adoption review so that the State may take EPA comments into account prior to final action.

If a State's antidegradation policy does not meet the Federal regulatory requirements, either through State action to revise its policy or through revised Federal requirements, the State would be given the opportunity to make its policy consistent with the regulation. If this is not done, EPA has the authority to promulgate the policy for the State pursuant to section 303(c)(4) of the Clean Water Act (see section 6.3, this Handbook).

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4.4 Protection of Existing Uses - 40 CFR 131.12(a)(1)

UPDATED INFORMATION

Letter: Mr. Derek Smithee, State of Oklahoma Water Resources Board. Questions and Answers on EPA's Existing Use Policy (2008) (PDF) - This letter answers Oklahoma's questions on several issues related to existing uses.

This section requires the protection of existing uses and the level of water quality to protect those uses. An "existing use" can be established by demonstrating that:

- fishing, swimming, or other uses have actually occurred since November 28, 1975; or
- that the water quality is suitable to allow the use to be attained—unless there are physical problems, such as substrate or flow, that prevent the use from being attained.

An example of the latter is an area where shellfish are propagating and surviving in a biologically suitable habitat and are available and suitable for harvesting although, to date, no one has attempted to harvest them. Such facts clearly establish that shellfish harvesting is an "existing" use, not one dependent on improvements in water quality. To argue otherwise would be to say that the only time an aquatic protection use "exists" is if someone succeeds in catching fish.

Full protection of the existing use requires protection of the entire water body with a few limited exceptions such as certain physical modifications that may so alter a water body that species composition cannot be maintained (see section 4.4.3, this Handbook), and mixing zones (see section 4.4.4, this Handbook). For example, an activity that lowers water quality such that a buffer zone must be established within a previous shellfish harvesting area is inconsistent with the antidegradation policy.

Section 131.12(a)(l) provides the absolute floor of water quality in all waters of the United States. This paragraph applies a minimum level of protection to all waters. However, it is most pertinent to waters having beneficial uses that are less than the section 101(a)(2) goals of the Act. If it can be proven, in that situation, that water quality exceeds that necessary to fully protect the existing use(s) and exceeds water quality standards but is not of sufficient quality to cause a better use to be achieved, then that water quality may be lowered to the level required to fully protect the existing use as long as existing water quality standards and downstream water quality standards are not affected. If this does not involve a change in standards, no public hearing would be required under section 303(c). However, public participation would still be provided in connection with the issuance of a NPDES permit or amendment of a section 208 plan or section 319 program. If, however, analysis indicates that the higher water quality does result in a better use, even if not up to the section 101(a)(2) goals, then the water quality standards must be upgraded to reflect the uses presently being attained (131.10(i)).

If a planned activity will foreseeably lower water quality to the extent that it no longer is sufficient to protect and maintain the existing uses in that water body, such an activity is inconsistent with EPA's

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antidegradation policy, which requires that existing uses are to be maintained. In such a circumstance, the planned activity must be avoided or adequate mitigation or preventive measures must be taken to ensure that the existing uses and the water quality to protect them will be maintained.

Section 4.4.1, this Handbook, discusses the determination and protection of recreational "existing" uses, and section 4.4.2, this Handbook, discusses aquatic life protection "existing" uses (of course, many other types of existing uses may occur in a water body).

4.4.1 Recreational Uses

Recreational uses traditionally are divided into primary contact and secondary contact recreation (e.g., swimming vs. boating; that is, recreation "in" or "on" the water.) However, these two broad uses can logically be subdivided into a variety of subcategories (e.g., wading, sailing, power boating, rafting). The water quality standards regulation does not establish a level of specificity that each State must apply in determining what recreational "uses" exist. However, the following principles apply.

- The State selects the level of specificity it desires for identifying recreational existing uses (that is, whether to treat secondary contact recreation as a single use or to define subcategories of secondary recreation). The State has two limitations:
    - the State must be at least as specific as the uses listed in sections 101(a) and 303(c) of the Clean Water Act; and
    - the State must be at least as specific as the written description of the designated use classifications adopted by the State.

- If the State designated use classification system is very specific in describing subcategories of a use, then such specifically defined uses, if they exist, must be protected fully under antidegradation. A State with a broadly written use classification system may, as a matter of policy, interpret its classifications more specifically for determining existing uses—as long as it is done consistently. A State may also redefine its use classification system, subject to the constraints in 40 CFR 131.10, to more adequately reflect existing uses.
- If the use classification system in a State is defined in broad terms such as primary contact recreation, secondary contact recreation, or boating, then it is a State determination whether to allow changes in the type of primary or secondary contact recreation or boating activity that would occur on a specific water body as long as the basic use classification is met. For example, if a State defines a use simply as "boating," it is the State's decision whether to allow something to occur that would change the type of boating from canoeing to power boating as long as the resulting water quality allows the "boating" use to be met. (The public record used originally to establish the use may provide a clearer indication of the use intended to be attained and protected by the State.)

The rationale is that the required water quality will allow a boating use to continue and that use meets the goal of the Act. Water quality is the key. This interpretation may allow a State to change

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activities within a specific use category but it does not create a mechanism to remove use classifications; this latter action is governed solely by the provisions of the standards regulation (CWA section 131.10(g)).

One situation where EPA might conceivably be called upon to decide what constitutes an existing use is where EPA is writing an NPDES permit. EPA has the responsibility under CWA section 301(b)(1)(C) to determine what is needed to protect existing uses under the State's antidegradation requirement, and accordingly may define "existing uses" or interpret the State's definition to write that permit if the State has not done so. Of course, EPA's determination would be subject to State section 401 certification in such a case.

4.4.2 Aquatic Life/Wildlife Uses

No activity is allowable under the antidegradation policy which would partially or completely eliminate any existing use whether or not that use is designated in a State's water quality standards. The aquatic protection use is a broad category requiring further explanation. Non-aberrational resident species must be protected, even if not prevalent in number or importance. Water quality should be such that it results in no mortality and no significant growth or reproductive impairment of resident species. Any lowering of water quality below this full level of protection is not allowed.

A State may develop subcategories of aquatic protection uses but cannot choose different levels of protection for like uses. The fact that sport or commercial fish are not present does not mean that the water may not be supporting an aquatic life protection function. An existing aquatic community composed entirely of invertebrates and plants, such as may be found in a pristine alpine tributary stream, should still be protected whether or not such a stream supports a fishery.

Even though the shorthand expression "fishable/swimmable" is often used, the actual objective of the Act is to "restore and maintain the chemical, physical, and biological integrity of our Nation's waters" (section 101(a)). The term "aquatic life" would more accurately reflect the protection of the aquatic community that was intended in section 101(a)(2) of the Act.

Section 131.12(a)(1) states, "Existing instream water uses and level of water quality necessary to protect the existing uses shall be maintained and protected." For example, while sustaining a small coldwater fish population, a stream does not support an existing use of a "coldwater fishery." The existing stream temperatures are unsuitable for a thriving coldwater fishery. The small marginal population is an artifact and should not be employed to mandate a more stringent use (true coldwater fishery) where natural conditions are not suitable for that use.

A use attainability analysis or other scientific assessment should be used to determine whether the aquatic life population is in fact an artifact or is a stable population requiring water quality protection. Where species appear in areas not normally expected, some adaptation may have occurred and site-specific criteria may be appropriately developed. Should the coldwater fish population consist of a threatened or endangered species, it may require protection under the Endangered Species Act. Otherwise, the stream need only be protected as a warmwater fishery.

4.4.3 Existing Uses and Physical Modifications

A literal interpretation of 40 CFR 131.12(a)(1) could prevent certain physical modifications to a water body that are clearly allowed by the Clean Water Act, such as wetland fill operations permitted under section 404 of the Clean Water Act. EPA interprets section 131.12(a)(l) of the antidegradation policy to be satisfied with regard to fills in wetlands if the discharge did not result in "significant degradation" to the aquatic ecosystem as defined under section 230.10(c) of the section 404(b)(l) Guidelines.

The section 404(b)(1) Guidelines state that the following effects contribute to significant degradation, either individually or collectively:

... significant adverse effects on (1) human health or welfare, including effects on municipal water supplies, plankton, fish, shellfish, wildlife, and special aquatic sites (e.g., wetlands); (2) on the life stages of aquatic life and other wildlife dependent on aquatic ecosystems, including the transfer, concentration, or spread of pollutants or their byproducts beyond the site through biological, physical, or chemical process; (3) on ecosystem diversity, productivity, and stability, including loss of fish and wildlife habitat or loss of the capacity of a wetland to assimilate nutrients, purify water, or reduce wave energy; or (4) on recreational, aesthetic, and economic values.

These Guidelines may be used by States to determine "significant degradation" for wetland fills. Of course, the States are free to adopt stricter requirements for wetland fills in their own antidegradation polices, just as they may adopt any other requirement more stringent than Federal law requires. For additional information on the linkage between water quality standards and the section 404 program, see Appendix D.

If any wetlands were found to have better water quality than "fishable/swimmable," the State would be allowed to lower water quality to the no significant degradation level as long as the requirements of section 131.12(a)(2) were followed. As for the ONRW provision of antidegradation (131.12(a)(3)), there is no difference in the way it applies to wetlands and other water bodies.

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4.4.4 Existing Uses and Mixing Zones

Mixing zones are another instance when the entire extent of the water body is not required to be given full existing use protection. The area within a properly designated mixing zone (see section 5.1) may have altered benthic habitat and a subsequent alteration of the portions of the aquatic community. Any effect on the existing use must be limited to the area of the regulatory mixing zone.

4.5 Protection of Water Quality in High-Quality Waters - 40 CFR 131.12(a)(2)

UPDATED INFORMATION

Memo: Tier 2 Antidegradation Reviews and Significance Thresholds (2005) (PDF) - Recommendation regarding significance thresholds and lowering of water quality in high quality waters in the context of tier 2 antidegradation reviews.
Interim Economic Guidance for Water Quality Standards (1995) – This document provides guidance for use by states and tribes in understanding the economic factors that may be considered, and the types of tests that can be used to determine if a designated use cannot be attained, if a variance can be granted, or if degradation of high-quality water is warranted.

This section provides general program guidance in the development of procedures for the maintenance and protection of water quality where the quality of the water exceeds levels necessary to support propagation of fish, shellfish, and wildlife and recreation in and on the water. Water quality in "high-quality waters" must be maintained and protected as prescribed in section 131.12(a)(2) of the WQS regulation.

High-quality waters are those whose quality exceeds that necessary to protect the section 101(a)(2) goals of the Act, regardless of use designation. All parameters do not need to be better quality than the State's ambient criteria for the water to be deemed a "high-quality water." EPA believes that it is best to apply antidegradation on a parameter-by-parameter basis. Otherwise, there is potential for a large number of waters not to receive antidegradation protection, which is important to attaining the goals of the Clean Water Act to restore and maintain the integrity of the Nation's waters. However, if a State has an official interpretation that differs from this interpretation, EPA will evaluate the State interpretation for conformance with the statutory and regulatory intent of the antidegradation policy. EPA has accepted approaches that do not use a strict pollutant-by-pollutant basis (USEPA, 1989c).

In "high-quality waters," under 131.12(a)(2), before any lowering of water quality occurs, there must be an antidegradation review consisting of:

- a finding that it is necessary to accommodate important economic or social development in the area in which the waters are located (this phrase is intended to convey a general concept regarding what level of social and economic development could be used to justify a change in high-quality waters);
- full satisfaction of all intergovernmental coordination and public participation provisions (the intent here is to ensure that no activity that will cause water quality to decline in existing high-quality waters is undertaken without adequate public review and intergovernmental coordination); and

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- assurance that the highest statutory and regulatory requirements for point sources, including new source performance standards, and best management practices for nonpoint source pollutant controls are achieved (this requirement ensures that the limited provision for lowering water quality of high-quality waters down to "fishable/swimmable" levels will not be used to undercut the Clean Water Act requirements for point source and nonpoint source pollution control; furthermore, by ensuring compliance with such statutory and regulatory controls, there is less chance that a lowering of water quality will be sought to accommodate new economic and social development).

In addition, water quality may not be lowered to less than the level necessary to fully protect the "fishable/swimmable" uses and other existing uses. This provision is intended to provide relief only in a few extraordinary circumstances where the economic and social need for the activity clearly outweighs the benefit of maintaining water quality above that required for "fishable/swimmable" water, and both cannot be achieved. The burden of demonstration on the individual proposing such activity will be very high. In any case, moreover, the existing use must be maintained and the activity shall not preclude the maintenance of a "fishable/swimmable" level of water quality protection.

The antidegradation review requirements of this provision of the antidegradation policy are triggered by any action that would result in the lowering of water quality in a high-quality water. Such activities as new discharges or expansion of existing facilities would presumably lower water quality and would not be permissible unless the State conducts a review consistent with the previous paragraph. In addition, no permit may be issued, without an antidegradation review, to a discharger to high-quality waters with effluent limits greater than actual current loadings if such loadings will cause a lowering of water quality (USEPA, 1989c).

Antidegradation is not a "no growth" rule and was never designed or intended to be such. It is a policy that allows public decisions to be made on important environmental actions. Where the State intends to provide for development, it may decide under this section, after satisfying the requirements for intergovernmental coordination and public participation, that some lowering of water quality in "high-quality waters" is necessary to accommodate important economic or social development. Any such lower water quality must protect existing uses fully, and the State must assure that the highest statutory and regulatory requirement for all new and existing point sources and all cost-effective and reasonable BMPs for nonpoint source control are being achieved on the water body.

Section 131.12(a)(2) does not REQUIRE a State to establish BMPs for nonpoint sources where such BMP requirements do not exist. We interpret Section 131.12(a)(2) as REQUIRING States to adopt an antidegradation policy that includes a provision that will assure that all cost-effective and reasonable BMPs established under State authority are implemented for nonpoint sources before the State authorizes degradation of high quality waters by point sources (see USEPA, 1994a.)

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Section 131.12(a)(2) does not mandate that States establish controls on nonpoint sources. The Act leaves it to the States to determine what, if any, controls on nonpoint sources are needed to provide for attainment of State water quality standards (See CWA Section 319.) States may adopt enforceable requirements, or voluntary programs to address nonpoint source pollution. Section 40 CFR 131.12(a)(2) does not require that States adopt or implement best management practices for nonpoint sources prior to allowing point source degradation of a high quality water. However, States that have adopted nonpoint source controls must assure that such controls are properly implemented before authorization is granted to allow point source degradation of water quality.

The rationale behind the antidegradation regulatory statement regarding achievement of statutory requirements for point sources and all cost effective and reasonable BMPs for nonpoint sources is to assure that, in high quality waters, where there are existing point or nonpoint source control compliance problems, proposed new or expanded point sources are not allowed to contribute additional pollutants that could result in degradation. Where such compliance problems exist, it would be inconsistent with the philosophy of the antidegradation policy to authorize the discharge of additional pollutants in the absence of adequate assurance that any existing compliance problems will be resolved.

EPA's regulation also requires maintenance of high quality waters except where the State finds that degradation is "necessary to accommodate important economic and social development in the area in which the waters are located." (40 CFR Part 131.12(a) (Emphasis added)). We believe this phrase should be interpreted to prohibit point source degradation as unnecessary to accommodate important economic and social development if it could be partially or completely prevented through implementation of existing State-required BMPs.

EPA believes that its antidegradation policy should be interpreted on a pollutant-by-pollutant and waterbody-by-waterbody basis. For example, degradation of a high quality waterbody by a proposed new BOD source prior to implementation of required BMPs on the same waterbody that are related to BOD loading should not be allowed. However, degradation by the new point source of BOD should not be barred solely on the basis that BMPs unrelated to BOD loadings, or which relate to other waterbodies, have not been implemented.

We recommend that States explain in their antidegradation polices or procedures how, and to what extent, the State will require implementation of otherwise non-enforceable (voluntary) BMPs before allowing point source degradation of high quality waters. EPA understands this recommendation exceeds the Federal requirements discussed in this guidance. For example, nonpoint source management plans being developed under section 319 of the Clean Water Act are likely to identify potential problems and certain voluntary means to correct those problems. The State should consider how these provisions will be implemented in conjunction with the water quality standards program.

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4.6 Applicability of Water Quality Standards to Nonpoint Sources Versus Enforceability of Controls

The requirement in Section 131.21(a)(2) to implement existing nonpoint source controls before allowing degradation of a high quality water, is a subset of the broader issue of the applicability of water quality standards versus the enforceability of controls designed to implement standards. A discussion of the broader issue is included here with the intent of further clarifying the nonpoint source antidegradation question. In the following discussion, the central message is that water quality standards apply broadly and it is inappropriate to exempt whole classes of activities from standards and thereby invalidate that broader, intended purpose of adopted State water quality standards.

Water quality standards serve the dual function of establishing water quality goals for a specific waterbody and providing the basis for regulatory controls. Water quality standards apply to both point and nonpoint sources. There is a direct Federal implementation mechanism to regulate point sources of pollution but no parallel Federal regulatory process for nonpoint sources. Under State law, however, States can and do adopt mandatory nonpoint source controls.

State water quality standards play the central role in a State's water quality management program, which identifies the overall mechanism States use to integrate the various Clean Water Act water quality control elements into a coherent management framework. This includes, for example: (1) setting and revising water quality standards for all surface waterbodies, (2) monitoring water quality to provide information upon which water quality-based decisions will be made, progress evaluated, and success measured, (3) preparing a water quality inventory report under section 305(b) which documents the status of the State's water quality, (4) developing a water quality management plan which lists the standards, and prescribes the regulatory and construction activities necessary to meet the standards, (5) calculating total maximum daily loads and wasteload allocations for point sources of pollution and load allocations for nonpoint sources of pollution in the implementation of standards,(6) implementing the section 319 management plan which outlines the State's control strategy for nonpoint sources of pollution, and (7) developing permits under Section 402.

Water quality standards describe the desired condition of the aquatic environment, and, as such, reflect any activity that affects water quality. Water quality standards have broad application and use in evaluating potential impacts of water quality from a broad range of causes and sources and are not limited to evaluation of effects caused by the discharge of pollutants from point sources. In this regard, States should have in place methods by which the State can determine whether or not their standards have been achieved (including uses, criteria, and implementation of an antidegradation policy). Evaluating attainment of standards is basic to successful application of a State's water quality standards program. In the broad application of standards, these evaluations are not limited to those activities which are directly controlled through a mandatory process. Rather, these evaluations are an important component of a State's water quality management program regardless of whether or not an enforcement procedure is in place for the activity under review.

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Water quality standards are implemented through State or EPA-issued water quality-based permits and through State nonpoint source control programs. Water quality standards are implemented through enforceable NPDES permits for point sources and through the installation and maintenance of BMPs for nonpoint sources. Water quality standards usually are not considered self-enforcing except where they are established as enforceable under State law. Application of water quality standards in the overall context of a water quality management program, however, is not limited to activities for which there are enforceable implementation mechanisms.

In simple terms, applicability and enforceability are two distinctly separate functions in the water quality standards program. Water quality standards are applicable to all waters and in all situations, regardless of activity or source of degradation. Implementation of those standards may not be possible in all circumstances; in such cases, the use attainability analysis may be employed. In describing the desired condition of the environment, standards establish a benchmark against which all activities which might affect that desired condition are, at a minimum, evaluated. Standards serve as the basis for water quality monitoring and there is value in identifying the source and cause of a exceedance even if, at present, those sources of impact are not regulated otherwise controlled.

It is acceptable for a State to specify particular classes of activities for which no control requirements have been established in State law. It is not acceptable, however, to specify that standards do not apply to particular classes of activities (e.g. for purposes of monitoring and assessment). To do so would abrogate one of the primary functions of water quality standards.

4.7 Outstanding National Resource Waters (ONRW) - 40 CFR 131.12(a)(3)

Outstanding National Resource Waters (ONRWs) are provided the highest level of protection under the antidegradation policy. The policy provides for protection of water quality in high-quality waters that constitute an ONRW by prohibiting the lowering of water quality. ONRWs are often regarded as highest quality waters of the United States: That is clearly the thrust of 131.12(a)(3). However, ONRW designation also offers special protection for waters of "exceptional ecological significance." These are water bodies that are important, unique, or sensitive ecologically, but whose water quality, as measured by the traditional parameters such as dissolved oxygen or pH, may not be particularly high or whose characteristics cannot be adequately described by these parameters (such as wetlands).

The regulation requires water quality to be maintained and protected in ONRWs. EPA interprets this provision to mean no new or increased discharges to ONRWs and no new or increased discharge to tributaries to ONRWs that would result in lower water quality in the ONRWs. The only exception to this prohibition, as discussed in the preamble to the Water Quality Standards Regulation (48 F.R. 51402), permits States to allow some limited activities that result in temporary and short-term changes in the water quality of ONRW. Such activities must not permanently degrade water quality or result in water quality lower than that necessary to protect the existing uses in the ONRW. It is difficult to give an exact definition of "temporary" and "short-term" because of the variety of activities that might be considered. However, in rather broad terms, EPA's view of temporary is weeks and months, not years. The intent of EPA's provision clearly is to limit water quality degradation to the shortest possible time. If a construction activity is involved, for example,

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temporary is defined as the length of time necessary to construct the facility and make it operational. During any period of time when, after opportunity for public participation in the decision, the State allows temporary degradation, all practical means of minimizing such degradation shall be implemented. Examples of situations in which flexibility is appropriate are listed in Exhibit 4-1.

Exhibit 4-1. Examples of Allowable Temporary Lowering of Water Quality in Outstanding National Resource Waters

Example 1. A national park wishes to replace a defective septic tank-drainfield system in a campground. The campground is located immediately adjacent to a small stream with the ONRW use designation. • Under the regulation, the construction could occur if best management practices were scrupulously followed to minimize any disturbance of water quality or aquatic habitat.
Example 2. Same situation except the campground is served by a small sewage treatment plant already discharging to the ONRW. It is desired to enlarge the treatment system and provide higher levels of treatment. • Under the regulation, this water-quality-enhancing action would be permitted if there was only temporary increase in sediment and, perhaps, in organic loading, which would occur during the actual construction phase.
Example 3. A National forest with a mature, second growth of trees which are suitable for harvesting, with associated road repair and re-stabilization. Streams in the area are designated as ONRW and support trout fishing. • The regulation intends that best management practices for timber harvesting be followed and might include preventive measures more stringent than for similar logging in less environmentally sensitive areas. Of course, if the lands were being considered for designation as wilderness areas or other similar designations, EPA's regulation should not be construed as encouraging or condoning timbering operations. The regulation allows only temporary and short-term water quality degradation while maintaining existing uses or new uses consistent with the purpose of the management of the ONRW area.

Other examples of these types of activities include maintenance and/or repair of existing boat ramps or boat docks, restoration of existing sea walls, repair of existing stormwater pipes, and replacement or repair of existing bridges.

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4.8 Antidegradation Application and Implementation

Any one or a combination of several activities may trigger the antidegradation policy analysis. Such activities include a scheduled water quality standards review, the establishment of new or revised load allocations, waste load allocations, total maximum daily loads, issuance of NPDES permits, and the demonstration of need for advanced treatment or request by private or public agencies or individuals for a special study of the water body.

Nonpoint source activities are not exempt from the provisions of the antidegradation policy. The language of section 131.12 (a)(2) of the regulation: "Further, the State shall assure that there shall be achieved the highest statutory and regulatory requirements for all new and existing point sources and all cost-effective and reasonable best management practices for nonpoint source control . . ." reflects statutory provisions of the Clean Water Act. While it is true that the Act does not establish a federally enforceable program for nonpoint sources, it clearly intends that the BMPs developed and approved under sections 205(j), 208, 303(e), and 319 be aggressively implemented by the States.

4.8.1 Antidegradation, Load Allocation, Waste Load Allocation, Total Maximum Daily Load, and Permits

In developing or revising a load allocation (LA), waste load allocation (WLA), or total maximum daily load (TMDL) to reflect new information or to provide for seasonal variation, the antidegradation policy, as an integral part of the State water quality standards, must be applied as discussed in this section.

The TMDL/WLA/LA process distributes the allowable pollutant loadings to a water body. Such allocations also consider the contribution to pollutant loadings from nonpoint sources. This process must reflect applicable State water quality standards including the antidegradation policy. No waste load allocation can be developed or NPDES permit issued that would result in standards being violated. With respect to antidegradation, that means existing uses must be protected, water quality may not be lowered in ONRWs, and in the case of waters whose quality exceeds that necessary for the section 101(a)(2) goals of the Act, an activity cannot result in a lowering of water quality unless the applicable public participation, intergovernmental review, and baseline control requirements of the antidegradation policy have been met. Once the LA, WLA, or TMDL revision is completed, the resulting permits must incorporate discharge limitations based on this revision.

When a pollutant discharge ceases for any reason, the waste load allocations for the other dischargers in the area may be adjusted to reflect the additional loading available consistent with the antidegradation policy under two circumstances:

- In "high-quality waters" where after the full satisfaction of all public participation and intergovernmental review requirements, such adjustments are considered necessary to accommodate important economic or social development, and the "threshold"

level requirements (required point and nonpoint source controls) are met.

- In less than "high-quality waters," when the expected improvement in water quality (from the ceased discharge) would not cause a better use to be achieved.

The adjusted loads still must meet water quality standards, and the new waste load allocations must be at least as stringent as technology-based limitations. Of course, all applicable requirements of the section 402 NPDES permit regulations would have to be satisfied before a permittee could increase its discharge.

If a permit is being renewed, reissued or modified to include less stringent limitations based on the revised LA/WLA/TMDL, the same antidegradation analysis applied during the LA/WLA/TMDL stage would apply during the permitting stage. It would be reasonable to allow the showing made during the LA/WLA/TMDL stage to satisfy the antidegradation showing at the permit stage. Any restrictions to less stringent limits based on antibacksliding would also apply.

If a State issues an NPDES permit that violates the required antidegradation policy, it would be subject to a discretionary EPA veto under section 402(d) or to a citizen challenge. In addition to actions on permits, any waste load allocations and total maximum daily loads violating the antidegradation policy are subject to EPA disapproval and EPA promulgation of a new waste load allocation/total maximum daily load under section 303(d) of the Act. If a significant pattern of violation was evident, EPA could constrain the award of grants or possibly revoke any Federal permitting capability that had been delegated to the State. Where EPA issues an NPDES permit, EPA will, consistent with its NPDES regulations, add any additional or more stringent effluent limitations required to ensure compliance with the State antidegradation policy incorporated into the State water quality standards. If a State fails to require compliance with its antidegradation policy through section 401 certification related to permits issued by other Federal agencies (e.g., a Corps of Engineers section 404 permit), EPA could comment unfavorably upon permit issuance. The public, of course, could bring pressure upon the permit issuing agency.

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For example applications of antidegradation in the WLA and permitting process, see Exhibit 4-2.

Exhibit 4-2. Examples of the Application of Antidegradation in the Waste Load/Load Allocation and NPDES Permitting Process

Example 1. Several facilities on a stream segment discharge phosphorus-containing wastes. Ambient phosphorus concentrations meet the designated class B (non-fishable/swimmable) standards, but barely. Three dischargers achieve elimination by developing land treatment systems. As a result, actual water quality improves (i.e., phosphorus levels decline) but not quite to the level needed to meet class A (fishable/swimmable) standards. Can the remaining dischargers now be allowed to increase their phosphorus discharge without an antidegradation analysis with the result that water quality declines (phosphorus levels increase) to previous levels? • Nothing in the water quality standards regulation explicitly prohibits this. Of course, changes in their NPDES permit limits may be subject to non-water quality constraints, such as BPT, BAT, or the NPDES antibacksliding provisions, which may restrict the increased loads.
Example 2. Suppose, in the above situation, water quality improves to the point that actual water quality now meets class A requirements. Is the answer different? • Yes. The standards must be upgraded (see section 2.8).
Example 3. As an alternative case, suppose phosphorus loadings go down and water quality improves because of a change in farming practices (e.g., initiation of a successful nonpoint source program.) Are the above answers the same? • Yes. Whether the improvement results from a change in point or nonpoint source activity is immaterial to how any aspect of the standards regulation operates. Section 131.10(d) clearly indicates that uses are deemed attainable if they can be achieved by "... cost-effective and reasonable best management practices for nonpoint source control." Section 131.12(a)(2) of the antidegradation policy contains essentially the same wording.

Antidegradation, as with other water quality standards activities, requires public participation and intergovernmental coordination to be an effective tool in the water quality management process. 40 CFR 131.12(a)(2) contains explicit requirements for public participation and intergovernmental coordination when determining whether to allow lower water quality in high-quality waters. Nothing in either the water quality standards or the waste load allocation regulations requires the same degree of public participation or intergovernmental coordination for such non-high-quality waters as is required for high-quality waters. However public participation would still be provided in connection with the issuance of a NPDES permit or amendment of a 208 plan. Also, if the action that causes reconsideration of the existing waste loads (such as dischargers withdrawing from the area) will result in an improvement in water quality that makes a better use attainable, even if not up to the "fishable/swimmable" goal, then the water quality standards must be upgraded and full public review is required for any action affecting changes in standards.

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Although not specifically required by the standards regulation between the triennial reviews, we recommend that the State conduct a use attainability analysis to determine if water quality improvement will result in attaining higher uses than currently designated in situations where significant changes in waste loads are expected.

The antidegradation public participation requirement may be satisfied in several ways. The State may hold a public hearing or hearings. The State may also satisfy the requirement by providing public notice and the opportunity for the public to request a hearing. Activities that may affect several water bodies in a river basin or sub-basin may be considered in a single hearing. To ease the resource burden on both the State and public, standards issues may be combined with hearings on environmental impact statements, water management plans, or permits. However, if this is done, the public must be clearly informed that possible changes in water quality standards are being considered along with other activities. It is inconsistent with the water quality standards regulation to "back-door" changes in standards through actions on EIS's, waste load allocations, plans, or permits.

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EPA
United States
Environmental Protection
Agency

July 2014

Proposed Determination of the U.S. Environmental Protection Agency Region 10 Pursuant to Section 404(c) of the Clean Water Act

Pebble Deposit Area, Southwest Alaska

Region 10, Seattle, WA
www.epa.gov/bristolbay

July 2014

Proposed Determination of the U.S. Environmental Protection Agency Region 10 Pursuant to Section 404(c) of the Clean Water Act Pebble Deposit Area, Southwest Alaska

U.S. Environmental Protection Agency
Region 10
Seattle, WA

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value of $300 million (sales from fishers to processors) and employment for over 11,000 full- and part-time workers (EPA 2014: Chapter 5).

In February 2011, Northern Dynasty Minerals Ltd. (NDM) formally submitted information to the U.S. Securities and Exchange Commission (SEC) that put forth plans for the development of a large-scale mine at the headwaters of this pristine ecosystem (Figure ES-2). Their proposal outlines several stages of mine development, the smallest being a 2.0-billion-ton mine[1] and the largest being a 6.5-billion-ton mine[2] (Ghaffari et al. 2011, SEC 2011), both of which are larger than 90% of the known ore deposits of this type in the world (EPA 2014: Chapter 4).

The Pebble deposit is a large, low-grade, porphyry copper deposit (containing copper-, gold-, and molybdenum-bearing minerals) that underlies portions of the South Fork Koktuli River (SFK), North Fork Koktuli River (NFK), and Upper Talarik Creek (UTC) watersheds. Based on information provided by NDM to the SEC (Ghaffari et al. 2011, SEC 2011), mining the Pebble deposit is likely to involve excavation of the largest open pit ever constructed in North America, covering up to 6.9 square miles (17.8 km^2) and reaching a depth of as much as 0.77 mile (1.24 km) (EPA 2014: Chapter 6); for reference, the maximum depth of the Grand Canyon is approximately 1 mile. Disposal of resulting waste material would require construction of up to three mine tailings impoundments covering an additional 18.8 square miles (48.6 km^2) and waste rock piles covering up to 8.7 square miles (22.6 km^2) (EPA 2014: Chapter 6) in an area that contains highly productive streams and wetlands. The volume of mine tailings and waste rock produced from the smallest mine proposed by NDM to the SEC (Ghaffari et al. 2011, SEC 2011) would be enough to fill a professional football stadium more than 880 times, whereas the largest mine would do so more than 3,900 times.

In total, these three mine components (mine pit, tailings impoundments, and waste rock piles) would cover an area larger than Manhattan. Mine construction and operation would also require the construction of support facilities, including a major transportation corridor, pipelines, a power-generating station, wastewater treatment plants, housing and support services for workers, administrative offices, and other infrastructure. Such facilities would greatly expand the "footprint" of the mine and affect additional aquatic resources beyond the scope of this proposed determination. Although NDM's preliminary plans (Ghaffari et al. 2011, SEC 2011) could change, any mining of this deposit would, by necessity, require similar mine components, support facilities, and operational features.

Given the extent of streams, wetlands, lakes, and ponds both overlying the Pebble deposit and within adjacent watersheds, excavation of a massive mine pit and construction of large tailings impoundments and waste rock piles would result in discharge of dredged or fill material into these waters. This discharge would result in complete loss of fish habitat due to elimination, dewatering, and

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[1] Ghaffari et al. (2011) call the 2.0 stage mine the "Investment Decision Case," which describes an initial 25-year open pit mine life upon which a decision to initiate permitting, construction, and operations may be based.

[2] Ghaffari et al. (2011) call the 6.5 stage mine the "Resource Case," which is based on 78 years of open pit production and seeks to assess the long-term value of the project in current dollars.

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fragmentation of streams, wetlands, and other aquatic resources. In addition, water withdrawal and capture, storage, treatment, and release of wastewater associated with the mine would significantly impair the fish habitat functions of other streams, wetlands, and aquatic resources. All of these losses would be irreversible.

Based upon information known to EPA about the proposed mine at the Pebble deposit and its potential impacts on fishery resources, and as a result of multiple inquiries, concerns, and petitions to EPA to use its authorities to protect these fishery resources, EPA decided to conduct an ecological risk assessment before considering any additional steps. After three years of study, two rounds of public comment, and independent, external peer review, EPA released its *Assessment of Potential Mining Impacts on Salmon Ecosystems of Bristol Bay, Alaska*[3] (Bristol Bay Assessment) (EPA 2014) in January 2014. The Bristol Bay Assessment established that the extraction, storage, treatment, and transportation activities associated with building, operating, and maintaining one of the largest mines ever built would pose significant risks to the unparalleled ecosystem that produces one of the greatest wild salmon fisheries left in the world. In simple terms, the infrastructure necessary to mine the Pebble deposit jeopardizes the long-term health and sustainability of the Bristol Bay ecosystem.

The Bristol Bay Assessment characterizes the significant ecological resources of the region and describes potential impacts on salmon and other fish from large-scale porphyry copper mining at the Pebble deposit. The Bristol Bay Assessment evaluated these impacts using three mine scenarios that represent different stages of mining at the Pebble deposit, based on the amount of ore processed.

- Pebble 0.25 stage mine (approximately 0.25 billion tons of ore over 20 years)
- Pebble 2.0 stage mine (approximately 2.0 billion tons of ore over 25 years)
- Pebble 6.5 stage mine (approximately 6.5 billion tons of ore over 78 years)

Ghaffari et al. (2011) indicate that the total mineral resources at the Pebble deposit are now believed to be approximately 12 billion tons of ore. Thus, it is expected that development of a mine at the Pebble deposit would ultimately be much larger than the 0.25 stage mine and could exceed the 6.5 stage mine. NDM has stated to the public that "the Pebble deposit supports open pit mining utilizing conventional drill, blast and truck-haul methods, with an initial mine life of 25 years and potential for mine extensions to 78 years and beyond" (NDM 2011). This statement, along with others to investors, indicates that NDM is actively considering a mine size between 2.0 and 6.5 billion tons.

Nevertheless, EPA also assessed the impacts of a much smaller mine footprint in the Bristol Bay Assessment. The 0.25 stage mine is based on the worldwide median size porphyry copper deposit (Singer et al. 2008). Although this smaller size is dwarfed by the mine sizes that NDM put forward to the SEC (Ghaffari et al. 2011, SEC 2011), its impacts would still be significant.

[3] For more information about EPA's efforts in Bristol Bay or copies of the Bristol Bay Assessment, see http://www.epa.gov/bristolbay.

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SECTION 4. BASIS FOR PROPOSED DETERMINATION

4.1 Section 404(c) Standards

The purpose of the CWA is to "restore and maintain the chemical, physical, and biological integrity of the Nation's waters" (33 U.S.C. 1251(a)). The CWA sets several goals, including attainment and preservation of "water quality which provides for the protection and propagation of fish, shellfish and wildlife" (33 U.S.C. 1251(a)(2)).

To this end, Section 404(c) specifically authorizes EPA to exercise its discretion to act "whenever" it determines that the discharge of dredged or fill material will have an unacceptable adverse effect on specific aquatic resources. Section 404(c) provides:

> The Administrator is authorized to prohibit the specification (including the withdrawal of specification) of any defined area as a disposal site, and he is authorized to deny or restrict the use of any defined area for specification (including the withdrawal of specification) as a disposal site, whenever he determines, after notice and opportunity for public hearings, **that the discharge of such materials into such area will have an unacceptable adverse effect on municipal water supplies, shellfish beds and fishery areas (including spawning and breeding areas), wildlife, or recreational areas**. Before making such determination, the Administrator shall consult with the Secretary. The Administrator shall set forth in writing and make public his findings and his reasons for making any determination under this subsection. [emphasis added]

Importantly, Section 404(c) specifically directs EPA to consider adverse effects from the discharge of dredged or fill material to fishery areas, including spawning and breeding areas. The statute's broad reference to fishery areas and to breeding and spawning areas includes aquatic areas that support and provide fish habitat, as well as aquatic areas where fish breed or spawn.

Section 404(c) does not define the term "unacceptable adverse effect." EPA's regulations at 40 CFR 231.2(e) define "unacceptable adverse effect" as:

> Impact on an aquatic or wetland ecosystem which is likely to result in significant degradation of municipal water supplies or **significant loss of or damage to fisheries**, shellfishing, or wildlife habitat or recreation areas. In evaluating the unacceptability of such impacts, consideration should be given to the relevant portions of the Section 404(b)(1) Guidelines (40 CFR 230). [emphasis added]

In addition, the preamble to EPA's final rule promulgating 40 CFR Part 231 further explained that "[t]he term 'unacceptable' in EPA's view refers to the significance of the adverse effect" (44 *Federal Register* [FR] 58076, 58078). EPA also discussed that, for example, an unacceptable adverse effect "is a large impact" and "one that the aquatic and wetland ecosystem cannot afford" (44 FR 58078).

Section 404(c) and EPA's implementing regulations at 40 CFR Part 231 make clear that EPA may exercise its discretionary authority at any time, whether or not a Section 404 permit application has been submitted or such a permit has been issued (40 CFR 231.1(a), (c); 44 FR 58076–77). In the

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outright loss of fish habitat, including spawning and breeding areas, and the degradation of downstream waters. The following sections evaluate effects on fishery areas resulting from losses of anadromous fish streams (Section 4.2.1), losses of tributaries of anadromous fish streams (Section 4.2.2), losses of wetlands, lakes, and ponds (Section 4.2.3), and streamflow alterations (Section 4.2.4).[34]

4.2.1 Effects of Loss of Anadromous Fish Streams

The Pebble 0.25 stage mine would eliminate or dewater nearly 5 miles (8 km) of streams with documented occurrence of anadromous fish, specifically coho and Chinook salmon (Johnson and Blanche 2012) (Table 4-1, Figure 4-1).[35] Dewatered streams would no longer have sufficient water to support previously existing uses by the fish species and life stages that were present, either continually or seasonally, pre-mine. The greatest impacts would be at the TSF location in the NFK watershed. Coho salmon spawn or rear in nearly 50% of the stream length within the TSF footprint (Table 4-2). These streams include the third-order NFK tributary that drains the TSF site, as well as two second-order tributaries of that third-order stream and three first-order tributaries of those second-order streams.[36] Coho salmon also would lose rearing habitat to the Pebble 0.25 stage mine pit drawdown zone, specifically at least 0.7 mile (1.1 km) in two second-order tributaries at the headwaters of the SFK and 0.2 mile (0.3 km) in a first-order tributary of UTC.

Table 4-1. Length of documented anadromous fish streams lost (eliminated, dewatered, or fragmented) under the Pebble 0.25 stage mine, and the anadromous fish species documented to occur in those streams.

Type of Loss	AWC Streams	
	Stream Length (miles)[a]	Anadromous Fish Documented in Streams[b]
Eliminated	3.8	Coho, Chinook
Dewatered	0.9	Coho, Chinook
Fragmented	0.0	-
TOTAL LOSS	4.7	

Notes:
[a] From the National Hydrography Dataset (USGS 2012) and the Anadromous Waters Catalog (Johnson and Blanche 2012).
[b] From the Anadromous Waters Catalog (Johnson and Blanche 2012). Individual species do not necessarily occupy the entire affected length.
AWC = Anadromous Waters Catalog.

[34] This proposed determination focuses on effects of the discharge of dredged or fill material associated with the construction and routine operation of the Pebble 0.25 stage mine. Section 4.3.1.2 discusses cumulative effects associated with mine expansion at the Pebble deposit, and Section 4.4 addresses effects associated with accidents and failures.

[35] It is important to note that the spatial extent of habitat loss and the salmon species directly affected by such loss are entirely dependent on the placement of major mine components within the SFK, NFK, and UTC watersheds. For example, as seen in Figure 4-1, placement of TSF 1 in the stream valley to the south of its location in the BBA (EPA 2014) would result in greater habitat losses for Chinook salmon and possibly losses for chum salmon as well. Similarly, slightly shifting the waste rock pile from its location in the BBA would cause habitat loss for sockeye as well as coho salmon, and far greater loss of wetlands, lakes, and ponds.

[36] The stream orders described herein are based on NHD mapping (USGS 2012), viewed at 1 inch:0.3 mile scale; any mapping that identified additional tributaries could change these orders.

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Figure 4 1. Reported salmon distributions under the Pebble 0.25 stage mine. Species distributions are based on the Anadromous Waters Catalog (Johnson and Blanche 2012). Light blue areas indicate streams and rivers from the National Hydrography Dataset (USGS 2012) and lakes and ponds from the National Wetlands Inventory (USFWS 2012); dark blue areas indicate wetlands from the National Wetlands Inventory (USFWS 2012).

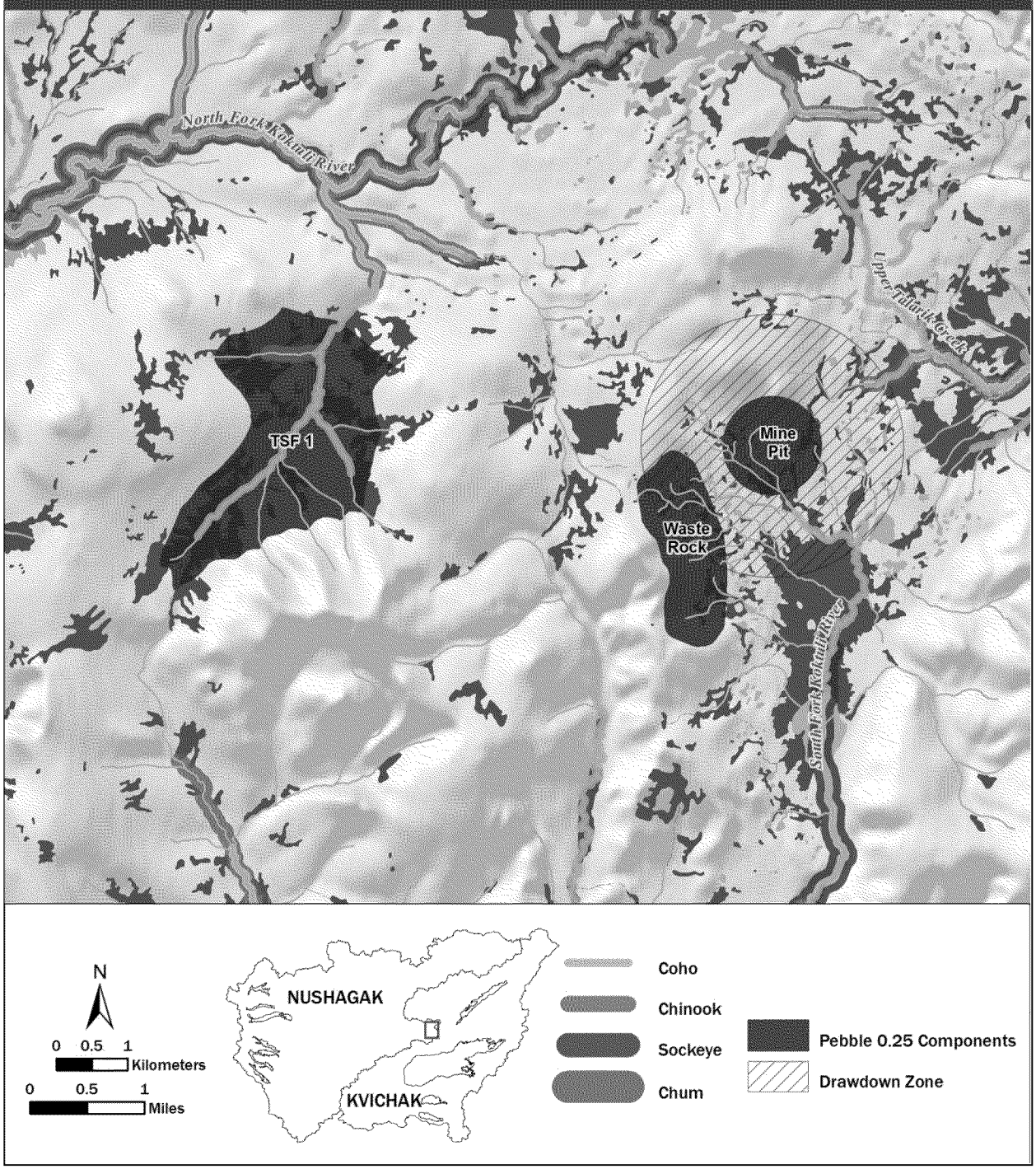

Table 4-2. Coho and Chinook salmon stream habitat lost (eliminated, dewatered, or fragmented) in the South Fork Koktuli River, North Fork Koktuli River, and Upper Talarik Creek watersheds under the Pebble 0.25 stage mine.

Species	Length of Stream (miles) by Watershed[a]			
	SFK	NFK	UTC	TOTAL[b]
Coho salmon	0.7	3.4	0.2	4.3
Chinook salmon	0.0	0.5	0.2	0.6

Note:
[a] From the National Hydrography Dataset (USGS 2012) and the Anadromous Waters Catalog (Johnson and Blanche 2012).
[b] The overall total of 4.9 miles is greater than reported in Table 4-1 because there is some overlap between coho and Chinook salmon habitat, which this table reports separately but Table 4-1 does not. The apparent discrepancy between the total length of Chinook salmon habitat and the sum of the NFK and UTC lengths is due to rounding.

As described in Section 3.2.4, the anadromous fish streams that the Pebble 0.25 stage mine would eliminate or dewater are of high quality, particularly for juvenile salmonids. These streams likely provide abundant and nutrient-rich food sources for fish, due to the dominance of deciduous shrubs in their riparian zones that produce abundant leaf litter and help fuel the production of macroinvertebrates, a key food for salmonids (Table 3-3). The third-order NFK tributary and all three of the dewatered coho salmon streams in the SFK and UTC watersheds possess contiguous ponds or seasonally to permanently inundated wetlands resulting from beaver activity (USFWS 2012). These features provide excellent rearing habitat and important overwintering and flow velocity refugia for salmonids (Section 3.2.4) (Nickelson et al. 1992, Cunjak 1996, Collen and Gibson 2001, Lang et al. 2006). Indeed, research shows that fish distribution in southwest Alaska headwater systems may be most extensive in late summer and early fall (Elliott and Finn 1983, Quinn 2005), coinciding with the period of increased food availability and maximum growth for juvenile salmon (Quinn 2005). Thus, the coho salmon streams that the Pebble 0.25 stage mine would eliminate or dewater likely play an important role in the life cycle of that species in all three watersheds.

Although their losses would not be as extensive as losses for coho salmon, Chinook salmon also would lose habitat in the NFK and UTC watersheds. Chinook salmon rear in the third-order beaver-modified stream that the TSF would eliminate, along with a different first-order tributary than those documented to support coho.[37] This currently documented Chinook salmon rearing habitat covers 0.5 mile (0.8 km) of streams. Chinook salmon also rear in the aforementioned 0.2-mile (0.3-km) beaver-modified UTC tributary used by juvenile coho salmon. Overall, the Pebble 0.25 stage mine would eliminate or dewater at least 0.6 mile (1.0 km) of habitat for Chinook salmon.

Altogether, the Pebble 0.25 stage mine would eliminate or dewater at least 4.7 miles (7.6 km) of streams with documented occurrence of coho and Chinook salmon. This large impact on anadromous fish streams is unprecedented in the context of the CWA Section 404 regulatory program in Alaska. The eliminated and dewatered habitat would permanently lose the ability to support salmon, because it either would no longer exist or would likely undergo irreversible changes in key components such as its physical structure and substrate (Beechie et al. 1994). As described in Appendix J of the BBA (EPA

[37] Fish surveys have documented coho salmon juveniles in a short (260-foot) reach at the downstream end of this tributary.

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2014), areas that do not support salmon for many years are not likely to become productive again (Reeves et al. 1991a, Reeves et al. 1991b, Paulsen and Fisher 2005, Katz et al. 2007). Both the 20-year life of the Pebble 0.25 stage mine and the 40 years or more during which dewatering would persist are many times longer than the 2- to 5-year life span of coho and Chinook salmon. Thus, as successive year classes of salmon return and are unable to reach their natal spawning grounds and produce fry, the cycle of spawning would be interrupted. Displaced spawners that attempt to return to lost habitat for the first few generations after the loss and that do not die without spawning may stray elsewhere to spawn, but success will depend on availability of suitable spawning habitat and its capacity to support additional fish. The substantial spatial and temporal extent of stream habitat losses to the Pebble 0.25 stage mine suggest that these losses would reduce the overall capacity and productivity of Chinook, and particularly coho, salmon in the SFK, NFK, and UTC watersheds.

Coho salmon would lose at least 4.3 miles (7.0 km) of habitat to the Pebble 0.25 stage mine, representing more than 2% of the total documented coho salmon habitat in the three watersheds and more than 5% of documented coho habitat in the NFK watershed (Table 3-6). Habitat losses for Chinook salmon would be less than 1% of documented habitat. However, compounding the spatial and temporal magnitude of these effects is the fact that these losses likely would affect multiple, distinct populations of coho and Chinook salmon. Effects would occur in multiple streams spanning all three watersheds, each with diverse spawning and rearing conditions that create a mosaic of habitats and attendant life-history variability (Section 3.3.6.2). Adaptation to the spatially and temporally unique conditions of their natal streams can result in reproductive isolation and genetic variation that salmon homing behavior maintains or enhances (Section 3.3.1), resulting in the development of discrete, genetically distinct populations. Chinook salmon populations tend to be relatively small (Healey 1991) and exhibit a diversity of life-history traits (e.g., variations in size and age at migration, duration of freshwater and estuarine residency, time of ocean entry) (Lindley et al. 2009). Olsen et al. (2003) similarly describe coho populations as generally small and isolated, exhibiting local adaptation to diverse habitats. Research has shown that such distinct populations can occur at very fine spatial scales (Section 3.3.6.2). For example, sockeye salmon that use spring-fed ponds and streams as close as approximately 0.6 mile (1 km) apart exhibit differences in traits (e.g., spawn timing, spawn site fidelity, and productivity) that suggest they may comprise discrete populations (Rand et al. 2007, Ramstad et al. 2010, Quinn et al. 2012). In coho salmon, genetic population structure also occurs at a fine geographic scale, with many populations found in small first- and second-order headwater streams (Olsen et al. 2003).

The fine-scale population structuring that results from the diversity of aquatic habitats in the watersheds helps to maintain the integrity of overall Bristol Bay salmon stocks and contributes to their resilience to perturbation. As described by Olsen et al. (2003):

> Fishery management and conservation actions affecting coho salmon in Alaska must recognize that the genetic population structure of coho salmon occurs on a fine geographic scale. Activities or conditions that cause declines in population abundance are more likely to have strong negative impacts for coho than for species in which genetic variation is distributed over a broader geographic scale (e.g., chum salmon). Coho salmon are probably more susceptible to extirpation, less likely to be augmented or "rescued" by other populations through straying (gene flow), and the loss of populations means loss of

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> significant amounts of overall genetic variability. These risks underscore the importance of single populations to the long term viability of coho salmon in Alaska and justify managing and conserving coho salmon at a fine geographic scale.

Lindley et al. (2009) voice similar concerns for Chinook salmon, noting that degradation of habitats in the Central Valley of California "changed the Chinook salmon complex from a highly diverse collection of numerous wild populations to one dominated by fall Chinook from four large hatcheries." The loss of such diversity defeated what Healey (1991) described as "a strategy for spreading mortality risks in uncertain environments." Lindley et al. (2009) equate this strategy to managing a financial portfolio—hence the term "portfolio effect" (Section 3.3.6.2)—and conclude that the buffering capacity of such life-history diversity manifests itself as greater resilience in the face of environmental variation.

It is not known how many different populations of coho and Chinook salmon may exist within the SFK, NFK, and UTC watersheds. However, the findings described above and in Section 3.3.6.2 indicate that the headwater and beaver-modified habitats eliminated or dewatered by the Pebble 0.25 stage mine could support populations that are distinct from those using habitats farther downstream in each watershed. Besides destroying the intact, headwater-to-larger river networks of the SFK, NFK, and UTC watersheds, stream losses that eliminate local, unique populations could translate into a substantial loss of genetic variability with impacts extending well beyond the footprints of the lost habitats. As Lindley et al. (2009) found for Central Valley Chinook salmon, these losses could erode the genetic diversity that is crucial to the stability of the overall Bristol Bay salmon fisheries (Hilborn et al. 2003, Schindler et al. 2010, EPA 2014: Appendix A). Thus, loss of the SFK, NFK, and UTC watersheds' discrete fish populations could have significant repercussions well beyond that suggested by their absolute proportion within the larger watersheds. Coho and Chinook, the two rarest of North America's five species of Pacific salmon (Healey 1991), seem particularly vulnerable to losses of small, discrete populations. These species have the greatest number of population extinctions among the five species of Pacific salmon (Nehlsen et al. 1991, Augerot 2005). Many of the patterns of population extinction relate to freshwater rearing. For example, Chinook salmon populations that rear for 1 to 3 years in freshwater—the dominant type in Bristol Bay watershed (Healey 1991)—have a higher rate of extinction than populations that migrate to sea within their first year of life (Gustafson et al. 2007). Thus, the elimination or dewatering of nearly 5 miles (8 km) of salmon streams caused or facilitated by the discharge of dredged or fill material for the Pebble 0.25 stage mine could reduce the overall productivity of the SFK, NFK, and UTC watersheds for both species, at a level that the aquatic ecosystem may not be able to afford.

Adverse impacts on coho or Chinook salmon populations could, in turn, threaten the sustainability of downstream commercial, subsistence, or recreational fisheries (Sections 3.3.3 through 3.3.5). Coho and Chinook salmon are the two smallest components of the Bristol Bay commercial fishery. However, overall Nushagak River stocks are the largest for the Bristol Bay district (Table 3-9), and the Nushagak River Chinook salmon run is frequently one of the world's largest (EPA 2014: Appendix A).[38] Although sockeye salmon represent the bulk of subsistence food harvests for Alaska Natives in the region,

[38] The Nushagak River Chinook stock represents 80% of Chinook commercial harvest in the Bristol Bay district; the coho stock represents 33% of the harvest, which is approximately equal to the Egegik River stock (Table 3-9).

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Chinook salmon are a large subsistence component for villages on the Nushagak River (Aleknagik, Dillingham, Ekwok, Koliganek, and especially New Stuyahok) (Table 3-10). The importance of Chinook as a subsistence resource is reflected in Alaska Native cultural practices: as the first of the Pacific salmon to return each year, Chinook salmon are the subject of a regional ritual known as the First Salmon celebration that emphasizes traditional values (EPA 2014: Appendix D). Losses that threaten the subsistence Chinook fishery could undermine this strong, centuries-old cultural connection that, in turn, serves a wide range of economic, social, and cultural functions (Section 3.3.4).

Coho, Chinook, and sockeye salmon support significant recreational fisheries as well, with the three representing the most harvested species in the region (Table 3-11). In fact, the Nushagak River—to which the SFK and NFK flow—supports the largest Chinook sport fishery in the United States and, in turn, a network of private and commercial sport-fishing camps overseen by Choggiung, Ltd., the Alaska Native village corporation for Dillingham, Ekuk, and Portage Creek (NMWC 2007, Choggiung 2014).

The elimination and dewatering of anadromous fish streams would also adversely affect downstream habitat for salmon and other fish species. As described in Section 3.2.4, headwater streams such as those within the mine footprint are important sources of water, nutrients, organic material, macroinvertebrates, and algae for habitats lower in the watersheds, and thereby provide important year-round subsidies for juvenile salmonids in those waters (Vannote et al. 1980, Wipfli and Gregovich 2002, Meyer et al. 2007, Wipfli et al. 2007) (Figures 4-2 through 4-4). Where they provide spawning grounds for coho or Chinook salmon, the lost streams are also a source of MDN for downstream waters (Section 3.3.6.1). Because of their crucial influence on downstream water flow, chemistry, and biota, impacts on headwaters reverberate throughout entire watersheds (Freeman et al. 2007, Meyer et al. 2007). Elimination or dewatering of nearly 5 miles (8 km) of streams by the Pebble 0.25 stage mine would fundamentally alter surface and groundwater hydrology and, in turn, the flow regimes of receiving—or formerly receiving—streams. Such alterations would reduce the extent and frequency of stream connectivity to off-channel habitats, as well as reduce groundwater inputs and their modifying influence on the thermal regimes of downstream habitats (Section 4.2.4). These lost streams also would no longer support or export macroinvertebrates, which are a critical food source for developing alevins, juvenile salmon, juvenile northern pike, and all life stages of other salmonids and forage fish.

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Figure 4 2. Reported salmon distributions in the South Fork Koktuli River, North Fork Koktuli River, and Upper Talarik Creek watersheds, downstream of the Pebble 0.25 stage mine. Species distributions are based on the Anadromous Waters Catalog (Johnson and Blanche 2012).

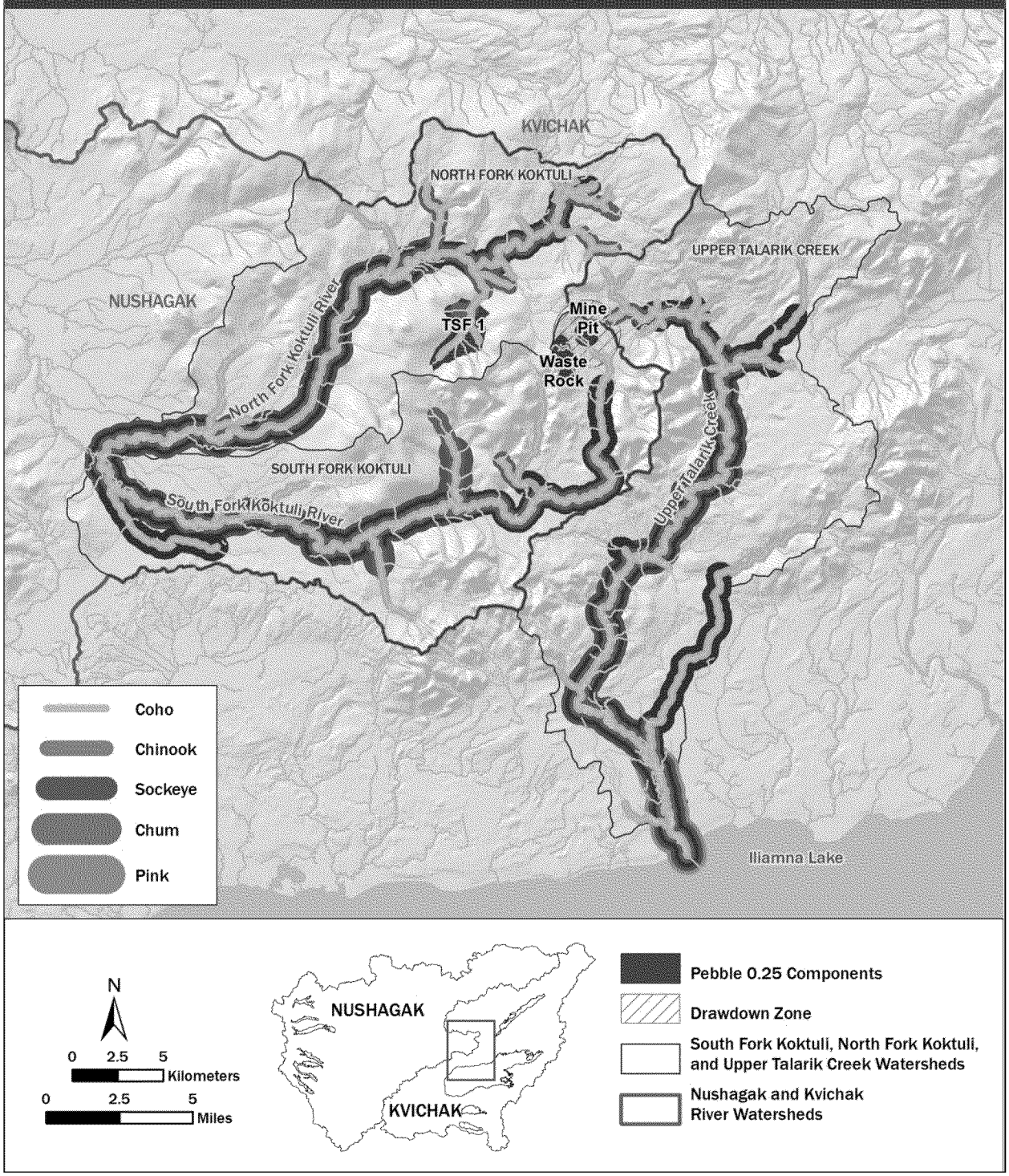

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Figure 4 3. Reported rainbow trout and Dolly Varden distribution in the South Fork Koktuli River, North Fork Koktuli River, and Upper Talarik Creek watersheds, downstream of the Pebble 0.25 stage mine. Species distributions are based on the Alaska Freshwater Fish Inventory (point data, ADF&G 2012) and the Anadromous Waters Catalog (line data, Johnson and Blanche 2012).

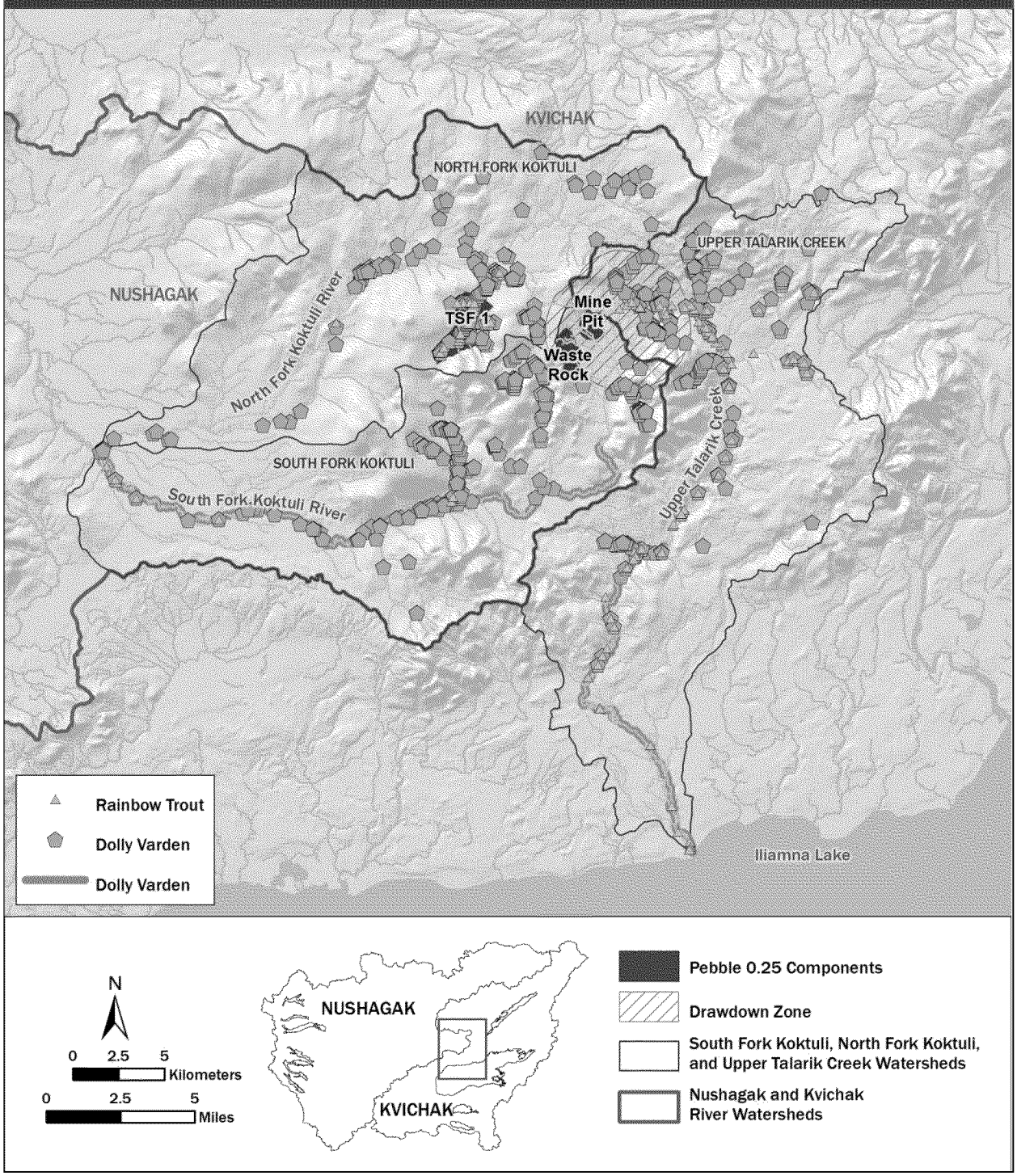

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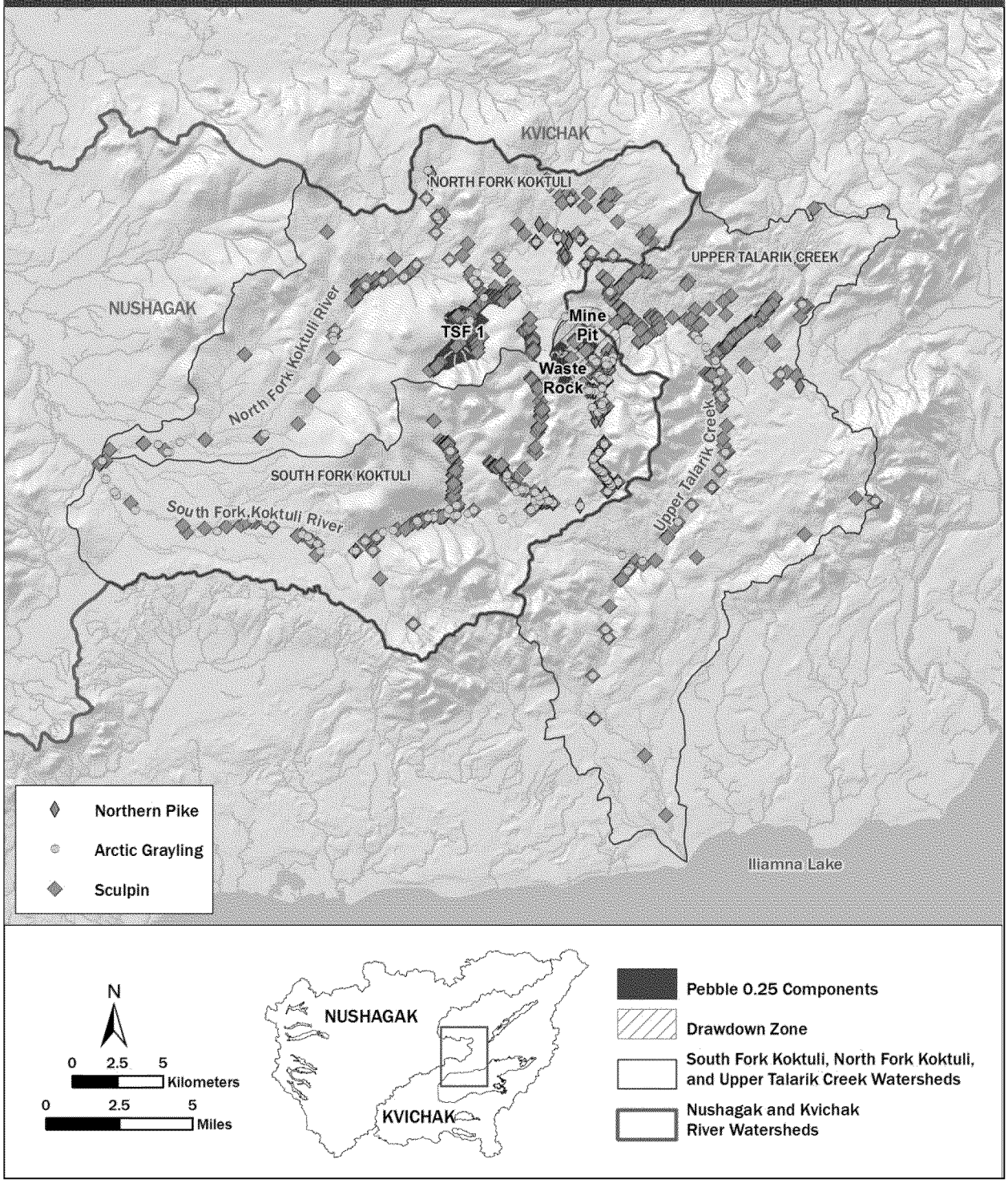
Figure 4 4. Reported distribution of other non salmon fish species in the South Fork Koktuli River, North Fork Koktuli River, and Upper Talarik Creek watersheds, downstream of the Pebble 0.25 stage mine. Species distributions are based on the Alaska Freshwater Fish Inventory (ADF&G 2012).



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Upstream energy subsidies may be most important above the point where spawning salmon provide large seasonal influxes of MDN to the system. Based on current mapping (Johnson and Blanche 2012), Frying Pan Lake and the upper SFK, which support rearing sockeye and coho salmon, Arctic grayling and northern pike, are above documented salmon spawning grounds (Figures 4-2 and 4-4; also EPA 2014: Figures 7-2 through 7-4). The UTC tributary used by juvenile coho and Chinook salmon and rainbow trout also does not receive MDN from spawning salmon.

EPA Region 10 believes that the discharge of dredged or fill material associated with the Pebble 0.25 stage mine could have unacceptable adverse effects on fishery areas in the SFK, NFK, and UTC watersheds, as well as downstream fishery areas. This conclusion is based on several factors, including the outright loss of nearly 5 miles (8 km) of habitat under the Pebble 0.25 stage mine; the particular importance of that habitat to juvenile salmon; the degradation of additional downstream salmon rearing habitat (as well as spawning areas); the resulting erosion of the genetic diversity that is key to the uniquely abundant wild Bristol Bay salmon stocks; the economic and cultural importance of the fisheries that rely on those stocks; and the strong connection between the near total absence of current perturbation in the SFK, NFK, and UTC watersheds and the health of Bristol Bay's salmon stocks. Placement of the TSF or waste rock pile in different locations from those assessed in the BBA (EPA 2014) likely would result in even greater impacts, in terms of spatial extent and/or the number of salmon species affected (Figures 4-1 and 4-2). Although EPA Region 10 cannot be certain of the full extent of the implications of these losses, it is apparent that impacts of this magnitude could compromise the sustainability of fish populations within the SFK, NFK, and UTC watersheds, as well as downstream fishery areas.

Risks to salmon from the Pebble 0.25 stage mine are particularly compelling when the status of other North American and global salmon stocks are considered. These stocks have already experienced significant declines and extinctions (Section 3.3.6.3 and EPA 2014: Appendix A). In fact, Pacific salmon are no longer found in 40% of their historical breeding ranges in the western United States, and where they do remain, populations tend to be significantly reduced or dominated by hatchery fish (NRC 1996). The status of Pacific salmon elsewhere further highlights the health and abundance of salmon stocks within the Bristol Bay watershed and the value of the Bristol Bay watershed as a "salmon sanctuary or refuge" (Rahr et al. 1998, Pinsky et al. 2009). The uniquely pristine conditions in which intact, diverse, and connected habitats extend from headwaters such as those of the SFK, NFK, and UTC watersheds to the ocean, with minimal human influence, are in stark contrast to the effects of human development in the aforementioned watersheds with extinct or severely depleted salmon runs.

Adding further support to EPA Region 10's proposed determination is the fact that the stream losses associated with the Pebble 0.25 stage mine would adversely affect other fisheries, as well. Based on currently available fish survey data, the eliminated or dewatered anadromous fish streams also support three non-anadromous salmonid species (rainbow trout, Dolly Varden, and Arctic grayling) and three

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other fish species (northern pike, ninespine stickleback, and slimy sculpin) (Figures 4-5 and 4-6).[39] The three salmonid species, along with northern pike, all support subsistence and recreational fisheries in downstream waters (Fall et al. 2006, Krieg et al. 2009). Rainbow trout, in fact, are the species for which this widely acclaimed sport-fishing area is best known (Dye and Schwanke 2012, EPA 2014: Appendix A), particularly in the Kvichak River watershed, to which UTC flows. ADF&G (1990) describes rainbow trout as the "cornerstone" of the area's sport-fishing industry.

All four of these species may migrate substantial distances (120 miles [200 km] to 200 miles [320 km]) within their freshwater habitats (Section 3.3.1). Research shows that there may be multiple populations of at least one of these species—rainbow trout—within the Bristol Bay watershed (Gwartney 1985, Burger and Gwartney 1986, Minard et al. 1992, Krueger et al. 1999, Meka et al. 2003), suggesting that the portfolio effect may be important to that fishery's sustainability as well. Most of the individuals observed in fish surveys in the Pebble 0.25 stage mine footprint were sub-adults (Table 4-3) (ADF&G 2012), indicating that fish that rear in the headwater tributaries may contribute to downstream harvests. In fact, researchers have concluded that headwater streams may be important source areas for downstream populations of Dolly Varden in southeast Alaska (Bryant et al. 2004). Thus, the loss of headwater rearing habitat for those fish species due to stream losses under the Pebble 0.25 stage mine could adversely affect the productivity of downstream subsistence and recreational fisheries. Ninespine stickleback and slimy sculpin, which are ubiquitous in the three watersheds, also contribute to these fisheries, because they are prey for species such as rainbow trout, Dolly Varden, Arctic grayling, and northern pike (Table 3-3; EPA 2014: Appendix B).

[39] The AWC documents anadromous "Arctic char" in the SFK mainstem, downstream of Frying Pan Lake. As described in Appendix B of the BBA (EPA 2014), taxonomic distinctions between Arctic char and Dolly Varden have been inconsistent in the past and recent field work suggests that fish in the Koktuli River likely are Dolly Varden. The AWC does not document any anadromous Dolly Varden (or Arctic char) habitat within or above the mine footprint. A few AFFI surveys identify the observed fish as resident, but most characterize the life history as "unknown."

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MEMORANDUM

To: Emily Anderson, Wild Salmon Center
From: Siobhan Fennessy, Ph.D., PWS, Fennessy Consulting, LLC
Subject: Comments on the Pebble Mine Final EIS on selenium and impacts to waterbirds
Date: August 21, 2020

I was retained by the Wild Salmon Center to review the Pebble Project FEIS and other documents to comment on the potential impact of selenium to waterbirds in the Bristol Bay watershed.

Professional Qualifications

I currently hold the Philip and Sheila Jordan Professorship in Environmental Studies and Biology at Kenyon College. My research focuses on wetland ecosystem ecology, their restoration and, over the past 25 years the development of monitoring and assessment methods that have been used to assess the ecological condition or 'health' of wetlands on a watershed basis, implement Wetland Water Quality Standards in Ohio, and to assess the ecological condition of the nation's wetlands in the National Wetland Condition Assessment (NWCA) effort led by the US Environmental Protection Agency (USEPA). I've been certified by the Society of Wetland Scientists as a Professional Wetland Scientist since 1995. As part of my graduate program research, I studied the use of constructed wetlands to ameliorate mine drainage from abandoned coal mines.

I was previously on the faculty of the Geography Department of University College London (University of London), with a research appointment at the Station Biologique de la Tour du Valat (France) working under Luc Hoffman, who was the founder of WWF and the Ramsar Convention on Wetlands of International Importance. I then worked for the Ohio EPA's Section 401 and Wetlands Unit where I was the lead on developing Ohio's Water Quality Standards for Wetlands, the rules used to protect wetlands in the state. While there, I founded the State's wetland monitoring and assessment program, developing rapid assessment methods and developing biological monitoring tools such as the Ohio Rapid Assessment Method. These were foundational to subsequent efforts by the USEPA to develop a national program for wetland monitoring and assessment. The assessment methods were used in the NWCA that took place in 2011and 2016 (and 2021).

I am involved nationally and internationally with organizations working on wetland science, preservation and restoration. I serve as a Scientific Expert on the Scientific and Technical Review Panel of the Ramsar Convention on Wetlands of International Importance (https://ramsar.org/). The Ramsar convention is the oldest international treaty organized to protect nature, in this case wetlands and waterfowl. I recently completed work as a Coordinating Author on the Intergovernmental Platform on Biodiversity and Ecosystem Services (IPBES) Assessment for the Americas (https://ipbes.net/assessment-reports/americas; (based in Colombia), and a Lead Author on the IPBES Global Assessment of Land Degradation and Restoration (https://ipbes.net/assessment-reports/ldr (based in Germany). Finally, I'm serving my third term as a member of the U.S. National Academies of Science, Engineering, and Medicine's (NASEM) committee to review the ecological restoration of the Florida Everglades, as part of the Committee for the Independent Scientific Review of Everglades Restoration Progress (https://www.nationalacademies.org/our-work/independent-scientific-review-of-everglades-restoration-progress-viii). Prior to that, I served on NASEM's Water Science and Technology Board for 6 years (2 terms; https://www.nationalacademies.org/wstb/water-science-and-technology-board).

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This report provides my technical assessment of the FEIS for the Pebble Mine project and is based on my 30 years of scientific experience working on the ecology of wetland ecosystems.

Executive Summary

Selenium is likely to enter aquatic ecosystems as a result of PLP's proposed mining operations. The FEIS fails to fully address the ecotoxicologial effects that selenium bioaccumulation and biomagnification will have on wildlife in Bristol Bay, such as waterbirds. Selenium can cause developmental deformities, embryo and chick death, emaciation, breaking of feathers and beaks, feather loss, decreased growth rates, compromised immune function, and oxidative stress. Because selenium is subject to bioaccumulation and biomagnification, the predictable impacts of selenium toxicity will be felt over a much larger area than the footprint of the Pebble mine project, extending to the Nushagak River estuary and Bristol Bay. The biotransport of selenium through bird movements and bird migration means that selenium contamination may cover a much larger area of the Bristol Bay region and beyond.

The risk of selenium toxicity to waterbirds through contamination of the aquatic ecosystems of the Bristol Bay watershed has been systematically underreported in the FEIS. Wetlands and other waters that become contaminated with selenium can cause severe ecotoxic effects in biota. The diverse array of wetlands in the Nushagak watershed can retain selenium in sediments and at the same time, are prime locations for shore and waterbird foraging. The planned Water Treatment Plants will rely on a chemical treatment process that assumes all selenium will be removed from wastewater. However, the treatment process, as currently designed is predicted to exceed the state limit of 5 µg/L for selenium in effluents within 6 years of operation. In addition, the FEIS fails to employ the revised criteria for tissue selenium concentrations, which were devised because water-borne selenium concentrations are not a fully reliable indicator of potential toxicity. Without evidence, the FEIS concludes that there are no risks from selenium.

The Bristol Bay region supports diverse and abundant waterbird populations that are at significant risk for selenium toxicity. The Nushagak Estuary is rich in tidal mud-flats that support a diverse bird community. Staging and wintering waterfowl are also abundant at the entrance to Nushagak Bay. As such, it is recognized as a site of Regional Importance by the Western Hemispheric Shorebird Reserve Network. These populations are in the path of any spill to the Nushagak River.

The FEIS acknowledges that selenium releases might occur if there is an accidental spill at the mine site. In this case, selenium would make its way downstream via streamflow and be available to biota. What the FEIS fails to recognize is that ecosystems contaminated with selenium take long periods of time to recover. Even if the source of selenium contamination stops, impacts continue for years, if not decades. The FEIS suggests any selenium will quickly be diluted and flushed away and so will have no impact. Flushing does not mitigate selenium contamination, nor prevent serious adverse toxic impacts to waterbirds, fish, and other biota. Claims to the contrary show either a profound lack of understanding of selenium chemistry, or an attempt to obfuscate what the predictable effects of selenium will be.

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Note: definitions used in this report were adopted from Frissell 2019:

> "**Bioaccumulation** is the gradual accumulation of substances in an organism. Bioaccumulation of pollutants can occur from water, from suspended particles, from sediments and through food chains. The rate at which accumulation occurs in an organism depends not only on the availability of the pollutant but on a range of biological, chemical and environ mental factors. The ultimate level of bioaccumulation is governed by the ability of the organism to excrete the pollutant or, alternatively, store it. This latter often leads to the attainment of very high concentrations and sometimes no equilibrium level is ever reached. (Bryan and Darricot 1979).
>
> **Biomagnification**, also known as bioamplification, is the process whereby certain substances such as persistent organic pollutants or heavy metals enter aquatic ecosystems and then move up the food chain in progressively greater concentrations as they are incorporated into the diet of aquatic organisms such as zooplankton and benthic macroinvertebrates, which in turn are eaten by fish, which then may be eaten by bigger fish, large birds, animals, or humans. The substances become increasingly concentrated in tissues or internal organs as they move up the food chain.
>
> **Biotransport** here refers to the movement of pollutants from one locale to another via the migration or dispersal of animals that have bioaccumulated body burdens of those pollutants, most importantly via dietary consumption."

To prepare this report, I reviewed the:

- FEIS
- reports of other Pebble Team experts, including:
  - Chris Frissell
  - Andre Sobolewski
  - Kendra Zamzow et al.
- primary scientific literature,
- reports, documents provided by from state and federal agencies and tribes
- reports from NGOs

Scope of this Report

This report builds on concerns expressed by Zamzow et al. (2019), Frissell (2019), and Sobolewski (2020) about the lack of rigor, comprehensiveness, and completeness in the analysis in the FEIS on the environmental impacts of selenium. Specifically, that the FEIS fails to address

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the adverse impacts of the selenium that is likely to enter the waters of the Bristol Bay watershed. Once in the environment, it can be transported over long distances, leading to contamination of areas currently considered pristine (Frissell 2019). Because selenium is an element, it cannot be degraded, and will be subject to bioaccumulation and biomagnification in aquatic ecosystems. The result is that the predictable impacts of selenium toxicity will be felt over a much larger area than the footprint of the mine project, extending to the Nushagak River estuary and into Bristol Bay. Moreover, the biotransport of selenium through bird movements and migration, means that selenium impacts may cover a much larger area of the Bristol Bay region.

An earlier report by Zamzow et al. (2019) focused on the sources of selenium from the mining process, the fact that discharges of selenium are likely to exceed Alaska water quality criteria, the failure of the wastewater treatment planned to adequately reduce selenium concentrations, and the resulting ecotoxic effects. Frissell (2019) focused on the environmental effects of bioaccumulation, biomagnification, and biotransformation of selenium and other persistent pollutants on biota, particularly in fish species, including salmon. Sobolewski (2020) reports that the water treatment system proposed in the FEIS will not meet state water quality criteria and provides an analysis of the likely effluent selenium concentrations. In this report I do not reconstruct the compelling analyses of the failings of the FEIS with respect to selenium that are covered by Zamzow et al. (2019), Frissell (2019), and Sobolewski (2020), instead I give a brief summary of the key issues of selenium discharge from the Pebble Mine and focus on the on the risk of selenium toxicity to water birds that could result from the Pebble Project. These risks are largely ignored in the FEIS.

Introduction

Selenium (Se) is a metalloid element (i.e., a chemical element with some metallic and some non-metallic properties) that is an essential micronutrient for animals and humans. Trace concentrations are needed for normal growth and development, however, at concentrations that are only slightly higher than beneficial levels it quickly becomes toxic (i.e., the window between being essential and toxic is narrow; Hamilton 2004, Ackerman and Eagles-Smith 2009). Typical selenium concentrations in soil and sediment range from 0.01 – 2.0 mg/kg although higher concentrations are found in soils derived from rock that is naturally high in selenium (seleniferous soils). When selenium is uncovered in the mining process, it can be mobilized and transported as dust or in particulate or soluble forms in the aquatic environment.

Selenium comes in a variety forms that vary in their biological availability and toxicity. Overall, selenium toxicity in aquatic ecosystems is a function of its concentration, the particular selenium species that are present, the hydraulic residence time and the susceptibility of the receiving environment (Chapman et al., 2009). selenium typically enters the food chain from sediments,

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where it is retained a selenite, and then incorporated into tissue as an organo-selenium compound. From there, selenium can be ingested by biota at higher trophic levels (e.g., plants → invertebrates → fish → birds); and its concentration per unit body weight increases at each trophic level (i.e., it biomagnifies, Luoma and Presser, 2009). As the FEIS acknowledges, selenium release can be significant at both acidic and circumneutral pH, making its transport away from the Pebble mine site much more likely.

Wetlands and other waters are habitats where selenium can exert ecotoxic effects. Wetlands in the Nushagak watershed, for example, are highly biodiverse and are prime locations for shore and waterbird foraging. Selenium can be retained in these environments where it can bioaccumulate and biomagnify until it reaches toxic concentrations. The risk of selenium toxicity to waterbirds through contamination of the aquatic ecosystems of the Bristol Bay watershed has been systematically ignored in the FEIS.

Selenium Toxicity to Waterbirds

The effects of selenium toxicity to waterbirds are well documented (Hoffman 2002, Adams et al. 2003, Ackerman and Eagles-Smith 2009, Ohlendorf et al. 2019) and are acknowledged in the FEIS. Developmental deformities, embryo and chick death are the most obvious and easy to diagnose effects of selenium toxicity. Developmental deformities can be lethal or sublethal, causing impairment that affects the ability of the organism to survive.

Selenium can be taken up directly from water or through diet (Hamilton 2004). Plants typically absorb selenium from water while the dominant pathway of exposure for aquatic animals is diet (Hamilton 2004). When taken up by plants, selenium can substitute for sulfur (S) in proteins creating organic selenide, such as selenocysteine or selenomethionine, amino acids that are the building blocks of proteins. This is the primary form of selenium found both in aquatic animals. The transformation to organic forms makes selenium readily bioavailable to consumers such as invertebrates, who ingest it by eating either living plant tissues or filtering organic particles (Turner 2013). Selenium bioaccumulates in these consumers, and once ingested, it is subject to biomagnification in their tissues. As its concentrations build up with each trophic transfer, its effects are much more pronounced in egg-laying fish and birds because of the maternal transfer to eggs. The developing embryo is exposed to high concentrations of selenium (via selenocysteine or selenomethionine), resulting in teratogenic effects and higher rates of embryo mortality (Brix et al, 2000, Spallholz and Hoffman 2002). For instance, Hoffman and Heintz (1988; in Hamilton 2004)) found mallard ducks fed a diet with 10 ppm selenomethionine had a 40-44% decrease in the total number of eggs hatched compared to a control group. In a review of selenium toxicity in water birds, Hoffman (2002) reports that

- 10 ppm selenomethionine in feed resulted in decreased growth in black-crowned night herons,

- 2.2 mg/L in drinking water consumed for 12 weeks caused selenium accumulation in the liver and impaired immune function in mallard ducks,
- 2, 4, and 8 ppm concentrations of selenomethionine in mallard food led to increasing levels of selenium accumulation in the liver and increased plasma GSH peroxide activity (which is a step toward teratogenesis). In this study by Hoffman et al. (1991), selenium accumulated in the liver in a dose-dependent manner. At 16 and 32 ppm, weight loss, mortality, and liver lesions were seen.

In perhaps the most famous example of selenium poisoning, irrigation runoff in the Kesterson Reservoir in the Sacramento-San Joaquin River delta. Selenium in runoff from seleniferous soils became concentrated in the reservoir water, resulting in the death and deformities of bird embryos and reduced body weight in adult birds as the selenium bioaccumulated in the food chain. In a typical progression, selenium moved from water, to plants, invertebrates, fish and birds (Ohlendorf et al. 1988). In one study, clutches of eggs (nests) of Grebes, American coots, and several species of ducks, stilts, and avocets were followed. Of those nests, 40% had dead embryos (one or more) and 20% contained chicks with developmental abnormalities (Ohlendorf 2002). Since that time, Kesterson Reservoir has been the subject of many studies documenting the dramatic toxic impacts of selenium to avian life. The reservoir has since been closed and sealed off (Hamilton 2004).

The FEIS fails to acknowledge the added risk of sublethal impacts of selenium to migratory species. Sublethal effects occur when adults have elevated selenium concentrations that cause health impairments but not death. These include emaciation, breaking of body structures made of keratin (e.g., feathers, beaks), and feather loss, decreased growth rates, compromised immune function, and oxidative stress (Ohlendorf et al. 1988, Hoffman 2002). Keratin is a protein that is naturally high in sulfur. When selenium concentrations are elevated selenium substitutes for sulfur in these proteins and alters their function with the result that body structures with high keratin content are damaged, putting the life of the bird in danger (Spallholz and Hoffman 2002). Immune function can also be compromised, for example in mallard ducks that were exposed to selenium for 12 weeks as selenomethionin (equivalent to 2.2 mg/L in water; Fairbrother and Fowles 1990). In adults, selenium can cause mass wasting (weight loss and loss of strength), reducing their fitness for the sustained flight needed in migration (Hamilton 2004).

Thresholds for Adverse Effects of Selenium

There are several toxicological endpoints for selenium such as teratogenesis, embryo death, and chick mortality; none of these are addressed in the FEIS. Field and lab studies have been completed to estimate selenium toxicity in eggs and body tissues (Adams et al. 2003). In a comprehensive review, Hamilton (2004) documented the general convergence of laboratory and field tests for selenium thresholds for adverse effects in fish and birds. Evidence pointed to a

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threshold for water of less than 2 µg/L. It is important to note that the 2 µg/L limit is *not* considered safe because no margin of safety was added to the criterion[1]. Safety factors are used to revise toxicity thresholds to account for any uncertainty in deriving the criterion and to be conservative in the effort to protect aquatic and human health.

Because waterbird species vary in their ability to bioaccumulate selenium, proposals to establish criteria for toxicity are based on concentrations in body tissues and the concentrations in water needed to maintain those tissue concentrations at or below the threshold levels. Factors used to develop criteria include the dietary sources of selenium (i.e., the proportion of plants, invertebrates, fish etc. in their diet), the efficiency of trophic transfer, the species of interest, and the life history stage of the individual (Ackerman and Eagles-Smith 2009). If thresholds are established that protect the most vulnerable species from the adverse impacts of selenium, then all species should be protected. USEPA used this approach when setting multimedia selenium criteria in 2016 (Table 1). The updated EPA selenium criteria for tissue concentrations are ignored in the FEIS.

Table 1. Comparison of 2016 and 1999 selenium criteria (USEPA 2016).

	Chronic					Short-term
Criterion Version	Egg-Ovary[1] [mg/kg dw]	Whole Body[1] [mg/kg dw]	Muscle[1] [mg/kg dw]	Water Lentic[1] [µg/L]	Water Lotic[1] [µg/L]	Water[1] [µg/L]
2016 Selenium Criterion	15.1	8.5	11.3	1.5 (30 day)	3.1 (30 day)	Intermittent exposure equation
1999 Selenium Criteria	N/A	N/A	N/A	5 (4 day)	5 (4 day)	Acute Equation based on water column concentration

The FEIS fails to employ the revised tissue criteria, which demonstrate that water-borne selenium concentrations are not a fully reliable indicator of potential toxicity (Chapman et al. 2009). Tissue concentrations are considered a far more accurate indicator of potential toxicity than waterborne concentrations (Chapman et al. 2009, Luoma and Presser 2009). This is important to understand when establishing an acceptable selenium concentration to protect aquatic life.

[1] For example, in its Proposed Aquatic Life and AquaticDependent Wildlife Criteria for selenium in California's San Francisco Bay and Delta in June 2016, the US EPA proposed dissolved and particulate water column selenium criteria of 0.2 µg/L and 1 µg/g, respectively.

Aquatic Birds in the Bristol Bay Watershed

As part of baseline characterization of the Pebble mine site, raptor and water bird species in the region of the Pebble Project were surveyed in 2004-2005 (with a swan survey in 2006). These surveys were not repeated, which makes any analysis done in the FEIS reliant on out of date data (FEIS p. 3.23-54, 3.23-57-63). However, the data show that the region supports diverse and abundant waterbird populations that are at significant risk if the Pebble Mine project goes ahead. Bald Eagles nest and feed along the coast and along all of the major salmon spawning rivers in the Bristol Bay and Cook Inlet regions. Golden eagles are also abundant, including at the mine site. Migratory birds (waterfowl, shorebirds) use lakes, rivers, bays and wetlands during the spring and fall migration. The FEIS reports that the most commonly detected waterbird species (with more than 1,000 individual birds detected), in decreasing order of abundance across all surveys, were: glaucous-winged gull (9,317 birds), harlequin duck (3,809 birds), greater scaup (1,958 birds), long-tailed duck (1,714 birds), Barrow's goldeneye (1,140 birds), and green-winged teal (1,040 birds; pg 3.23-57).

The FEIS summarizes the water bird surveys as follows (pg 3.23-58):

"… ABR (2011d, 2015c) recorded 70 species of birds in marine waters of Cook Inlet, including Iliamna, Iniskin, and Chinitna bays. The greatest number of bird species and density occurred in spring (primarily due to large numbers of shorebirds). Large numbers of waterfowl migrate through the area in spring and fall, and a substantial number of birds winter in the protected bays, especially sea ducks. The highest densities of birds in spring and summer occur in nearshore waters and near the mouths of the bays, while the highest densities in winter occur in the offshore waters of the bays (ABR 2011d). "

The Nushagak Estuary is the last 19 miles of the lower Nushagak River before it empties into Bristol Bay (pg 4.27-117). It supports an area is rich in tidal mud-flats that are exposed during low tides and support a diverse bird community. The Nushagak Bay is recognized by the Audubon Society as an important staging and molting area for eiders, geese and scoters in both the fall and spring, with some Black Scoters (*Melanitta Americana*) and King Eiders over wintering (note the numbers of Black Scoters are declining; https://www.audubon.org/field-guide/bird/black-scoter. Staging and wintering waterfowl are also abundant at the entrance to Nushagak Bay. Although counts of shorebirds in Nushagak Bay are limited, aerial surveys have recorded more than 10,000 small sandpipers. In September 1997 an aerial survey recorded 22,236 total shorebirds including 21,872 Dunlin (a species of sandpiper, *Calidris alpine*) and 121 Greater Yellowlegs (*Tringa melanoleuca*). As a result of the diverse bird life, Nushagak Bay is recognized as a site of Regional Importance by the Western Hemispheric Shorebird Reserve Network (WHSRN) (https://www.audubon.org/important-bird-areas/nushagak-bay). The Bay is also a primary portion of the spring summer habitat for Beluga whales (Mooney et al. 2018).

The FIES acknowledges that contaminants including selenium may end up in the Nushagak Estuary and Bay, posing the risk of significant harm (pg. 4.27-117, 4.27-122, 4.27-138).

Pathways of Selenium Release and Transport to Wetlands and Other Aquatic Habitats

There are many ways that selenium can be released in the Bristol Bay watershed, including discharge from WTP, spills from tailings storage facilities and transport downstream, and dust transport. These sources are acknowledged in the FEIS but there is no discussion of selenium accumulation in wetlands and other aquatic sites, either in their water columns, sediments, or uptake in the food chain as it moves to higher trophic levels. This is a major omission in the analysis of selenium impacts in the FEIS.

Wetlands, including estuaries, are particularly well-suited to accumulate selenium where it can enter the food chain (Johnson et al, 2009, Turner 2013). Wetlands are known for the diverse and valuable ecological functions they provide (also called ecosystem services), including water quality improvement through the retention of water pollutants. Constructed wetlands have been built as treatment systems to improve the quality of mine drainage (Fennessy and Mitsch 1989), including that contaminated with selenium. Constructed wetlands in California's Imperial Valley retained 56% - 70% of the selenium that entered the wetland. Most of selenium accumulated in the sediments where it was available for uptake and trophic transfer (Johnson et al. 2009). Natural wetlands also work in this way as 'kidneys of the landscape,' improving water quality. Estuaries have been found to be vulnerable to selenium, accumulating it in sediments where it is transferred to detritus feeders, then to fish and wading birds. In the relatively pristine Bristol Bay watershed, it is possible that the selenium that moves downstream from the mine site will be retained in downstream wetlands, posing a risk to aquatic life as it biomagnifies to toxic levels in the food chain.

The Duration of Ecosystem Recovery from Selenium Toxicity

The FEIS fails to recognize that ecosystems contaminated with selenium take long periods of time to recover (Hamilton 2004). Predictably, even if the source of selenium contamination stops, selenium impacts continue for years, if not decades. For instance, 10 years after selenium inputs to Belews Lake, NC were stopped, elevated levels were found in the sediment, benthic invertebrates, and fish, with deformities still occurring in fish (Lemly 1997; in Hamilton 2004). Selenium is persistent because it is effectively recycled through different ecosystem compartments (surface water, ground water, sediments, sediment porewater, particulate detritus, bacteria, benthic invertebrates, plants, algae, zooplankton, fish, and birds). Hamilton (2004) reviewed several case studies, including at the Kesterson Reservoir. Despite the fact the reservoir was sealed in a vain attempt to clean up selenium contamination, winter rains caused pools of water to form with water concentrations of up to 1600 µg selenium/L; this was subsequently

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transferred to invertebrates and other biota. Similarly, selenium concentrations in fish were found to be two times higher than the toxicity threshold in Marin Lake, TX, two years after selenium inputs were stopped. Tissue levels had dropped by only 25% after 5 years (Hamilton 2004). The time needed for ecosystem recovery (if it is possible) is discussed in more detail below.

Selenium Discharge from Water Treatment Plants

The planned WTPs are highly complex and will rely on a chemical treatment process that assumes all selenium will be removed. However, in an analysis of the major shortcomings of the proposed WTP, Sobolewski (2020) raised concern that the treatment process proposed by Pebble will be less effective than predicted (Table 2), and that selenium will accumulate in the treatment system over time. The FEIS predicts that effluent concentrations will be 0.5 µg/L with an astonishing 98.8% removal rate (Table 2). Sobolewski (2020) developed a spreadsheet model to predict selenium levels in the WTP effluent, and reports that the model results:

> "… flatly contradicts the assertion by Pebble that selenium concentrations will not build up in this closed water management circuit. Not only will it increase, but it will reach concentration that will overload the capacity of WTP #2 to meet the state discharge criteria for selenium. As currently designed, the state limit of 0.005 mg/L (or 5 µg/L) for selenium will be exceeded in effluents from the proposed water treatment plant within 6 years of operation."

The FEIS brushes away the potential for toxicological impacts to waterbirds or other biota with no attempt made to determine the water concentrations that would be protective of bird species with different diets. As an example of how such an analysis could be done, Luoma and Presser (2018) analyzed selenium concentrations in South San Francisco Bay to determine the water concentrations needed to meet national tissue criteria (i.e., the maximum allowable selenium tissue concentration) proposed to protect the eggs of aquatic birds. Using the Ecosystem-Scale selenium Modeling approach to assess food webs and develop selenium criteria, they found water column selenium concentrations that would protect bird species with different diets (e.g. varying proportion of plants, invertebrates and fish) ranged from a low of 0.14 to a high of 0.82 µg/L (Luoma and Presser 2018).

This indicates that for some species in susceptible environments, the predicted effluent limits will not prevent selenium toxicity.

The lack of rigorous analysis calls into question the competency of the FEIS (e.g., 4.27-147). Even if we are to accept the prediction made in the FEIS that effluent concentrations will be 0.5 µg/L (Sobolewski 2020), the potential for selenium impacts through biomagnification remains. As Frissell (2019) states (pg 4):

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> "It is also important to recognize these contaminants can cause the effects considered here even when discharges remain at trace quantities below applicable water quality standards and typical permitted conditions."

Table 2. FEIS predicted effluent concentrations and removal efficiencies for WTP#2 during mine operation made by HDR (2019) adapted from Sobolewski (2020). For comparison, water criteria needed to protect waterbird eggs for a range of species and diets is shown.

Selenium Influent concentration (µg/L)	Effluent concentration (µg/L)	Percent Selenium removal	Luoma and Presser (2018) water Se concentration to meet national bird tissue criteria in San Francisco Bay (µg/L)
41	0.5	98.8%	0.14 to 0.82

Spills

The only instance in which the FEIS acknowledges that selenium release might occur is through accidental spills at the mine site (FEIS 4.27), i.e., a tailings dam failure, although there is no serious attempt at analysis of the adverse impacts that would result. At the mine, tailings will be separated into bulk and pyritic tailings (which have a higher potential for leaching) and stored in a tailings storage facility (TSF, or tailings ponds). Pyritic TSF will have a full water cover which the FEIS states makes them more susceptible to tailings releases (spills).

In the event of a spill from a release of pyritic tailings into the NSK and/or SFK, contaminants, including selenium would make their way downstream via streamflow and be available to biota. The FEIS states that if a tailings dam failure and resulting spill were to occur in the NFK, TSS and other materials would be transported all the way to the Nushagak River Estuary (pg 4.27-97). The spill would contribute to higher selenium concentrations downstream over a period of decades if the tailings are not recovered (pg 4.27-98). If the spill is to the SFK side, up to 220 acres of habitat will be impacted. In either the NFK or the SFK, tailings recovery from downgradient streams, rivers, and wetlands seems highly unlikely (no explanation is given in the FEIS about what methods might be used). The FEIS also states that tailings fluids will have selenium concentrations above water quality standards (pg 4.27-138), and if spilled selenium remained at elevated levels for several weeks (pg 4.27-139). The FEIS also states that (pg 4.27-164):

> "Selenium concentrations generally accumulate in waterbodies such as ponds and lakes that are not readily flushed. Therefore, although the potential duration of impacts may extend beyond the initial period of exposure to

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> elevated levels of selenium, the flushing of the system by rain and snow melt would reduce impacts of elevated selenium through dilution."

With a spill, the FEIS also states:

> "The elevated levels would last for a ***few weeks*** while the flows are flushed downstream. Remaining contaminants would then be flushed downstream and released into Nushagak Bay, part of greater Bristol Bay, where they would become heavily diluted. Any changes to the pH, texture, or chemistry of the soil would likely not exceed soil quality criteria dilution suggests any selenium would be diluted enough not to be a problem" (emphasis mine)

The latter claims are baseless, and directly contradict what is known about the chemistry of selenium, the ability of plants and algae to take it up from the water column, and for it then to biomagnify through the food chain (pg 4.27-142).

The notion that the selenium in spills can be quickly flushed away and diluted to low levels has been thoroughly disproven by studies that the FEIS does not cite. To the contrary, selenium in streams can have impacts for years to come. For example, Maier et al. (1998; in Hamilton 2004) report that a pulse of selenium entering a stream raised the water selenium concentration from less than 1 µg/L to 10.9 µg/L within 3 hours. In response, concentrations increased in stream invertebrates (which are eaten by water birds) from 1.7 µg/g to 4.7 µg/g in 3 hours and remained elevated (at 4.5 µg/g) <u>even after 11 *months*</u>. This is despite the fact that water concentrations returned to the background concentration of less than 1 µg/L after <u>only 11 *days*</u> (i.e., selenium concentrations were at background concentrations between 11 days and 11 months post selenium release, yet selenium circulated in the system at levels that caused adverse impacts). The fact is that a spill can quickly load a lotic ecosystem with selenium, and that selenium will stay in the ecosystem far beyond the period when water concentrations return to low levels. In a study of headwater streams subject to selenium inputs from coal mining, Cianciolo et al. (2020) found that the highest selenium concentrations in streams with mine runoff, and 75% of streams studied had no evidence of dilution of selenium with distance downstream with fish and salamanders bioaccumulating potentially toxic levels. Clearly, headwater streams can transport selenium well beyond the source.

In sum, flushing does not mitigate selenium contamination, nor prevent serious adverse toxic impacts to waterbirds, fish, and other biota. I find claims made in the FEIS to the contrary to be sloppy and unsubstantiated, and show either a profound lack of understanding of selenium chemistry, or an attempt to minimize what the predictable effects of selenium will be.

If a spill were to transport selenium to the Nushagak River estuary, important avian habitat found there, including mudflats, would likely be contaminated. Mudflats provide important foraging

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grounds for many species of waterbirds. Globally, mudflats are threatened with climate change impacts due to sea level rise which can cause drowning of this important habitat (Clausen and Clausen 2014). The FEIS states it is possible that, in the case of a spill, that tailings will wash onto mudflats, with subsequent transport into Bristol Bay (pg 4.27-117). This could readily lead to selenium bioaccumulation through the food chain with potential serious toxicity impacts to resident bird populations. This also points to foreseeable cumulative impacts to resident waterbird populations if the impacts of selenium toxicity are exacerbated by climate change. The FIES fails to address this issue.

What is totally lacking in the FEIS is data or analysis to determine which species are most at risk for selenium toxicity. Waterbirds nest, incubate eggs, and rear young on or near ponds, wetlands, and streams near the proposed discharge locations or downstream from them. The FEIS gives no consideration of the species that nest and rear young in the mine area, near the sites of WTP discharges, or in the Nushagak estuary in terms of the impacts that elevated selenium levels might have on these populations. In what seems to be characteristic of much of the FEIS, the analysis is limited to out of date data that is little more than a list of species with a few bird count estimates. In so doing, the FEIS neglects the potential and risk of adverse impacts from selenium toxicity.

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Review of the Assessment of Water Temperatures
August 20, 2020
Gordon H. Reeves, PhD.

SUMMARY

The analysis of the effect of the projected altered temperature regime in the FEIS is highly flawed and the conclusions about the effect of the mine operation are indefensible and unsupported by the data and logic presented. Additionally, there is a large amount of uncertainty associated with the conclusions that is not represented in the FEIS.

- The FEIS does not accurately represent the potential impacts of the elevated water temperatures. The FEIS fails to recognize that: (1) small changes in water temperature can have significant ecological effects (e.g., time and size of fry at emergence); (2) there will be cascading effects of changes in the timing of life-history events (phenology); and (3) there will be cumulative effects as a result of the interaction of changes resulting from higher water temperatures with other environmental modifications, such as altered stream flows resulting from climate change As a result, the assessment of potential effects of the proposed mine and the conclusions in the EIS are invalid and most likely wrong.
- The analysis in the FEIS uses temperature standards from the Alaska Department of Environmental Conservation that are not ecologically appropriate. These temperatures are based to a large extent from populations throughout a species' distributional range, with very from Alaska and fewer from western Alaska. The author of the report (Weber-Scannell 1991) from which these temperatures were taken noted that there were critical limitations of applying these temperatures to fish in Alaska. These standards fail to recognize the influence of local adaptation of the affected populations, which EPA (2014) noted was critical to consider in the mine assessment.

ASSESSMENT OF WATER TEMPERATURE EFFECTS ANALYSIS

The conclusion of the FEIS that the effect of elevated water temperatures resulting from the mine operation on native fish will not result in harm to fish in the affected streams or Bristol Bay is not supported by the data presented or the justifications provided. The analysis fails to recognize basic aspects of the ecology and biology of Pacific salmon, the limitations of the literature they used, cascading effects of potential temperature impacts at one life history stage on later stages, and cumulative effects from other environmental changes are likely to have detrimental consequences to fish populations in the affected streams.

The FEIS contends that the projected changes of water temperatures are within "ADEC thresholds" and, therefore, the reported increases could have no ecological consequences. Alaska's Water Quality Standards for temperature were last revised in 1997 (ADEC 2018) and relied heavily on temperatures reported in Weber-Scannell (1991), among others. Heavily cited in the FEIS, Weber-Scannell reviewed and summarized the scientific literature on water temperatures for the different species of Pacific salmon (and other native fish in Alaska). The reported temperatures are from populations throughout a species' distributional range, with very

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few citations from Alaska and fewer from western Alaska. For species with large geographic distributions, such as Pacific Salmon, considerable differences in temperature may be experienced that can result in differences in thermal tolerances and preferences (Fangue et al. 2006). Weber-Scannell (1991) noted that there were critical limitations of applying these temperatures to fish in Alaska, stating that "Many of the studies that relate changes in temperature effects on fish examine higher ranges than area usually experienced by fish in Alaska. Therefore, acceptable upper and lower temperature ranges from the published literature **are often not applicable** to fish naturally occurring at higher latitudes." (Abstract p. iii), which includes the affected area. Relatively small increases in water temperatures may have biologically significant impacts on Pacific salmon "...even when maximum water temperatures remain well below critical thresholds recognized by regulatory agencies (McCullough 1999).". The FEIS uses the ADEC water temperatures as the standard for assessing the potential impacts of the mine despite their clear limitations and applicability and states that changes in summer water temperatures will be relatively small, and as a result there will be no negative effect on salmon. This is clearly a false conclusion because ecological consequences are likely to happen at temperatures well below the ADEC standards.

Identifying intraspecific variability in performance traits and environmental tolerance limits is critical to understanding how species and populations will respond to an altered environment (Eliason et al. 2017). Pacific salmon are well known for their natal homing and low dispersal across diverse habitats (Groot and Margolis 1991), resulting in populations that are adapted to their particular environment, even at a local level of a few kilometers (Taylor 1991; Fraser et al. 2011). Larson et al. (2017) found genetic differences among local populations of adult sockeye salmon in the Wood River system in Bristol Bay relative to water temperatures at which spawning occurs. Physiology (Crossin et al. 2004; Eliason et al. 2017) and morphology, including sockeye salmon in the Wood River watersheds (Lisi et al. 2013) also have been correlated with local environmental conditions in adults relative to water temperature. Egg development (Beacham and Murray 1987; Murray and Beacham 1987; Whitney et al. 2013, 2014) and temperature tolerance (Chen et al. 2013), growth rates (Beer and Anderson 2001), and swimming performance of fry (Sopinka et al. 2013, Eliason et al. 2017) and adults (Eliason et al. 2011) may be population specific. EPA (2014) noted that the diverse environmental conditions in the Bristol Bay area has led to large variation among populations of Pacific Salmon species and local adaptation (p. 7-34-5). It is, therefore, essential to acknowledge and consider intraspecific variability in performance traits (e.g., growth, survival, etc.) and environmental tolerance limits to understand how species and populations will respond to a changing environment is critical when assessing the impacts of environmental alterations (Peterson et al. 2019), especially with regards to water temperature (Eliason et al. 2017, Bennett et al. 2019).

The FEIS acknowledges that salmon populations in Bristol Bay are adapted to local conditions (p. 3.24-75) but then blatantly fails to consider that the effected populations are adapted to local water temperatures. It repeatedly contends that because the modified temperatures are within the limits set by the Alaska Department of Environmental Conservation that there will be no adverse impacts (4.24 – 22-26) (see earlier discussion on these standards). Local adaptation of growth rate to water temperature (Beer and Anderson 2001; Finstad et al. 2004, Metcalfe et al. 2016) appears strongest at low, rather than high, temperatures (Jensen et al. 2000). A recent study (Campbell et al. 2020) on the Copper River Delta near Cordova, Alaska, compared growth rates of young-of-the-year (0+) Coho salmon in streams with different summer temperature regimes, 4-5°C and 10-13°C. The latter was assumed to be within the optimum range

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for growth for Coho salmon and the former well outside the range (Brett 1952, Konecki et al. 1995). Fish from the two streams grew at the same rate, however. The failure of the FEIS to consider that fish in the affected streams are adapted to local conditions makes the conclusions about the effects of elevated water temperatures from the mine indefensible and underestimates the negative consequences of the altered temperature regime from the mine operation will likely have on the native fish.

It is crucial to examine the consequences of changing environmental conditions to timing of life-history events (phenology) to more accurately understand potential effects of environmental alterations (Miller-Rushing et al. 2010). It may be possible for effects of an altered temperature regime to be positive at one life-history stage but negative at another, which results in decreased survival for the population. Egg and alevin development depend on the accumulation of degree days. (Neuheimer and Taggart 2007) over the incubation period. As a result, spawn timing is finely tuned to local environmental conditions, notably water temperatures during the incubation period (Beacham and Murray 1990), to promote juvenile emergence at a time of year favorable for growth and viability (Webb and McLay 1996; Brannon et al. 2004; Campbell et al. 2019). Slight increases in temperature can accelerate rate of development, resulting in smaller (Beacham and Murray 1990) and less well developed (Fuhruman et al. 2018) fish emerging earlier (McCullough 1999, Sparks et al. 2019, Adelfio et al. 2019; Fig. 1). Changes to thermal that disrupt life-history timing cues can result in mismatches between fish and their environments or food resources, adversely affecting survival (Angilletta et al. 2008, Einum and Fleming 2000, Letcher et al. 2004). These potential effects are acknowledged in the FEIS (4.24 – 23).

Increased water temperatures during incubation in the winter can result in a time an earlier time of emergence of fry and an extended growing season. Holtby (1988) found that an increase of 0.7 °C (1.3 °F), which is the smallest projected increase from the mine (p. 4.24 - 24), in winter water temperatures following timber harvest in Carnation Creek on the west coast of Vancouver Island, British Columbia, resulted in Coho salmon emerging 6 weeks earlier than before timber harvest. Size at age of juveniles in the first year following emergence increased because of the extended growing season, resulting in fish growing faster and larger and more completing their freshwater-rearing life history in one year rather than two. Coho salmon also smolted and moved to sea about 2 weeks earlier following timber harvest; however, marine survival declined, possibly as a result of the decoupling of the timing of smolt migration from marine plankton blooms (Holtby and Scrivener 1989). Similarly, warmer winter temperatures increased the length of the growing season of recently emerged Sockeye salmon in southwest Alaska. Like Coho salmon in Carnation Creek, Sockeye salmon grew faster, and more underwent smolt transformation at age 1+ during warm periods rather than at age 2+ in cooler periods (Schindler et al. 2005). However, age-1+ smolts were smaller than age-2+ smolts and were expected to have decreased marine survival. Pacific Salmon are particularly susceptible to cascading effects because of the importance of synchronization of the multiple events in their life cycle can be altered by slight changes in environmental conditions (Lytle and Poff 2004, Crozier et al. 2008). It is critical, therefore, to consider how effects can cascade over the life-history of a fish and not to limit analysis to a single life-history stage. The FEIS recognizes the likelihood of cascading effects as a result of changes in water temperatures when reviewing the literature on the topic (4.24 – 23) but then dismisses it without justification. Thus, the FEIS very likely misrepresents the potential impacts of elevated water temperatures caused by mine operations.

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The FEIS wrongly dismissed the significance of changes in water temperatures that may that may occur in a short time window. On the South Fork of the Koktuli River, water temperatures where projected not to change during the much of the incubation period for salmon but in April an increase of o.85°C was expected (4.24 -26). As a result, the FEIS stated that "…it is unlikely that the potential increases in April water temperatures would be sufficient to either enhance or adversely affect developing alevins in the SFK." This is incorrect; there would likely be accelerated development and emergence of fry. Adelfio et al. (2018) showed the minor increases in spring temperatures would accelerate the emergence timing of Coho salmon fry on the Copper River Delta, AK. by up to 30 days, which could have effects on the survival of the fry and later life-history stages.

The FEIS failed to consider the potential cumulative effects of a higher water temperatures resulting from the mine operations and an alteration of stream flows from a changing climate. Concurrent with an increase in water temperatures from the proposed mine, there is likely to be changes in stream flow from climate change as the precipitation goes from snow to rain. The SNAP projections for Nondalton (Figure 2), which is near the proposed mine site, show air temperatures in March and April 2040 approaching 0°C (32°F). This is the critical temperature where precipitation would fall as rain rather than snow and any snow would begin to melt. Wobus et al. (2015) projected substantial changes in mean winter flow and peak flow dates, and water in the near future. Hydrographs will no longer be dominated by a single spring thaw event, but will instead be characterized by numerous high flow events throughout the winter, which is also predicted for other areas that will experience similar temperature changes (Hamlet and Lettenmaier 2007, Tague and Grant 2009). Smaller fish are more susceptible to displacement at higher flows and, thus, the overall effect of warmer winter temperatures could be a decrease in survival.

In summary, the conclusion of the FEIS that the impact of altered stream temperature is low. It uses State of Alaska temperature standards for the assessment that are not ecologically appropriate. These are temperatures derived from optimal temperatures for the various species ignoring the influence of local adaptation, which EPA (2014) noted was critical to consider. The FEIS also fails to recognize: (1) that small changes in water temperature can have significant ecological effects (e.g., time and size at emergence); (2) that there will be cascading effects of changes in the timing of life-history events (phenology); and (3) the cumulative effects of the interaction of effects from increased water temperatures and other environmental changes (stream flow). As a result, the assessment of potential effects of the proposed mine and the conclusions in the FEIS are invalid, most likely wrong, and have a very large degree of uncertainty.

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Figure 1. Change in the time of emergence of Coho and Chinook Salmon fry as a result of a 1°C increase in the base water temperature during incubation (from: McCullough 1999).

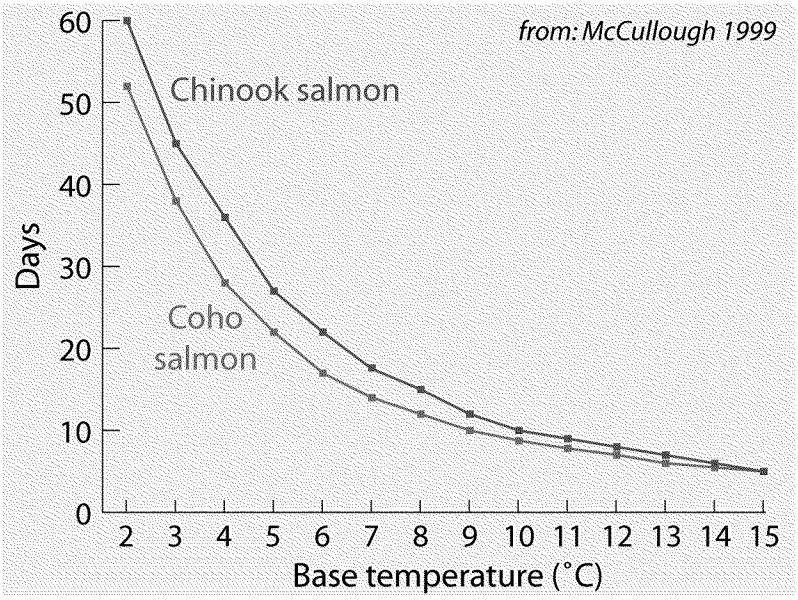
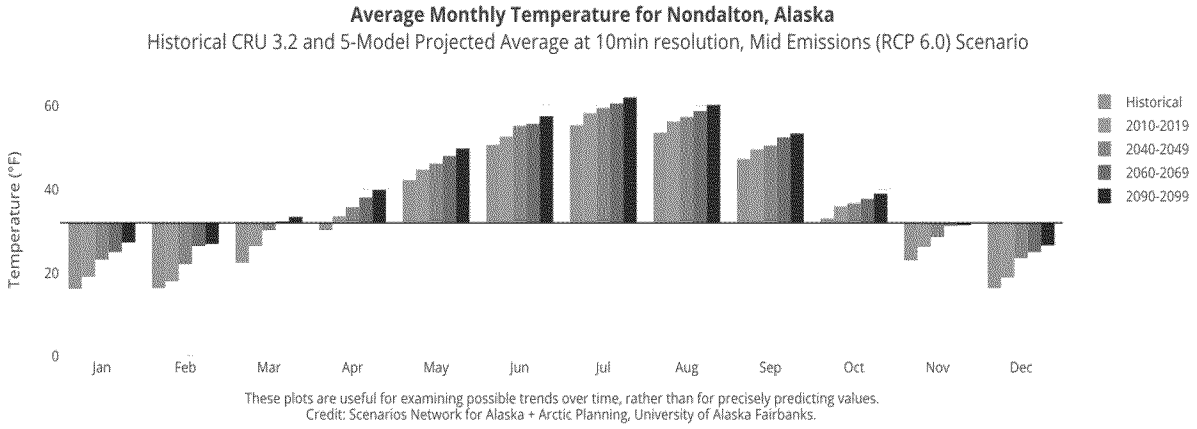


Figure 2. Projected average monthly air temperatures for Nondalton, Alaska based on Scenarios Network for Alaska and Arctic Planning (SNAP) climate data.
https://snap.uaf.edu/tools/community-charts



Dear U.S. Army Corps of Engineers,
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Regulatory Division, CEPOA-RD
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JBER, Alaska 99506-0898
poaspecialprojects@usace.army.mil

I'm a geologist who specializes in geologic hazards, and have been involved in a wide range of earthquake, tsunami, and landslide hazard studies. I've reviewed many documents describing what is known about geologic hazards near the proposed Pebble Mine, and have also done my own fieldwork in the area studying these hazards. After its release on July 24, 2020, I reviewed the Army Corps of Engineers final EIS for Pebble Mine, and unfortunately many issues that have been well-known for years are still not addressed.

An EIS should provide thorough case-specific assessment of geologic hazards. Earthquake-induced failures of mine facilities represent one of the biggest potential hazards to the plan detailed in the ACOE EIS. However, the EIS bases its estimate of the strongest possible shaking at the mine site on unsubstantiated and optimistic assumptions about the location of the Lake Clark Fault. Also, the EIS does not include standard modeling of tsunami hazards to facilities near the coastlines of Lake Iliamna and Cook Inlet.

PLP has been aware of these gaps for many years (Higman, 2008). These analyses could have been conducted using established scientific methods, for a reasonable budget, at any time.

Shallow local earthquake risk:

One of the major potential risks to project facilities is a shallow earthquake originating close to the mine site. An adequate EIS must analyze both the size and location of these potential earthquakes. This determines the magnitude of shaking that mine facilities must be designed to withstand. There is no pre-existing peer-reviewed literature on fault locations in the immediate area of the Pebble site, and despite more than a decade of warnings, PLP has not performed the necessary science to evaluate these hazards. Instead, the EIS makes optimistic and unsubstantiated assumptions about the location of the nearby Lake Clark Fault, likely understating the hazard it poses to mine facilities.

To assess seismic risk, the EIS estimates the strength of shaking quantified in terms of the peak acceleration of the ground during earthquakes with various hypothetical sources. The strength of shaking from such an earthquake is primarily a function of both the size (moment magnitude, abbreviated M_W) of the earthquake, and its distance from the proposed mine facilities. The case they identify as producing the strongest shaking is an M_W 8.0 earthquake in the subducting oceanic slab below the mine site, producing shaking of 0.61g. Even though an earthquake similar to 1964 would be much larger, with a M_W of 9.2, the longer distance to the rupture means it would produce much less severe shaking (0.16g), albeit for a longer time. Another scenario that produced relatively strong shaking was a M_W 6.5 earthquake 7 miles directly beneath the mine facilities on an unknown fault (a "floating earthquake"), at 0.56g.

The Lake Clark Fault is the closest mapped fault to the mine site, and is estimated as capable of producing a M_W 7.5 earthquake -- much larger than the M_W 6.5 "floating earthquake." Therefore, the exact location of this fault is key to establishing the level of seismic risk to project facilities. USGS mapping of this fault extends to the end of Lake Clark, 14 miles away from the mine site (Suppl. Fig. 1**a**). From that point, the fault extends towards the mine site, but its exact path is unknown. It may splay into multiple smaller faults, shift direction, or continue straight. The EIS and supplementary data submitted by PLP acknowledge that the details of this fault near the mine site are unknown.

However, by the estimation given in the EIS, the closest possible location of the Lake Clark Fault is 6 miles from the mine site (Suppl. Fig. 1**e**). The EIS predicts that a M_W 7.5 earthquake at this location would produce 0.57g of shaking at the pyritic tailings storage facility, and 0.48g at the bulk tailings storage facility. These numbers are less then the 0.61g they calculate for the deep intraslab subduction zone quake, but barely. Small differences in the exact location of this fault would produce large differences in the amount of expected shaking at mine facilities.

Therefore, assertion that the Lake Clark Fault is 6 or more miles from mine facilities is a key assumption; if it were instead 2 miles away, the shaking would be approximately 0.8 g - by far the strongest source of shaking for mine facilities. If one only relies on the peer-reviewed science to estimate the distance to this little-studied fault, it's very plausible it's within 2 miles (Suppl. Fig. 1**b**).

According to PLP's submitted information, "Pebble Limited Partnership has postulated possible extensions or splays of the Lake Clark fault based on a preliminary examination of the geology and geomorphology in the area surrounding the Pebble mine site." No analysis of this evidence is provided in PLP's documentation, and none has been published in a peer-reviewed source. PLP has provided a map showing several possible splays of the Lake Clark Fault, one coming 5.9 miles from a tailings facility (Knight-Piesold 2019 fig 4.2,, also Suppl. Fig. 1**e**). However, no reasoning is provided for the "possible" extensions of the Lake Clark Fault shown in this figure.

In what seems to be an internal contradiction, the analyses cited in the EIS seem to show that the fault is much nearer to the mine site than 6 miles. A figure from Goodman (2008) shows bedrock faulting directly within the mine site (the graben defined by faults ZG1, ZG2, and ZH), and attributes this faulting to Tertiary movement on the Lake Clark Fault complex (Suppl. Fig. 1**d**). No explanation is given for why these fault traces were not included in their map of potential Lake Clark Fault splays. Also, Rankin (2009) analyzes aeromagnetic and gravity data to show extensions of the Lake Clark Fault that are 2.5 miles from a point labeled "Pebble," as measured by the scale on the figures. These figures lack any geographic reference, so it is difficult to determine what it is shown, but we estimated the alignment by comparing to the Haeussler & Saltus (2004), aeromagnetic map (Suppl. Fig. 1**c**). The result shows one splay in Rankin (2009) running right through the tailings facilities. Also, the gravity figure plots a NW / SE trending fault that bounds a deep-seated tectonic block and runs very close to the dot marked "Pebble" - within about a mile. The discussion concerning these faults is consistent with Goodman (2008): The regional interpretation based on magnetic and gravity data supports the idea that the faults observed at the Pebble Prospect are in fact splays of the Lake Clark Fault. Based on these analyses, a future rupture on this fault could propagate directly beneath mine

facilities, potentially generating both stronger shaking than the 0.61 g design constraint they are currently employing, and surface tilting or offset that poses an additional hazard to those facilities.

Though both Goodman (2008) and Rankin (2009) date from over a decade ago, neither were made available for review until they were released in RFI 139, which came out in February 2020, well after comments were closed on the draft EIS. Given these appear to be the only interpretations of the tectonic context within which the Pebble prospect sits, they are highly relevant to seismic hazards, and provide a great starting point for the fieldwork that has yet to be done despite the EIS being finalized.

Throughout the EIS this work is described as "preliminary." Seismic risk mitigation is a key component of project design and of environmental risk, and this crucial detail should not be "preliminary" in a final EIS. Though the possibility that the Lake Clark Fault passes very near the mine prospect has been public knowledge for over a decade (Higman, 2008), PLP and ACOE contractors have conducted only minimal field investigations. A glaciologist examined lidar collected by PLP (Hamilton, 2010) and did not find obvious lineations. However, PLP's lidar data is not sufficiently high quality to be used for this purpose. In chapter 5, Mitigation, the EIS includes further lidar and aeromagnetic data analysis as a measure in "Applicant's proposed avoidance and minimization." These studies should have already been done and incorporated into the EIS. They also acknowledge work that my colleagues and I have done identifying liquefaction features that provide evidence of strong Holocene shaking, but they have conducted no such research themselves, though it could provide direct constraint on the sort of shaking that might impact mine facilities.

Investigating evidence of shaking, even where there is no surface evidence of faults, is a crucial step. Damaging earthquakes, and the faults that produce them, do not always have a surface expression that can be identified in advance by geologists. A 1997 paper by Lettis et. al. examined a database of 148 reverse earthquakes of 5.4-8.7 magnitude on continental crust, and found that, in contrast to plate-boundary quakes, the majority of intraplate earthquakes occurred in places where there was no Quaternary evidence of faulting. Not only are significant earthquakes possible on "blind" faults that do not show surface lineation, in intraplate settings like the Pebble Mine site, **most** earthquakes occur on such faults.

Absent conclusive evidence that the Lake Clark Fault turns away from the mine site, the prudent and conservative assumption would be to assume the Maximum Credible Earthquake is a M_W 7.5 to 8.0 earthquake with a shallow rupture at the mine site. Such an earthquake would be likely to produce much stronger shaking than what the EIS optimistically assumes, and could lead to the failure of facilities built with these optimistic assumptions as constraints.

Given that the peer-reviewed literature and PLP's reports don't rule out the possibility of fault rupture directly under mine facilities, peak ground acceleration doesn't account for all the hazard posed to these facilities. It is also possible that direct deformation of the ground surface (either surface rupture or tilting) could affect facilities. Thus it's important that the EIS be amended to include this sort of effect.

Tsunami models

PLP acknowledges that tsunamis in Cook Inlet or Lake Iliamna could impact their proposed facilities, however they provide no specific modeling to constraint the nature of these hazards. To understand tsunami hazards, it's necessary to take several steps which are well-known and widely executed by tsunami engineers and scientists. First, specific potential tsunami sources need to be assessed and characterized, including earthquakes that deform the sea or lake bottom, landslides that begin in or enter the water, and volcanic eruptions that can trigger landslides or can produce tsunamigenic pyroclastic flows. Once these sources are identified, the initial tsunami source wave can be characterized - either by looking at displacement for relatively simple earthquake sources, or by a coupled landslide and tsunami model for landslide sources. The propagation of this tsunami can then be modeled by any of a number of well-tested tsunami propagation models. Finally, the shallow-water and onshore impacts can be modeled, where fine-scale and nonlinear effects are strong and can lead to dramatic variability in impacts over relatively small spatial scales. It's important to do this final step with specific facility designs included in the model (e.g. see Jordan Cove Liquefaction Project and Pacific Connector Pipeline Project, DOE/EIS-0532, FERC 2019).

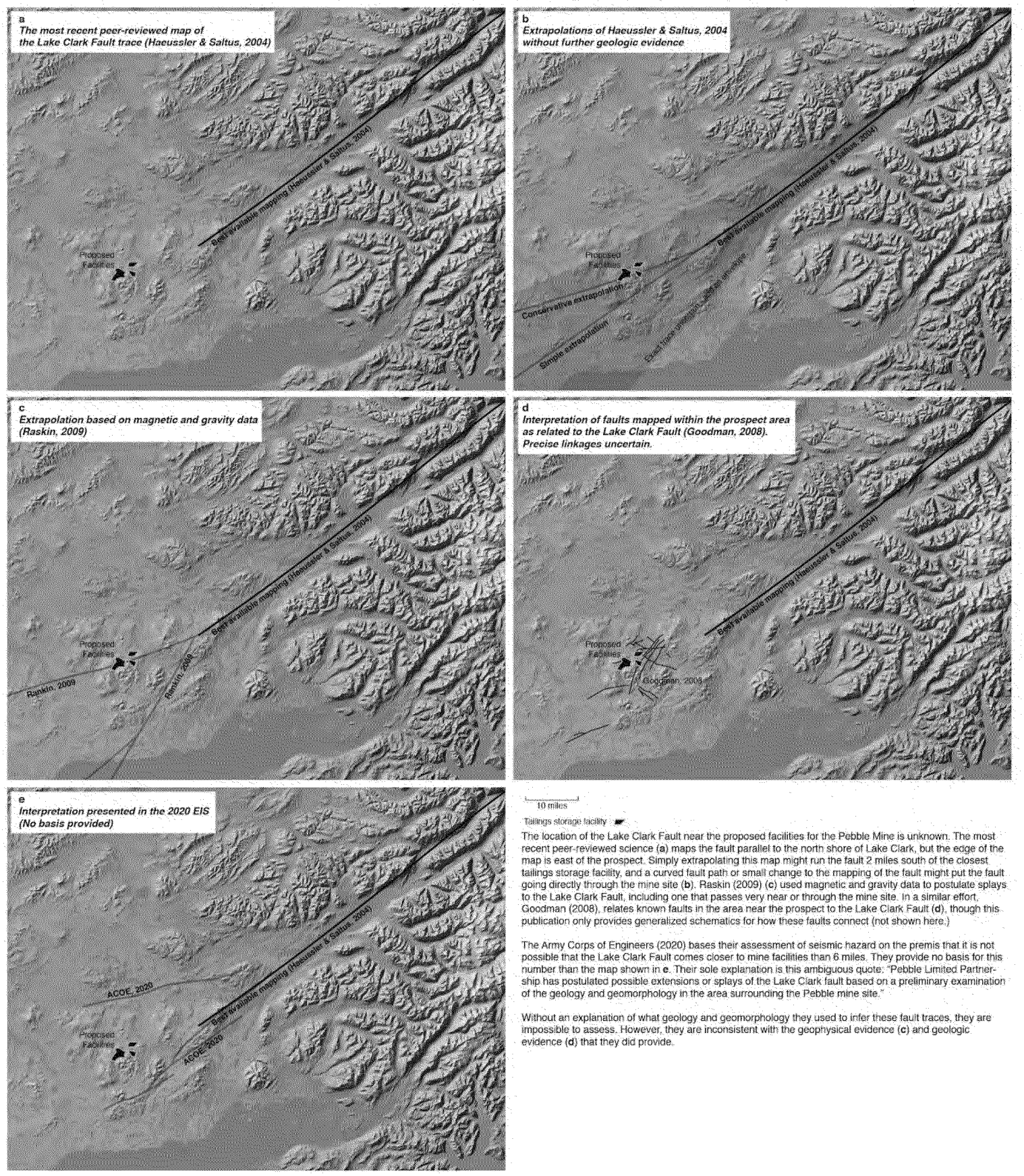
The EIS doesn't do any of these steps thoroughly, and only presents cursory discussion of the first step - identifying potential sources. It cites a broad tsunami design zone map (ASCE 2017), but does not include the specific work that is required to adequately assess hazards.

Thanks for your consideration,

Bretwood Higman

Dr. Bretwood Higman

Supplemental figure 1



The location of the Lake Clark Fault near the proposed facilities for the Pebble Mine is unknown. The most recent peer-reviewed science (**a**) maps the fault parallel to the north shore of Lake Clark, but the edge of the map is east of the prospect. Simply extrapolating this map might run the fault 2 miles south of the closest tailings storage facility, and a curved fault path or small change to the mapping of the fault might put the fault going directly through the mine site (**b**). Raskin (2009) (**c**) used magnetic and gravity data to postulate splays to the Lake Clark Fault, including one that passes very near or through the mine site. In a similar effort, Goodman (2008), relates known faults in the area near the prospect to the Lake Clark Fault (**d**), though this publication only provides generalized schematics for how these faults connect (not shown here.)

The Army Corps of Engineers (2020) bases their assessment of seismic hazard on the premis that it is not possible that the Lake Clark Fault comes closer to mine facilities than 6 miles. They provide no basis for this number than the map shown in **e**. Their sole explanation is this ambiguous quote: "Pebble Limited Partnership has postulated possible extensions or splays of the Lake Clark fault based on a preliminary examination of the geology and geomorphology in the area surrounding the Pebble mine site."

Without an explanation of what geology and geomorphology they used to infer these fault traces, they are impossible to assess. However, they are inconsistent with the geophysical evidence (**c**) and geologic evidence (**d**) that they did provide.

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Rankin, 2009, Pebble Cu-Au-Mo Porphyry Deposit :Analysis and Structural Interpretation of Geophysical Data -- Prepared by Rankin Consultancy for the Pebble Limited Partnership, included in RFI 139.

DEPARTMENT OF THE ARMY
ALASKA DISTRICT, U.S. ARMY CORPS OF ENGINEERS
REGULATORY DIVISION
P.O. BOX 6898
JBER, AK 99506-0898

August 20, 2020

Regulatory Division
POA-2017-271

Mr. James Fueg
Pebble Limited Partnership
3501 C Street, Suite 501
Anchorage, Alaska 99503

Dear Mr. Fueg:

As you are aware, the U.S. Army Corps of Engineers, Alaska District (District) has completed the Final Environmental Impact Statement (FEIS) developed for review of your permit application submitted in December of 2017. The FEIS completed the National Environmental Policy Act analysis required for your proposed discharge of dredged and fill material into waters of the United States, including wetlands.

The District will next develop a Record of Decision (ROD) for your proposed discharge. As part of the ROD the District made Clean Water Act Section 404(b) (1) factual determinations that discharges at the mine site would cause unavoidable adverse impacts to aquatic resources and, preliminarily, that those adverse impacts would result in significant degradation to those aquatic resources. Therefore, the District has determined that in-kind compensatory mitigation within the Koktuli River Watershed will be required to compensate for all direct and indirect impacts caused by discharges into aquatic resources at the mine site. Direct and indirect impacts at the mine site total 2,825 acres of wetlands, 132.5 acres of open waters, and 129.5 miles of streams.

The District has also determined that compensatory mitigation is required for unavoidable adverse impacts to aquatic resources from discharges associated with the transportation corridor and the port site. Direct and indirect impacts associated with the transportation corridor and port site total 460 acres of wetlands, 231.7 acres of open waters, and 55.5 miles of streams.

The required components of a compensatory mitigation plan are identified in the Code of Federal Regulations at 33 CFR Part 332 and 40 CFR Part 230 Compensatory Mitigation for Losses of Aquatic Resources; Final Rule (Rule). According to the Rule, compensatory mitigation means the restoration (re-establishment or rehabilitation), establishment (creation), enhancement, and/or in certain circumstances, preservation of wetlands, streams and other aquatic resources. There are three approved mechanisms for providing compensatory mitigation, which include mitigation banks, in-lieu fee programs, and permittee-responsible mitigation with preference, in that order. Your mitigation plan may include a combination of means and mechanisms but must comply with all required components of Rule and be found sufficient to offset the unavoidable adverse impacts to the aquatic resources identified above.

Please submit the required compensatory mitigation plan to the District within 90 days from the date of this letter. The District will review the compensatory mitigation plan upon submittal to determine if the amount and type of compensatory mitigation offered is sufficient to offset the identified unavoidable adverse impacts to aquatic resources and overcome significant degradation at the mine site, and to determine whether the plan meets all requirements identified in the Rule.

If you have any questions regarding this matter please contact me by telephone at (907) 753-2712 or by email at poaspecialprojects@usace.army.mil.

Sincerely,

David S. Hobbie

David S. Hobbie
Regional Regulatory Division Chief

Independent Expert Engineering Investigation and Review Panel

Report on Mount Polley Tailings Storage Facility Breach

January 30, 2015

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Independent Expert Engineering Investigation and Review Panel

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EXECUTIVE SUMMARY

THE EMBANKMENTS

Three contiguous embankments confinethe Mount Polley tailings storage facility (TSF) .Of these, the Perimeter Embankment, where the breach occurred, was the northern flank of the TSF.

The embankments are composed of a core with the function of acting as an impervious element Downstream of the core, a filterzone restrains material in the core from outward migration .The core and filterare then supported by a rockfillzone .In the upstream direction, the core is supported by an upstream fillzone composed of rockfill and/or tailings .

THE BREACH

The breach occurred within the Perimeter Embankment At the time of the breach, the TSF was permitted under the Ministry of Energy and Mines, Permit M-200, with approval to raise the crest by 2 5metres .The breach occurred early on August 4, 2014 at a crest elevation 1 metre short of its permitted elevation Loss of containment was sudden, with no warning .The recorded pond elevation at 6:30 pm on August 3, 2014 was 2 3 metres below the crest .

THE MANDATE

Following the breach of the tailings storage facility at the Mount Polley Mine, the Government of British Columbia, through the Ministry of Energy and Mines, together with the Williams Lake Indian Band and the Soda Creek Indian Band, established an independent expert investigation and review panel (the Panel) to investigate and report on that breach .The Panel was required to submit a finalreport to the Ministry of Energy and Mines and the Williams Lake Indian Band and the Soda Creek Indian Band on or before January 31, 2015 .

The purpose of the investigation has been as follows:

- To investigate and report on the cause of the failure of the tailings storage facility that occurred on August 4, 2014 at the Mount Polley Mine (the Mine) in BC .
- In addition, the Panel may make recommendations to government on actions that could be taken to ensure that a similar failure does not occur at other mine sites in BC .
- The Panel is authorized, as part of its investigations and report, to comment on what actions could have been taken to prevent this failure and to identify practices or successes in other jurisdictions that could be considered for implementation in BC .

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Further, it was expected that the Panel would:

- Identify any mechanism(s) of failure of the tailings storage facility.
- Identify any technical, management or other practices that may have enabled or contributed to the mechanism(s) of failure. This may include an independent review of the design, construction, operation, maintenance, surveillance and regulation of the tailings storage facility.
- Identify any changes that could be considered to reduce the potential for future such occurrences.

PANEL ACTIVITIES

The Panel began its inquiry with multiple hypotheses for failure:

- Human intervention
- Overtopping
- Piping and cracking
- Foundation failure

The Panel found no evidence of failure due to either human intervention or failure due to overtopping, notwithstanding the fact that an episode of overtopping over portions of the Perimeter Embankment occurred in May 2014. The question of piping and cracking, which is a common cause of failure of earth dams, received corresponding attention. Although factors of concern were identified by the Panel, it did not find evidence that piping and/or cracking caused the breach.

This reduced the focus of the Panel to failure in the foundation of the embankment. Visual evidence of bodily outward displacement and rotation of the embankment remnants were consistent with foundation failure. A foundation can be weak and fail in a number of ways. One is the presence of a weak layer that had been undetected during design. Another is the presence of a brittle stratum that loses strength as it comes under load and becomes too weak to support the load applied by the embankment and TSF contents, so that failure ensues. Yet another possibility is the presence of a layer that is compressible under the applied load and, when stressed, develops high pore pressure that results in weakening of an otherwise much stronger material. This is termed undrained failure. It was the object of the site studies undertaken by the Panel to determine which of these foundation failure mechanisms prevailed.

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EXECUTIVE SUMMARY

The Panel undertook comprehensive Surface Investigations that provided detailed, observable information on the sliding mechanism that had occurred .A challenging and complex Subsurface Investigation was also undertaken, partly in collaboration with the site investigation program initiated by the both the Mines Inspector and Mount Polley Mining Corporation (MPMC), and in addition, by the Panel alone.

The Subsurface Investigation was particularly valuable in definingthe controlling stratigraphy in the breach area and identifying that the failure occurred in a glaciolacustrine layer, called Upper GLU No indication of pre-shearing or the presence of markedly strain-weakening materials was detected, leaving undrained failure in the Upper GLU as the only viable hypothesis.The type and extent of pre-failure site investigations were not sufficientto detect this stratum or to identify its critical nature.The Panel's Subsurface Investigation was structured to obtain undisrupted samples of the Upper GLU and subsequently determine its properties.

The Upper GLU was found to be preconsolidated prior to embankment construction, but became normally consolidated under the loads applied by construction of the Perimeter Embankment.That is, it had experienced prior consolidation and strengthening under loads in its geological past, but not under the loads associated with the Perimeter Embankment, which created the normally consolidated state .Under these conditions, the Upper GLU was compressible and susceptible to undrained failure.This condition had not been recognized in the design of the TSF.

Laboratory tests were performed to determine the undrained strength of the Upper GLU and these parameters were utilized in computer analyses to calculate whether failure should have occurred under the applied load.The results were confirmatory.

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EXECUTIVE SUMMARY

CONCLUSIONS

The Panel concluded that the dominant contribution to the failure resides in the design. The design did not take into account the complexity of the sub-glacial and pre-glacial geological environment associated with the Perimeter Embankment foundation. As a result, foundation investigations and associated site characterization failed to identify a continuous GLU layer in the vicinity of the breach and to recognize that it was susceptible to undrained failure when subject to the stresses associated with the embankment.

The specifics of the failure were triggered by the construction of the downstream rockfill zone at a steep slope of 1.3 horizontal to 1.0 vertical. Had the downstream slope in recent years been flattened to 2.0 horizontal to 1.0 vertical, as proposed in the original design, failure would have been avoided. The slope was on the way to being flattened to meet its ultimate design criteria at the time of the incident.

REGULATORY OVERSIGHT

The Panel reviewed the roles and responsibilities of the B.C. Ministry of Energy and Mines (the Regulator) and its interactions related to the MPMC TSF. The Panel found that inspections of the TSF would not have prevented failure and that the regulatory staff are well qualified to perform their responsibilities. The Panel found that the performance of the Regulator was as expected.

THE FUTURE

The Panel has examined the historical risk profile of the current portfolio of tailings dams in B.C. and concluded that the future requires not only an improved adoption of best applicable practices (BAP), but also a migration to best available technology (BAT). Examples of BAT are filtered, unsaturated, compacted tailings and reduction in the use of water covers in a closure setting. Examples of BAP bear on improvements in corporate design responsibilities, and adoption of Independent Tailings Review Boards. Specific recommendations are made in the body of the report.

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1 | Introduction

Following the breach of the tailings storage facility at the Mount Polley Mine on August 4, 2014, the Government of British Columbia, through the Minister of Energy and Mines, together with the Williams Lake Indian Band and the Soda Creek Indian Band, established an independent expert engineering investigation and review panel (the Panel) to investigate and report on that breach.

1.1 PURPOSE OF THE PANEL

The purpose of the Panel is as follows:

- To investigate into and report on the cause of the failure of the tailings storage facility (TSF) that occurred on August 4, 2014 at the Mount Polley Mine (the Mine) in BC.
- In addition, the Panel may make recommendations to government on actions that could be taken to ensure that a similar failure does not occur at other mine sites in BC.
- The Panel is authorized, as part of its investigation and report, to comment on what actions could have been taken to prevent this failure and to identify practices or successes in other jurisdictions that could be considered for implementation in BC.

Under its Terms of Reference, it is expected that the Panel will:

- Identify any mechanism(s) of failure of the TSF.
- Identify any technical, management or other practices that may have enabled or contributed to the mechanism(s) of failure. This may include an independent review of the design, construction, operation, maintenance, surveillance and regulation of the TSF.
- Identify any changes that could be considered to reduce the potential for future such occurrences.

1.2 PANEL MEMBERS

The members of the Panel are:

- Dr. Norbert R. Morgenstern (Chair), CM, AOE, FRSC, FCAE, PhD, PEng.
- Mr. Steven G. Vick, M Sc, PE.
- Dr. Dirk Van Zyl, Ph D, PE, PEng.

The detailed Terms of Reference are included as Appendix A.

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2 | What Did the Panel Do?

2.1 PANEL ACTIVITIES

In furtherance of its mandate, the Panel undertook the following:

- It retained Thurber Engineering Ltd. (Thurber) to conduct field investigations, data compilation, laboratory testing, and analyses. All of this work proceeded under the direction of the Panel.
- It assembled and inspected related documents in the files of the Mine, its consultants who have acted as the Engineer of Record (EOR), and the Ministry of Energy and Mines (MEM).
- It solicited and collected relevant information from the public at large.
- It conducted a number of personal interviews to clarify information recorded in documents.
- It convened regular formal meetings with recorded minutes.
- It interpreted all of the above to arrive at conclusions and recommendations.

2.2 SUPPORTING INFORMATION

As directed by the Terms of Reference, the Panel has provided this final report, along with the appendices, to the Minister of Energy and Mines, the Williams Lake Indian Band and the Soda Creek Indian Band. The background reports and information used by the Panel for the preparation of this report were also made available to these parties through an online data room. The Panel considers the supporting information and substantiating documentation to be an integral part of its report that is necessary for a proper understanding of its findings.

The B.C. Ministry of Energy and Mines and Ministry of Environment, Conservation Officer Services, have directed the Panel to withhold some of the documents, and redact portions of other documents, so that the Panel's inquiry does not compromise any other investigations and to ensure it is in compliance with the privacy protection provisions of *Freedom of Information and Protection of Privacy Act* (FIPPA) (see Appendix A). The redaction of personal information was completed by Shared Services BC. As a result, these documents, which may have been cited in this report are not available at this time.

The background information was provided to the Panel by many different sources. Appendix B contains further details on background reports and information, and how these were organized and provided to the Minister of Energy and Mines, the Williams Lake Indian Band and the Soda Creek Indian Band.

Within the text of the report and appendices, specific documents are referenced by an endnote, which contains the document number as it relates to where it can be found in the data room. See Appendix B for more details.

Additional technical references are also cited by endnote directly within the body of this report. Endnotes can be found at end of each section of the report. The collected technical references can be found at the end of the report.

The observations of the Panel are supported by referenced documents where possible. The findings of the Panel are outlined in the sections of the report that follow. Conclusions and recommendations are presented in detail at the end of the report.

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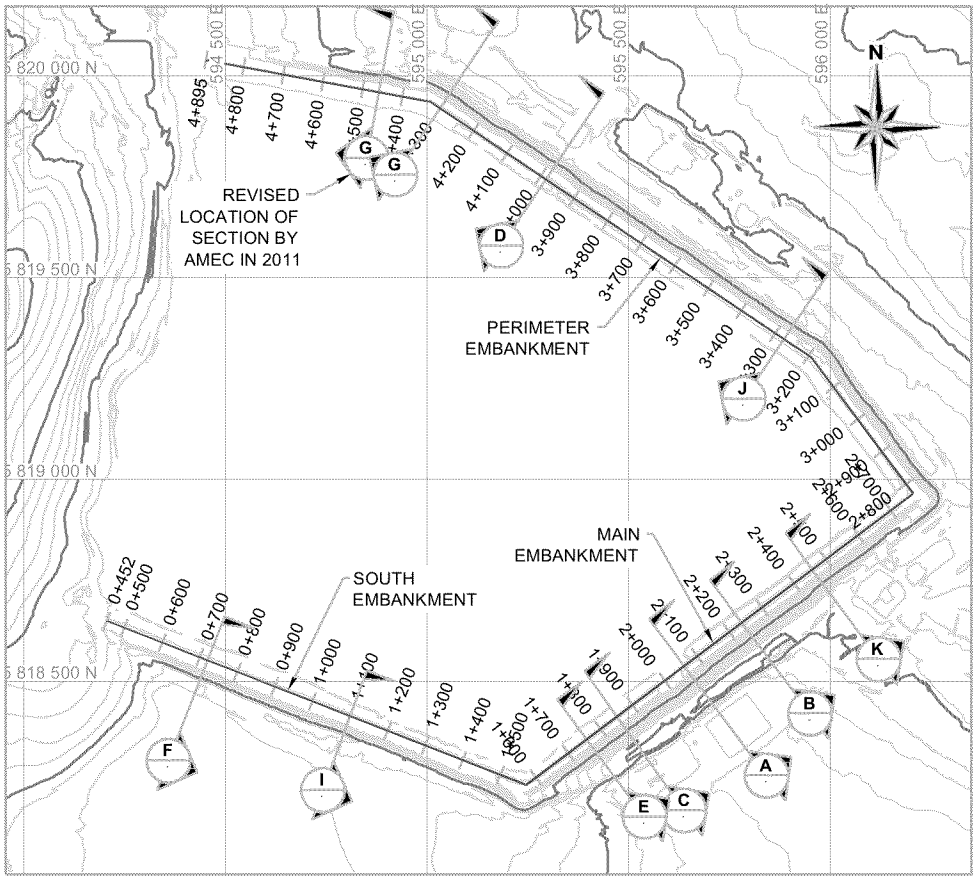
3 | Tailings Storage Facility (TSF)

3.1 DESCRIPTION OF TSF

Mount Polley Mining Corporation (MPMC) operates the Mine, and the British Columbia Ministry of Energy and Mines (MEM) is the Regulator From the firstapproved and constructed portion of the TSF, in 1995, to early 2011, Knight Piésold (KP) was the Engineer of Record (EOR) Subsequently, AMEC assumed the responsibility as EOR and had that role at the time of the breach BGC were to assume that responsibility after the 2014 construction season .

Figure 3.1.1 is a plan of the TSF adapted from the last As-Built Construction Report .[1] It indicates that the TSF was composed of three embankments: the Main Embankment, the Perimeter Embankment, and the South Embankment .The TSF is closed to the west by rising natural ground .The figurealso indicates the location of instrumented control sections utilized by the succession of EORs .The breach occurred in the Perimeter Embankment near Section G .

FIGURE 3.1.1: TAILINGS STORAGE FACILITY PLAN



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3.2 CONSTRUCTION OF TSF AND POND ELEVATION

The Main Embankment and the Perimeter Embankment were the firstto go into construction, with the Starter Dam completed in 1996 .The South Embankment followed in later years .**Figures 3.2.1** and **3.2.2** present the sections of the Main and Perimeter Embankments at the end of the 2013 construction season .**Figure 3.2.1** is for the Main Embankment at Section A, approximately the highest section .**Figure 3.2.2** is for the Perimeter Embankment and represents the closest instrumented section (Section D) to the breach zone at the time of failure.

FIGURE 3.2.1: MAIN EMBANKMENT AT SECTION A

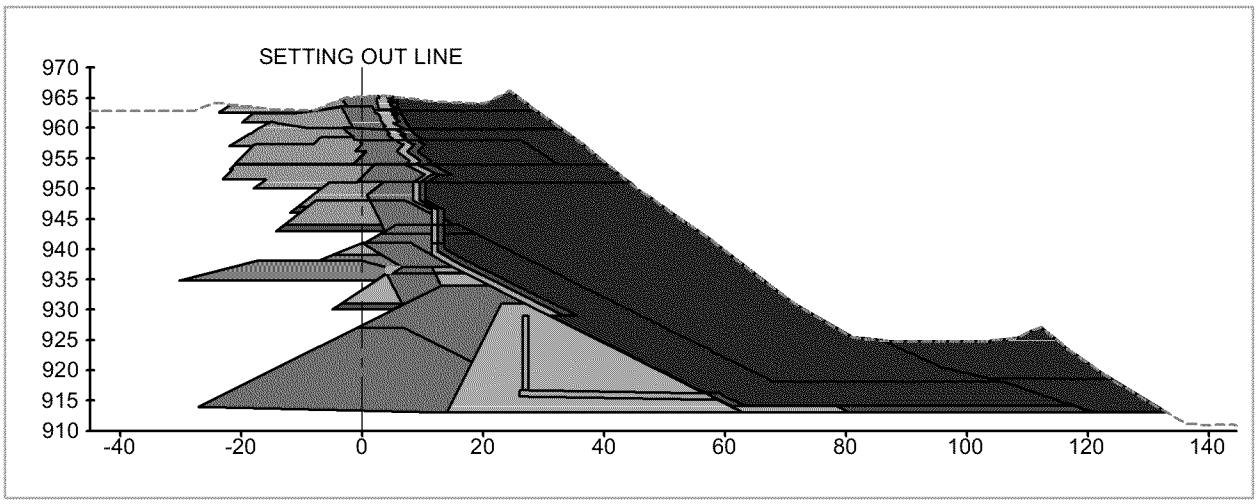
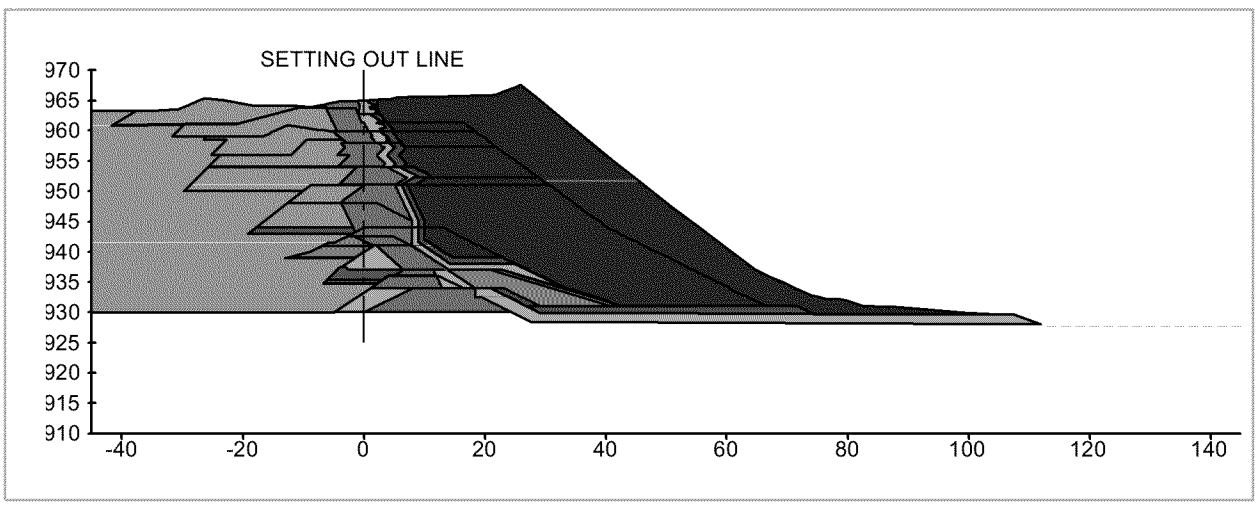


FIGURE 3.2.2: PERIMETER EMBANKMENT AT SECTION D



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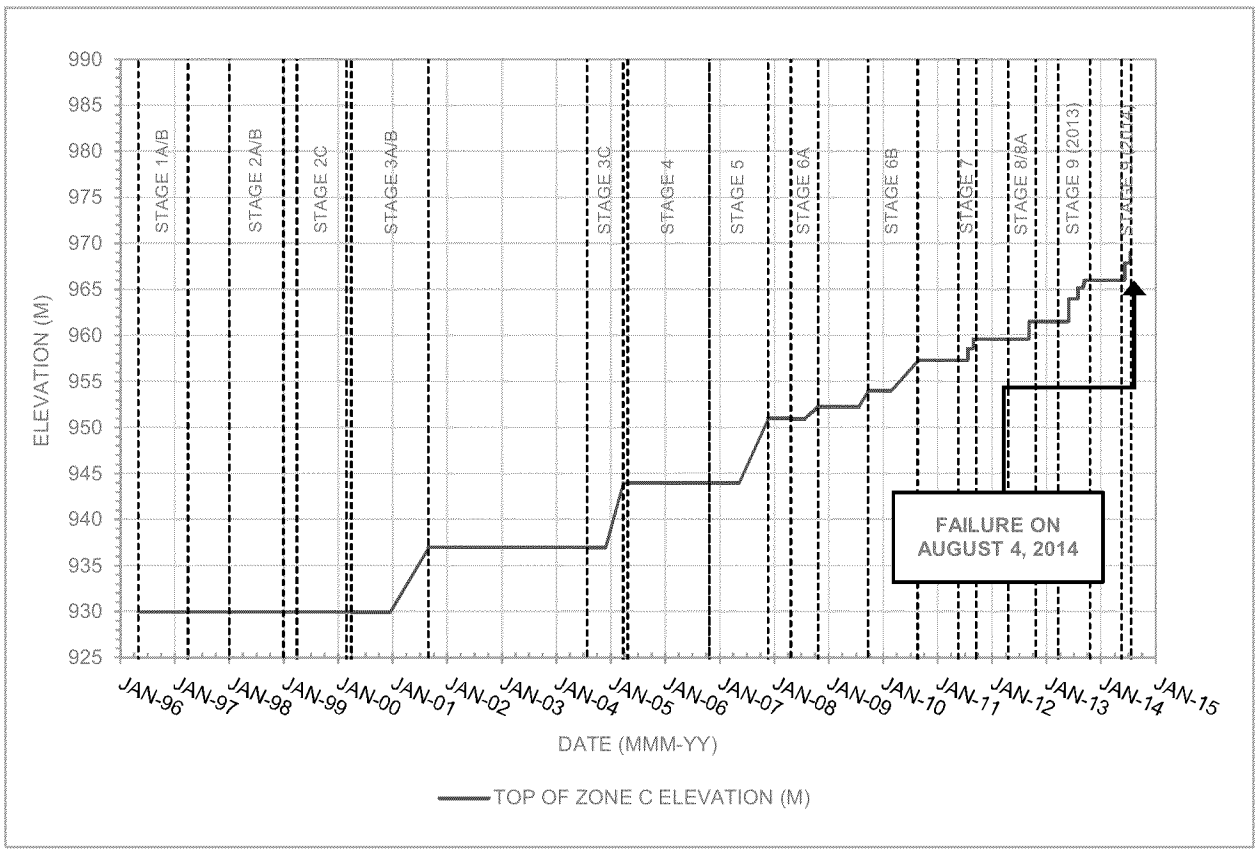
3 | Tailings Storage Facility (TSF)

The history of the construction of the embankments is summarized in **Figure 3.2.3,** which indicates each stage of dam raising up to the occurrence of the breach The Starter Dam for the embankment was constructed in 1996 to a crest elevation of 927 0 metres (m) The embankments were subsequently raised together in stages as shown . Construction of the Stage 9 raise from approximately elevation (El) 967 5m to El 970 0 m was started at the end of April 2014 Following completion of Stage 9, Stage 10 was planned to raise the crest to El 972 5m, which would have provided adequate storage to the end of September 2015 Stage 10 was under review for approval at the time of the breach .

FIGURE 3.2.3: MOUNT POLLEY TSF AND ZONE C SHELL TOP ELEVATIONS VERSUS TIME



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3.3 POND ELEVATION AT TIME OF BREACH

At the time of the breach, the TSF was permitted under MEM Permit M-200 with approval to raise the crest to El 970 m. The breach occurred early on August 4, 2014 at a core elevation of El. 969.1 m. Loss of containment was sudden, with no identified precursors. The recorded pond elevation at 6:30 pm on August 3, 2014 was El. 966.83 m.

Loss of containment was sudden, with no identified precursors.

ENDNOTE

1) MP00044

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4 | How Did This Dam Fail?

4.1 CLASSIFICATION OF DAM FAILURE

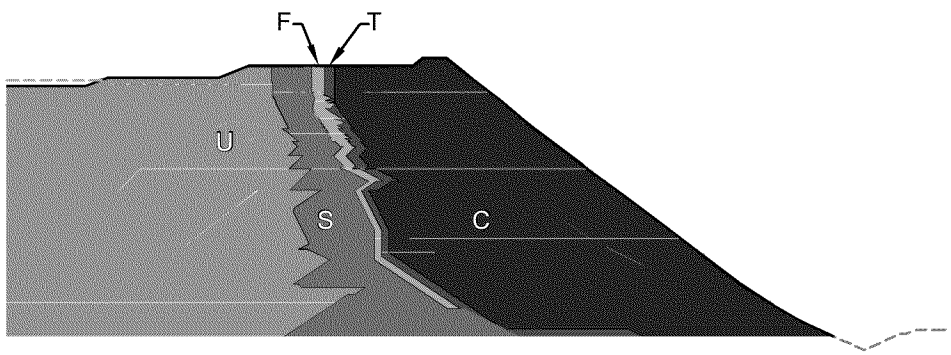
The following directional conventions are adopted throughout, with the dam as the frame of reference:

- Upstream — toward the impoundment interior
- Downstream — away from the impoundment interior
- Right — to the right, looking downstream
- Left — to the left, looking downstream

Figure 4.1.1 shows a simplifiedcross-section of the dam .It is constructed of both earth and rockfilland would be classified as a zoned earth and rockfill dam .The specific zones are:

U Zone Upstream fill
C Zone Rockfill
S Zone Till core
F Zone Filter
T Zone Transition

FIGURE 4.1.1: SIMPLIFIED CROSS-SECTION OF THE MOUNT POLLEY DAM



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The impervious element of the dam is the till core (Zone S), composed of glacial deposits (till) excavated from selected borrow areas .The duty of the rockfillzone (Zone C) is to support the core, without which the core would not be stable .When seepage flowsthrough the core or if it became cracked, its relatively fine-grainedmaterial might erode into the rockfill .The duty of the filter(Zone F) and transition (Zone T) is to collect any seepage coming through the core and to prevent finesfrom migrating out of it Zone T is a transition to Zone C and it is intended to stop migration of filtermaterial into Zone C .While Zone C is somewhat compacted to improve its density, this is not sufficientto preclude migration of Zone F into Zone C . Hence, a transition Zone T is needed .

Zone U is composed either of tailings or rockfillif tailings beach material cannot be delivered in time It should be noted that the core of the dam is inclined slightly in an upstream direction .This configurationis known as modifiedcentreline construction Zone U provides support on the upstream side of the core It also has other functions such as keeping clear water away from the core Zone U tailings would tend to migrate into and fill any cracks that might develop in the core, preserving its function .

4.2 POTENTIAL FAILURE MODES

Assessing potential failure modes should be consistent with the characteristics of the breach; it was relatively sudden and with no apparent warning .In addition, by outward comparison, the Perimeter Embankment appears less vulnerable than the Main Embankment design section (**Figure 3.2.1**) .The Main Embankment is higher, is designed on the same principles as the Perimeter Embankment, and Zone U has a less developed beach .Moreover, by the time of the breach, small movements had previously been detected in the Main Embankment foundation, and they were being managed by design and construction changes in response to observations .The Panel concluded that, in order to account for such an abrupt event in the Perimeter Embankment, local features likely prevailed .

The Panel concluded that, in order to account for such an abrupt event in the Perimeter Embankment, local features likely prevailed.

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4.3 FOUR CLASSES OF FAILURE MECHANISMS CONSIDERED

Based on the experience of the Panel with both water and tailings dams, the Panel determined that the following four classes of failure mechanisms required consideration:

- Human intervention
- Overtopping
- Piping and cracking
- Foundation failure

Before considering each in turn, it is necessary to understand the timeline of activities at the site prior to the failure

The timeline constructed from construction and personal reports is presented in **Table 4.3.1** The breach section extends approximately from survey station (Sta) 4+200 to 4+300 .(refer to **Figure 3.1.1**) .Key observations are:

- Last construction ending at 6:30 pm, August 3, 2014
- Site observation indicating no issues at 10:30 pm, August 3, 2014
- Operations at perimeter seepage pond, no issues at 11:45 pm, August 3, 2014
- Perimeter seepage pond water fluctuation beginning at 12:45 am, August 4, 2014
- Power lost (likely due to breach) at 1:15 am, August 4, 2014
- Breach identified at 2:05 am, August 4, 2014

TABLE 4.3.1: TIMELINE OF EVENTS AND ACTIVITIES AT BREACH SECTION AND ADJACENT AREAS

DATE	ACTIVITY	POND EL.	SOURCE
7/10	Zone F (filter) trenching from 4+300 to 4+750, El .9670	966 55	Construction Daily Report (MPMC)
7/14	Zone S (till) placement from 4+305 to 4+925, El .968 5	966 55	Construction Daily Report [1]
7/15	Zone S (till) placement from 3+980 to 4+305, El .968 5 Zone S (till) placement from 4+420 to 4+770, El .968 8	966 55	Construction Daily Report [1] *
7/16	Zone S (till) placement from 3+990 to 4+768 @ El .968 5 (completed to PE pipe) [1] Zone S (till) placement from 4+395 to 4+757 @ El .968 8	966 53	Construction Daily Report [1] *
7/17	Zone S (till) placement from 3+995 to 4+395 @ El .9691 (completed to PE pipe)	966 60	Construction Daily Report [1] *
7/24	Zone C (rock) placement from 4+525 to 4+650, El .968 8	966 68	Construction Daily Report [1] *
	Extreme rainfall, Perimeter overflowing [ii]		TSF Leadhand Report
7/25	Zone C (rock) placement from 4+335 to 4+525, El .968 8	966 73	Construction Daily Report [1]*
	Perimeter still in "Red" with all pumps running, only 1 7 metres left in perimeter overflow		TSF Leadhand Report [2]

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TABLE 4.3.1: TIMELINE OF EVENTS AND ACTIVITIES AT BREACH SECTION AND ADJACENT AREAS *continued*

DATE	ACTIVITY		POND El.	SOURCE
7/26	Perimeter held @ "6" on scale all day but still overflowing Till pit level went up 20 cm overnight Retrieved piezo below corner 1			TSF Leadhand Report [2]
7/28	Zone C (rock) placement from 4+180 to 4+335, El .968 8		966 70	Construction Daily Report [1]*
8/01	Zone C (rock) placement (grading down near Corner 1), El .969 0 Raising of PE pipe in the C zone		966 80	Construction Daily Report [1]*
	Last placement of Zone C (rock) in breach area with four 733s (60T) and one D-8R			Panel Interview 10/22/14
8/02	Placing Zone C on the PE pipe after raising it		966 82	Construction Daily Report [1]*
8/03	6:30 am to 6:30 pm	Placing C zone on the PE pipe after raising it (completed) Grading C Zone (rock) from corner 5 to the PE pipe that has been recently placed by Peterson	966 83	Construction Daily Report [1]*
	10:30 pm	Good berm, good slope, no visible cracks		Shifter Dump Logbook (Mine Ops), B-crew night shift [3]
	11:00 pm	East Perimeter Pond going to alarm in high level within the hour		Dam Breach Report [4]
	11:30 pm	Second pump (perimeter pond) started, nothing unusual noticed		Dam Breach Report [4]
	11:45 pm	Drove from perimeter pond across dam crest to PE pipe and back to Corner 5 (across breach area), nothing unusual noticed		Panel Interview 10/22/14
	12:00 midnight	Second pump drawing down perimeter pond water level (recollection of control instrumentation)		Panel Interview 10/22/14
8/04	12:15 am	Pond water starts to level out (recollection of control instrumentation)		Panel Interview 10/22/14
	12:45 am	Pond water level starts to slightly increase (recollection of control instrumentation)		Panel Interview 10/22/14
	1:00 am	Pond water level rising sharply (recollection of control instrumentation)		Panel Interview 10/22/14
	1:15 am	Lights went out in electrical shop, mill shut down, pond water level spikes sharply (recollection of control instrumentation)		Dam Breach Report [4] Panel Interview 10/22/14
	2:05 am	Dewatering operator discovers that tailings dam had breached		Dam Breach Report [4]

* PHOTO AVAILABLE IN CONSTRUCTION DAILY REPORT.

[i] "PE PIPE" IS THE RETURN-WATER HDPE LINE FROM THE SEEPAGE RECYCLE PUMP THAT CROSSES THE DAM CREST AT THE LOCATION OF SECTION D, APPROX STA .3+960 (SEE PHOTO IN CONSTRUCTION DAILY REPORT OF 8/02/14).

[ii] "PERIMETER" REFERS TO PERIMETER SEEPAGE POND ."OVERFLOW" REFERS TO OVERFLOW FROM PERIMETER SEEPAGE POND INTO TILL BORROW PIT (PANEL INTERVIEW, 10/22/14).

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4.3.1 HUMAN INTERVENTION

Human intervention may be accidental, such as discharge from a tailings line eroding the structure in an uncontrolled manner, or wilful destruction .A tailings pipeline on the Perimeter Embankment crest was not in service at the time of the breach, and the Panel has found no other evidence of failure due to human intervention .

4.3.2 OVERTOPPING

Although water management had been challenging in later years, and an episode of overtopping over portions of the Perimeter Embankment had occurred in May 2014, freeboard was being carefully monitored around the time of the breach as a result of prior insistence on the part of the Ministry of Energy and Mines (MEM) .The freeboard with respect to the core at the time of the failure was 2 3 metres (m) .[5]

The Panel has found no evidence of failure due to overtopping prior to breach development.

The Panel has found no evidence of failure due to overtopping prior to breach development .

4.3.3 PIPING AND CRACKING

Piping and cracking of the core of an earth-rockfill dam can lead to internal erosion and ultimately loss of containment .This is one of the most common causes of failure of earth dams and has been much studied .The failure of the Omai Tailings Dam[6] provides an example of a failure by piping and internal erosion.

The following factors were of concern to the Panel:

1) Modified centreline tailings dams, while within precedent, are disposed to longitudinal cracking.
2) Following Stage 5, the core width was reduced to 5 m, which is thin for the planned hydraulic head; again, this has precedent but requires careful filter and transition design and construction.
3) The filter and transition were particularly thin and required meticulous care to be constructed as intended.
4) Details of filter and transition construction in as-built drawings indicated departure from intended design.[7]
5) Much of the as-placed filter material failed to meet applicable filter criteria and requirements for internal stability of its grading .
6) The core had been overtopped in one location for a brief period in 2014, resulting in softening and enhanced deformability .
7) The core was not contained by the steep rockfill shell in as stiff a manner as might have been possible.
8) A cavity was detected in the core remnant of the left abutment of the breach that was the result of internal erosion, see Appendix C .
9) Observed flow to the seepage collection system exhibited a transient spike on April 22, 2013, of the kind

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sometimes characteristic of internal erosion (see Appendix F for details).

Notwithstanding these concerns, the Panel notes:

1) No abnormal seepage observations were detected except for the spike on April 22, 2013 (see Appendix F).
2) Sonic drillholes were located as close to the abutments of the breach as safely possible.They did not detect any suspicious piping pathways .
3) Excavation of the right abutment of the breach did not find any piping pathways through the core.
4) Grading of samples of filter material recovered from the breach area indicate that internal erosion did not produce large flows or overall loss of core integrity (see Appendix C).

Accordingly, and despite the concerns identifiedby the Panel, it did not findevidence that the breach was caused by piping and/or cracking resulting in uncontrolled internal erosion .

4.3.4 FOUNDATION FAILURES

Observations from the Surface Investigations provided clear evidence for shearing, bodily lateral displacement, and rotation of the embankment that resulted in the breach.

Observations from the Surface Investigations (see section 5 1 and Appendix C for details) provided clear evidence for shearing, bodily lateral displacement, and rotation of the embankment that resulted in the breach .The Panel concluded that the primary cause of the breach was dislocation of the embankment due to foundation failure .This resulted in loss of containment of both the clear water contained in the tailings storage facility (TSF), and tailings, which flowedout of the breach .Clearly, the foundation has behaved in a weaker manner than anticipated in the design A major focus of this investigation was therefore to determine the foundation characteristics that account for the observed failure mode and to compare the outcome with the design basis .

A number of circumstances can contribute to such weak behaviour, and all require careful assessment .

It is well-known that glaciated terrain can be exposed to glacial drag forces and leave in the underlying sediments and bedrock, if relatively soft, continuous weak surfaces at the residual strength of the material .The residual strength is the weakest resistance that the material can offerand arises from preferred orientation of platy clay particles .Valley rebound folding and expansion in soft bedrock can also result in weak residual strength materials, but these processes have not acted at the TSF Examples of large tailings facilities on glacially sheared material at

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low strengths are the Mildred Lake Settling Basin at the Syncrude Canada Ltd site [8] and the large TSF at the Zelazny Most Copper Mine.[9] In both cases, movements are slow and are managed by adaptive response to observations.

Another source of unanticipated behaviour can be a deposit within the foundation of a dam that exhibits pronounced strain-weakening behaviour; that is, it loses considerable resistance once its peak resistance is attained. This type of behaviour was discovered during the forensic investigation into the Aznalcollar (Los Frailes) Tailings Dam failure in Spain.[10] The movements in that case were sudden, without any observable precursors. The instrumentation at the time was minimal.

A further source of unanticipated behaviour arises when a structure is being built in stages on a soft substrate that is contractant; that is, it tends to contract, or densify. When such a soil is subjected to shearing due to loading that occurs slowly, the resulting volume changes strengthen the soil as it densifies. This is known as drained loading. However, if the contractant soil were to be loaded too quickly for water to be expelled and permit volume change, pore pressures develop that weaken the soil. This is known as undrained loading, and the resistance is less than its drained equivalent.

Undrained response can also be initiated if the soil displays a rapid reduction in resistance as yielding is initiated, even under drained conditions. This has sometimes been called spontaneous liquefaction when flowslides develop. While the Mount Polley failure was not sufficiently mobile to be regarded as a flow, the concept of spontaneous undrained response cannot be disregarded in a broadly based inquiry such as this. The implications for stability of the undrained response of soft, contractant soils to staged construction were presented at length in a classic paper by Ladd [11] and are discussed in a widely accepted graduate-level text by Duncan and Wright.[12] The Kingston flyash slurry spill is an example of a TSF that failed by this undrained mechanism (http://www.tva.gov/kingston/rca/).

All of the above hypotheses regarding the characteristics of the ground conditions in the breach zone were considered in the Technical Commentary that follows. The Technical Commentary presents the findings arising from both surface and subsurface investigations, laboratory studies, computational analyses, and design, construction, and monitoring reviews, in support of the explanation of the cause of failure.

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ENDNOTES

1) MP10000

2) MP10021

3) MP10022

4) MP10013

5) MP00188

6) Vick, S G , 1996 .The failure of the Omai Tailings Dam .*Geotechnical News*, September, pp .34-39 .

7) MP00044

8) Alencar, J , Morgenstern, N R .and Chan, D H , 1994 . Analysis of foundation deformations beneath the Syncrude tailings dyke .*Canadian Geotechnical Journal*, Vol .31, pp .868-884 .

9) Jamiolkowski, M , 2014 .Soil mechanisms and the Observational Method: Challenges at the Zelazny Most copper tailings disposal facility .*Geotechnique*, Vol .64, pp .590-618 .

10) Gens, A .and Alonso, E E , 2006 .Aznalcollar dam failure – Part 2: Stability conditions and failure mechanism .*Geotechnique*, Vol .56, pp .185-201 .

11) Ladd, C C , 1991 .Stability evaluations during staged construction .*Journal of Geotechnical Engineering*, American Society of Civil Engineers, Vol .117, pp .540-615 .

12) Duncan, J M .and Wright, S G , 2005 .*Soil Strength and Slope Stability* .John Wiley and Sons, Inc ,.New Jersey, 298 p .

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5 | Panel Observations

5.1 SURFACE INVESTIGATIONS

Surface investigations of the breach and adjacent areas were conducted to gather evidence about the cause of the failure, to document this evidence, and to provide necessary context for related Panel activities Appendix C provides a comprehensive account of the surface investigations from which this summary has been compiled The electronic version of Appendix C also contains a virtual three-dimension (3-D) flyoverto help orient the reader to features and interrelationships described here .

5.1.1 DATA COLLECTION

The surface investigations made use of imagery from a variety of sources, fieldmapping on the ground, and exploratory excavation of key features .Data sources and collection activities included the following:

- Review of pre-failure satellite imagery
- Review of a helicopter video made by the Cariboo Regional District during failure
- Review of post-failure helicopter photos by the Panel and airphoto stereopairs
- Review and preprocessing of Panel ground photos
- Preparation of topographical base maps and cross-sections
- Field mapping of ground features and exposures
- Excavation and logging of exploratory works in a remnant section of the dam core

5.1.2 KEY FEATURES

An oblique view of the breach area looking upstream is provided in **Figure 5.1.1** .This and the following image were obtained from the Cariboo Regional District's video The video was taken on the morning of August 4, 2014, about 8 hours after breach initiation with breach outflowstill in progress .It provides a unique opportunity to observe how many of the key post-breach features were formed .

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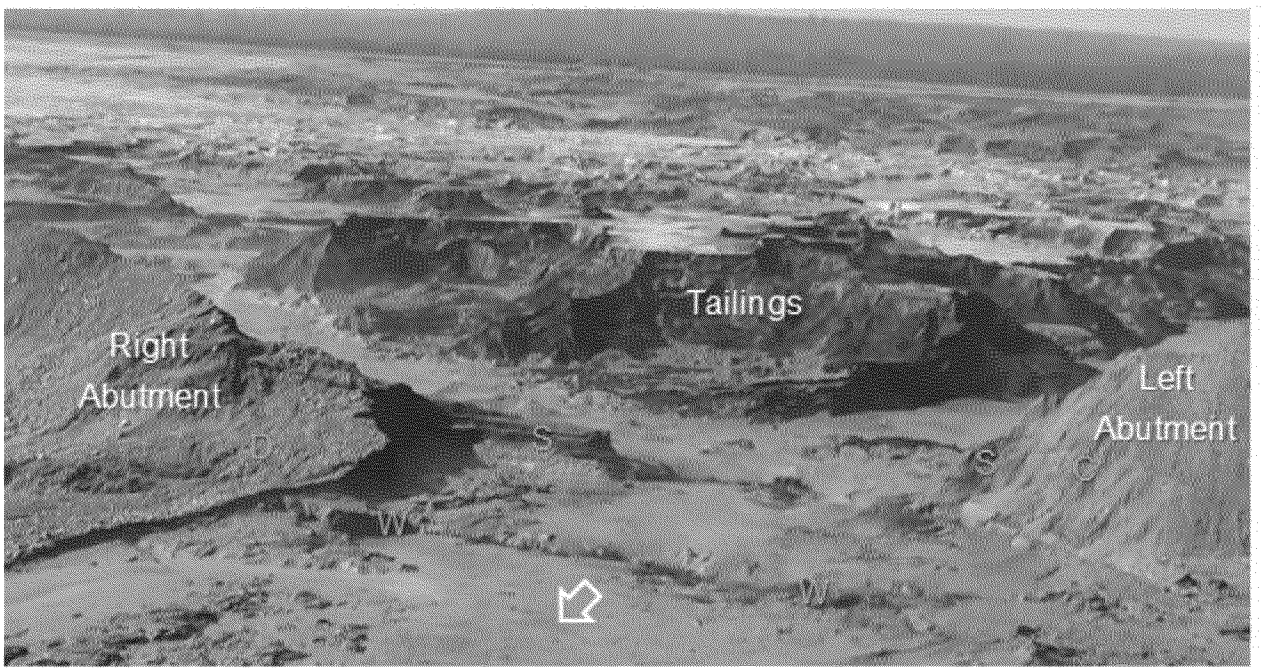
5 | Panel Observations

FIGURE 5.1.1: VIEW LOOKING UPSTREAM THROUGH THE BREACH ARROW SHOWS DIRECTION OF OUTFLOW



The labelled features in **Figure 5.1.1** can be interpreted with reference to the internal zoning of the dam previously provided as **Figure 4.1.1** On the upstream side of the breach, remnant projections of the dam core (S) can be seen on the left and right abutments The projection on the right abutment acts like a jetty in directing flowtoward the left abutment .

Zone C rockfill(C) is exposed on the left abutment, where it has been eroded by these redirected breach outflows . On the right abutment, the surface of the displaced rockfill(D) was subject to erosional overflowduring earlier stages of breach development It was subsequently protected from erosional undercutting in the main channel by the projecting core remnant and eddies that developed downstream .

The whaleback feature (W) is a linear, uplifted ridge of foundation till that extends across the entire width of the breach Highly erosion-resistant in both native and compacted forms, the upthrusted till here acts as the control section for breach outflow .

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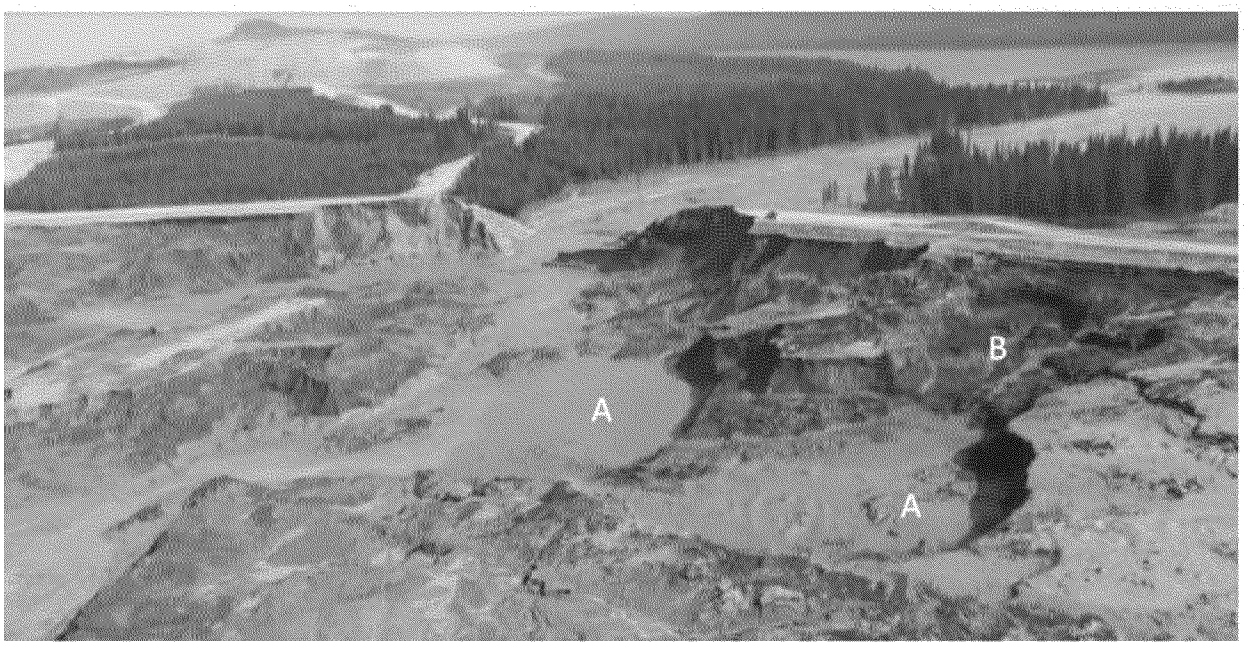
A reverse-angle perspective looking downstream through the breach is provided in **Figure 5.1.2**. It shows the damage to the upstream side of the dam and the processes that caused it.

FIGURE 5.1.2: VIEW LOOKING DOWNSTREAM SHOWING UPSTREAM SIDE OF DAM AND REMAINING TAILINGS



At this point, two major flowchannels have developed within the impoundment that converge at the upstream entry to the breach. In the distance (centre left), one of these can be seen flowingalong the left side of the dam. As is did so, it eroded away the supporting tailings. This caused the upstream side of the dam to collapse, leaving the prominent near-vertical face. These structural effectsare again best appreciated with reference to **Figure 4.1.1**.

Conditions adjacent to the right side of the dam illustrate how the combined action of fluvialerosion and tailings flowslidingproduced similar effects. The active flowslide(B) has left a semicircular headscarp that is progressing back and undermining the Zone U tailings supporting the upstream side of the dam core. Arcuate headscarps of earlier flowslides(A) have captured and concentrated overland flowsfrom surface water remaining in the impoundment. The resulting cascades readily transport flowslidedebris, while at the same time causing backward erosion of the headscarps by scour within their terraced plunge pools.

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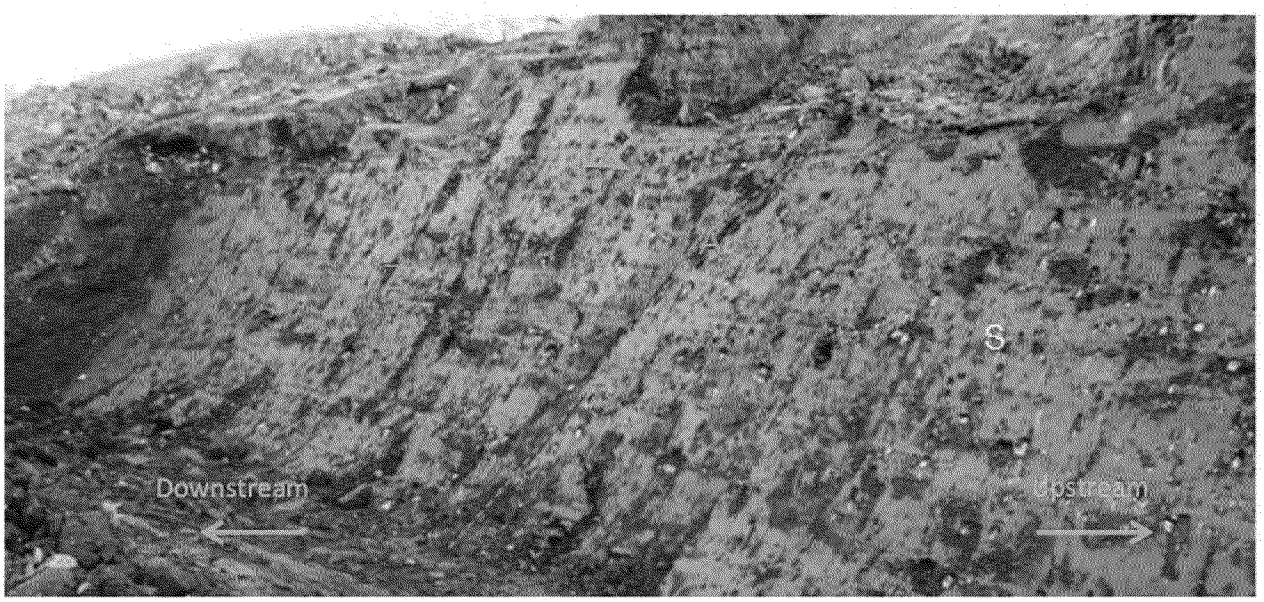
5.1.3 FOUNDATION SLIDING

The surface investigations produced direct evidence for foundation sliding as the initiating mechanism for the breach.This is most clearly demonstrated by a shear surface observed within the remnant core projection on the right abutment at the location shown previously in **Figure 5.1.1** .

Figure 5.1.3 shows an excavated exposure of the shear surface (A) through the Zone S core material (S) .The marker bed (Z) was not present on the upstream footwall side (right in photo), indicating at least 3 3 metres (m) of downthrow on the downstream hanging wall Appendix C, section 3 7, contains more detail on the orientation and configuration of the shear surface.

FIGURE 5.1.3: SHEAR SURFACE THROUGH REMNANT DAM CORE ARROW INDICATES DIRECTION OF DOWNDROP



The surface trace and 3-D orientation of the shear are shown on the core remnant in Figure 51 4, with a dip angle and direction as indicated .

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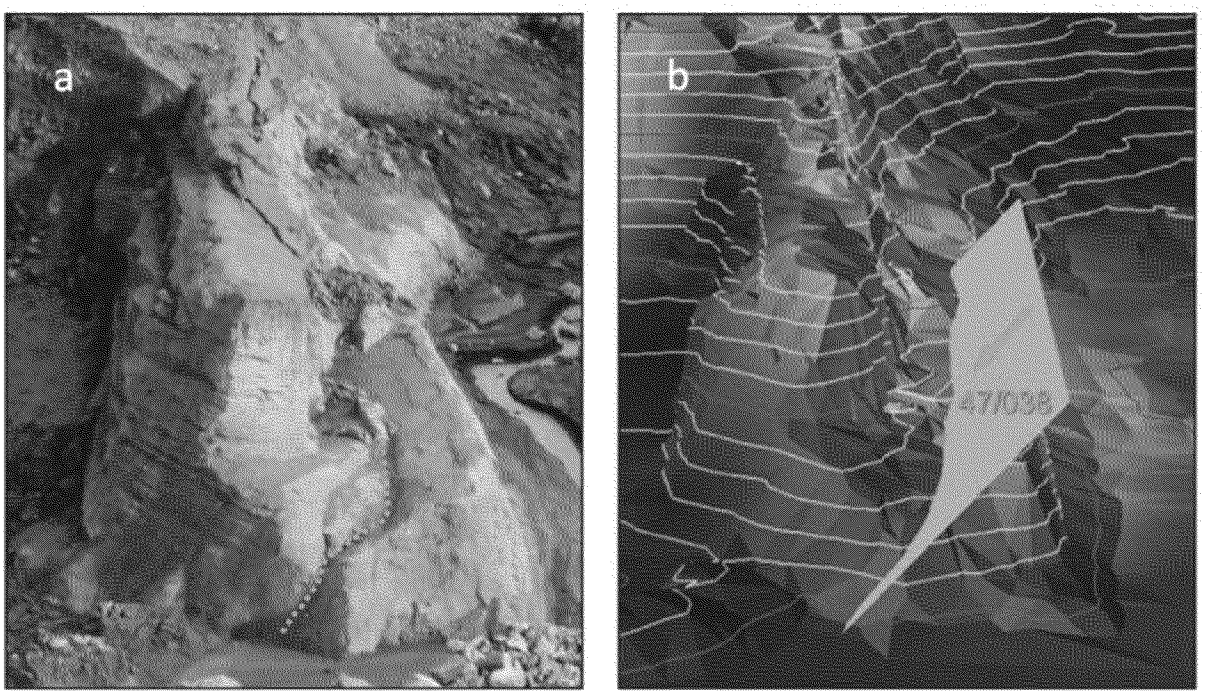
FIGURE 5.1.4: PHOTO (a) AND SURFACE MODEL (b) SHOWING SHEAR SURFACE ORIENTATION



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Other artifacts of foundation sliding are evident elsewhere As indicated in **Figure 5.1.5**, lift lines in the Zone C rockfill on the left abutment (C) are tilted at an inclination of 7° to 10°, with corollary inclinations on the right abutment of 5° to 14° Also shown in **Figure 5.1.5** are the Zone S core (S), with a containment dike (K) under construction in the background Scarps higher on the left abutment were produced by post-sliding downdrop of large slump blocks into the breach due to erosional undercutting at foundation level.

FIGURE 5.1.5: APPARENT BEDDING ROTATION ON LEFT ABUTMENT OF BREACH (SEPT. 4, 2014 PHOTO)

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Figure 5.1.6 shows the right abutment, with the left abutment in the background Noteworthy features include open cracks (O) and headscarps (H) at higher elevations At the downstream toe, upthrust of foundation till (L) ranging from 2 8 m to 3 5 m has occurred along an alignment collinear with the whaleback (W).

The mass of rockfill (D) from the upper headscarps to the lower upthrusted till was rotated and displaced by foundation sliding It was preserved when surface sheet flowwas terminated by breach downcutting on the left side . From displacement of surface lineations, lateral (downstream) translation of 11 m occurred in the vicinity of the arrows in the figure .

FIGURE 5.1.6: SLIDING-RELATED FEATURES AT RIGHT ABUTMENT SEPT. 4, 2014 PHOTO

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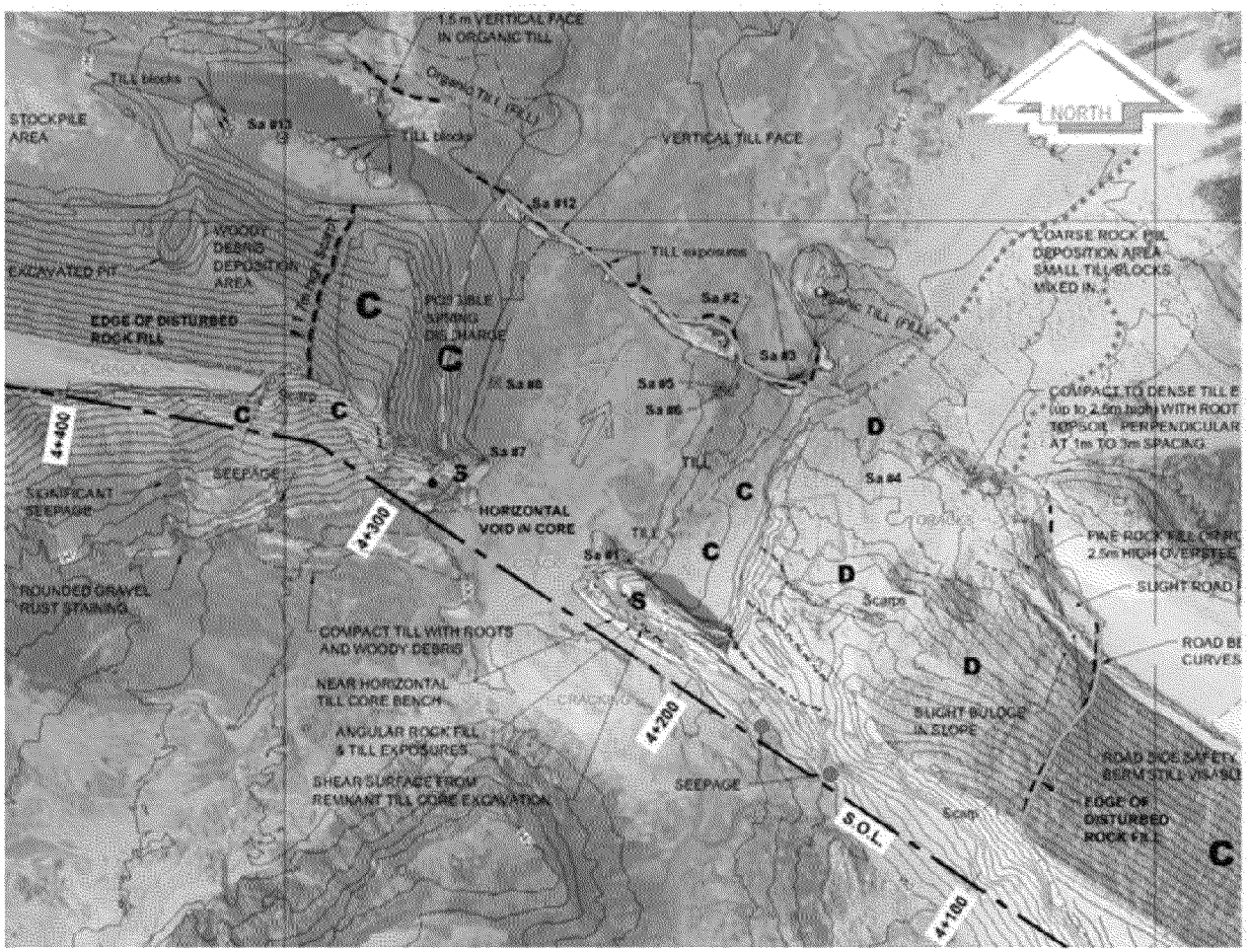
5 | Panel Observations

Surface investigations delineate the limits of foundation sliding given in **Figure 5.1.7**, with the solid and dashed yellow lines indicating observed and inferred boundaries, respectively .These are superimposed on the post-failure orthophoto and contours to show the extent of mass movement in relation to the breach Arrows indicate directions of movement from surface observations .

FIGURE 5.1.7: PLAN SHOWING DIRECTION AND EXTENT OF MASS MOVEMENTS



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Movements are summarized in **Table 5.1.1** below.

TABLE 5.1.1: MEASURED AND INFERRED SLIDE MOVEMENTS

LOCATION	DISPLACEMENTS AND ORIENTATIONS	
DOWNSTREAM TOE	Vertical: Horizontal:	2 8 to 3 5 m upward 11 m downstream
UPSTREAM SHEAR SURFACE	Vertical: Dip:	>3 3 m downward 47 degrees
RIGHT ABUTMENT	Rotation:	5 to 14 degrees
LEFT ABUTMENT	Rotation:	7 to 10 degrees

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5.1.4 INTERNAL EROSION

A void shown in **Figure 5.1.8** was observed on the upstream side of the left abutment, measuring 0 7 m by 0 3 m and extending back 1 1 m into the Zone S core The angular corners and abrupt transitions at the opening are distinct from the smoother, more rounded surfaces produced by surface erosion at other locations.

FIGURE 5.1.8: VOID ON UPSTREAM SIDE OF LEFT ABUTMENT

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Additionally, Zone F filtermaterial immediately downstream from the core was sampled in the right abutment excavation. Gradation data show that none of these samples met filtercriteria that would have enabled them to prevent transport of fines from the till. Together, these factors suggest internal erosion as the likely cause of the left abutment void.

This filtermaterial also has an internally unstable gradation, such that its finerfraction is free to pass through the voids in the coarser fraction under sufficient flowvelocity. However, the fact that this finerfraction is still present means that high discharge through the filter, and therefore through the core, did not occur. Moreover, painstaking excavation and thorough logging found no evidence of other such voids in the excavated core. Nor were continuous cracks or softened zones indicative of hydraulic fracturing discovered. These factors suggest that internal erosion was not pervasive over the breach area or sufficiently severe to have compromised core integrity overall.

These factors suggest that internal erosion was not pervasive over the breach area or sufficiently severe to have compromised core integrity overall.

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5.2 SUBSURFACE INVESTIGATIONS

5.2.1 INTRODUCTION

Following the breach of the Mount Polley Perimeter Embankment, site investigation programs were initiated by the Mines Inspector team with Klohn Crippen Berger (KCB) as the geotechnical lead, Mount Polley Mining Corporation (MPMC) with Golder Associates (Golder) as the geotechnical lead, and the Panel, with the support of Thurber Engineering Limited (Thurber) .This section summarizes the Panel's program, its outcome, and key findingsthat affectother aspects of the Panel's activities Appendix D provides further details of Thurber's work, results and interpretations Results of the KCB work are available in Appendix B .[1] The Panel relied on factual data collected by both Thurber and KCB, but made its own interpretations of these data.

5.2.2 JOINT SITE INVESTIGATION

In early September 2014, MPMC invited the Panel to participate in a coordination meeting with KCB and Golder to review proposed joint site investigation plans consisting of:

- Geophysics — Direct current resistivity, induced polarity and seismic refraction surveys.
- Drilling and coring — Sonic drilling to allow initial foundation characterization at the dam breach and adjacent areas, and mud rotary drilling and sampling with focus on clays and silts designated the Upper Glaciolacustrine Unit (Upper GLU).
- In situ testing and instrumentation — cone penetration test (CPT) and piezometer and inclinometer installation at selected locations.

Safe work plans had to be implemented to establish access limits with respect to the remaining breach abutments. These limits influenced the locations of the final geophysics lines and the drillhole locations.

KCB fieldengineers took large numbers of samples from the sonic cores for routine or index testing in the KCB laboratory Index test results were shared with the Panel .Thurber also collected samples for index testing from a number of locations during the site mapping and other activities for testing in the Thurber laboratories All index test results are presented in Appendix D, Attachment 7.

Daily reports describing fieldworkprogress were shared with all parties .Weekly conference calls, in which the Panel participated, served to further coordinate the fieldworkand provide updates Adjustments were made to the detailed locations of the geophysics lines as well as drillholes as the program was implemented .**Figure 5.2.1** shows the final locations of the joint site investigation holes in and around the breach area.

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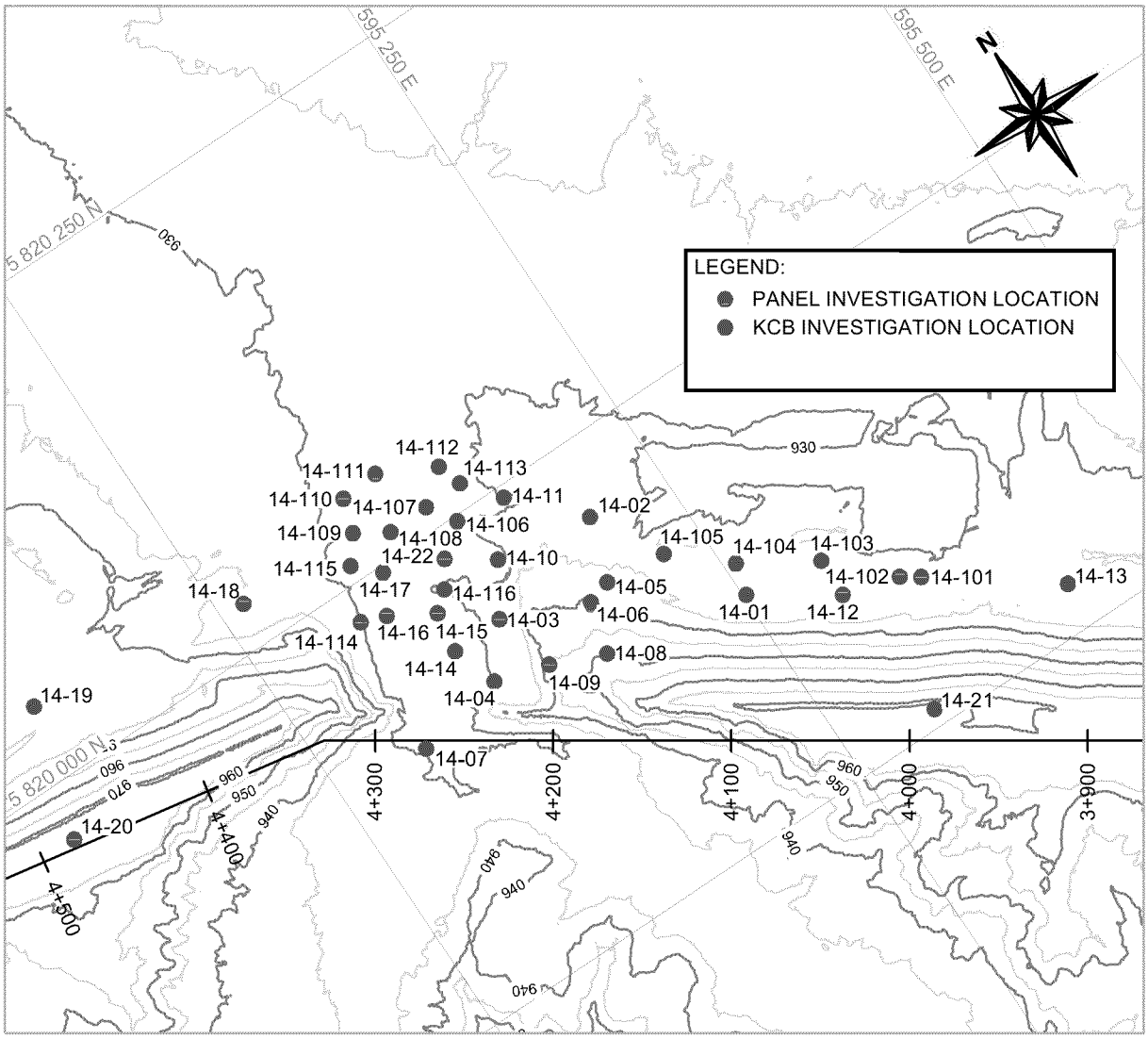
FIGURE 5.2.1: JOINT AND PANEL SITE INVESTIGATION DRILLHOLE LOCATIONS



Thurber's fieldengineer observed the sonic drilling by KCB and logged all the sonic holes in parallel with the KCB personnel .The Thurber logs of the KCB sonic holes are provided in Appendix D, Attachment 1 .Related seismic and resistivity surveys are also described in Appendix D, Attachment 1.

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5.2.3 PANEL SITE INVESTIGATION

About half of the locations for the KCB investigation were located in the failed section footprint as well as through the remaining embankment into the underlying foundation.The Panel developed a separate fieldprogram that allowed in situ testing and sampling at a larger number of locations where foundation materials had not been preloaded by the embankment .The Panel site investigation consisted of:

- CPT and vane testing to characterize the foundation stratigraphy and to identify sampling locations for advanced shear and consolidation testing (refer to section 53 for further details of the laboratory testing).
- Mud rotary drilling to obtain disturbed and undisturbed samples of the Upper GLU and other units for laboratory testing .
- Pressuremeter testing in the till to obtain shear strength and shear modulus values.
- Drilling and sampling using Large Penetration Testing (LPT) in selected areas of foundation till.

Details of drilling methods, in situ testing and related information are included in Appendix D Excavation, sampling and related laboratory testing are described in Appendix C .

5.2.4 PRE-FAILURE SITE INVESTIGATIONS IN BREACH AREA

Appendix D provides a summary of pre-failure site investigations for the Mount Polley tailings storage facility (TSF) . Knight Piésold (KP) performed site investigations in the early to mid-1990s for the design of the facility Additional site investigations and laboratory testing were done during operations, notably a sonic drilling and instrumentation program implemented by AMEC in 2011 .**Figure 5.2.2** shows all the geotechnical drillhole locations for pre-failure investigations in the breach area .

While a large number of locations are shown, many were condemnation holes or shallow test pits of limited usefulness for embankment design purposes As subsequently discussed, the Panel found the critical soils in the breach area at depths of about 8 m .There are only four locations where the holes were deeper than 8 m and where in situ or laboratory testing was done None of these locations were in the area where the breach occurred .

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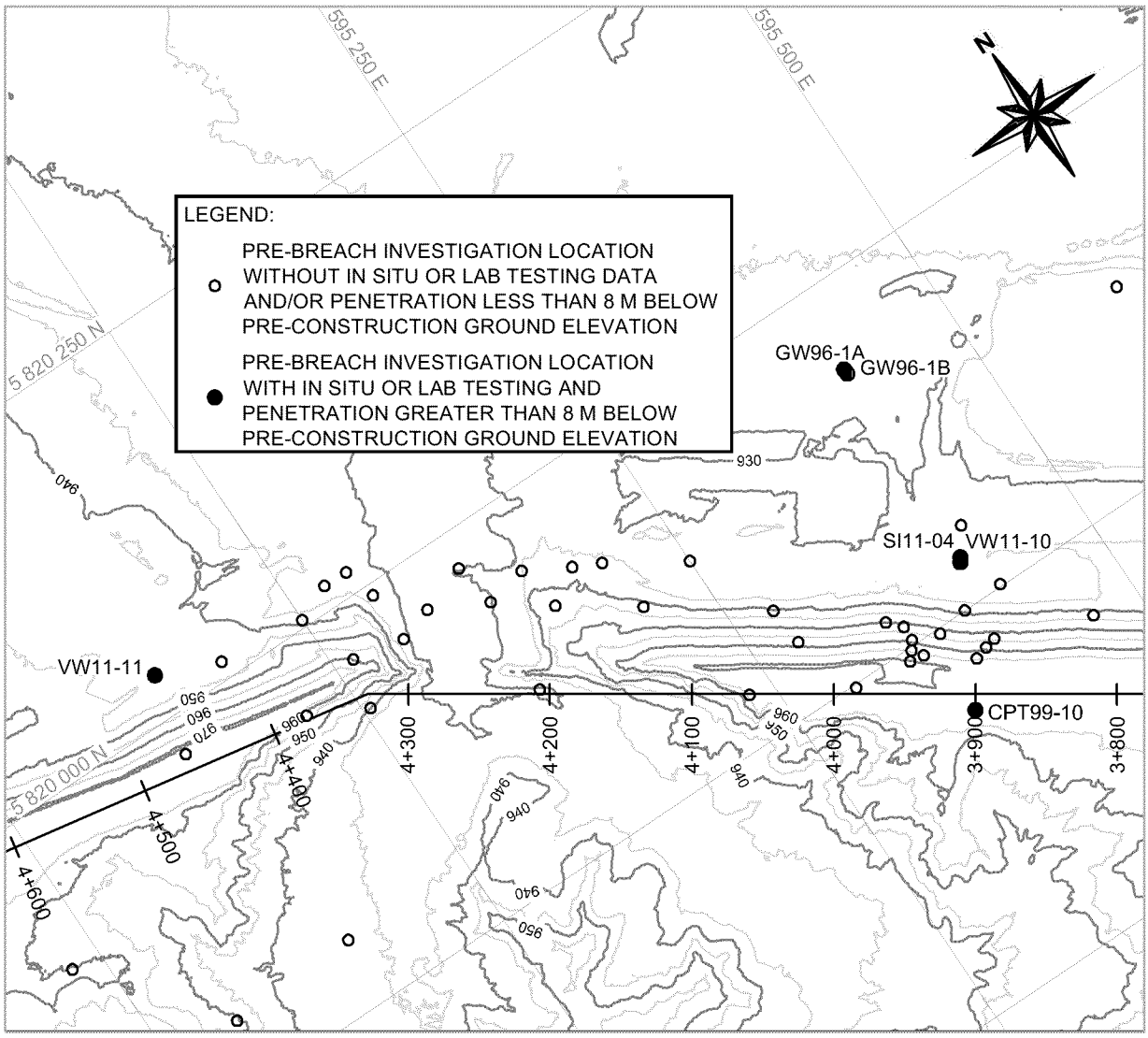
FIGURE 5.2.2 PRE-FAILURE SITE INVESTIGATION DRILLHOLE LOCATIONS IN BREACH AREA



Based on the subsurface investigations and related laboratory data, the Panel derived several key findingsthat informed its larger efforts .These are discussed in the following sections.

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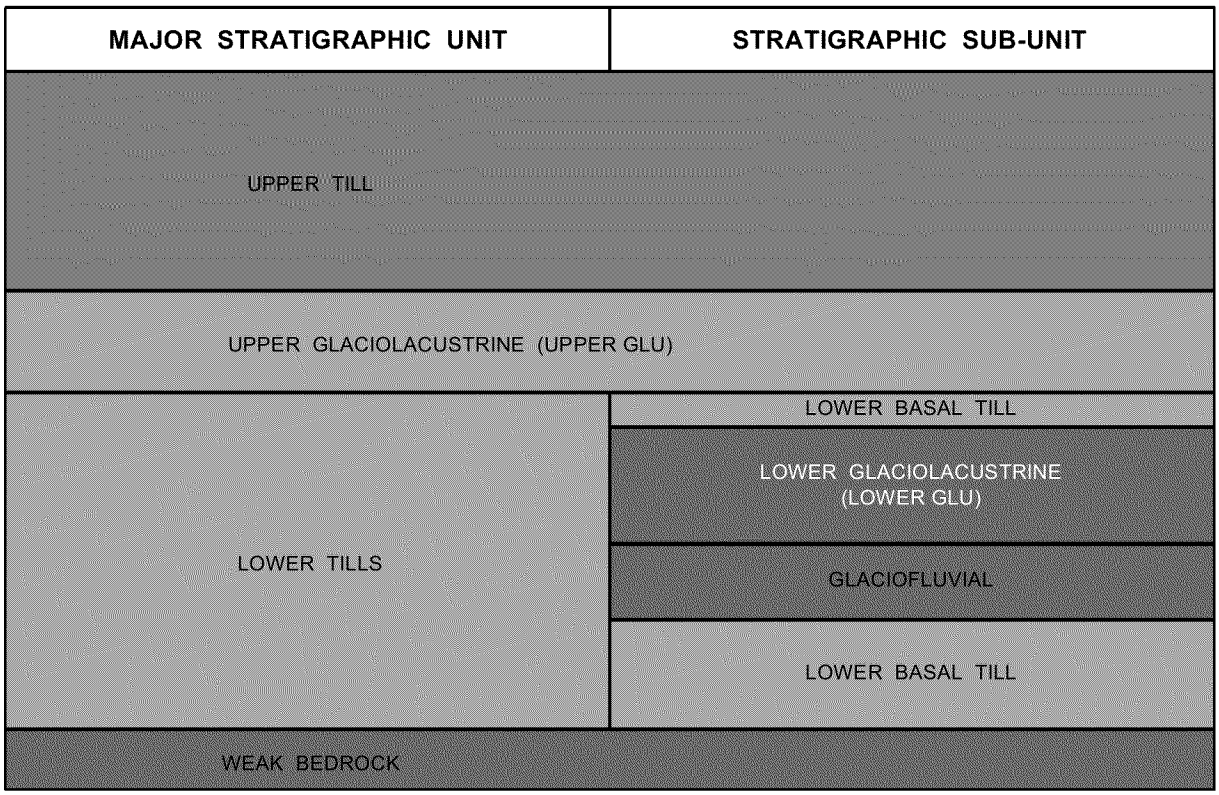
5.2.5 CONTROLLING STRATIGRAPHY

Soils in the breach area are of three main types, all glacially deposited.These include:

- Glaciolacustrine soils (designated GLU) deposited in standing water.
- Glaciofluvial, or streamchannel, deposits.
- Glacial tills produced by glacial transport and reworking.

Appendix D describes the interpreted depositional environment that results in the generalized sequence shown below.

FIGURE 5.2.3: GENERALIZED SOIL STRATIGRAPHY IN BREACH AREA



Of special significanceare the two glaciolacustrine units designated Upper and Lower GLU, shown in **Figure 5.2.3**, in turquoise and blue, respectively.Both consist of thinly laminated, or varved, silts and clays, and both classify predominantly as low- to high-plasticity clay (CL to CH).They can be distinguished by differencesin their pre-failure water content, CPT tip resistance, and overconsolidation ratio (OCR).Establishing these differences requires looking to areas outside the embankment footprint, or those covered by slide debris, in order to eliminate preloading effects .The resulting comparisons therefore reflectinitial pre-construction conditions .

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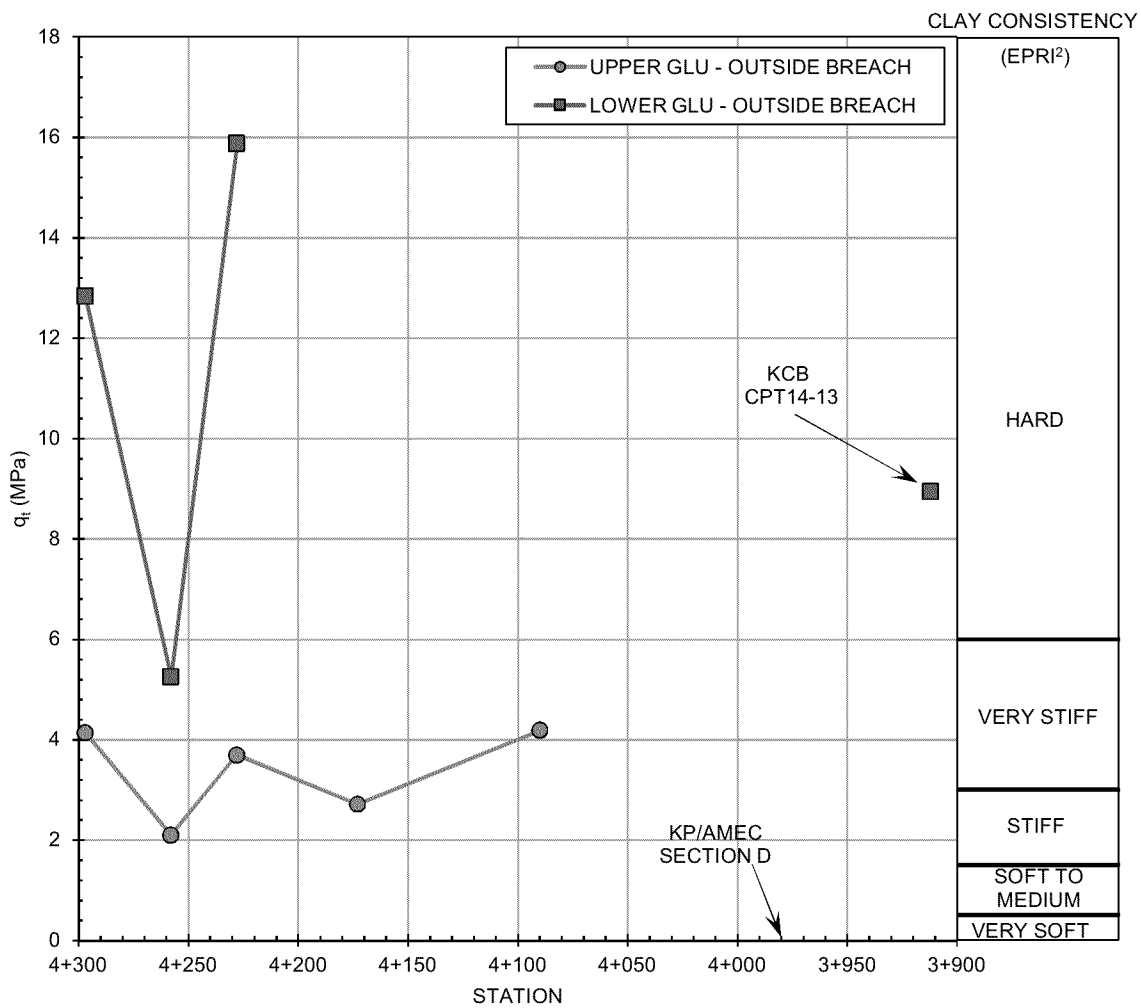
Firstly, the differencein water content is substantial .The average of mean values from individual borings for the Upper GLU is 32%, compared to 24% for the Lower GLU .

Secondly, CPT tip resistance in the two units is distinctly different .**Figure 5.2.4** shows that tip resistance q_t for the Upper GLU is less than one-half of that for the Lower GLU across the breach area Using q_t as a measure of clay consistency, the Upper GLU classifiesas stiffto very stiff,while the Lower GLU classifiesas very stiffto hard .

FIGURE 5.2.4: LONGITUDINAL VARIATION IN CPT TIP RESISTANCE



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During their depositional history, glaciolacustrine deposits can experience episodes of drying, freezing, glacial overriding, or other factors that consolidate them to varying degrees .The result is to induce an effective preconsolidation pressure, designated σ'_p, that has a substantial influenceon undrained strength properties .This effectcan also be expressed as the ratio of the preconsolidation pressure to the effectivestress in the ground, termed OCR .In general, higher OCR and higher σ'_p correlate with higher undrained strength .

But when the applied stress increases, for example, due to placement of overlying dam fill,OCR decreases .If the higher stress reaches or exceeds σ'_p, the beneficialeffectsof preconsolidation no longer pertain, and the clay is said to be normally consolidated with OCR = 1 0 .Together, the preconsolidation of a clay, the stresses it experiences, and the changes in these stresses are called its stress history, which has a major influenceon its undrained strength .

These factors are reflectedin the Upper and Lower GLU, where the initial pre-construction σ'_p and OCR are compiled on a composite plot in **Figure 5.2.5** using CPT data from RCPT14-107 and all available oedometer data.

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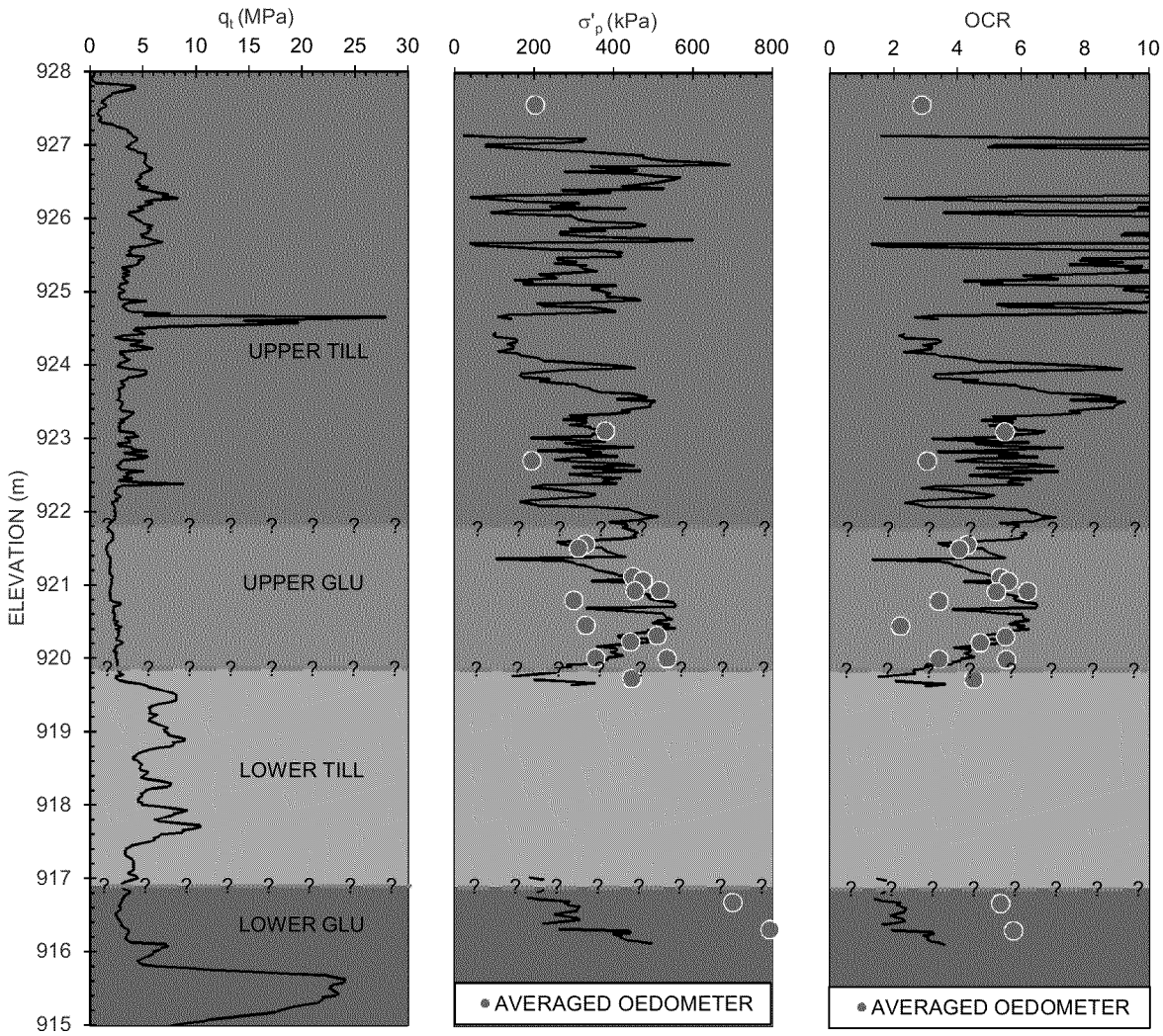
FIGURE 5.2.5: INITIAL PRE-CONSTRUCTION STRESS HISTORY



The continuous plots of σ'_p and OCR adopt published CPT correlations,[2] while the laboratory-derived data points are taken from Appendix E From laboratory data, the average σ'_p for the Upper and Lower GLU units is 433 kilopascals (kPa) and 748 kPa respectively, with corresponding OCRs of 6 0 and 6 9 .

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The differencesin properties are summarized in **Table 5.2.1.** Drawing D18 in Appendix D provides further details of the properties .

TABLE 5.2.1 PRE-CONSTRUCTION PROPERTIES OF UPPER AND LOWER GLU IN BREACH AREA

STRATIGRAPHIC UNIT	WATER CONTENT, AVG. AND RANGE	CPT TIP RESISTANCE, q_t AVG., RANGE, AND CONSISTENCY	PRECONSOLIDATION PRESSURE σ'_p AVG. AND RANGE	OVERCONSOLIDATION RATIO, OCR AVG. AND RANGE
Upper GLU	32% (19 — 53)	3 4 MPa (2 1 — 4 2) (stiff to v .stiff)	433 kPa (312 — 535)	6 0 (4 1 — 7 7)
Lower GLU	24% (19 — 29)	11 4 MPa (5 6 — 16) (v .stiff to hard)	748 kPa (701 — 794)	6 9 (6 7 — 7 2)

Taken together, these properties show that the Upper GLU is the weaker of the two units.

5.2.6 EXTENT AND CONTINUITY OF UPPER GLU

Having targeted the Upper GLU as the controlling stratum, it is of further interest to determine its extent .These results are also highly significant . **Figure 5.2.6** demonstrates that the Upper GLU is not pervasive throughout this entire section of the Perimeter Embankment . But is present in the area beneath the footprint between Sta .4+050 and Sta 4+300 Moreover, the greatest thickness directly underlies the remaining slide debris on the right side of the breach, thinning toward the left but still extending across the entire width .The maximum thickness also directly underlies the location of the downstream toe of the embankment at the time of failure

Having targeted the Upper GLU as the controlling stratum, it is of further interest to determine its extent. These results are also highly significant.

There are smaller-scale variations even within this area .**Figure 5.2.6** shows a localized thickening to the east, just at the limit of the slide from **Figure 5.1.7**.

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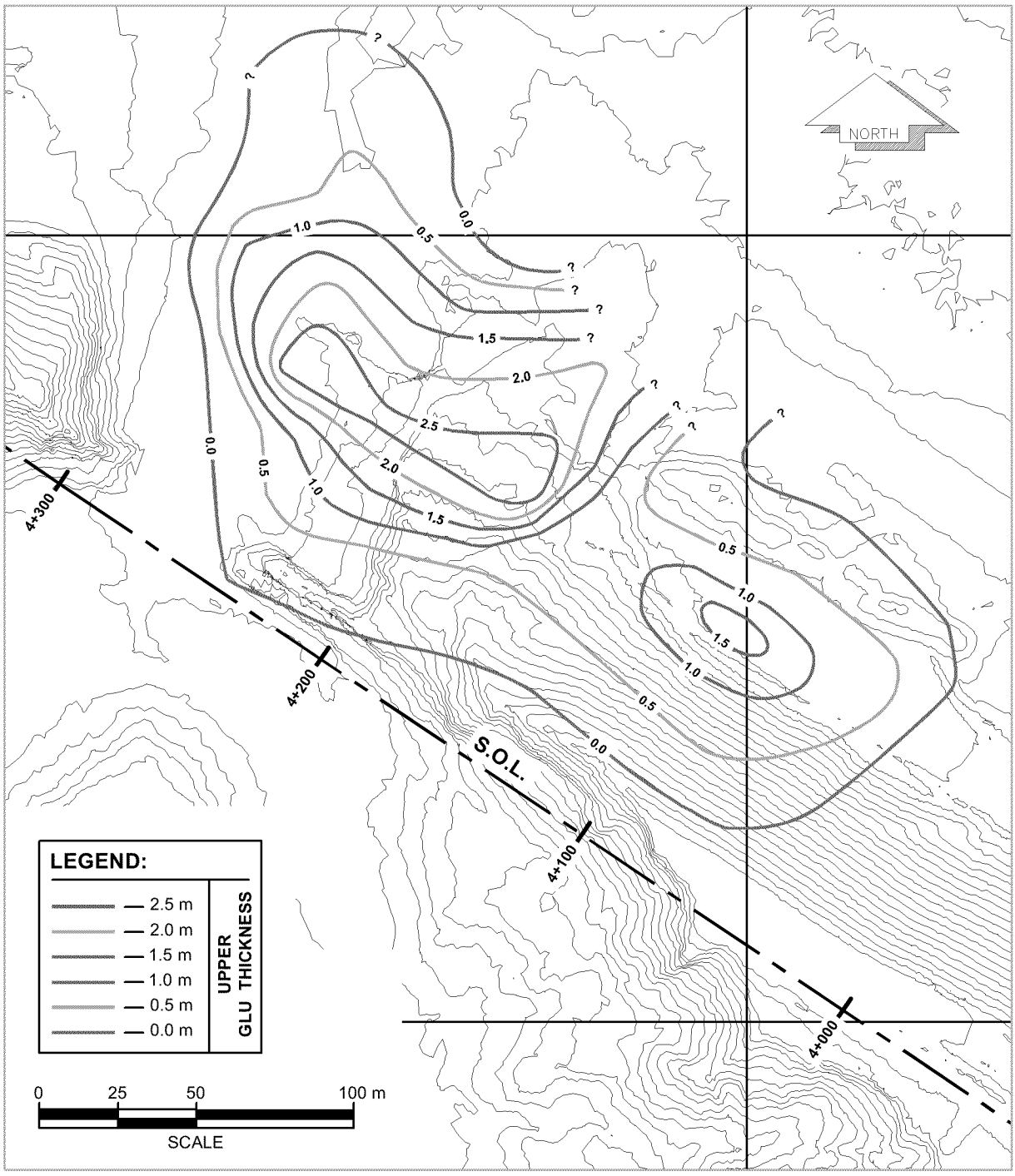
FIGURE 5.2.6: CONTOURS OF UPPER GLU THICKNESS IN BREACH AREA



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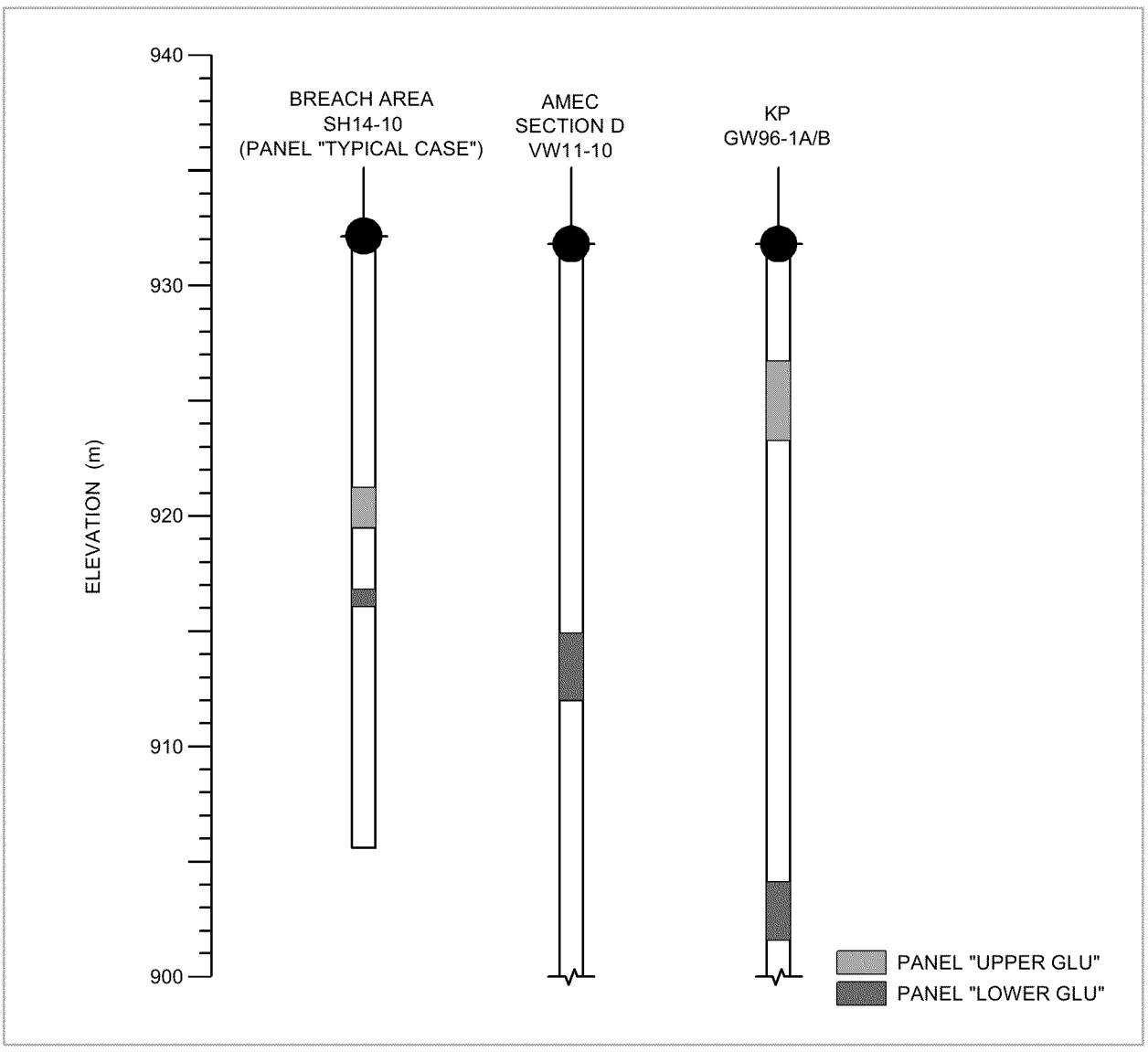
Stratigraphic variations on a larger scale are also apparent from **Figure 5.2.7**, which relates the Upper and Lower GLU units at the breach to glaciolacustrine soils elsewhere at boring locations presented previously in **Figure 5.2.2** . The Upper GLU at the breach shows apparent similarities to glaciolacustrine soils at similar elevation in GW96-1A that would be characterized as soft to medium-stiffaccording to their standard penetration test (SPT) blow count of 6 . On the other hand, the uppermost GLU layer encountered in VW11-10 has an average water content of 23%, which corresponds closely to that of the Lower GLU shown in **Table 5.2.1** .Details are provided in Appendix D .

FIGURE 5.2.7: COMPARISON OF GLU UNITS IN BREACH TO OTHER AREAS



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These illustrations of both small-scale and large-scale variation in stratigraphy and properties of the GLU materials serve to highlight the complexity that their depositional environment produced . This degree of geologic complexity discourages attempts at broader generalization beyond the immediate areas where subsurface data have been obtained .

Both small-scale and large-scale variation in stratigraphy and properties of the GLU materials serve to highlight the complexity that their depositional environment produced.

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5.2.7 LOCATION AND CHARACTERISTICS OF FAILURE SURFACE

Section 5.1 previously identified the entry of the failure surface through the surviving core remnant and into the upper foundation till. The subsurface investigations described here reveal the nature and location of the failure surface at depth.

As will be chronicled in section 5.4, the presence of a glacially pre-sheared surface in the dam foundation posed significant uncertainty throughout the design process. This type of pre-shearing, with the residual strength it produces, was also hypothesized as a potential failure mechanism by the Panel in section 4.3.4. Commensurate effort was devoted to detecting the presence of pre-shearing in foundation soils within the breach.

Pre-shearing in stiff, clayey soils manifests as a thin (a few millimetres to a few centimetres) zone with slickensides—shiny surfaces polished by shearing—on both sides of the zone or within it. These surfaces are continuous and traceable between borings, often along bedding. While detailed logging did show some small, discontinuous slickensided surfaces at random orientations, an expected condition in stiff clays, no continuous surfaces common to multiple borings were found. In this respect, the Panel's investigation at the breach corroborated the more general conclusion of the 2011 site investigation.[3]

Even so, the Upper GLU exhibited other signs of shearing inside but not outside the breach. For example, **Figure 5.2.8** compares the Upper GLU for these two locations.

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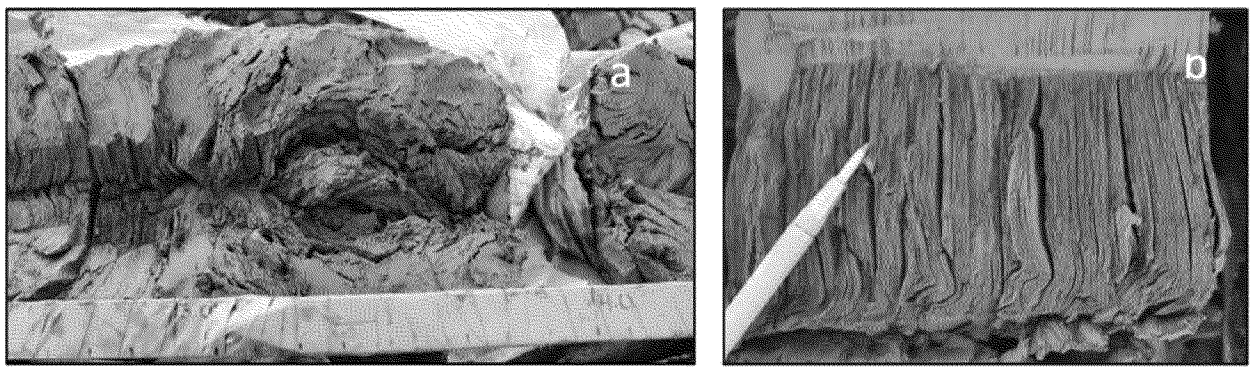
FIGURE 5.2.8 UPPER GLU (a) INSIDE THE BREACH, (b) OUTSIDE THE BREACH



The thinly laminated, planar varving outside the breach contrasts sharply with the contorted and folded laminations within it .This is consistent with shearing of the Upper GLU having occurred within the breach .

Additionally, CPT tip resistance q_t in the Upper GLU varies systematically .Drawings D19 and D20 in Appendix D show that average q_t inside the breach is only about one-third to two-thirds of that outside of it (inferred sensitivity of 1 0 to 3 0), reflecting the effects of remoulding attributable to shearing .Hence, both visual inspection and CPT data indicate that the failure produced shearing in the Upper GLU .This, together with its less favourable properties summarized in **Table 5.2.1**, identifies the Upper GLU as the location of the failure surface in the analyses to be presented in section 6 .

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5.2.8 COMMENTARY

The key findingsof the subsurface investigations with regard to the failure mechanism can be summarized as follows:

- The Upper GLU can be distinguished as a distinct foundation unit based on its water content and other properties .
- The failure occurred within varved silts and clays of the Upper GLU.
- There is no indication of pre-shearing in these or other foundation soils.
- Stratigraphic variability reflects a complex geologic environment and depositional history .

Beyond these immediate findingslie other insights that concern characterization of the GLU during the design process .These are summarized below:

- The discontinuous Upper GLU stratum, the seat of the failure, was infelicitously situated at the worst possible place in the dam foundation.
- The type and extent of pre-failure site investigations were not sufficient to detect this stratum or identify its critical nature .
- The strength behaviour of the GLU was misinterpreted .

The first two of these points are evident from the material presented above .The third requires explanation .

From the outset, the stiffnessof GLU materials in the Main Embankment foundation was recognized and attributed to overconsolidation.In response to a review comment by the Ministry of Energy and Mines (MEM), KP obtained samples of GLU materials at the Main Embankment in 1995[4]. Commenting on the characteristics of these soils, KP made the following observations:

Two additional Shelby samples were recently collected (May 16, 1995) during the soil investigation survey. These samples were obtained from the glaciolacustrine sediments and have confirmedthat the foundation materials consist of dense, overconsolidated materials. In fact, it was extremely difficultto insert the Shelby tubes in the fieldand it was not possible to extract the undisturbed samples from the tubes in the laboratory... It is unlikely that any significantpore pressure development will occur in these materials during construction of the embankment.

KP concluded that no significantpore pressures would develop, but did not directly relate this to the effective-stress strength properties its stability analyses adopted.This connection was made explicit much later in AMEC's 2011 Geotechnical Site Investigation[5].

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Among other things, the AMEC report compiled all available data for Liquidity Index (LI) at the Main Embankment, a laboratory parameter that can be correlated to preconsolidation pressure σ'_p. The report noted that a number of GLU samples had low LI values near zero, some of them even negative, pointing again to the overconsolidated condition of the GLU. Elaborating on the strength interpretation this supported, the report went on to say:

Moreover, for heavily overconsolidated soils with high fines contents (such as the GLU) that will shear in an undrained manner due to low hydraulic conductivity, the undrained shear strength will typically exceed the drained shear strength, owing to negative shear-induced pore pressure.

Thus, undrained strength could be disregarded for the GLU, with drained (effective-stress) strength applicable instead.

Review of the AMEC data calls into question the premise of this conclusion. While most of the LI values were indeed low, fully one-third of them were equal to or greater than 0.5. This means that significant portions of the GLU beneath the Main Embankment were not so heavily overconsolidated. From published correlations,[6] the Panel estimates that σ'_p for these higher LI values ranged from about 250 to 575 kPa, quite similar to the range for the Upper GLU at the breach from **Table 5.2.1**. These σ'_p values correspond to an average OCR of only about 3, given the loading conditions of the catalogued samples, insufficiently high to warrant neglecting undrained strength.

But more than this, the assessment did not account for stress history—how these loading conditions varied at different locations beneath the dam or how they would change over time. Stage 7 of the Main Embankment had just been completed at the time of 2011 site investigation. The Panel estimates that normally consolidated conditions (OCR=1) had already been reached beneath the crest of Stage 2 years before and would continue to propagate outward beneath the slope as the dam grew higher. The key factor that went unrecognized was that undrained strength behaviour would unequivocally control for these normally consolidated conditions.

The key factor that went unrecognized was that undrained strength behaviour would unequivocally control for these normally consolidated conditions.

The same effect, equally unrecognized, would occur at the Perimeter Embankment breach section. Normally consolidated conditions, and the governing undrained strength accompanying them, would first develop beneath the crest during Stage 5 and continue to spread thereafter. This would set the stage for much that followed.

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5.3 ADVANCED LABORATORY STUDIES

5.3.1 INTRODUCTION

A distinction can be made between routine and advanced laboratory studies .Routine laboratory studies are performed as part of the description and classificationof materials encountered in a site characterization study . Routine laboratory studies undertaken in this investigation have been reported as part of the description of materials identifiedin the site characterization investigation (see Appendix D) Advanced laboratory studies are undertaken to aid in the explanation of the physical response of a soil to loading Important responses are the reduction in volume of a soil when loaded, reflectedby consolidation testing, and the ultimate resistance of a soil specimen, as measured by a variety of shear strength tests .

5.3.2 SAMPLING

The joint site investigation, summarized in section 5 2, concentrated on the ground conditions adjacent to the breach that would have been affectedby the ground movements .The Panel-directed investigation concentrated on the ground conditions adjacent to the disturbed zone in order to provide the opportunity to inspect soil conditions that would not have been affectedby the ground movements .Obtaining undisturbed samples for both inspection and advanced laboratory studies was an integral objective of this investigation .

Obtaining undisturbed samples requires pushing a thin-walled sampler into the ground .Given the conditions encountered, this was not a straightforward exercise .The till contains numerous rocks, and even the fine-grained glaciolacustrine (GLU) deposits contain gravel-sized pieces, most likely deposited during melt of ice rafts .

The inventory of samples that were potentially useful for undisturbed sample testing is tabulated in Appendix E . All samples were subject to scanning at FP Innovations at the University of British Columbia (UBC) .This facility can undertake both X-ray and CT scanning on large items .Both digital radiography and CT scans were completed on all sample tubes .Observation of internal disturbance, voids or natural structure aided in the quality control .The horizontal CT scans ultimately proved best to determine complex interlayering and to detect voids .**Figure 5.3.1** displays a sample of till (MR14-104-SA8) that exhibits significantsample disturbance, together with a sample of the GLU (MR14-106E-SA3) that shows internal structure with minimal disturbance .Scans performed on the inventory of samples obtained are included in Appendix E .

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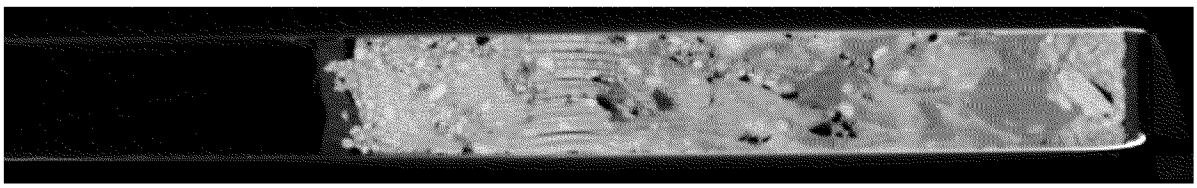
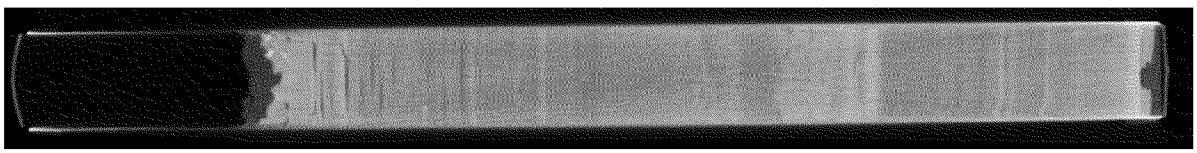
FIGURE 5.3.1: CT SCAN/TILL/GLU



TILL SAMPLE (MR14-104-SA8)

DEPTH: 11.4 TO 12.0 M / EL. 920.3 TO 919.7 M



UPPER GLU SAMPLE (MR14-106E-SA3)

DEPTH: 8.2 TO 8.8 M / EL. 920.5 TO 919.9 M

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5.3.3 OEDOMETER TESTS

Oedometer tests are used to study the reduction in void ratio (porosity), with applied load simulating the construction of the embankment in stages .The change in curvature of the settlement response provides a base for estimating the preconsolidation pressure of the deposit, which is the maximum pressure experienced by the deposit in its geological past . The technique is illustrated in **Figure 5.3.2** for both a till specimen and a GLU specimen .Till is fundamentally less compressible than the GLU, and the technique to estimate preconsolidation stress has greater uncertainty . The data reveal that these deposits are not highly overconsolidated and that the pressure to be applied by the embankment will exceed the preconsolidation pressure, creating normally consolidated conditions .Normally consolidated conditions are conducive for the soil to behave in a contractive manner when subjected to both vertical pressure and shear .

The data reveal that these deposits are not highly overconsolidated and that the pressure to be applied by the embankment will exceed the preconsolidation pressure, creating normally consolidated conditions.

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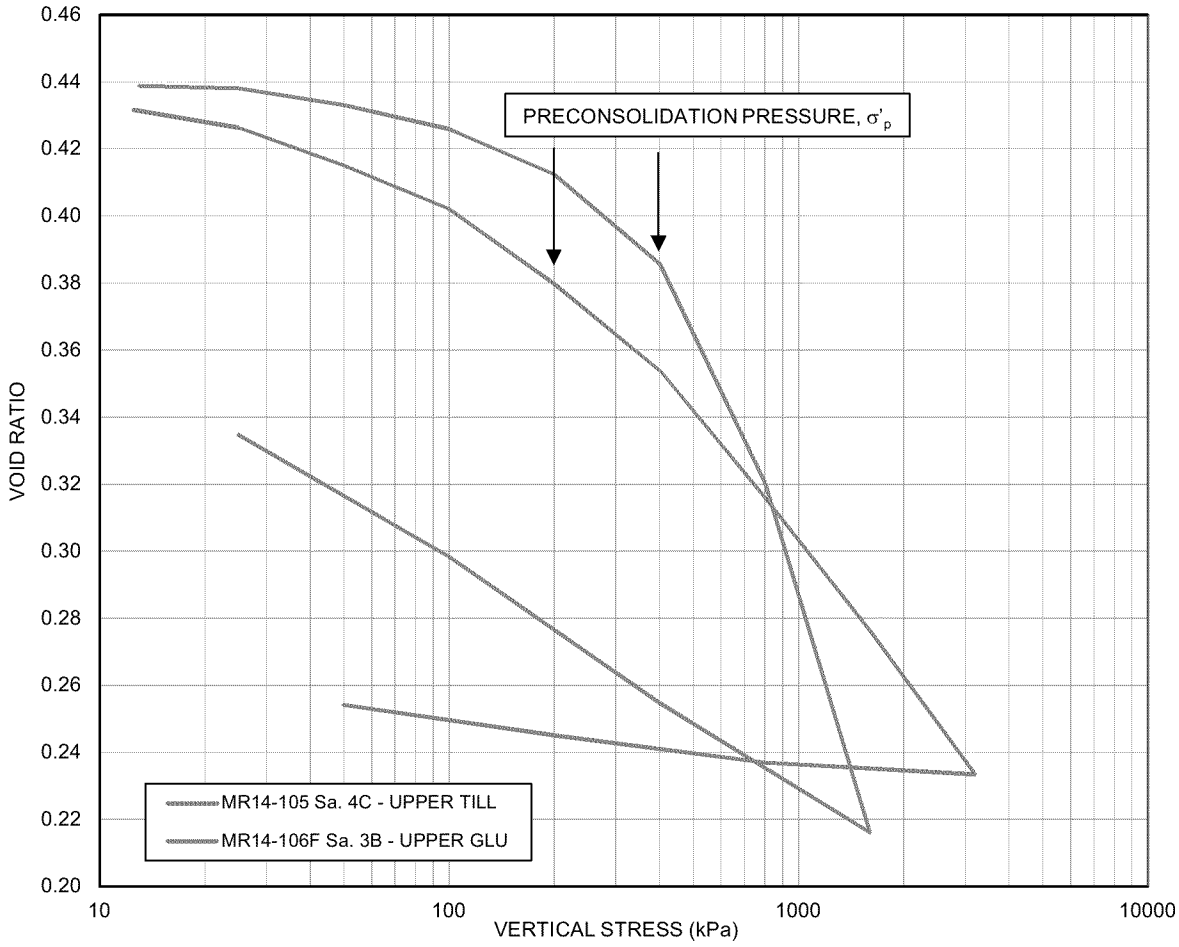
FIGURE 5.3.2: PRECONSOLIDATION STRESS EFFECT FOR BOTH TILL AND GLU



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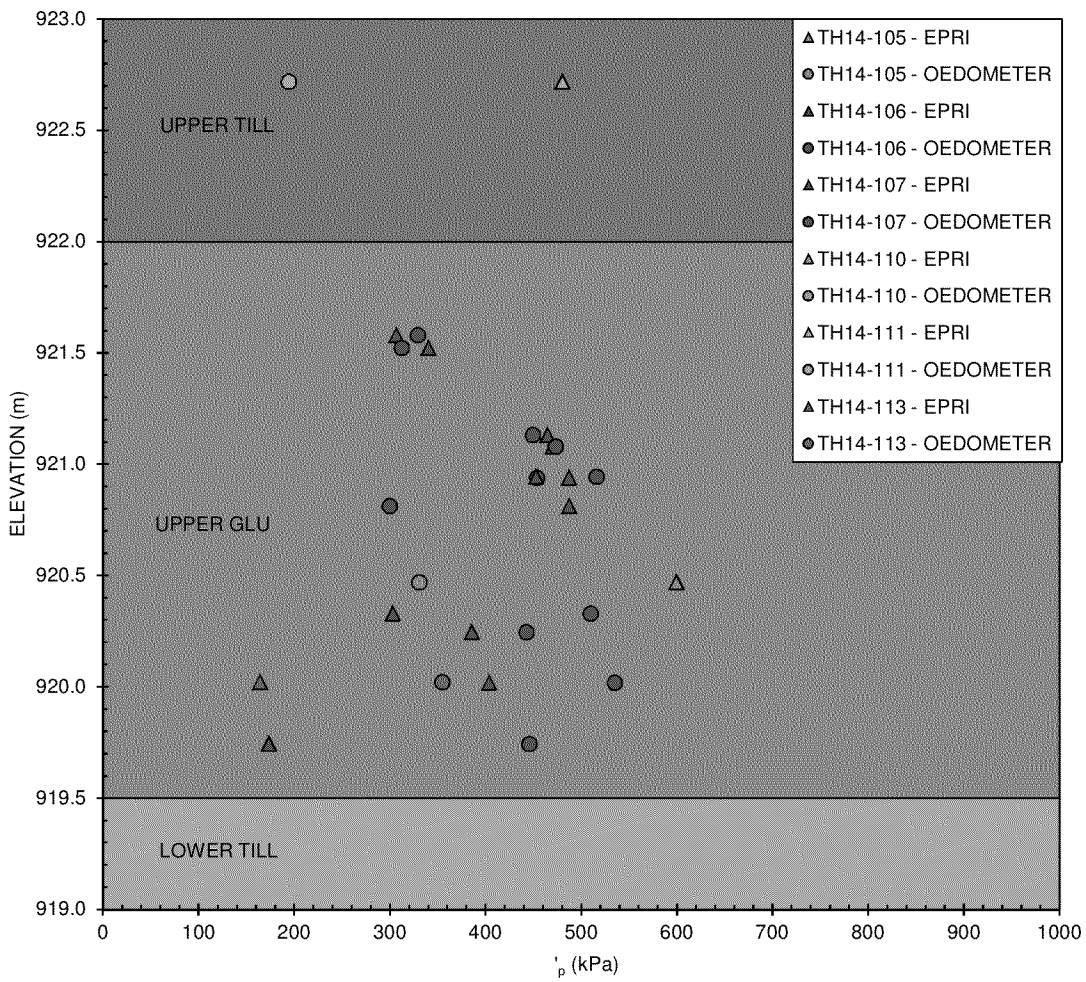
Preconsolidation pressure can also be inferred from the CPT testing conducted as part of the Panel's site investigation Again, only modest preconsolidation stresses have been determined. A comparison between the results obtained from the fieldtests with those obtained from the oedometer tests is shown in **Figure 5.3.3**, and the agreement is acceptable As the embankment was raised to a stress level beyond the preconsolidation stresses, the underlying GLU reverted to normally consolidated behaviour.

As the embankment was raised to a stress level beyond the preconsolidation stresses, the underlying GLU reverted to normally consolidated behaviour.

FIGURE 5.3.3: PRECONSOLIDATION PRESSURE WITH ELEVATION



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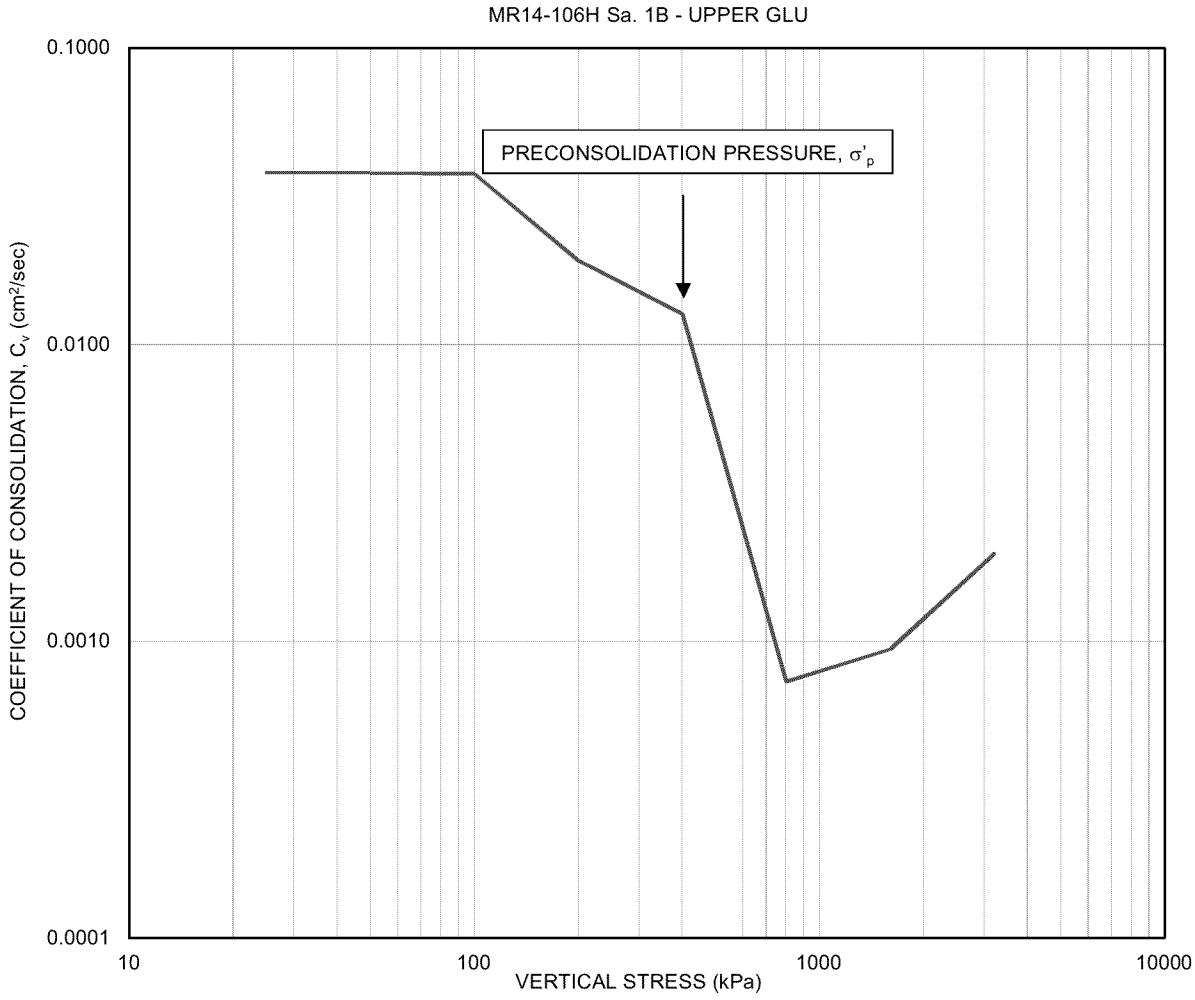
The data from oedometer tests are presented in Appendix E, including information on the coefficientof consolidation that reflectsthe rate of pore pressure dissipation on loading . **Figure 5.3.4** provides an example of this response.The significantreduction in this value in the GLU at pressures in excess of the preconsolidation stress is noteworthy .

FIGURE 5.3.4: VARIATION OF COEFFICIENT OF CONSOLIDATION WITH APPLIED VERTICAL STRESS



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5.3.4 DIRECT SIMPLE SHEAR (DSS) TESTS

The subsurface characterization has inferred a sub-horizontal shear zone at about El .920 m .The strength along this zone is best evaluated by DSS tests, which provide the ratio of undrained strength S_u to effective vertical consolidation stress σ_V', or simply the undrained strength ratio .Tests on specimens from the GLU unit that reflect the shear zone at about El 920–921 m are particularly relevant to the stability analyses that are discussed in section 6 . Accordingly, the test program has been extensive, varying initial confiningstress and initial shear stress .Testing with an initial shear stress (i e , stress bias) is intended to explore the influenceof a stage-constructed embankment that induces shear stresses in the ground prior to failure .

Another important feature exhibited by this test program on GLU specimens is a decline in resistance following its peak .This is called strain weakening .An example of a test exhibiting strain weakening is shown in **Figure 5.3.5** . As will be discussed, the presence of strain weakening contributes to understanding of the sudden nature of the breach mechanism .**Table 5.3.1** summarizes test characteristics and results from the DSS test program .Complete test results, with a brief description of test methodology, are presented in Appendix E .

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TABLE 5.3.1: SUMMARY OF DIRECT SIMPLE SHEAR (DSS) TEST RESULTS

SAMPLE	ELEVATION (m)	INFERRED PANEL SOIL UNIT	WATER CONTENT (%)	PLASTICITY INDEX	VERTICAL STRESS (kPa)	SHEAR BIAS	PEAK UNDRAINED STRENGTH RATIO
14-106A Sa1C-T1		UPPER GLU	43	31	600	0%	0.22
14-106A Sa1C-T2	921.1	UPPER GLU	37	31	600	10%	0.23
14-106A Sa1C-T3	921.1	UPPER GLU	38	31	600	20%	0.26
14-106A Sa1C-T4	921.1	UPPER GLU	33	31	300	20%	0.28
14-106C Sa1B-T1	921.2	UPPER GLU	44	33	600	30%	N/A
14-106C Sa1B-T2	921.2	UPPER GLU	43	33	600	25%	0.27
14-106C Sa1B-T3	921.2	UPPER GLU	39	33	600	10%	0.21
14-106G SA2B-T1	920.9	UPPER GLU	44	21	600	10%	0.21
14-106G SaB-T2	920.6	UPPER GLU	38	21	600	20%	0.26
14-107 Sa6C-T1	921.5	UPPER GLU	44	23	300	10%	0.27
14-107 Sa6C-T2	921.5	UPPER GLU	43	23	300	10%	0.25
14-107A Sa1A-T1	920.9	UPPER GLU	43	34	600	0%	0.21
14-107A Sa1A-T2	921.0	UPPER GLU	42	34	600	0%	0.20
14-107A Sa7	916.3	LOWER GLU	26	15	600	0%	0.30
14-109 Sa6B	916.6	LOWER GLU	22	13	300	10%	0.42
14-110 Sa6C	916.3	LOWER GLU	21	15	300	10%	0.27
14-113 Sa4B	922.9	UPPER TILL	13	7	300	10%	0.43
Average Peak Undrained Strength Ratio in Upper GLU						(no shear bias)	0.21
						(10% shear bias)	0.23
						(≥ = 20% shear bias)	0.27
						overall	0.24

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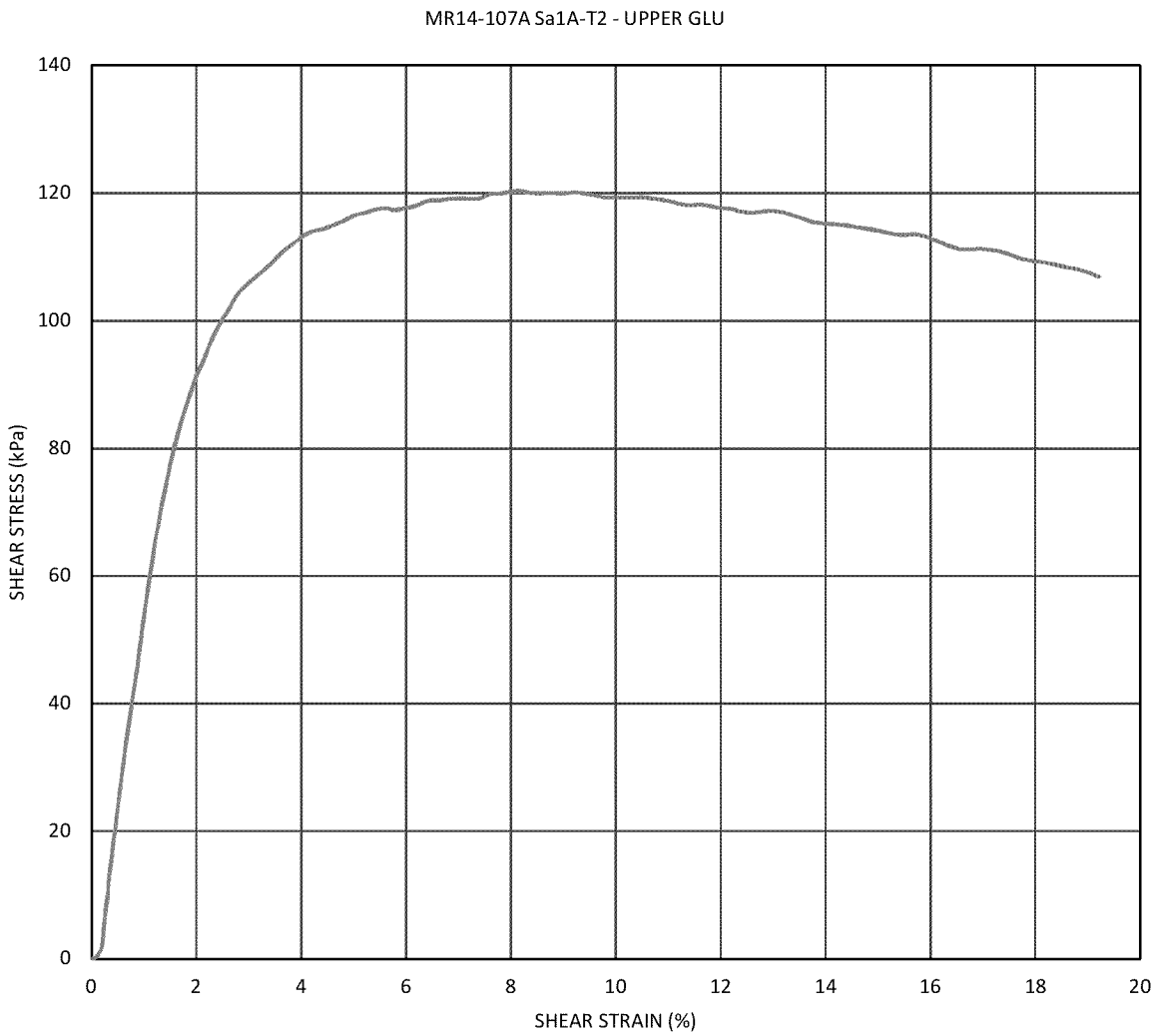
FIGURE 5.3.5: DSS TEST: GLU WITH STRAIN WEAKENING



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5.3.5 TRIAXIAL COMPRESSION TESTS

Triaxial compression tests with pore pressure measurements have also been conducted, in part for the record, and in part for use in stability analysis .The triaxial test data on till, together with the results from in situ pressuremeter tests, were used to inform the judgment of the Panel on an appropriate value to be used in the stability analyses.

Details of all triaxial tests are tabulated and presented in Appendix E .

5.3.6 DIRECT SHEAR TEST

While not used directly on any of its analyses, the Panel undertook a direct shear test on a pre-cut specimen of the GLU .This was primarily for the record, but affordedan opportunity for comparison with magnitudes adopted in some phases of the design .The Panel's measured residual strength of 16 degrees is at the lower end of the range used by others .The data are found in Appendix E .

5.3.7 DESIGN BASIS TESTING

The design of the Perimeter Embankment did not rely on any deep sampling of its foundation .Hence, no undisturbed samples were obtained, and no advanced laboratory tests were performed to provide data for purposes of comparison .

5.3.8 JOINT INVESTIGATION

Advanced laboratory studies were also performed on samples procured during the joint site investigation .The tests were not performed under the direction of the Panel, but are also included in a separate identifiablesection within Appendix E .

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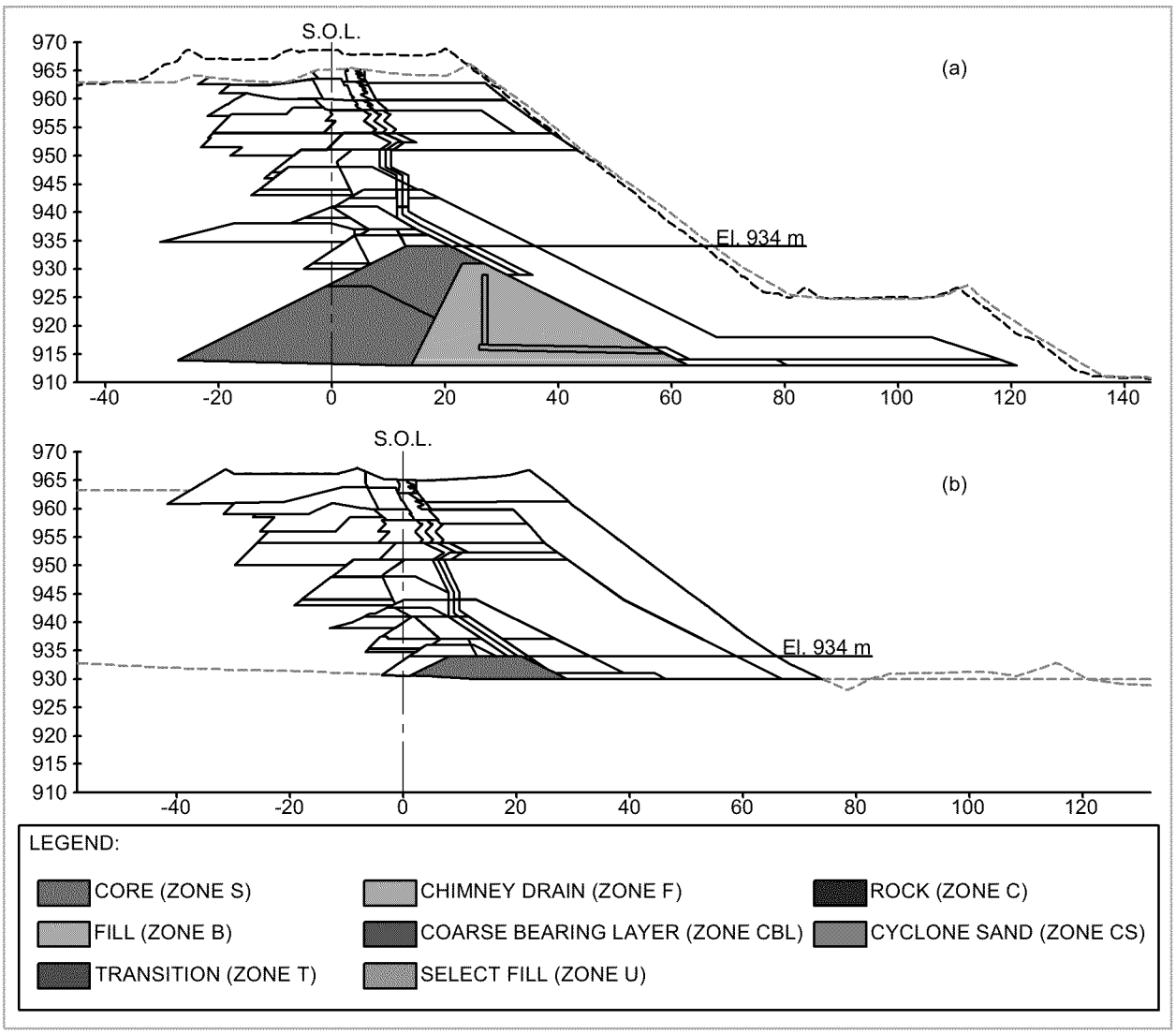
5.4 DESIGN, CONSTRUCTION AND OPERATION

This section describes the historical and sequential development of the Mount Polley Tailings Dam .The Main Embankment is included here along with the Perimeter Embankment to explain salient features and milestones related to design, construction and operation .The dam was developed in stages designated 1 through 9 that are treated in turn in the following discussion At each stage, as-built cross-sections for the Main Embankment and for the Perimeter Embankment at the breach location are used to portray the dam's progressive expansion .

5.4.1 STAGE 1: 1997 — 1998

FIGURE 5.4.1: STAGE 1 a MAIN EMBANKMENT b PERIMETER EMBANKMENT



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5 | Panel Observations

Design of the Main Embankment in May 1995[7] by KP established the direction for subsequent events. The overall plan incorporated dam raises to El. 960, of which Stage 1 would be the first, as illustrated in **Figure 5.4.1**. With planned raising by the "modified centreline" method,[8] the ultimate dam would rely on deposited tailings to provide structural support for the core. Fill would consist primarily of glacial till borrow soils, with sand tailings obtained by cycloning placed upstream of the core. The setting out line (S.O.L.) provided the reference for dimensioning the dam's fill zones and for stationing along its length.

Seismic criteria were based on a "low" consequence classification as defined by the Canadian Dam Association (CDA). The minimum factor of safety (FS) for the downstream dam slope was taken as 1.3 during impoundment operation and 1.5 at closure, design criteria that remained in effect for all subsequent raises. For the 2H:1V Stage 1 downstream slope, an effective-stress analysis (ESA) showed FS = 1.43, thereby satisfying the operational requirement.

Glaciolacustrine (GLU) fine sands, silts and clays were recognized from the outset to be present in the Main Embankment foundation. They were described as "typically dense to very dense and have been heavily overconsolidated by glaciers," with two samples confirming that they consisted of "stiff, overconsolidated materials."[9] In a crucial interpretation of their behaviour that would be relied upon throughout, a Ministry of Energy and Mines (MEM) query prompted KP to respond that "it is unlikely that any significant pore pressure development will occur in these materials during construction of the embankment."[10]

Refinement of the Stage 1 design and its component Stages 1A and 1B continued as construction approached. With encouragement from MEM's regulatory precursor, the Ministry of Employment and Investment, a narrow (1 m wide) chimney drain was added,[11] and four relief wells were installed in the foundation of the Main Embankment to reduce uplift pressures acting on GLU layers.[12]

In addition, the detailed Stage 1 design included a small dam only a few metres high to close off a topographic depression west of the Main Embankment. Designated the Perimeter Embankment and shown in **Figure 5.4.1(b)**, it would grow with subsequent stages to itself become a substantial structure contiguous with the Main Embankment. It would also host the site of the breach.

Construction of Stage 1 was completed in March 1997. Glacial till (Zone S and Zone B) was sourced from borrow excavations within the impoundment interior. The chimney drain materials (Zone F) were obtained by crushing, as would remain the case for subsequent raises. Both materials were subject to Construction Quality Assurance (CQA) testing. Vibrating wire piezometers were installed in both the embankment fill and foundation, with four of the six foundation instruments indicating elevated pressures. In response, a new operational stability criterion was established—an allowable ESA factor of safety of 1.1 at a trigger (action) level of 6 m of measured pressure head above the ground surface.[13, 14]

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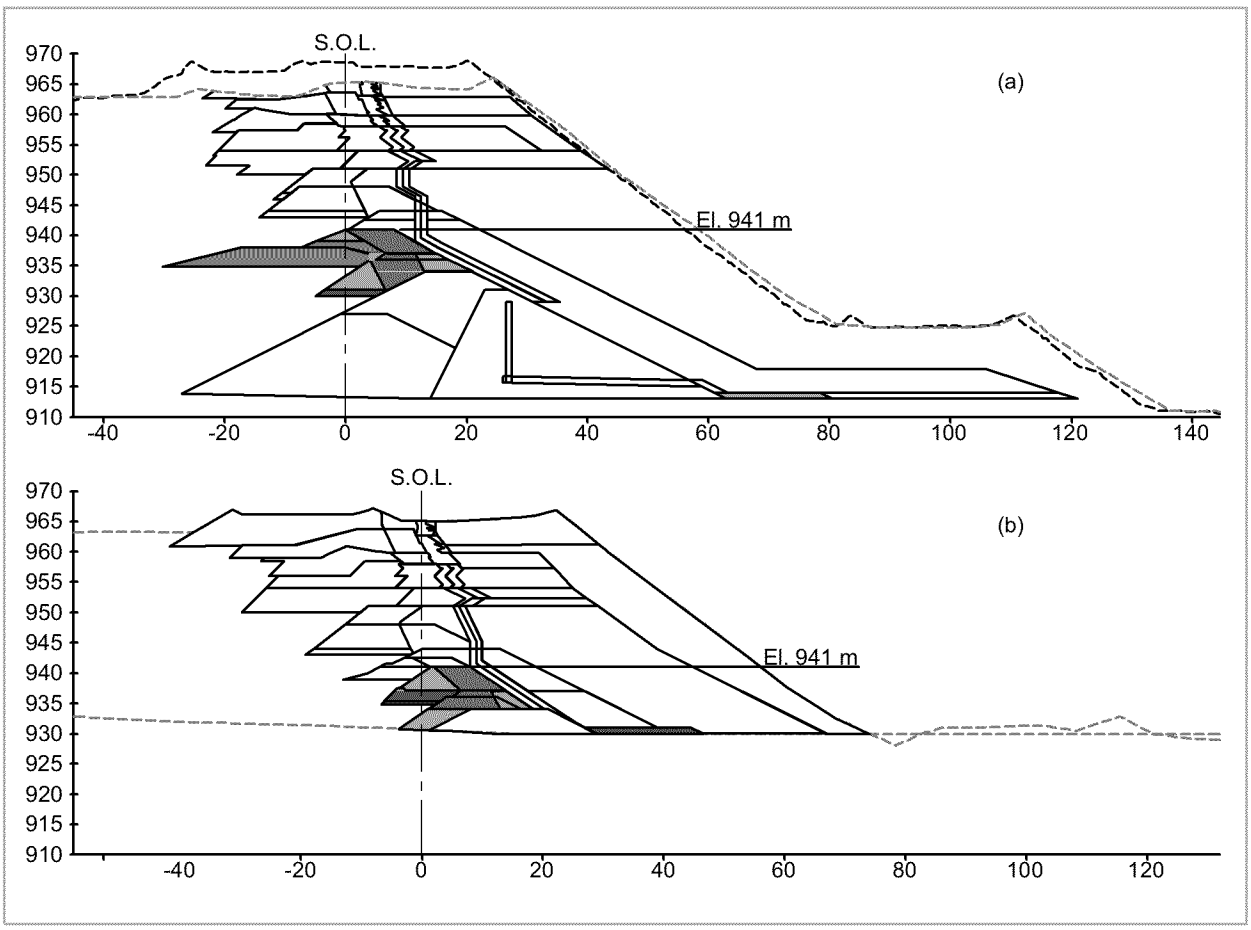
5.4.2 STAGE 2: 1998 — 2000

FIGURE 5.4.2: STAGE 2 (a) MAIN EMBANKMENT (b) PERIMETER EMBANKMENT



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Stage 2 was designed to be the first"modifiedcentreline" raise In the design, the core (Zone S) and chimney drain (Zone F) were extended upward, while adding a new zone of what was intended to be mine waste rock (Zone C) on the downstream slope and outward as a berm along the Main Embankment .[15] Another new feature for the Main Embankment was a longitudinal drain, designated the "upstream toe drain," on the upstream side of the core near the crest of the raise .Its purpose was to allow drainage of the deposited tailings and reduce the embankment phreatic surface An additional seven relief wells [16] and a relief trench were also included to reduce elevated foundation pore pressures .For the design configurationof the Main Embankment, FS = 1 67 was computed for the downstream slope, exceeding the minimum required value of 1 3 .[17]

The as-built configurationof the Stage 2 Main Embankment shown in **Figure 5.4.2(a)** differedfrom the design in several important respects .The intended Zone C mine waste fillwas not added to the downstream slope, and the berm along the toe was not constructed Rather than adhering to a "centreline" configuration,raise 2 utilized entirely "upstream" construction .[18] The same conditions prevailed for the Perimeter Embankment shown in **Figure 5.4.2(b)** . These as-built conditions were never reconciled with the Stage 2 stability analyses, which had been predicated on the original design configuration .

Operational trials and test fillsestablished the feasibility of using cyclone sand underflowupstream of the core (Zone CS), and Stage 2 was the firstto do so A limited trial zone of cyclone sand would remain in the downstream shell of the Perimeter Embankment at design Section D, but cycloning would later be abandoned for both operational and economic reasons .[19, 20]

In other operational matters, problems with the tailings pipeline system produced difficulties in maintaining the required tailings beach, with water directly contacting the embankments in some places .[21]

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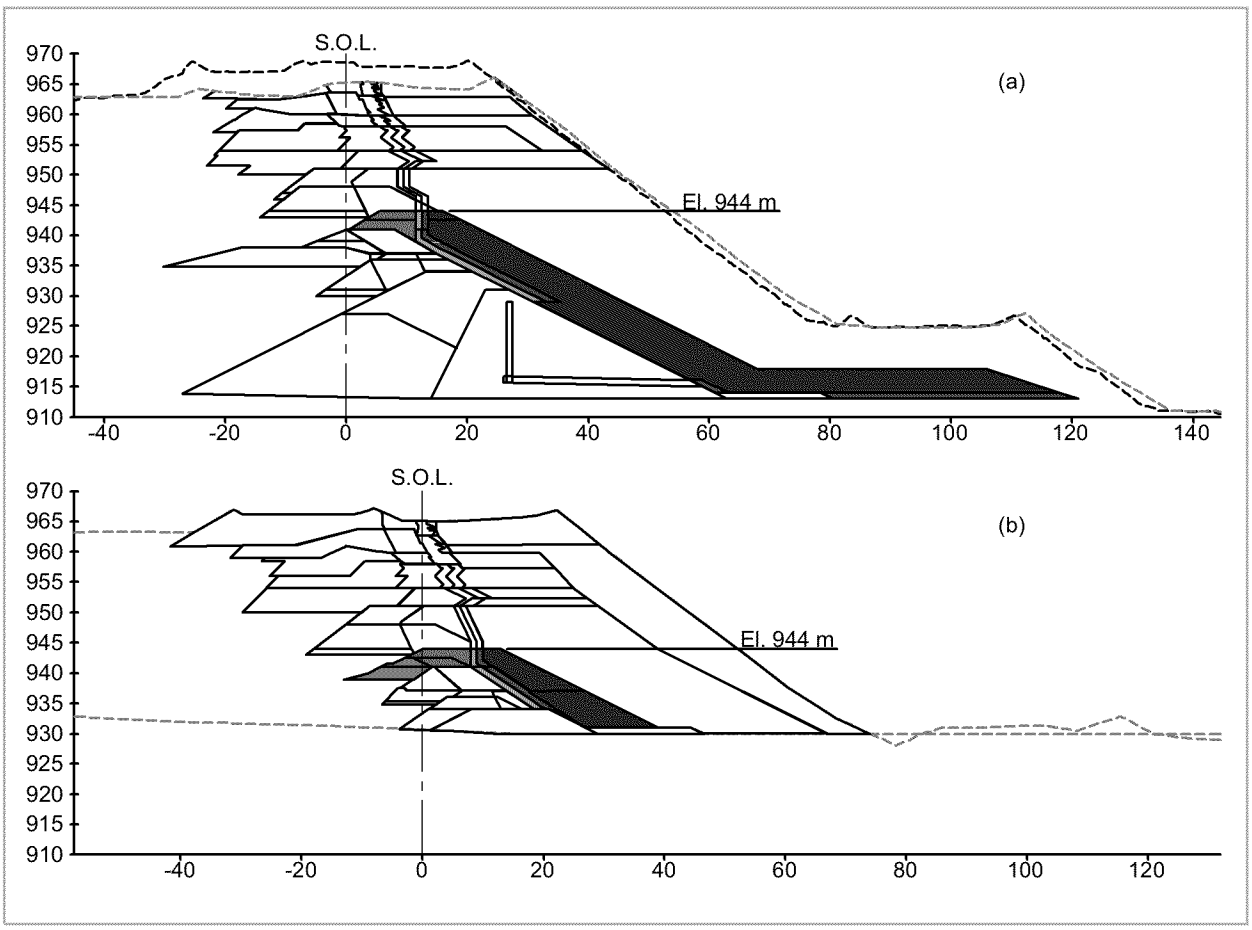
5.4.3 STAGE 3: 2000 — 2001

FIGURE 5.4.3: STAGE 3 (a) MAIN EMBANKMENT (b) PERIMETER EMBANKMENT



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As Stage 2 was being constructed, effortswere underway to select materials for the upcoming Stage 3 and the remainder of the dam A series of design studies in 1999 and 2000 developed a variety of configurationsand options using cyclone sand[22, 23] as well as a rockfillalternative .[24] Various combinations were considered for the Main Embankment, the Perimeter Embankment, and the newly added South Embankment that would confinethe third side of the impoundment beginning with Stage 3.

In May 2000, MPMC requested approval from MEM for a Stage 3 design using only cyclone sand for the Perimeter Embankment, with the Main Embankment raised using rockfill and the South Embankment with glacial till .[25] This was changed, however, in April 2001, when MPMC requested MEM approval for yet a different Stage 3 design using rockfill for the downstream Zone C in all three embankments .As shown by the as-built configuration in Figure 5 4-3, this plan was ultimately adopted for Stage 3 using rockfill sourced from a quarry .[26]

Despite the convoluted nature of the Stage 3 design process, an important milestone was that the Observational Method was formally invoked as the basis for design .[27] Thenceforward, each incremental raise was to be continually re-evaluated during operations, based on measured data from the piezometers and two inclinometers installed in July 2001 .Putting this into effect,however, would have to wait .Not long thereafter, Mine operations were suspended for economic reasons on October 13, 2001 .[28]

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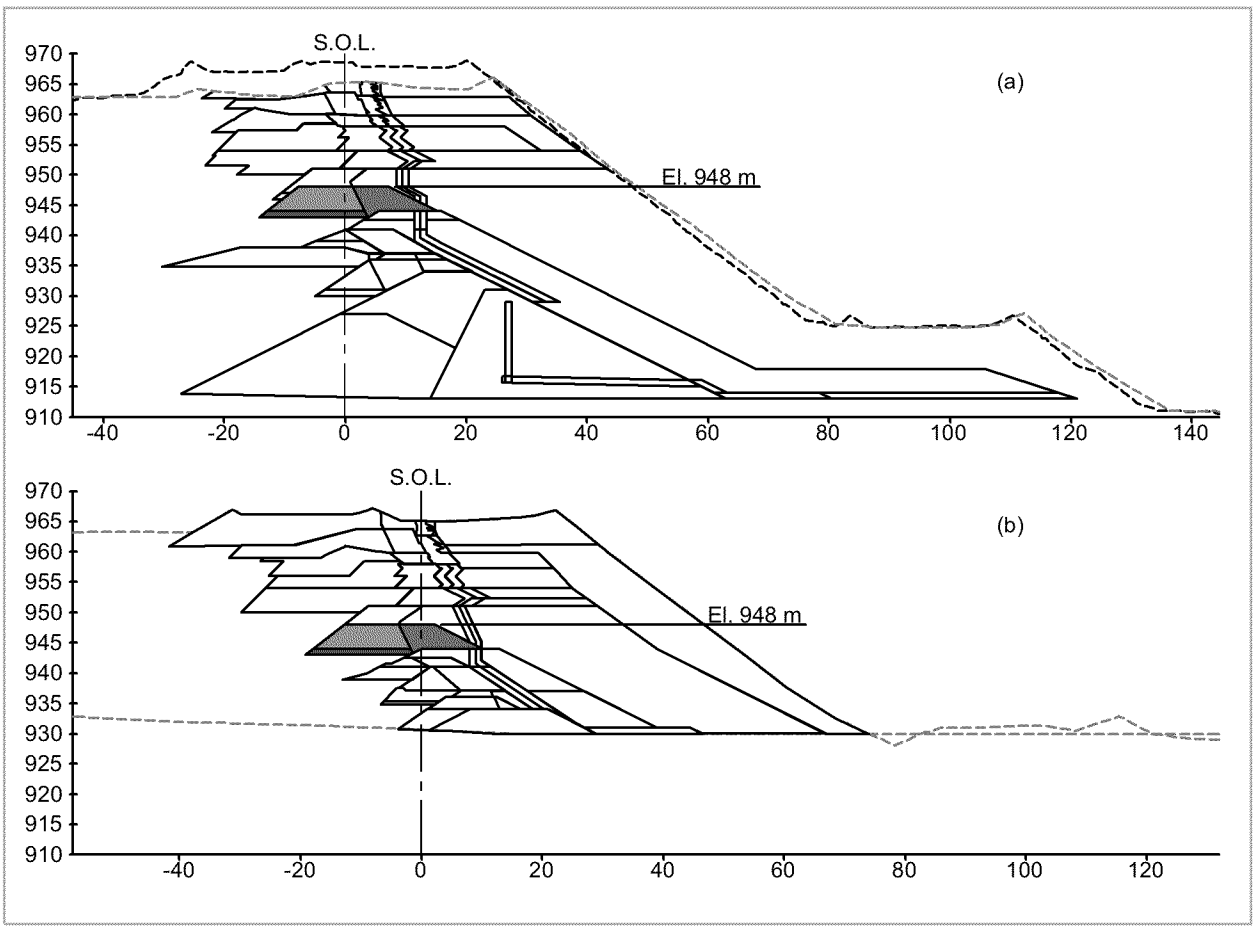
5.4.4 STAGE 4: 2005 — 2006

FIGURE 5.4.4: STAGE 4 (a) MAIN EMBANKMENT (b) PERIMETER EMBANKMENT



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After a hiatus of over 3 years, Mine operations resumed in February 2005 Design of the Stage 4 raise called for a small cap on the Stage 3 crest extending over the tailings in an "upstream" configuration,together with Zone C rockfillon the downstream slope Also included in the design was a rockfillbuttress on the downstream slope of the Main Embankment to increase the factor of safety to 15 in anticipation of closure requirements.[29]

As illustrated in **Figure 5.4.4**, only the cap was constructed in Stage 4 without any additional rockfill on the downstream slope, resulting in another "upstream"-type raise .[30] In constructing this raise, trial programs pioneered the use of hydraulic-cell deposition of tailings for the upstream Zone U, a practice that continued throughout construction .

Separately, operational problems in maintaining the required tailings beach continued, with water directly against the embankment in several areas .[31]

Renewed operation brought renewed queries from MEM concerning the glaciolacustrine foundation materials . One concerned the characteristics and effectson dam stability of softer GLU deposits at groundwater well GW96-1A downstream from the Perimeter Embankment .[32] In response, KP cited borrow area test pits and auger borings as confirmingthat "the glaciolacustrine deposit encountered in GW96-1A is a discontinuous unit and will not adversely affect the dam stability".[33]

The breach subsequently occurred 300 m due west of GW96-1A .

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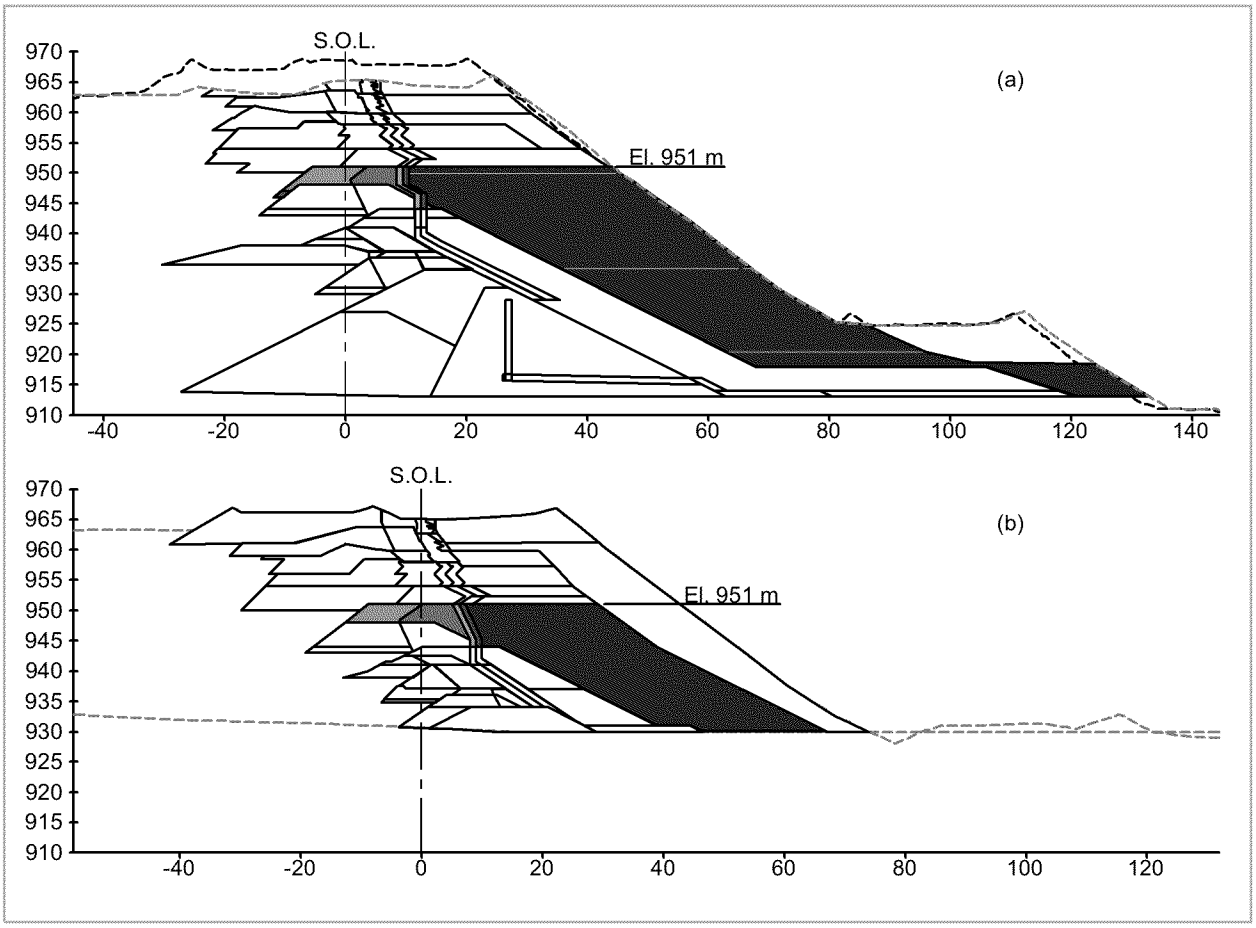
5.4.5 STAGE 5: 2006 — 2007

FIGURE 5.4.5: STAGE 5 (a) MAIN EMBANKMENT (b) PERIMETER EMBANKMENT



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The Stage 5 design once again incorporated the downstream Zone C rockfillthat had been deferred in previous stages, and this time it was built .But since the material would now be sourced from mine waste rather than quarried, mine production and delivery had to be accommodated .[34] Due to related restrictions, it was planned to place the Zone C outslope to an "interim" 1 4H:1V inclination—rather than the design basis 2 0H:1V—as a temporary expedient until mine waste delivery could catch up with construction .The steeper slope would be expanded and flattenedto 2 0H:1V "once the embankments have reached the Stage 5 design elevation".[35] An ESA factor of safety of 1 5 was reported for the steeper interim slopes of the Main Embankment and 19 for the Perimeter Embankment .

It was planned to place the Zone C outslope to an "interim" 1.4H:1V inclination—rather than the design basis 2.0H:1V—as a temporary expedient until mine waste delivery could catch up with construction.

Stage 5 construction proceeded from Stage 4 in a continuous, uninterrupted campaign and was completed in November 2007But instead of rectifying the interim steep slopes at this time as had been intended, such measures were left to future stages of embankment raising .[36]

Stage 5 saw the firstsubstantial enlargement of the Perimeter Embankment, with widening of the crest and expansion of the downstream Zone C rockfillas shown in **Figure 5.4.5(b)** .At the same time, an upstream toe drain was added to complement the companion drain already installed at the Main Embankment.

Operationally, chronic problems with maintaining the tailings beach continued, with procurement of enough tailings pipe to traverse the entire embankment perimeter now the anticipated solution.[37]

The year 2006 marked the 10-year interval for the mandatory third-party Dam Safety Review (DSR), which was prepared by AMEC .[38] The most salient aspects of this report concern its assessment of foundation strength and related dam stability Shear failure of the dam slope, including failure through the foundation, was firston a list of potential failure modes applicable to the Mount Polley dam in relation to "excessive loading at or near the crest or a weakness in the foundation". Noting the apparent overconsolidation of the glaciolacustrine materials, the report identifiedtwo conditions of particular interest: the possible presence of pre-sheared planes of weakness, and the potential for "brittle" response involving strength loss at small strains The DSR contained no mention of the behaviour of foundation materials in undrained shear .

The Dam Safety Review contained no mention of the behaviour of foundation materials in undrained shear.

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The DSR also remarked on the lack of a tailings placement strategy that had impeded systematic development of a tailings beach for so long, calling lack of such a beach a "deficiency"and noting that the dam had not been designed as a water dam .

Shortly after the DSR was submitted, at MPMC's request, AMEC produced a follow-up report that reviewed several possible optimization measures for the TSF .[39] One measure was to reduce the width of the core to as little as 3 m to 4 m Another was to eliminate the uppermost 1 m of the dam core, since this part of the crest "only provides freeboard ".

The optimization report also questioned the need for the Main Embankment buttress firstproposed for Stage 4 and partially constructed for Stage 5 .It concluded that foundation strengths used previously would result in adequate stability without a buttress The only proviso was the potential for pre-sheared planes of weakness in the foundation, a question that remained outstanding from the DSR .

With the water balance "finetuned to an accuracy that is in the range of centimeters" in terms of impoundment water elevation, the report proposed that the wave runup allowance, and therefore freeboard requirements, could be reduced .Remarking on beach development, it further stated that unless water was deep enough to affect stability of the Zone U tailings, there was "no rush" in developing a beach along the Main Embankment to correct the deficiency identified in the DSR .

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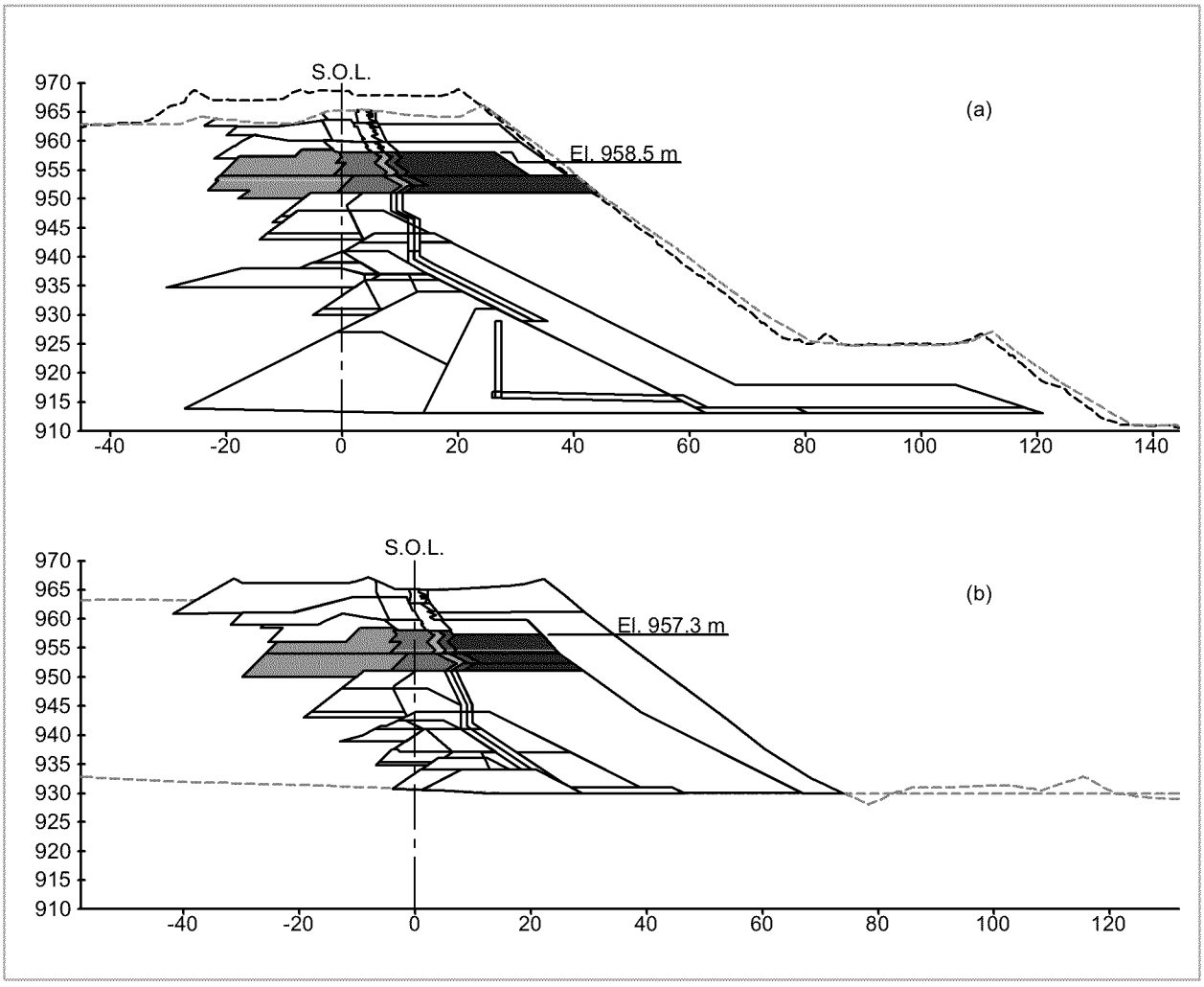
5.4.6 STAGE 6: 2007 — 2011

FIGURE 5.4.6: STAGE 6 (a) MAIN EMBANKMENT (b) PERIMETER EMBANKMENT



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5 | Panel Observations

The Stage 6 design for the Main Embankment incorporated two components: an additional 7 m of fillon the crest, and a Zone C rockfillbuttress at the downstream toe .The Zone S core was reduced from its former 8 m width to 5 m on the basis of the effectivenessof the upstream toe drains in lowering the phreatic surface and gradients within the core .[40] Stage 6 also introduced the practice of raising the Zone S core, the thin Zone F filterand the equally thin Zone T transition in an intricate zigzag configuration .

The Main Embankment buttress, firstincluded in the Stage 4 design but never fully constructed, was an outgrowth of two factors First was the effecton stability of the "interim" 1 4H:1V slopes that had persisted since Stage 5 Second were the foundation strength interpretations put forward in the DSR Stage 6 stability analyses adopted an estimated residual strength of 24° for the GLU foundation materials at the Main Embankment to account for the possible presence of pre-shearing.The resulting buttress produced an ESA factor of safety of 1 4, satisfying the FS = 1 3 design requirement for operation .

The Stage 6 design sought to accommodate the limited mine waste delivery rates experienced in Stage 5—and the consequent slope oversteepening—by extending construction over a 2-year period .Even so, the calculated FS = 1 4 for the Stage 6 Main Embankment indicated that the buttress would need to continue being raised in future dam stages, requiring more material . To make matters worse, KP noted that only non-reactive mine waste could be used, further constraining available quantities and confirming buttress construction as a continuing proposition .But once again, the Stage 6 buttress was not constructed as designed, turning out to be about 5 m below its design height and short of its design extent.[41]

But once again, the Stage 6 buttress was not constructed as designed, turning out to be about 5 m below its design height and short of its design extent.

None of these buttressing considerations pertained to the Perimeter Embankment .Residual strength parameters were not applied to its foundation, and the resulting factor of safety of 1 7 required no enhancement according to the FS = 1 3 criterion .

Elsewhere, beach deposition from the extended tailings discharge line had not been successful in preventing water accumulation against the Main Embankment.This increased flowsin the same upstream toe drain whose effectiveness had been cited as justification for reducing the width of the Stage 6 core.[42]

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Meanwhile, follow-up related to the DSR continued MEM requested that KP provide the results of its recommended direct shear testing, which essentially confirmedthe Stage 6 design ESA factor of safety .[43, 44] But beyond this was another item in KP's response that marked a milestone in two fundamental respects For the firstand only time during the design process, an undrained strength analysis (USA) was performed.This was also the only instance that the foundation clay behaviour would be taken as other than that of stiff and highly overconsolidated material.Using a typical S_u/σ_v', of 0 25 for soft, normally consolidated clays, KP found a USA factor of safety of 11 for the Stage 6 configuration.Not recognizing that this strength might indeed be the operational strength under static loading conditions, KP concluded that "there is also sufficientundrained strength in the lacustrine unit for the embankment to remain stable". This conclusion would henceforth never be called into question .

Not recognizing that this strength might indeed be the operational strength under static loading conditions, KP concluded that "there is also sufficient undrained strength in the lacustrine unit for the embankment to remain stable." This conclusion would henceforth never be called into question.

Operation of Stage 6 throughout 2009 and 2010 highlighted other matters.In 2009, movements in the GLU recorded at Inclinometer SI01-02 resulted in expanding the Main Embankment buttress in the immediate area.This proved to be effectivein arresting further displacements .[45] By 2010, the buttress had been extended along the west side of the Main Embankment, but still remained to be completed along its entire length .[46] In another development, a tension crack appeared at the downstream edge of Zone C at Sta 3+400 of the Perimeter Embankment Although interpreted to be an artifact of near-surface movement, a follow-up stability assessment was nonetheless recommended.

Inadequate tailings beach development along the Main and South Embankments was flaggedyet again, this time in an MEM inspection.Noting that an above-water beach was a requirement of the design, the inspector considered its absence at the southeast corner of the Main Embankment to be a "Departure from Approval" and ordered that a beach be "re-established as soon as possible in this area to meet the design objectives".[47]

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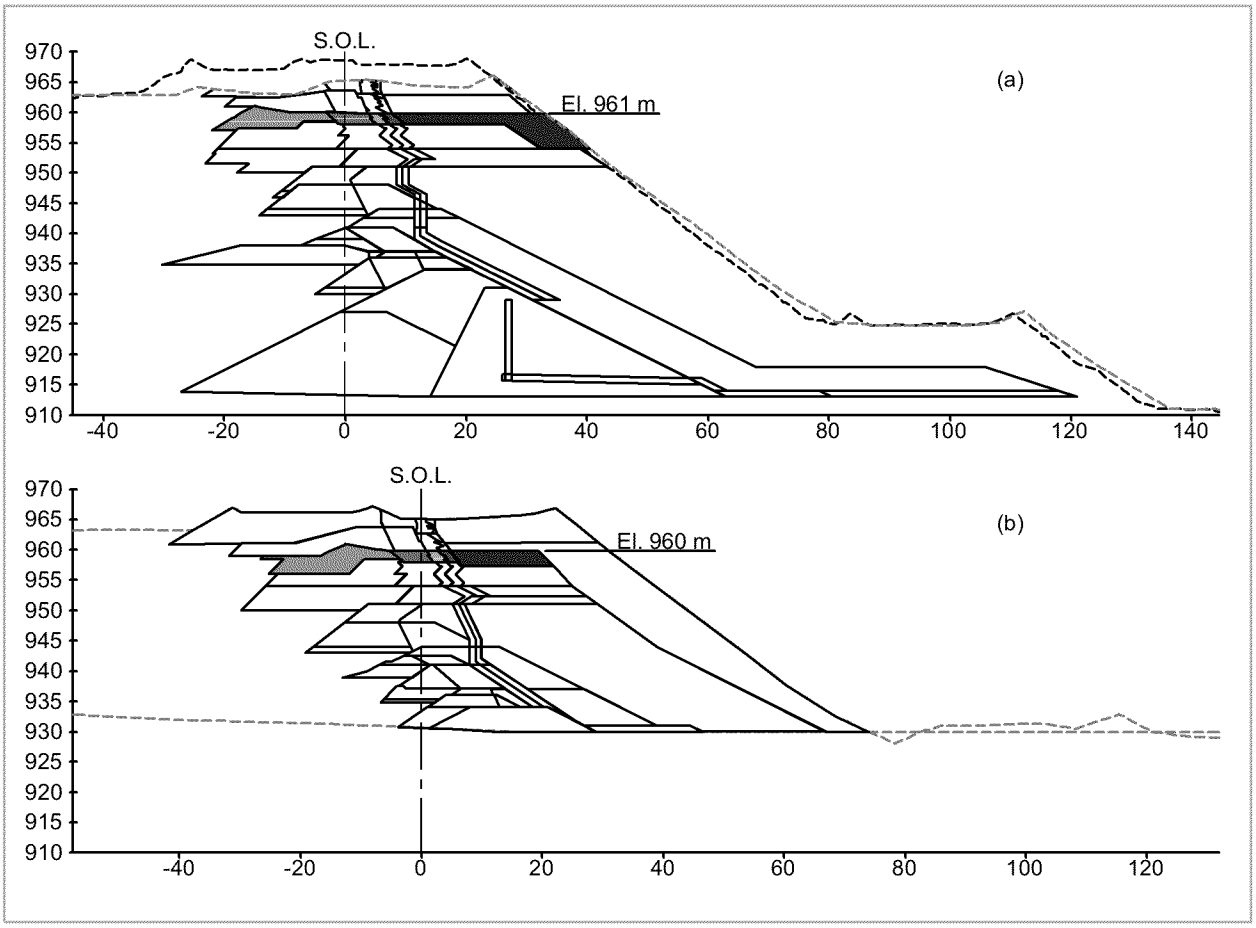
5.4.7 STAGE 7: 2011 — 2012

FIGURE 5.4.7: STAGE 7 (a) MAIN EMBANKMENT (b) PERIMETER EMBANKMENT



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5 | Panel Observations

In 2011, the Engineer of Record (EOR) responsibilites were transferred from KP to AMEC, and with them the design of Stage 7 for a height increase of 2 5m No new Zone C fillwould be added to flattenthe downstream slope, and no buttress expansion would be conducted .Continuing the stability analysis protocols from Stage 6 and the 2006 DSR, AMEC found that the ESA factor of safety using residual strength for the foundation GLU was unchanged from the Stage 6 value of 1 4.[48] for the Main Embankment Similar conclusions applied to the factor of safety for the Perimeter Embankment .

The same year also saw the completion of the 2011 Geotechnical Site Investigation, the firstmajor foundation exploration program since Stage 1 .It consisted of 11 sonic drillholes, with piezometers installed in each, plus three new inclinometers .[49] Emphasis was on definitivelyevaluating the DSR hypothesis that the glaciolacustrine foundation soils might contain pre-sheared planes of weakness and the operative residual strengths that would accompany them .

Careful inspection of recovered core revealed no indications of slickensidefeatures and no evidence of pre-shearing . Thus, residual strengths need no longer be considered .Neither, it was concluded, did these conditions indicate that the 2010 crack in the Perimeter Embankment was attributable to weak soil conditions in the area.

With respect to stress history, the 2011 report further concluded that the GLU was overconsolidated,consistent with previous interpretations .The softer conditions in monitor well GW96-1A adjacent to the Perimeter Embankment that MEM had questioned in 2005 were said to be "not of significantconcern in this instance as the drillhole location is approximately 140 m further downstream from the current toe of the dam ". In fact, the report said, "based upon available information, foundation conditions along the Perimeter Embankment appear more favourable than those along the Main Embankment" in terms of the presence and extent of clay-rich zones within the GLU.

At the Main Embankment, piezometers were installed generally beneath the buttress where measured pore pressures would be reflectiveof additional fill .This was not the case at the Perimeter Embankment, where all of the new piezometers were located 15–20 m from the downstream toe Similarly, Inclinometer SI11-04 installed during the program was 15 m away .

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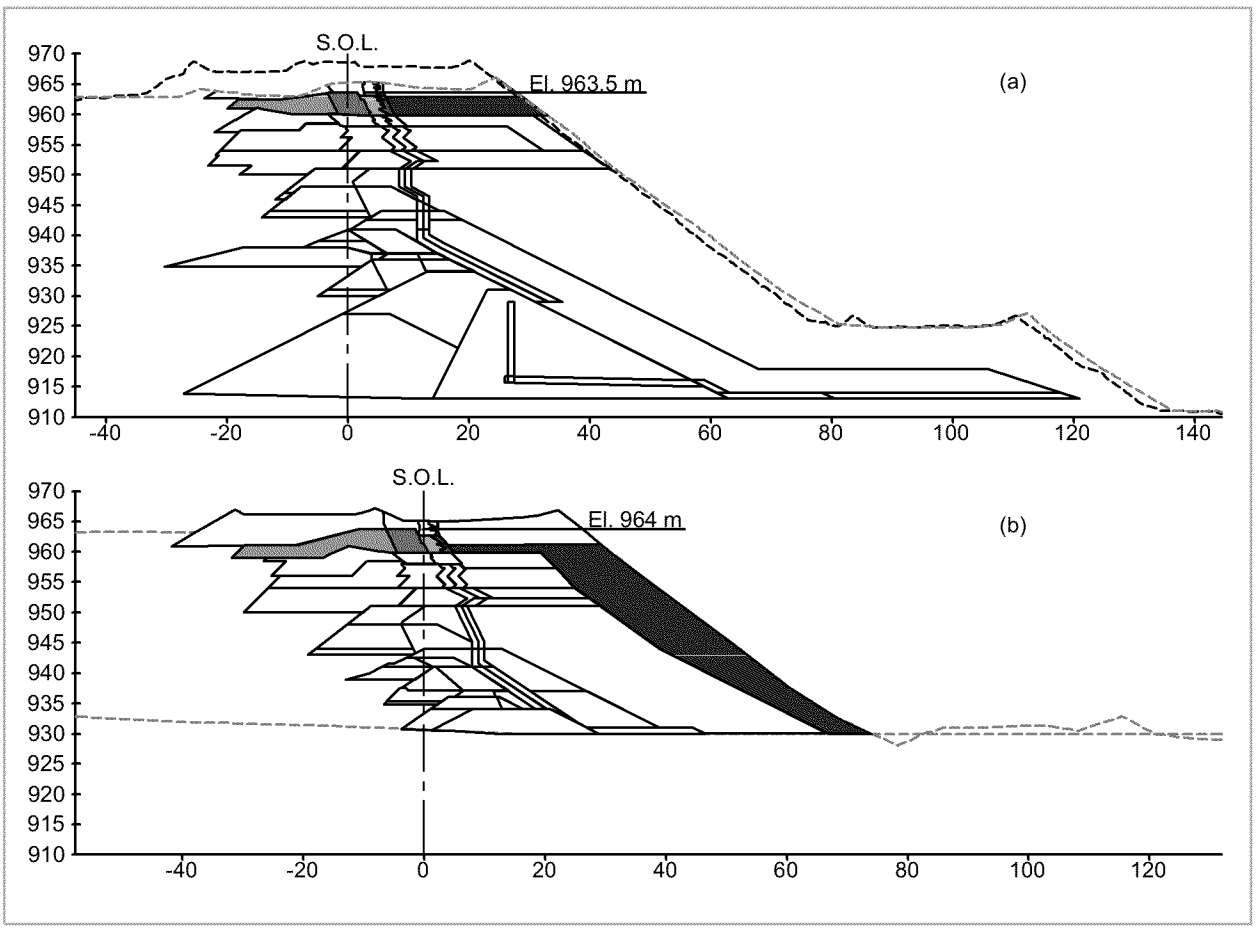
5.4.8 STAGE 8: 2012 — 2013

FIGURE 5.4.8: STAGE 8 (a) MAIN EMBANKMENT (b) PERIMETER EMBANKMENT



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5 | Panel Observations

Stage 8 was initially designed as a 3 5m raise, then increased to 5 m with an accelerated construction program .It would change to conventional "centreline" raising from the previous "modified centreline" that had progressively shifted the raises upstream Stage 8 fill was added only to the crest of Stage 7 Main Embankment,[50, 51] while the Perimeter Embankment was widened as well .But in both cases, flattening of the Stage 5 "interim" oversteepened slope to 2H:1V was deferred yet again—not until completion of Stage 5 raise as first proposed, but this time until completion of the entire dam .

Flattening of the Stage 5 "interim" oversteepened slope to 2H:1V was deferred yet again—not until completion of Stage 5 raise as first proposed, but this time until completion of the entire dam.

In evaluating the stability of the steepened slope, AMEC returned to the peak-strength interpretation for the GLU materials based on the findings of its 2011 field program For a peak effective-stress friction angle of 28°, the ESA factor of safety was found to be a barely adequate 1 31[52] for the Main Embankment .

The 2011 investigation showed the GLU materials at Section D of the Perimeter Embankment to be deeper than at the Main Embankment In stability analyses at Section D near the breach, the critical failure surface did not reach the GLU and remained within the overlying foundation till, producing a much higher factor of safety of 177 .

The larger issue of what minimum factor of safety should be required was addressed in a September 19, 2012 communication from MEM to MPMC that deserves to be quoted at length:

The factor of safety for the main embankment is only marginally above the short-term design criteria of 1.3... AMEC has interpreted Table 6-2 from the 2007 Dam Safety Guidelines somewhat differently than I have seen in the past. This table recommends a minimum factor of safety of 1.3 at the end of construction and 'before reservoir filling' and a factor of safety of 1.5 at the 'normal reservoir level.' AMEC has interpreted the construction period as the entire pre-closure period, and this is open to debate. However, I consider that sufficient mitigation measures are in place (i.e., piezometer trigger thresholds) to support this more liberal interpretation in this instance.[53]

Although questioning AMEC's interpretation of the Dam Safety Guidelines, MEM was prepared to accept FS = 1 3, but only in conjunction with the Observational Method .

In other matters, the recurring problem of tailings beach development was not directly addressed in the 2012 inspection report, but an airphoto showed no tailings beach over approximately 40% of the impoundment perimeter .[54] The report also noted that seepage had been present at the toe of the Perimeter Embankment near the breach section and that it had moved from previous years Based on interviews with MPMC personnel, the Panel believes that the likely source of the apparent seepage was actually a buried outlet of the upstream toe drain .[55, 56]

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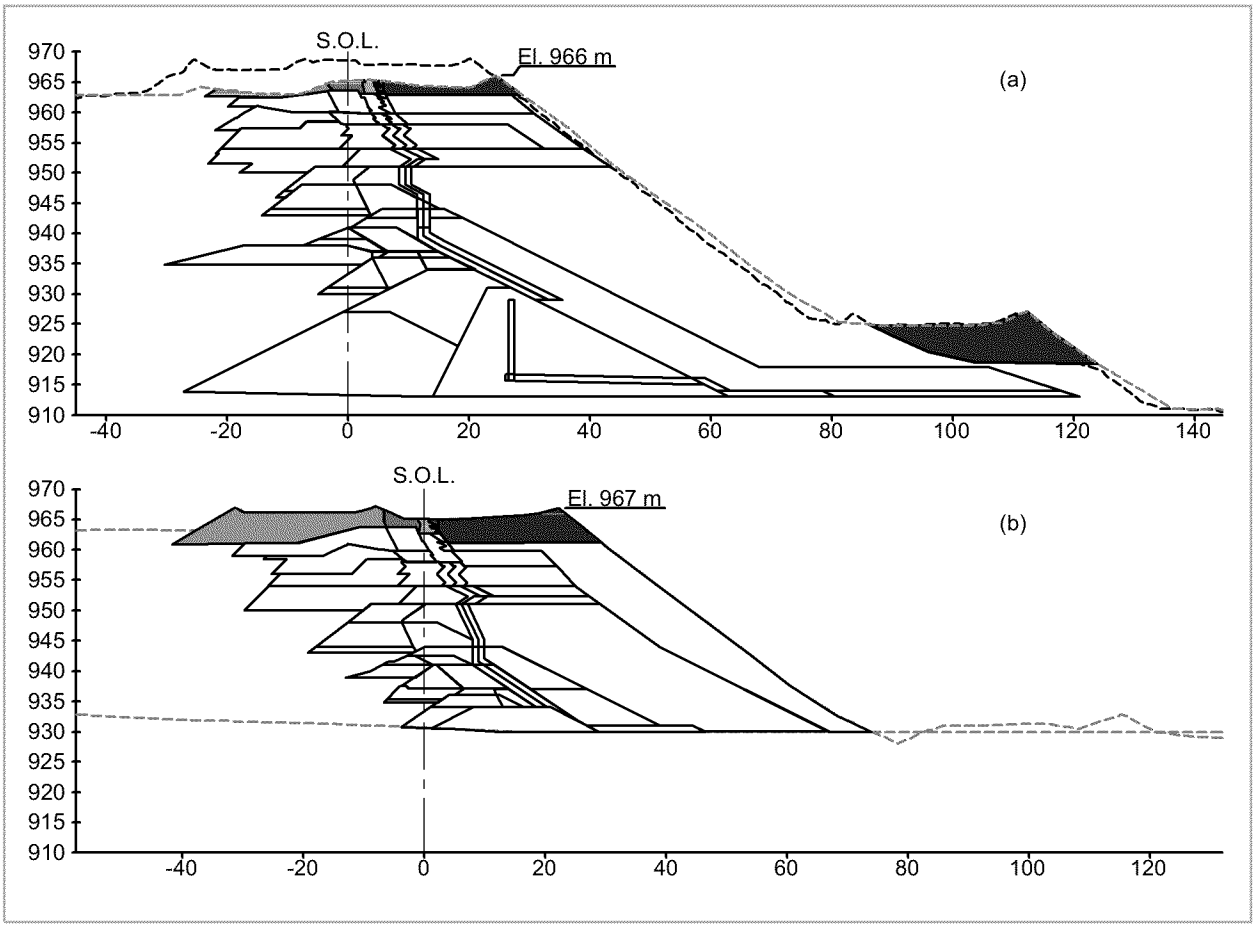
5.4.9 STAGE 9: 2013 — 2014

FIGURE 5.4.9: STAGE 9 (a) MAIN EMBANKMENT (b) PERIMETER EMBANKMENT



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Stage 9, whose construction was being completed when the breach occurred, encompassed a period of intense activity with a number of seminal events in the months, weeks and days preceding the failure. While AMEC remained the EOR until the planned completion of Stage 9 to El. 970, BGC would officially become the EOR beginning with construction of the planned Raise 10. Consequently, 2013 to 2014 was also a period of transition, with overlap in activities, if not responsibilities.

AMEC's April 11, 2013 design for Stage 9 planned a substantial 6.5m height increase by adding fill to the crest of Stage 8. Retaining the peak-strength interpretation for the GLU foundation materials, AMEC found that raising the Main Embankment buttress to El. 925 m would be needed to nominally achieve a minimum ESA factor of safety of 1.3.[57]

Commenting on the implications of this value, MEM's remarks on July 29, 2013, echoed its previous concerns:

The stability analyses indicate that the FOS for the 'Main Embankment' only marginally achieves the short term CDA design criteria of 1.3. ... Previous correspondence from MEM has highlighted the difference in interpretation of the CDA Guidelines. AMEC has considered the construction period to be the entire 'pre-closure' period while CDA Guidelines, Table 6-2 recommends a minimum FOS of 1.3 'before reservoir filling,' and a FOS of 1.5 at the 'normal reservoir level.'

MEM requires a commitment from Mount Polley that they are moving toward increasing these FOS for the main embankment as part of subsequent dam raises in an effort to move toward achieving a long term FOS equal to 1.5. It is expected that Mount Polley will continue their transition to centerline construction and provide additional buttressing with time.[58]

This marked a major change in direction. A factor of safety of 1.5, not 1.3, would become the governing criterion. Moreover, buttressing could no longer be deferred for either embankment. A factor of safety of 1.58 had been calculated for Section D of the Perimeter Embankment, once more unaffected by the GLU foundation materials. But even this value was approaching the new minimum of 1.5 that MEM was now aiming to enforce, and buttress preparation needed to begin.

This marked a major change in direction. A factor of safety of 1.5, not 1.3, would become the governing criterion.

By the end of the 2013 construction season, pre-stripping for a buttress around the Perimeter Embankment had been completed, including the area of the breach section.[59] In a Panel interview, the contractor who performed the work stated that portions of this area remained open at the time of the breach,[60] an assessment confirmed by MPMC.[61, 62]

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Meanwhile, attention was turning to longer-term prospects for continued dam raising, and the outlook was not good BGC made explicit the connection between the structural limitations of the dam and the ever-growing volumes of surplus water it was being called upon to contain .In a June 18, 2013 memorandum, it stated:

A continuous beach along the complete upstream length of the dam is the design requirement necessary for dam stability and needs to be achieved moving forward regardless of the finaltargeted crest elevation. The current water pond surplus does not allow for the development/maintenance of above-water beaches.[63]

It elaborated on this topic a month later, on July 25, 2013:

An above-water tailings beach separating the till core from the reclaim water pond constitutes a fundamental design element of the dam. Without a wide above-water beach, the MPMC tailings dam is effectivelybeing operated as a water-retaining dam, with the water pond effectivelyin direct contact with the till core, separated by only a narrow zone of tailings or waste rock.[64]

During the ensuing months, this chronic water-surplus problem would become acute For years, dam raising had managed to stay one step ahead of the rising water But on May 24, 2014, the water caught up . With Stage 9 nearing completion, what was described as "seepage flow"was observed over the dam core .[65] Intensive surveillance and construction activity over the following days and weeks succeeded in raising low areas around the embankment perimeter, restoring containment integrity, and saving the dam from overtopping failure .

For years, dam raising had managed to stay one step ahead of the rising water. But on May 24, 2014, the water caught up.

As the gravity of the water problem was becoming apparent, so was the consequent necessity of dam raising beyond Stage 9 .MPMC required some estimate of future dam footprint so that prerequisite stripping of additional areas could commence immediately BGC responded on October 22, 2013, with a memorandum that outlined an approach to dam raising that resurrected the residual-strength interpretation for GLU, while at the same time establishing new factor of safety criteria conforming to MEM's 2013 directive.[66]

This approach was formalized in BGC's design report for Stage 10 issued on July 25, 2014, just eight days before the breach .[67] The proposed raise would achieve a minimum FS = 1 5for the Main Embankment using peak effective-stressstrength for the GLU and full dissipation of load-induced pore pressures But this new design philosophy would go one step further .

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Notwithstanding AMEC's 2011 subsurface investigation, a "more conservative" approach would be taken by allowing for the possibility of brittle behaviour or pre-shearing in the GLU .This would apply an additional criterion of FS = 11 using residual strength in the GLU for what was characterized as a "reasonable worst-case scenario". So the residual-strength interpretation was now reintroduced after firstbeing suggested in the 2006 DSR, adopted in design of Stages 6 and 7, then abandoned in design of Stage 8 .

The BGC report also commented on the application of the Observational Method to these conditions Citing its chief progenitor Ralph Peck, the report recognized that this design strategy requires preplanned actions to deal with "every unfavourable situation that might be disclosed by the observations".[68] But it also acknowledged that any brittle behaviour detected by the instrumentation would result in strength reduction too rapid to recognize and respond to Hence the need, it said, for the minimum FS = 1 1 and its associated residual strength interpretation as a contingency As a result, the existing buttress on the Main Embankment would be raised, and a new buttress about 8 m high would be added to the Perimeter Embankment . This was to include what would become the area of the breach .

In a final irony, the Stage 10 buttress was scheduled for construction on the Perimeter Embankment in late 2014 or early 2015 .Had it been in place on August 3, 2014, the dam would have survived .

In a final irony, the Stage 10 buttress was scheduled for construction on the Perimeter Embankment in late 2014 or early 2015. Had it been in place on August 3, 2014, the dam would have survived.

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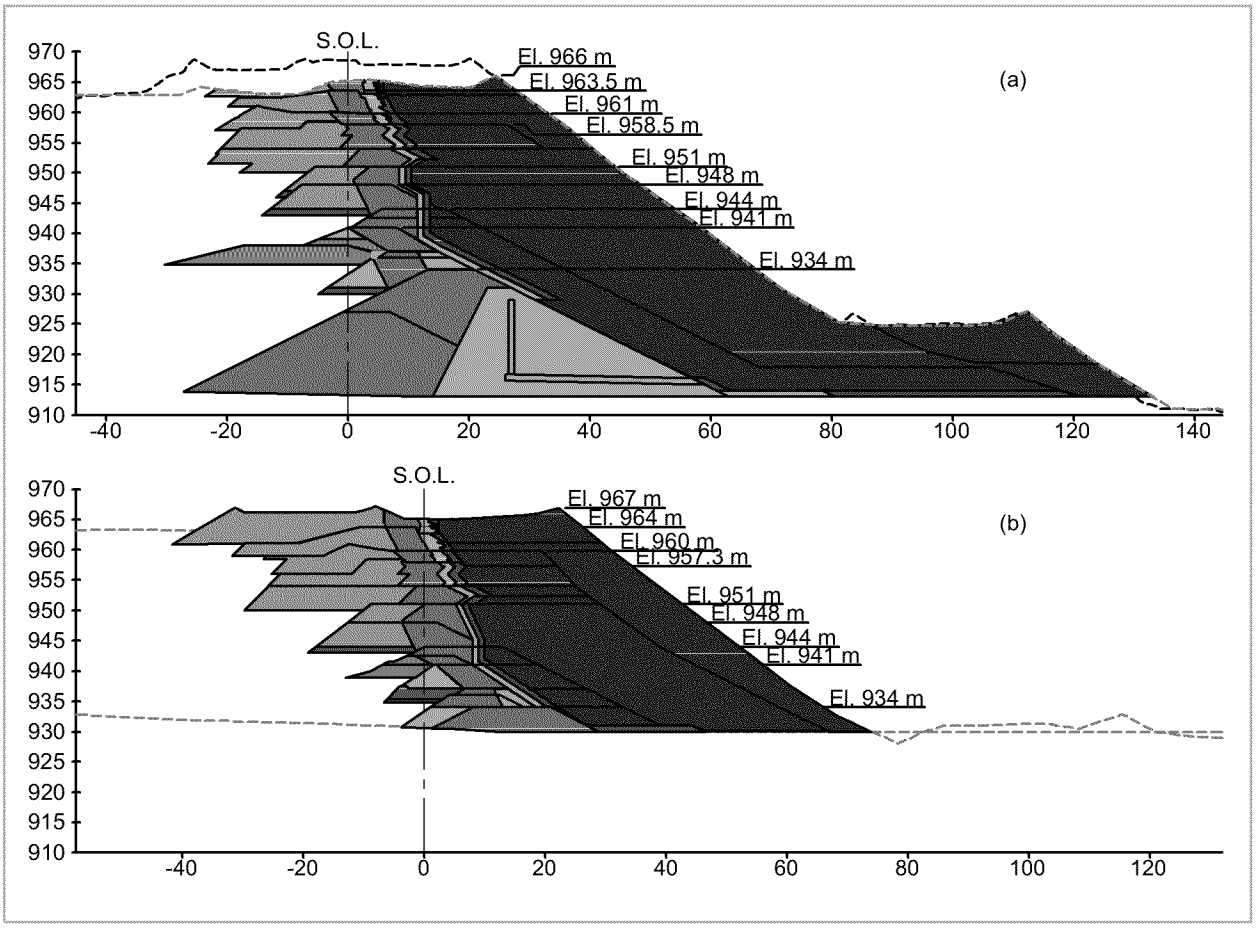
FIGURE 5.4.10: DAM CONFIGURATION ON AUGUST 3, 2014. (a) MAIN EMBANKMENT (b) PERIMETER EMBANKMENT AT BREACH SECTION



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5.4.10 COMMENTARY

The preceding account is in many ways a story of too little, too late From the beginning, dam raising proceeded incrementally, one year at a time, driven by impoundment storage requirements for only the next year ahead .More reactive than anticipatory, there was little in the way of long-term planning or execution . This was most clearly displayed by the absence of an adequate water balance or water treatment strategy, and the overtopping failure that nearly resulted .Moreover, the related absence of a well-developed tailings beach violated the fundamental premise of the design as a tailings dam, not a water-storage dam .

The preceding account is in many ways a story of too little, too late. From the beginning, dam raising proceeded incrementally, one year at a time, driven by impoundment storage requirements for only the next year ahead.

The same problem was apparent in production and scheduling for mine waste used in dam construction .The design was caught between the rising water and the Mine plan, between the imperative of raising the dam and the scarcity of materials for building it .Something had to give, and the result was oversteepened dam slopes, deferred buttressing, and the seemingly ad hoc nature of dam expansion that so often ended up constructing something different from what had originally been designed.

Ultimately, the tortuous, incremental nature of this process, and the constraints under which it was conducted, caused it to lose sight of basic precedent With a slope steepness ordinarily reserved exclusively for rockfill dams on sound rock foundations, the Perimeter Embankment at the breach section was allowed to reach a height of almost 40 m with an unbuttressed downstream slope of 1 3H:1V .

Not just the design process but also the design itself had shortcomings Even if not contributing directly to the failure, some design details were problematic Already thin to begin with, reducing the core width from 8 m to 5 m made it even more vulnerable to differential settlement and cracking Both the filter and transition zones were just 1 m wide, placing great demands on their performance .Yet in a sampling of as-placed Zone S filter gradations, the Panel found that 30% were too coarse to meet the D15<0 7 mm filter criterion and 70% had internally unstable grading,[69, 70] with only about 25% satisfying both filter and internal stability requirements .

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5 | Panel Observations

There were ambiguities in the governing factor of safety, adapted from CDA Guidelines never intended for tailings dams An FS = 1 3 design criterion using peak effective-stressstrength left little margin for error, and trigger-level factors of safety for critical piezometric conditions were even lower at 11 Such values may have made it easier to rationalize the departure from slope precedent, but harder to gauge just how closely dam raising was approaching the edge of the cliff.

There was an oversimplifiedconception of the complex stratigraphy of the glacial deposits described in section 5 2. An Upper GLU unit had been encountered in groundwater well GW96-1A and a lower unit in sonic borehole VW11-10 But only the lower unit was included in stability analysis of the Perimeter Embankment, and it had no influenceon calculated factors of safety The possibility that the upper unit might be present beneath the Perimeter Embankment was not accounted for in conceptualization of geologic conditions More than this, its stress history was much less favourable.

Yet the overarching problem, and the one the Panel findsmost troubling, is the failure throughout to adopt the appropriate undrained strength interpretation for the glaciolacustrine silts and clays in the foundation.These materials were assumed everywhere to be stiff, and therefore overconsolidated, although there was never any attempt to quantify their degree of overconsolidation or stress history.And even if they were overconsolidated to begin with, it was not recognized that the increasing loads imposed by the dam as it grew higher would eventually cause them to reach a normally consolidated state.

The overarching problem, and the one the Panel finds most troubling, is the failure throughout to adopt the appropriate undrained strength interpretation for the glaciolacustrine silts and clays in the foundation.

There is a fundamental differencein pore pressure behaviour between these two conditions and the undrained strengths they produce Overconsolidated clays are dilatant during undrained shearing That is, they tend to increase in volume, producing no positive pore water pressures By contrast, normally consolidated clays are contractive and do develop positive pore pressures.This differencein pore pressure response during shearing makes the undrained strength of a normally consolidated clay lower than the same material in an overconsolidated state But the design did not account for the undrained strength that would pertain if the dam were to fail rapidly—which proved in the end to be the case.

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Rather, the design was based exclusively on ESA in various forms using peak and residual strengths, all of which neglected pore pressures that would develop in normally consolidated GLU during rapid, undrained shearing. The design never incorporated an undrained strength analysis (USA), except in one instance. A USA performed for Stage 6 using an undrained strength typical of normally consolidated clays produced a factor of safety of only 1.1. But this was not seen to be the operative strength and was not considered further here or in subsequent stages. If undrained strength behaviour had been properly understood and applied throughout, the outcome could have been much different.

The Observational Method was invoked early on as the basis for design. This commonly accepted approach uses observed performance from instrumentation data for implementing preplanned design features or actions in response.

But there were a number of problems in applying this strategy to the Mount Polley dam that are treated in the following section. The first was simple geometry. The Observational Method relies on measuring the right things in the right places. While this was comparatively easy over the 1,000 m length of the Stage 1 dam, it became increasingly difficult as the length grew to 5 kilometres (km) by Stage 9. Nor could foundation instrumentation be installed beneath the dam crest and slopes where piezometric data mattered most. The slopes were too steep to be accessible, and few instruments installed on the crest could survive the near-constant construction there for very long. As a result, the few piezometers and inclinometers at the Perimeter Embankment were too far beyond the dam toe to produce critical data, and too far between to cover the area where the breach occurred.

Even more fundamentally, the piezometers as installed were only capable of measuring static ("water table") pore pressures and, if properly located, those induced by applied loads. But piezometers cannot measure pore pressures induced by undrained shearing because the location of the failure surface on which to measure them cannot be known in advance.

The remaining problem is that the Observational Method is useless without a way to respond to the observations. Constructing buttresses and obtaining the necessary mine waste had been hard enough under ordinary circumstances. Were the instruments to warn somehow of a rapidly developing failure, there would be no way to respond in time to avert it. Hence, the Observational Method could not be relied on to determine the need for buttressing, so the buttress would be required regardless.

This fact was belatedly recognized in the Stage 10 design just days before the breach—the final, fateful instance of too little, too late.

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5.5 INSTRUMENTATION AND MONITORING

5.5.1 PRE-BREACH MONITORING OF TSF

Geotechnical instrumentation was installed beginning with Stage 1 of Main Embankment construction in 1996 and early 1997 During the initial phase, the focus was on vibrating wire piezometers, survey monuments, drain flow monitoring, and monitoring wells .[71] The firstinclinometers on the Main Embankment were installed in July 2001 . During the pre-breach period, instrumentation was installed at a total of 12 sections for the three embankments, Main, Perimeter and South (see Appendix F, Drawing F1) Further details of the inclinometers, piezometers, and drain flow monitoring during pre-breach monitoring are presented in Appendix F, Attachment 1.

A total of 10 inclinometers were installed after the start of operations Of these, nine were still operating when the failure occurred: six at the toe of the Main Embankment and three along the toe of the Perimeter Embankment . One of the inclinometers along the Perimeter Embankment (SI11-04) was still being read, but was not reliable due to "a compression failure"[72] and had been replaced by Inclinometer SI12-04 Therefore, the Perimeter Embankment had two reliable inclinometers .

Vibrating wire piezometers were installed during ongoing construction activities at the 11 sections shown in Drawing F1 The last two sections (J and K) were added in 2011 As of August 2014, there were a total of 64 operating piezometers and 52 non-operating piezometers, of which 47 in the Main Embankment operated and 34 did not (see Appendix F, Attachment 1) Piezometers can fail not only due to instrumentation defects but also due to construction damage to piezometer cables For example, during Stage 4 construction from May 2005 to October 2006, "22 piezometers were accidentally destroyed," of which fivewere repaired .[73] In contrast, a number of the piezometers installed in 1996 and 1998 were still operating in 2014 .

Piezometers were installed in the dam foundation, in various embankment components, such as the upstream fill, core, and downstream transition zone, in drains located in the embankment and foundation, and in the tailings upstream from the embankment .

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The majority of the piezometers maintained steady pore pressures during 2014 Typical observations of piezometer pore pressure readings during construction were:

- Pore pressures in foundation piezometers typically increased due to fill placement and dissipated readily following construction .
- Pore pressures in piezometers located in embankment components (core and other downstream layers) and drains were stable .
- Pore pressures in tailings and upstream fill increased in response to the rising pool level.
- Piezometers located near the upstream toe drains experienced less pore pressure increases than those near the pond elevation .[74]

During the firstphase of construction in 1996–1997, artesian pressures were observed in three of the six foundation piezometers in the Main Embankment This prompted the development of trigger levels, or action levels, for many of the piezometers in the foundation and drains .[75]

As part of their annual construction manual in 2012, AMEC developed the instrumentation trigger framework shown in **Table F.1.1**,[76] Appendix F.This framework is for all the inclinometers and the Main Embankment foundation piezometers .The AMEC construction manual states that "embankment construction will be suspended if the inclinometers or piezometers fall under the yellow or red condition described in the Table, and/or if embankment foundation piezometer data indicates a significant increasing trend ". No corresponding trigger levels were established for the Perimeter Embankment piezometers because "factor of safety values .are sufficiently high that monitoring of piezometric trends, without definedtrigger levels, is deemed sufficient "[77]

Drain flowof the foundation drains and chimney drain was measured for the Main Embankment during the first phase of construction Flow measurements were also initiated when similar drains were installed in the Perimeter and South Embankments Upstream drains were installed in the tailings (also referred to as "upstream toe drains" [78]) at all the dams as they progressed in height, and these flowswere also measured starting in 1996 Flows from these drains report to the seepage collection ponds constructed downstream of each dam These flowswere measured monthly (weather permitting) in a manifold for the Main Embankment and across ditch profilesclose to the ends of the outlet pipe for the Perimeter and South Embankments .[79] In Appendix F, drain flowreadings are shown in **Figure F.1.2**, and these results are further discussed .

Survey monuments were used from Stage 1 construction until about 2010 to measure surface movements of the embankments .These were installed after completing the raise construction.

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5.5.2 PRE-BREACH MONITORING IN BREACH AREA

Locations of the inclinometers and piezometers in the breach area are shown in Appendix F, Drawing F2 In this area, one reliable inclinometer was located about 300 m east of the breach It was about 15 m to 44 m from the toe of the embankment at the time of the failure There were nine operating and 13 non-operating piezometers along this section of the Perimeter Embankment Locations of all the piezometers are shown in the sections in Appendix F, Drawings F3 and F4.

The upstream toe drain in the tailings shown in Drawings F3 and F4 was located at El 946 .3 m Seepage collection elements for the upstream toe drain are shown in Drawing F4 Flows were conveyed along a drainage ditch to the Perimeter Embankment seepage collection pond at the time of the breach.

5.5.3 PANEL KEY OBSERVATIONS

Section 5 2 clearly demonstrates that foundation conditions in the area of the breach were complex and that the Upper GLU layer was not continuous along the full length of the Perimeter Embankment .The foundation conditions assumed for the initial and ongoing design were based on only four drillholes deeper than 8 m, none directly in the area of the breach .A sentinel control section was therefore not identified,and instrumentation could not be installed to monitor this sentinel section.

Foundation piezometers could not be installed after the downstream slope was constructed at an angle of repose slope (1 3H:1V) .Access to the slope was impossible, and piezometers installed from the crest into the foundation would not have been at the correct locations to measure increased pore pressure below the advancing downstream slope Piezometers downstream from the dam toe (as at Section D) were too far away from the slope to provide any useful information, as was also the case for the inclinometer.

Foundation piezometers could not be installed after the downstream slope was constructed at an angle of repose slope (1.3H:1V).

The complex configuration of the internal embankment zoning made it very difficult, if not impossible, to install replacement piezometers in a specific fill zone at a specific depth.

The complex configurationof the internal embankment zoning made it very difficultif not impossible, to install replacement piezometers in a specific fill zone at a specific depth .Most piezometers were installed during the construction phases, and many were damaged during those stages.

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While some piezometers provided very useful information (e g , the tailings piezometers provided pore pressure values that could be applied to slope stability analyses), the Perimeter Embankment instrumentation overall could not have provided any warning of the looming failure Nor did it provide any monitoring relevant to the critical failure mode .

It should be noted that if failure were to occur suddenly, deformation monitoring could not provide timely warning and a more defensive design would be appropriate.The failure mode encountered here was sudden without any surface evidence and is an example of this behaviour In their design for the proposed Stage 10, BGC anticipated this issue and recognized that a berm would be required for the Perimeter Embankment.[80]

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5.6 WATER BALANCE

5.6.1 INTRODUCTION

A clear distinction can be made between the water balance actions and outcomes during the Phase 1 Active Mining, the Care and Maintenance period and the Phase 2 Active Mining .**Table 5.6.1** provides a summary of the mining activities, the Mine areas and the water management operating conditions Appendix G describes in more detail the design objectives, water balance models and their implementation as well as observations found in the TSF Annual Inspection Reports .The consequences of the operational conditions are presented in this section.

TABLE 5.6.1: MOUNT POLLEY MINE LIFE

YEAR	ACTIVITY	MINE PITS	WATER MANAGEMENT OPERATING CONDITIONS
1997 – 2001	Phase 1 Active Mining	Cariboo and Bell	Deficit
2001 – 2005	Care and Maintenance		Neutral
2005 – 2014	Phase 2 Active Mining	Wight, Springer, Southeast Zone, Pond Zone	Surplus

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5.6.2 PHASE 1 ACTIVE MINING

From 1997 to 2001 MPMC mined the Cariboo and Bell pits. The area of disturbance in the mining area was quite small and the overall TSF water balance was in a deficit. Water from Polley Lake and surface runoff on-site helped to provide the annual operating requirements.

5.6.3 CARE AND MAINTENANCE

As a result of low copper prices, the Mine suspended operations from October 2001 to February 2005. A small staff was maintained at the Mine and they managed the TSF water balance carefully, making sure that sufficient freeboard was maintained. Towards the end of the Care and Maintenance period, mine development in preparation for start-up was underway and surface water accumulated in the TSF. It was recognized at this time that plans would have to be developed to discharge water to the environment.

5.6.4 PHASE 2 ACTIVE MINING

During the second phase of Active Mining, the footprint of the Mine was expanded to a total of four additional pits and associated infrastructure and waste rock piles. MPMC and the designers knew that there was a surplus of water in the TSF and that strategies had to be developed to discharge water. MPMC also understood the need for permitted discharge from the TSF.

In 2009 MPMC prepared a report entitled *Mount Polley Mine Technical Assessment Report for a Proposed Discharge of Mine Effluent*.[81] In this report, alternative discharge approaches were evaluated. The approach selected was to apply for a permit to discharge water to Hazeltine Creek. A permit amendment was granted on November 7, 2012 that allowed the discharge of up to 1.4 million cubic metres (m^3) per year of filtered water to Hazeltine Creek. The maximum discharge is 35% of flow in the Creek and the window is April to October. In April of 2014 it was estimated that only 170,500 m^3 total discharge was possible, due to constraints of permit requirements.

Discharging small amounts of extra water to Hazeltine Creek did not have a significant impact on the water surplus. Permitting of a water treatment plant was pursued in late 2013 and the Terms of Reference for Discharge was issued by the Ministry of Environment on March 26, 2014. Completion of treatment plant construction was expected in September 2014 or later. This plant would allow total annual discharge of 3 million m^3.

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5.6.5 WATER BALANCE AND TSF CONSTRUCTION

During the life of the Mine, two water balance models were used. The first was compiled by KP and was used from start-up until about 2005. The second was based on a model modified by MPMC to account for the expanded footprint of Phase 2 Active Mining. MPMC updated the water balance regularly with site-specific climatic and operating data as well as bathymetric surveys of the TSF pool. The EOR reviewed the water balances throughout operations except from 2010 to 2014. The Panel could not find any documentation explaining the reason for this change in procedures .

The embankment of the TSF was raised on a regular basis, typically on an annual basis. The design engineers used the outcome of the water balance calculations by MPMC to select the height of the increase. The overall approach was well summarized by KP in 2005 in their report entitled *Design of the Tailings Storage Facility to Ultimate Elevation*:[82]

Each embankment raise will provide incremental storage capacity for approximately one-year of production. The filling schedule incorporates sufficient live storage capacity for containment of runoff from the 24-hour PMP volume of 679,000 m^3 at all times, which would result in an incremental raise in the tailings pond level of about 0.39 m, with an additional allowance of 1 m for freeboard for wave run-up.

The water balance model included the site-specific information to the date of analysis, and future conditions were based on average climatic conditions. They did not account for specific wet year conditions.

Figure 5.6.1 shows the accumulation of water in the TSF as determined from bathymetric surveys. The figure also shows approximate volumes reported in the records for three dates (refer to Appendix G).

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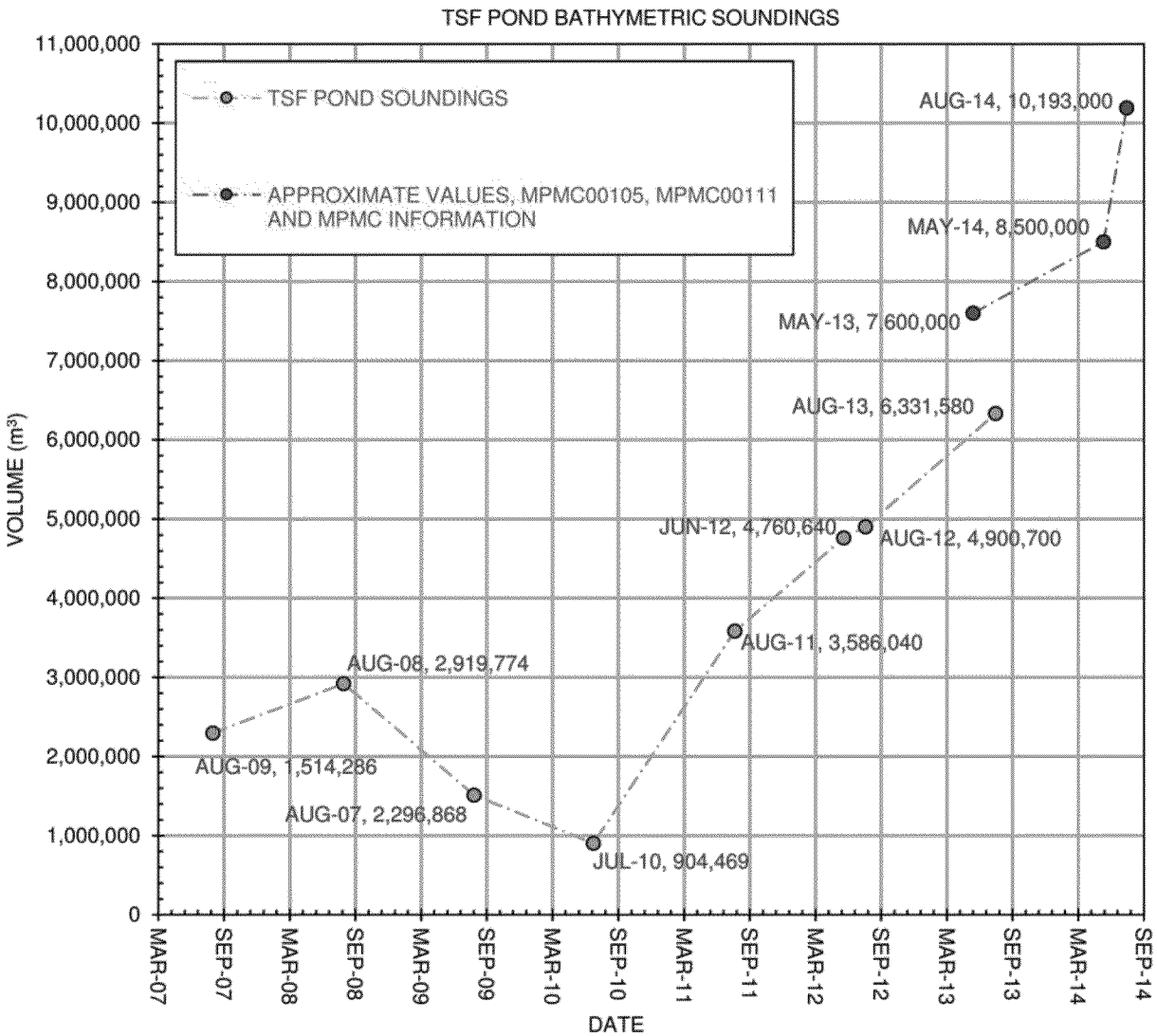
FIGURE 5.6.1: WATER ACCUMULATION IN TSF



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5.6.6 OVERTOPPING IN MAY 2014

On Saturday May 24, 2014, a potential "dam breach" event occurred at the TSF as a result of a large rainfall, approximately 24 mm in 24 hours, followed by ongoing rain On Monday May 26 the water level was at El 966 .3 m, which resulted in a freeboard of 0 7 m to the top of the constructed core at El 967 0 m, as stated in the 2013 Annual Construction Report (refer to Appendix G) The core was found to have a few low spots at 966 .3 m (Corner 3), 966 4 m (Corner 2), 965 5m (Corner 5) and 966 .2 m (at the pipe crossing on the Perimeter Embankment) Wet spots and standing water were observed at Corner 3 and the pipe crossing, but no major erosion due to large flows or direct seepage All the low areas were addressed through emergency construction measures by Thursday, May 29 when the pool water level increased to El .966 45 m The top of the Perimeter Embankment was increased to El .967 3 m All water collection systems were diverted from the TSF and water was routed for storage in the Cariboo Pit .

The pond elevation was monitored on a daily basis from the end of May until the time of the breach During that time, construction proceeded to increase the embankment height On August 3, 2014, the day before the breach, the freeboard was 2 3 m .

5.6.7 COMMENTARY

The way in which the water balance was utilized with annual raises had significant limitations.

The way in which the water balance was utilized with annual raises had significant limitations . Construction of annual embankment raises was based on water balance evaluations using average climatic conditions at the site .This does not provide a reliable approach to establishing adequate capacity for tailings and water storage Uncertainties in the water balance input parameters combined with uncertainties in climatic conditions and construction schedules cannot provide a robust design for water containment Construction delays due to site climate or availability of construction materials could impact the targeted capacity Overtopping of the embankment occurred at selected locations in May 2014 .

As indicated in section 4, the Perimeter Embankment did not fail due to overtopping; however, storing large volumes of water in the TSF had other implications.

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Throughout most of its term as the EOR, KP emphasized the importance of maintaining a beach width of at least 10 m .The Panel does not consider this to be a beach Nevertheless, the principle was clear: the Mount Polley TSF embankments were not designed as water-retaining dams, and a beach would provide some stabilizing function . It was impossible to maintain beaches against all the embankments throughout the year during the last years of operation because of the large volumes of water stored in the TSF Section 5 4 summarizes the chronic problems experienced in beach development .

MPMC was aware of the water surplus conditions at the start of Phase 2 operations .The pond volumes in **Figure 5.6.1** show that the last number of embankment raises were necessary to store water and not necessarily much higher tailings production . It is not clear to the Panel why it took so long to design and implement a water treatment strategy that would provide for a significantreduction in the amount of surplus water stored on the TSF .

It is not clear to the Panel why it took so long to design and implement a water treatment strategy that would provide for a significant reduction in the amount of surplus water stored on the TSF.

The pore pressure in the tailings piezometer at the breach location increased as a result of the higher pool elevation (refer to section 5 5) This happened despite the presence of the upstream toe drain The higher pore pressure had a secondary effect on the overall slope stability.

Finally, the volume of water in the pool at failure, about 10 million m^3, resulted in a much larger loss of solids from the TSF due to erosion than might have occurred if there was a smaller pool (refer to Appendix C) And a wider beach of unsaturated tailings might have delayed breach development long enough for emergency actions to have been taken .

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15) MP00008
16) MP00012
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18) MP10032
19) Panel Interview, 12/12/14 .
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21) MP00011
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25) MP00118
26) MP00038
27) MP00021
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29) MP00026
30) MP00031
31) MP00076
32) MP00137
33) MP00139
34) Panel Interview, 12/12/14 .
35) MP00028
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37) MP00077
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44) MP00225
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47) MP00181
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49) MP10012
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75) MP00019
76) MP00040
77) AMEC00132
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6 | Analysis of Breach Mechanics

6.1 INTRODUCTION

As demonstrated in sections 5 1 and 5 2, the breach of the Mount Polley Tailings Dam (the Dam) arose because of failure in the foundation of the Perimeter Embankment .According to Ministry of Energy and Mines (MEM) requirements, design with respect to overall stability must be compliant with CDA Guidelines .The specific guideline for a dam under construction and before reservoir filling requires a factor of safety (FS) of 13 where:

$$FS = \frac{\text{Available Strength}}{\text{Strength Required for Equilibrium}}$$

That is, the design requires a reserve resistance over and above that required to maintain equilibrium, and with this reserve resistance, it is expected that the structure will perform in a safe manner.This criterion has been accepted for tailings dams during construction, with a higher FS required if the dam has a long service life after it has been filled .

Many potential failure modes have to be considered to meet the requirements that FS = 1 3 The CDA Guidelines are not prescriptive with respect to potential failure modes It is the obligation of the designer, as EOR, to recognize the potential failure modes, to characterize the operational strength of the materials associated with these potential failure modes, to adopt an appropriate method of analysis to calculate the FS, and to ensure that the FS is equal to or greater than 1 3 during the construction of the dam .

The Perimeter Embankment failed during construction, and hence the FS = 1 .It moved sufficiently to lose containment of the impounded water and tailings that flowed out and eroded most of the displaced embankment .

In the following analyses, calculations will show that shear strengths determined by the Panel to reflect undrained failure of the Upper GLU beneath the Upper Till of the foundation are consistent with the strength required for limiting equilibrium, i e ,FS = 1 0 .

A detailed explanation of the process leading to failure of the Dam will be presented, and comparisons will be made with the assumptions that underpin the design in order to highlight the deficiencies associated with it.

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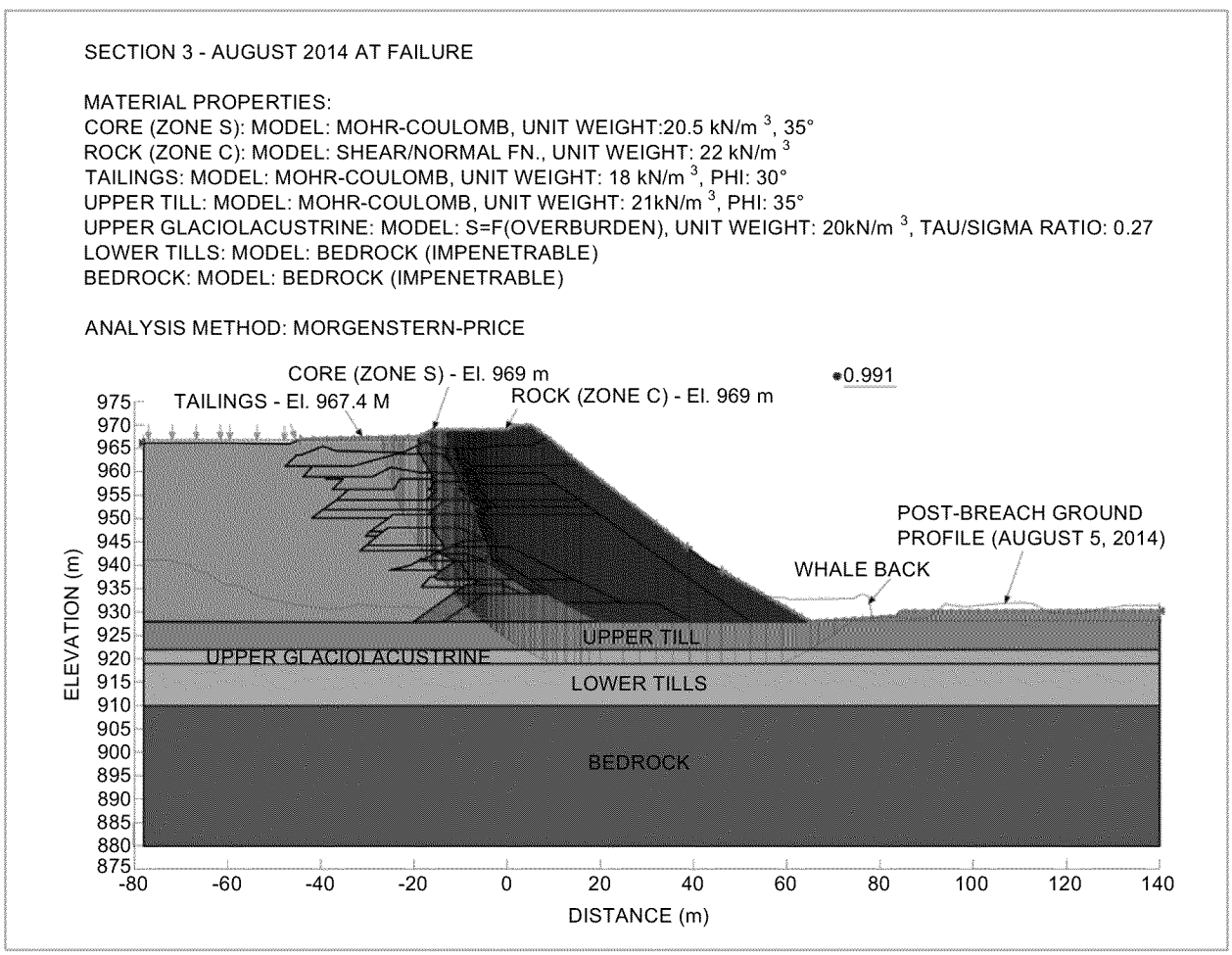
6.2 ANALYSES

6.2.1 LIMIT EQUILIBRIUM ANALYSES (2-D)

Analyses for purposes of designs are conventionally performed on two-dimensional (2-D) sections Cross-section 3 (see section 5 2; Appendix D) was assumed to represent the stratigraphy more or less in the middle of the displaced mass .

Figure 6.2.1 presents the detailed section It is based on the last LiDAR survey of the embankment prior to failure, a detailed reconstruction of the top of the structure and pond elevation based on construction inspector reports, and it includes a shallow excavation at the toe of the embankment as reported to the Panel More details associated with the compilation of this and related sections are presented in Appendix H.

FIGURE 6.2.1: DETAILED SECTION USED FOR LIMIT EQUILIBRIUM ANALYSIS HIGH WATER TABLE, UNDRAINED STRENGTH RATIO 0.27



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6 | Analysis of Breach Mechanics

The Morgenstern-Price method of stability analysis and the SLOPE-W computer program were used for the computations Both are recognized standard tools and were also used for the design of the structure at various stages .

Strength properties and densities for each stratum must be definedin order to calculate the FS .The values assumed are also displayed in **Figure 6.2.1** Only the upper of the two GLUs definedin section 5 2 is included due to its high water content, its lower cone penetration testing (CPT) tip resistance, and overconsolidation ratio (OCR) . Except for the strength of the Upper Till unit and the GLU, all strengths and densities are the same as those used in design studies Based on pressuremeter testing, experience of the Panel members, and the limited pore pressure response during undrained triaxial testing, a frictional resistance of 35° was adopted for the Upper Till Fully drained conditions are assumed up to failure .The magnitude of the undrained strength ratio in the GLU is then varied until FS=1 is obtained . For the case illustrated in **Figure 6.2.1**, this ratio is 0 27 In this case, the observed level of the pond is carried horizontally through the beach, which would, in most circumstances, be the design basis case (High Water Table case) .

However, the installation of drainage at the upstream face of the core creates downward flowthat will reduce the water pressure acting on the core of the Dam A potential limiting case is shown in **Figure 6.2.2**, and the calculated strength ratio is 0 22 (Low Water Table case) .The likely case is between these limits, with the Panel favouring a result above the average, say 0 25 .

The calculated value represents the average resistance mobilized by the GLU at the instant of failure .It should be noted that this value lies sensibly in the middle of the range of the measured undrained strength (see **Table 5.3.1**), consistent with the hypothesis that the breach resulted from undrained failure of the GLU at an elevation of about 920 metres (m) .

The actual available shear strength will vary with consolidation history as the Upper GLU responds to the stresses imposed by the embankment and the lateral loads transmitted by the impounded tailings and water .This will induce both normal and shear stresses in the Upper GLU .The Panel has not calculated these stresses in any detail . However, it is evident that the maximum applied stresses will substantially exceed the preconsolidation stress level associated with the Upper GLU .This response will reduce towards the breakout zone of the calculated slip surface and beyond, where the influenceof applied stresses diminishes .Where the preconsolidation pressure has been overcome, the available shear strength will be that of a normally consolidated soil .Beneath the toe of the embankment and beyond, available strength will be higher, depending upon the local stresses and the preconsolidation stresses .The calculated average resistance reflectsthis distribution Appendix E, Attachment 2 shows a comparison between vertical overburden stress and preconsolidation stress.

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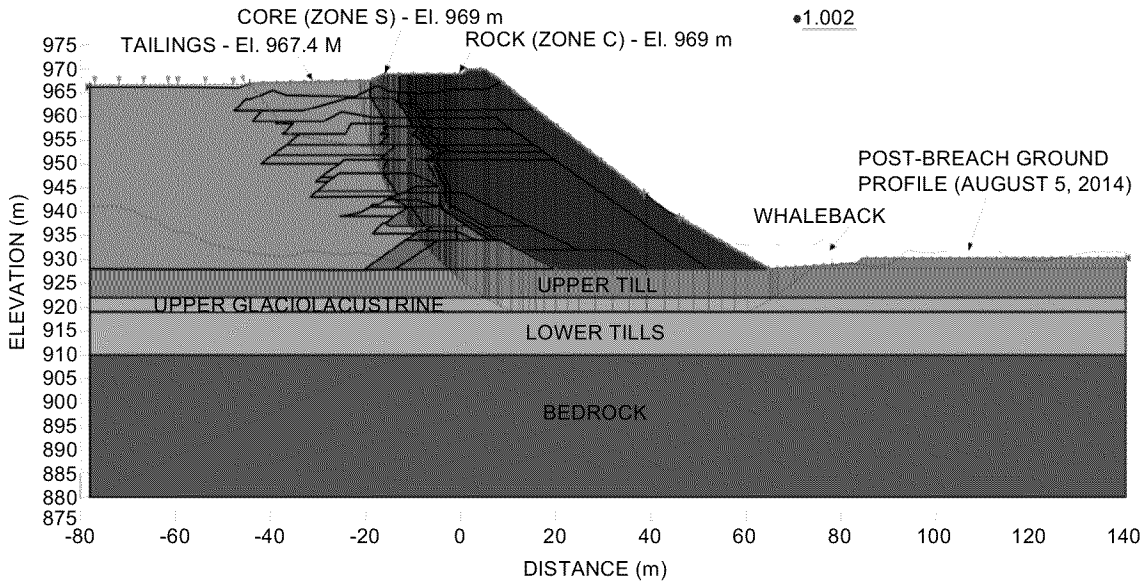
FIGURE 6.2.2: DETAILED SECTION USED FOR LIMIT EQUILIBRIUM ANALYSIS (LOW WATER TABLE, UNDRAINED STRENGTH RATIO 0.22)

SECTION 3 - AUGUST 2014 AT FAILURE

MATERIAL PROPERTIES:
CORE (ZONE S): MODEL: MOHR-COULOMB, UNIT WEIGHT:20.5 kN/m^3, 35°
ROCK (ZONE C): MODEL: SHEAR/NORMAL FN., UNIT WEIGHT: 22 kN/m^3
TAILINGS: MODEL: MOHR-COULOMB, UNIT WEIGHT: 18 kN/m^3, PHI: 30°
UPPER TILL: MODEL: MOHR-COULOMB, UNIT WEIGHT: 21kN/m^3, PHI: 35°
UPPER GLACIOLACUSTRINE: MODEL: S=F(OVERBURDEN), UNIT WEIGHT: 20kN/m^3, TAU/SIGMA RATIO: 0.22
LOWER TILLS: MODEL: BEDROCK (IMPENETRABLE)
BEDROCK: MODEL: BEDROCK (IMPENETRABLE)

ANALYSIS METHOD: MORGENSTERN-PRICE



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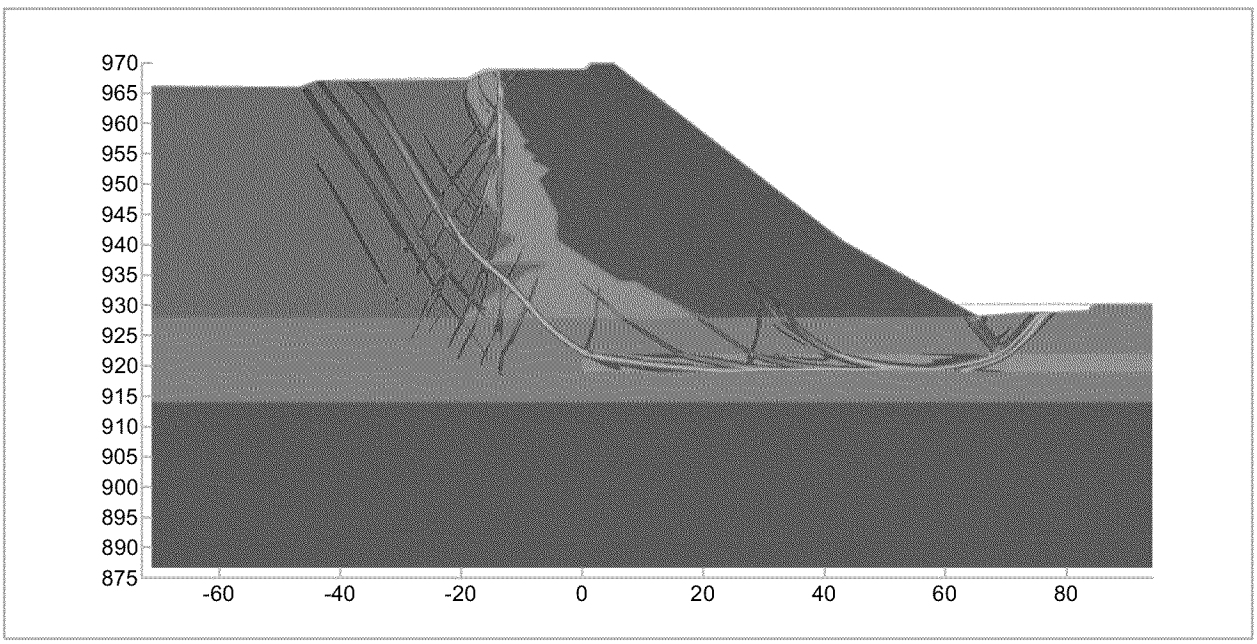
6.2.2 DEFORMATION ANALYSES (2-D)

An alternate way of assessing the undrained failure mechanism is to calculate the deformation patterns that develop at failure. While not a routine design procedure, the means for conducting such analyses are facilitated by powerful numerical simulation tools. In this case, PLAXIS, a well-recognized computer program developed specifically to model soil deformations, was adopted.

Figure 6.2.3 portrays the PLAXIS model at collapse. Prior to creating collapse, the model was constructed with essentially the same input parameters as used in the limit equilibrium analyses, except for the Upper GLU that is given a high strength to avoid yielding. The strength of the Upper GLU is then reduced until a deformation mechanism forms and the embankment collapses. This provides not only a measure of the strength of the Upper GLU at which failure occurs, but also an indication of the deformed shape arising from failure. In the model presented in **Figure 6.2.3**, collapse occurred at an undrained strength ratio of 0.29, which is to be compared with 0.27 calculated from the limit equilibrium analysis that incorporates the same boundary conditions. Lower undrained strength conditions would indicate significantly larger deformations. The figure also indicates the zones of localized strain that develop to facilitate motion. Variations of continuity of the Upper GLU with respect to this case yielded similar results.

FIGURE 6.2.3: PLAXIS MODEL AT COLLAPSE (UNDRAINED STRENGTH RATIO 0.29)



Both the entry and exit of the failure surface in the foundation correspond closely with field observations summarized in **Figure C4.2.2** in Appendix C.

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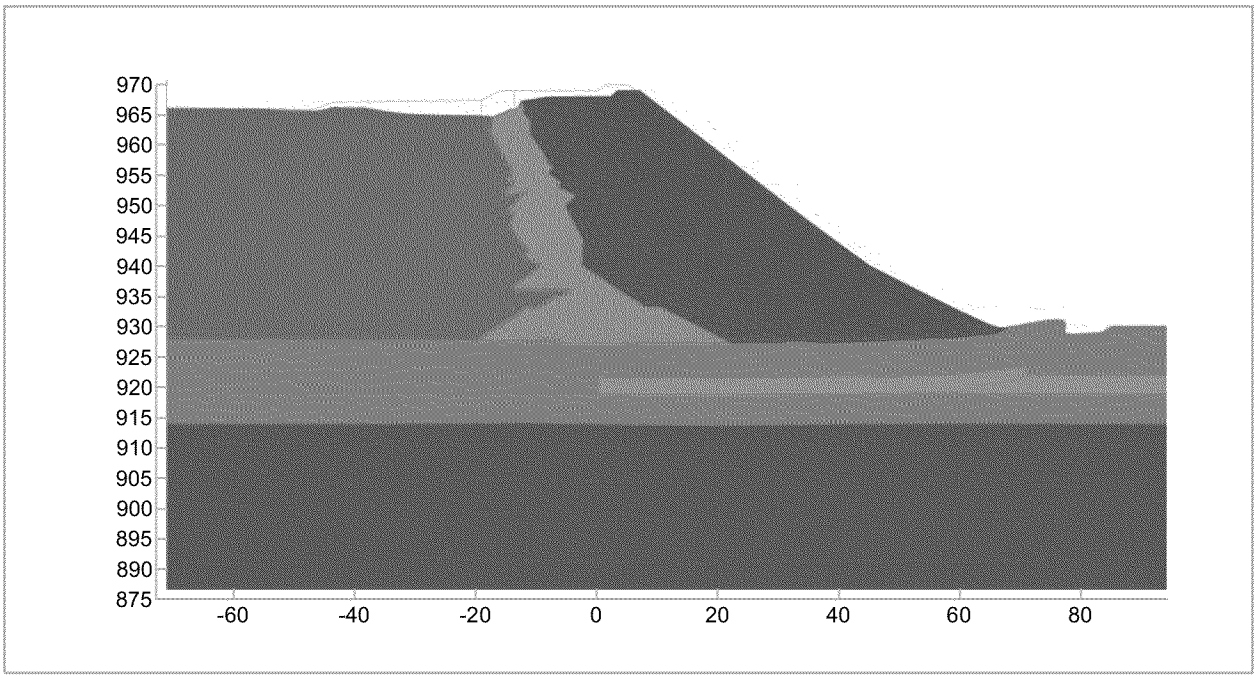
Figure 6.2.4 is a scaled-up display to illustrate the calculated deformations The rotational movement with a lesser lateral displacement are evident Particularly striking is the thrust feature that occurs very close to the whaleback feature identifiedin section 5 1 Also significantis subsidence of the crest that allowed overflowto begin, initiating the breach process as described in section 51 and Appendix C .

The PLAXIS analyses provide compelling support for the hypothesis that the movements of the Perimeter Embankment arose due to the undrained failure of the Upper GLU.

FIGURE 6.2.4: SCALED-UP FIGURE 6.2.3 TO ILLUSTRATE DEFORMATIONS



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6.2.3 LIMIT EQUILIBRIUM ANALYSES (3-D)

The length of the breach is relatively short compared to the height of the Perimeter Embankment at failure (~ 40 m) This is expressed as an Aspect Ratio (length/height) and is calculated to be 2 6At this Aspect Ratio, three-dimensional restraints might be a significantfactor influencingthe analysis of the breach mechanism At small Aspect Ratios, the side resistance acting on the potential moving mass increases in significance This is ignored in the 2-D analyses described above, which are used routinely in design Nevertheless, the Panel regarded it of value to assess three-dimensional considerations in order to fully explore the factors affecting the breach mechanism .

Three-dimensional limit equilibrium analyses have been conducted using the computer program SVSlope 3D, a widely accepted program for conducting such analyses The geometry and boundary conditions are a three-dimensional extension of the case illustrated in **Figure 6.2.1** All soil properties used in the 3-D analysis are the same as those employed in **Figure 6.2.1** .

Figure 6.2.5 presents the 3-D case The FS with an undrained strength ratio of 0 27 and an Aspect Ratio of 2 6is calculated to be 1 3 .This is a significant increase over the 2-D case, and it merits interpretation.

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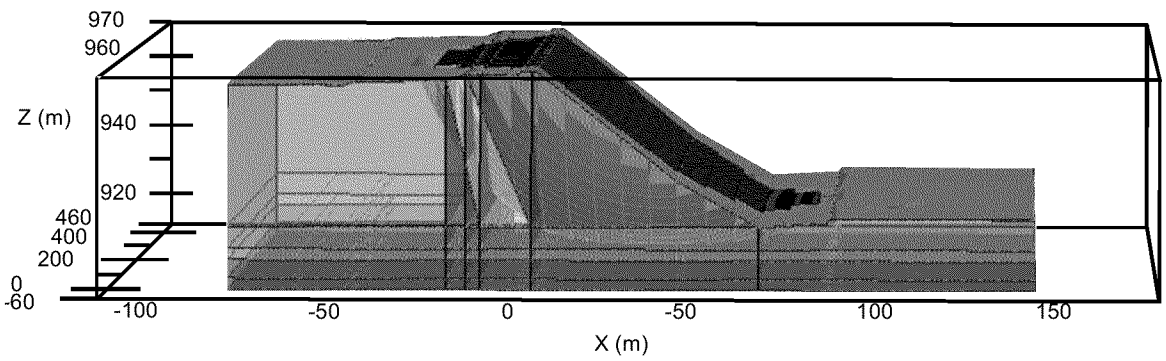
FIGURE 6.2.5: 3-D LIMIT EQUILIBRIUM ANALYSIS UNDRAINED STRENGTH RATIO 0.27, ASPECT RATIO 2.6, FS IS ABOUT 1.3

CALCULATION METHOD: M-P
SEARCH METHOD: ENTRY AND EXIT
FS: 1.288
CENTRE POINT: X: 37.591 Y: 200.000 Z: 981.233
ELLIPSOID ASPECT RATIO: 2.600, RX:70.168

MODEL



MATERIAL		MATERIAL PROPERTIES	
TAILINGS	MOHR COULOMB	UNIT WEIGHT = 18 (kN/m^3)	PHI=30°
UPPER TILL	MOHR COULOMB	UNIT WEIGHT = 21 (kN/m^3)	PHI=35°
UPP GLU	VERTICAL STRESS RATIO	UNIT WEIGHT = 20 (kN/m^3)	RATIO=0.27
LOWER TILLS	BEDROCK		
ZONE S	MOHR COULOMB	UNIT WEIGHT = 20.5 (kN/m^3)	PHI=35°
ZONE C	SHEAR NORMAL FUNCTION	UNIT WEIGHT = 22 (kN/m^3)	

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As shown in Appendix D, Drawing D19, the sensitivities of the Upper GLU in the failure zone is about 1–3, based on CPT-measured tip resistances . Hence, as deformations developed in the Upper GLU, the available resistance reduced due to strain weakening and soil remoulding Based on the observed sensitivity, it could have dropped to an undrained strength ratio of perhaps 0 13 Repeating 3-D limit analyses with these values yields an FS of about 1 1, which is close to collapse Hence, as movements developed, the available resistance of the Upper GLU was reduced due to strain weakening to a degree that the three-dimensional restraints to movements at an Aspect Ratio of 2 6were overcome .The idealizations involved in these 3-D analyses do not permit greater accuracy than expressed here Going forward, a review of some of the assumed strength parameters that influencedthe 3-D modelling and a more detailed representation of local geology that influencethe 3-D results would be warranted .**Figure 6.2.6** displays visual evidence of the remolding processes that have occurred due to shearing of the GLU.

As deformations developed in the Upper GLU, the available resistance reduced due to strain weakening and soil remoulding.

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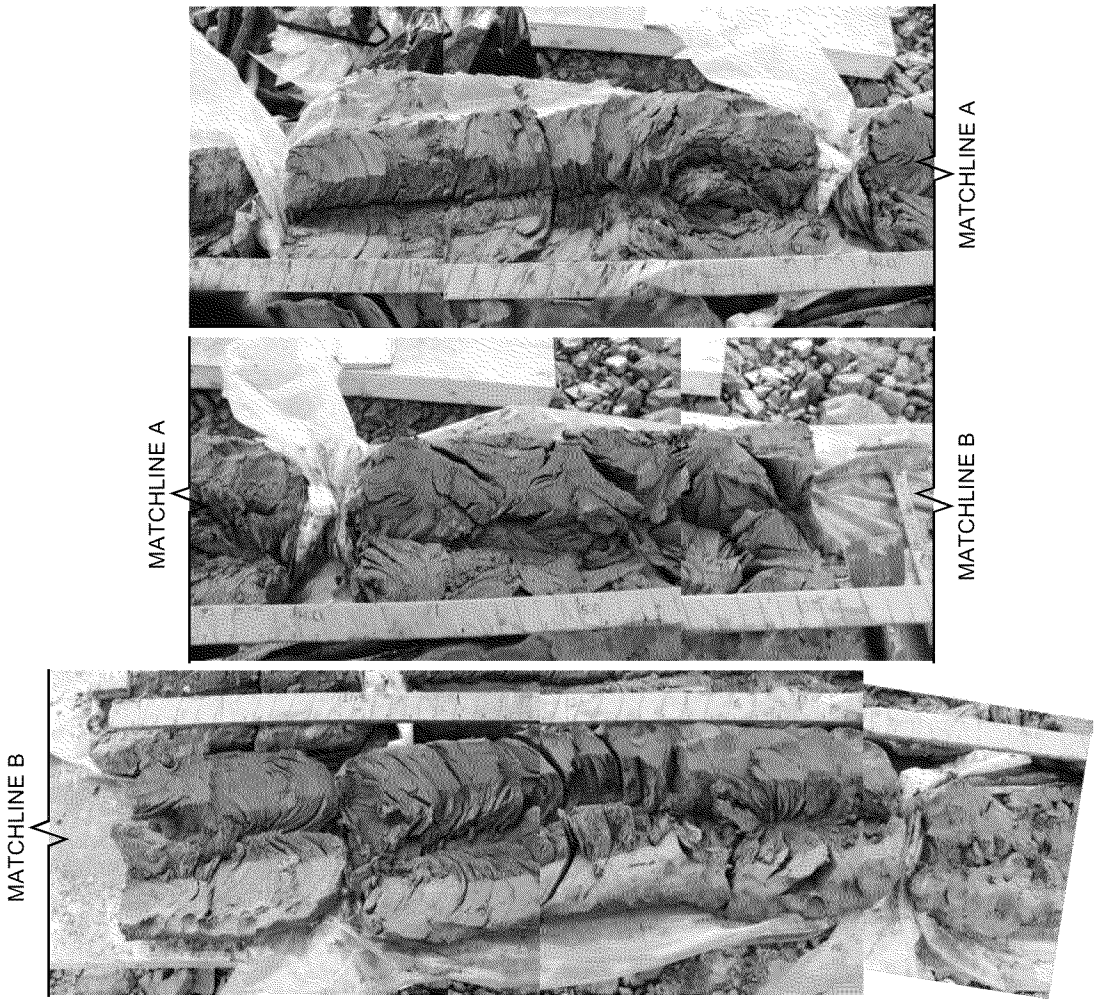
FIGURE 6.2.6: TYPICAL SHEARING IN THE UPPER GLU



UPPER GLU DEPOSIT, EXHIBITING HEAVILY DEFORMED AND CHAOTIC BEDDING INCLUDING OVERTURNED FOLDS.
NOTE: GREY SCALE BAR UNITS ARE DECIMAL FEET.

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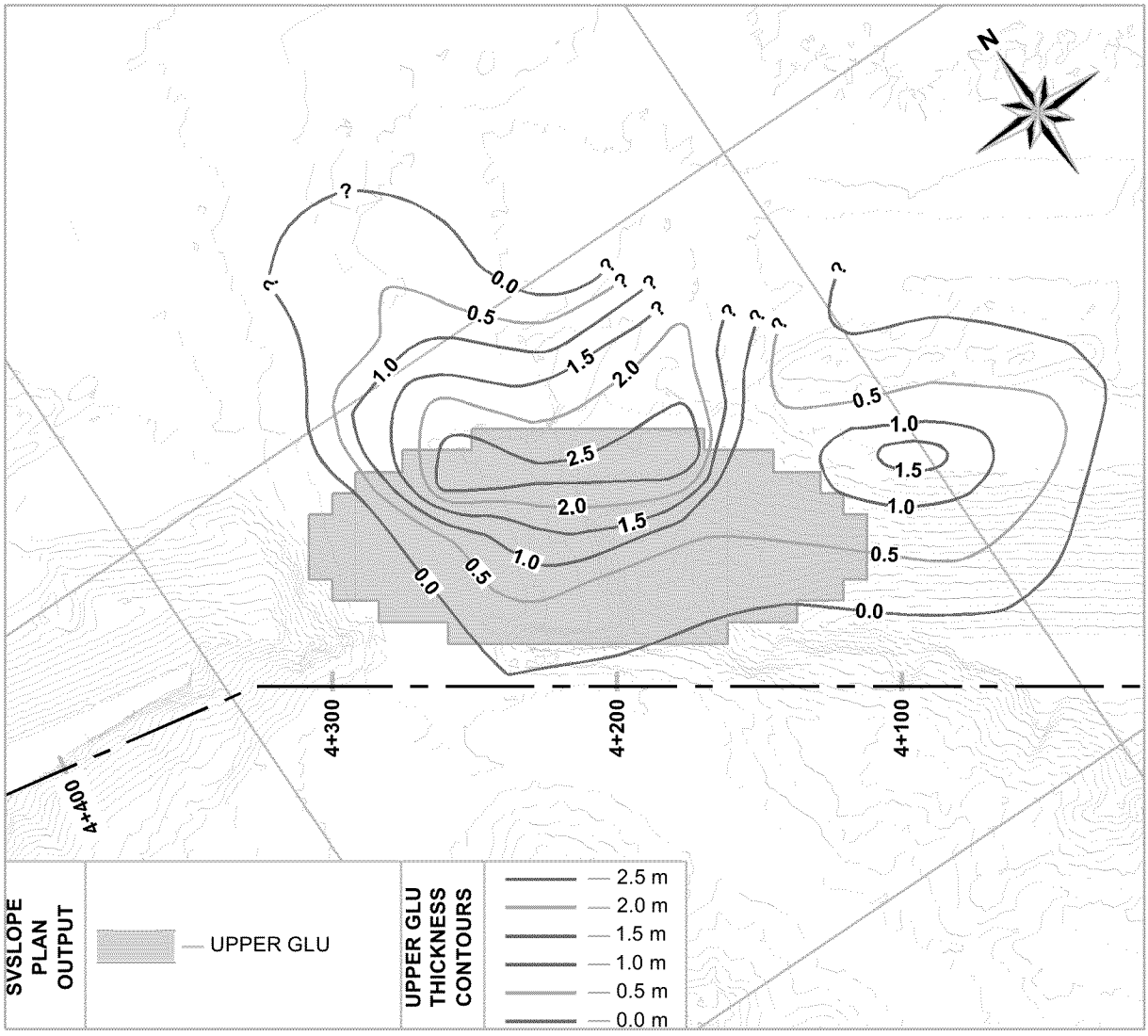
Additional support for the insight provided by the 3-D interpretation can be found by comparing the footprint of the 3-D analysis with the Aspect Ratio of 2 6where it intersects the Upper GLU .The distribution of the thickness contours of Upper GLU is presented in **Figure 5.2.6** .This comparison is shown in **Figure 6.2.7**, which indicates a striking fitbetween the extent of the Upper GLU mobilized in the 3-D analysis (shown in cyan) with the extent of the deepest portion of the Upper GLU .

FIGURE 6.2.7: COMPARISON OF THE 3-D ANALYSIS WITH THE THICKNESS CONTOURS OF THE UPPER GLU



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6.3 TRIGGER ANALYSIS

6.3.1 INTRODUCTION

Both the 2-D and 3-D analyses discussed above reflect a simplified interpretation of how failure began and subsequently progressed .They indicate that the foundation was brought to failure under fully drained conditions until the undrained strength was reached and the collapse of the embankment subsequently mobilized the undrained shear strength After initial failure, the Upper GLU behaved in a strain-weakening manner, reducing its resistance as reflected by the observed sensitivity of the deposit .Ultimately, the increased load associated with the weakening material overcame the residual resistance of the stronger zones, allowing the unconstrained 3-D mechanism to develop .The calculations presented provide average undrained strength ratios at failure that are generally consistent with the magnitudes observed in the laboratory.

In order to understand the failure mechanism in more detail, it is of value to address two questions:

1) **Was the loading path to failure fully drained?**
2) **Was the shear strength at failure mobilized uniformly?**

6.3.2 PORE PRESSURE HISTORY

To address the first question, it is possible to calculate the pore pressure development and dissipation during embankment construction If the pore pressures remain high, the available shear strength is reduced accordingly . This type of evaluation is an integral part of any stability assessment involving stage construction on soft constructed soils, such as are present beneath the breach zone .

Calculations involve the estimates of stresses on a structure, the magnitude of pore pressure reaction, and its subsequent dissipation with time as construction proceeds through the various stages to completion .The data obtained from consolidation testing (see Appendix E) are used to calculate the rate of pore pressure dissipation . Pore pressures dissipate as a result of water flow to drainage boundaries, and in the case of Upper GLU, dissipation will be enhanced by horizontal flow reflecting the laminated structure of the Upper GLU .Details of the pore pressure predictions for both one-dimensional (vertical only) and two-dimensional (vertical and horizontal) water flow are presented in Appendix H In the latter case, some estimates of anisotropy of the flow parameters have also been made .

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The calculated values at the time of failure suggest that an average excess pore pressure of about 50 kPa might exist in the potential shear zone.This is a small percentage of the applied load and, if it does exist, is not particularly consequential.Moreover, in the experience of the Panel, laboratory tests tend to underestimate the coefficients of consolidation in place due to scale effects,and it is likely that the potential for lateral drainage in the analyses due to stratigraphic variations has been underestimated.The Panel concludes that the loading path to failure has been essentially drained with transient episodes of undrained loading.The small peak of pore pressure development beneath the crest of the embankment in 2014 may have had some impact on the ultimate trigger, as the embankment was close to failure at this time.

Loading the Upper GLU to failure under predominantly drained conditions also implies the imposition of shear stresses as well as vertical stresses.As shown in Appendix E, Attachment 5, consolidating specimens under a shear stress not only has an effecton available resistance, but also reduces the subsequent tolerable strain to failure.Given the high stresses that acted on the Upper GLU prior to the finalconstruction campaign in 2014, it would have taken only a small additional load to initiate undrained failure, and little incremental deformation.This is consistent with the collapse of the embankment without any apparent warning .

Given the high stresses that acted on the Upper GLU prior to the final construction campaign in 2014, it would have taken only a small additional load to initiate undrained failure, and little incremental deformation. This is consistent with the collapse of the embankment without any apparent warning.

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6.3.3 PROGRESSIVE FAILURE

The strength at failure will only be mobilized uniformly if it does not vary with deformation .Failure will begin initially at a position where the local stresses equal the strength .As additional load is applied, yielding spreads to adjacent locations because resistance is limited at locations that have already yielded .This spreading of the yield zone migrates until a failure mechanism develops and unrestrained movement occurs with mobilization of a uniform shear strength .

However, as emphasized in section 5 3, the Upper GLU exhibits strain-weakening behaviour .After yielding has been initiated, the local resistance reduces with increasing load, requiring stress transfer to accommodate not only the influenceof additional externally applied load, but also the influenceof the reduced capacity of already failed material to resist the applied stresses .The transfer process proceeds to ultimate failure, but the average resistance at ultimate failure is less than the peak resistance .

This process is known as progressive failure .Once progressive failure has been initiated, the development of ultimate collapse can be sudden, depending on the shape of the whole stress-strain relation .As noted in section 6 2 3, the observed sensitivity of the Upper GLU indicates that it might display an ultimate resistance of one-half to one-third of its peak value .

While the mechanics of progressive failure are generally understood, the ability to calculate it is a complex undertaking and is generally reserved for research endeavours or other special studies Progressive failure analyses have not been undertaken in this study, but Lobbestael et al (2013) provide a useful overview and example of how progressive failure calculations might be performed.The Panel is of the view that progressive failure was involved in the initiation of collapse of the Perimeter Embankment and subsequent motion .Its influenceis embedded in the back-calculated average resistance .

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6.4 FAILURE MECHANISM

The Panel's Terms of Reference require it to: "report on the cause of the failure of the tailings storage facility at the Mount Polley Mine".

The failure of the tailings storage facility (TSF) was caused by deformation of the Perimeter Embankment that allowed the containment to be breached between survey stations 4+200 and 4+300 .The deformation arose because of inadequate resistance of a continuous layer of glaciolacustrine clays (Upper GLU) that existed at about El 920 m, beneath the overlying till .The GLU deposit had properties that became increasingly contractive when sheared, following consolidation under the applied embankment loads to a normally consolidated state .This made the Upper GLU disposed to undrained failure .Moreover, the Upper GLU exhibited strain-weakening properties when sheared, such that overall resistance of the formation reduced as deformation developed, ultimately overcoming all of the resistance of the stabilizing elements in the section .Hence, the root cause of the breach was the undrained failure of the Upper GLU under the imposed load of the Perimeter Embankment on August 4, 2014 .

The root cause of the breach was the undrained failure of the Upper GLU under the imposed load of the Perimeter Embankment on August 4, 2014.

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6.5 CAUSES OF FAILURE

As outlined in the Terms of Reference, it is expected that the Panel will "identify any technical, management, or other practices that may have enabled or contributed to the mechanism(s) of failure .This may include design, construction, maintenance surveillance and regulation of the facility".

The dominant contribution to the failure resides in its design . The design did not take into account the complexity of the sub-glacial and pre-glacial geological environment associated with the Perimeter Embankment foundation As a result, foundation investigations and associated site characterization failed to identify a continuous GLU layer in the vicinity of the breach and to recognize that it would be disposed to undrained failure when subjected to the stresses associated with the Dam .

The design did not take into account the complexity of the sub-glacial and pre-glacial geological environment associated with the Perimeter Embankment foundation.

At the time of Stage 4 (2006 – 2007), Knight Piésold (KP) had proposed a design for the Perimeter Embankment with a 2H:1V downstream slope and raises of the core and filterwith a parallel inclined alignment to El 965 m This design has been projected in **Figure 6.5.1** to the core elevation at the time of failure (El 969 m), and adopting an undrained strength ratio of 0 27 and a high water table, the calculated FS is 1 02 At El 965 m, the FS is 1 04, much less than the design target of 1 3 Based on the back-calculated undrained strength ratio, the design was doomed to fail .

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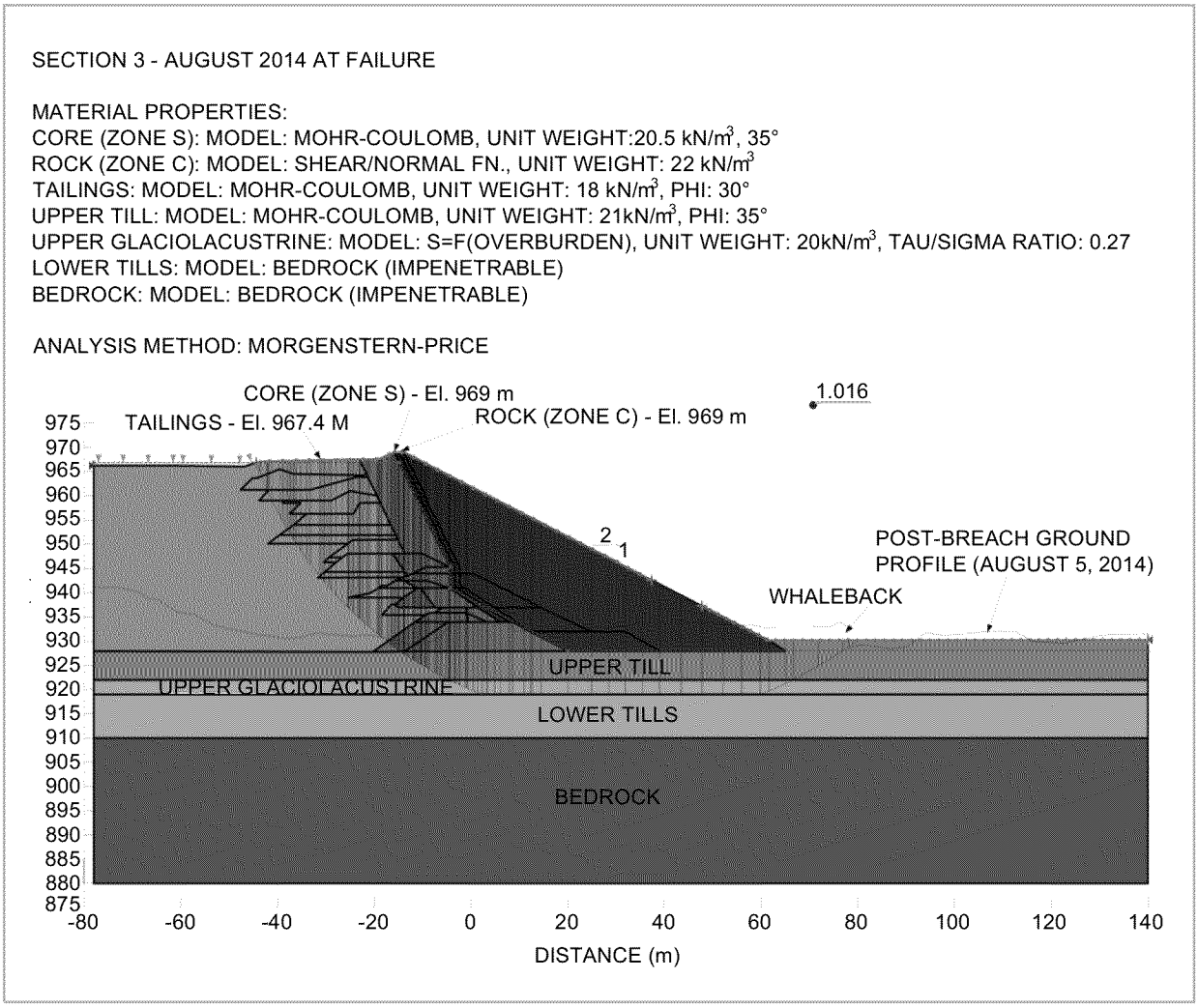
FIGURE 6.5.1: 2-D LIMIT EQUILIBRIUM 2H:1V SLOPE TO ELEVATION 969 M UNDRAINED STRENGTH RATIO 0.27, HIGH WATER TABLE, FS 1.02



Hence, the omissions associated with site characterization may be likened to creating a loaded gun Notwithstanding the large number of experienced geotechnical engineers associated with the TSF over the years, the existence of this loaded gun remained undetected .

The omissions associated with site characterization may be likened to creating a loaded gun.

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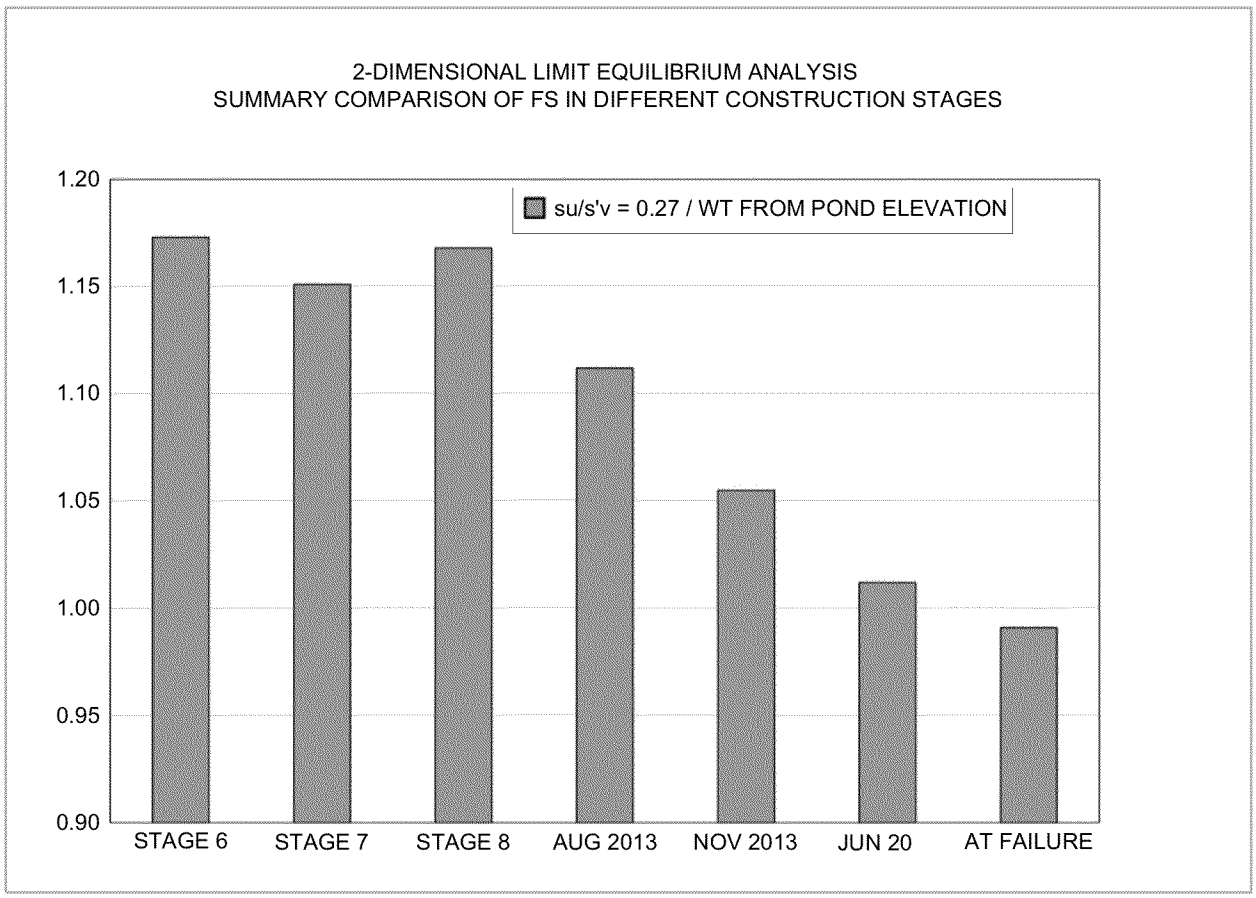
The lack of recognition of a critical potential failure mode resulted in a misapplication of the Observational Method and, therefore, a false appreciation that the structure was performing as intended during stages of raising.The Observational Method is a powerful tool to manage uncertainty in geotechnical practice.However, it relies on recognition of the potential failure modes, an acceptable design to deal with them, and practical contingency plans to execute in the event observations lead to conditions that require mitigation.The lack of recognition of the critical undrained failure mode that prevailed reduced the Observational Method to mere trial and error.

Figure 6.5.2 shows the variation of the calculated FS with each stage, from Stage 6 to failure, based on the as-built section for each stage El 965 m corresponds approximately to the height of the structure at the end of the 2013 construction season At this stage, the FS is calculated to be only about 1 05, which is similar to the FS for the original design with a 2H:1V slope.

FIGURE 6.5.2: VARIATION IN FS FOR EACH STAGE FROM STAGE 6 TO FAILURE



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6 | Analysis of Breach Mechanics

Prior to 2014, the Zone C fill began to be constructed as an angle of repose slope of 1 3H:1V. This appeared to have been an expedient measure and, as illustrated in **Figure 6.5.2**, ultimately resulted in failure of the Perimeter Embankment on August 4, 2014. If constructing unknowingly on the Upper GLU stratum, and not recognizing the potential undrained failure constituted loading the gun, building with a 1 3H:1V angle of repose slope over this stratum pulled the trigger. It appears that the 1 3H:1V slope began as an expedient temporary measure to facilitate construction during Stage 5. It became more or less permanent for subsequent phases, although concerns had been raised before the failure. The circumstances associated with the relative permanency of the 1 3H:1V slope are not well understood by the Panel. The complex issues that prevailed during construction are summarized in section 5 4. **Figure 6.5.3** indicates that, had the downstream slope incorporating the widened crest been flattenedto 2H:1V, the FS would have been 1 28. This was close to the required value of 1 3, and the embankment would not have failed. Moreover, the slope of 2H:1V was required, in any case, to support reclamation and closure criteria.

If constructing unknowingly on the Upper GLU...constituted loading the gun, building with a 1.3H:1V angle of repose slope over this stratum pulled the trigger.

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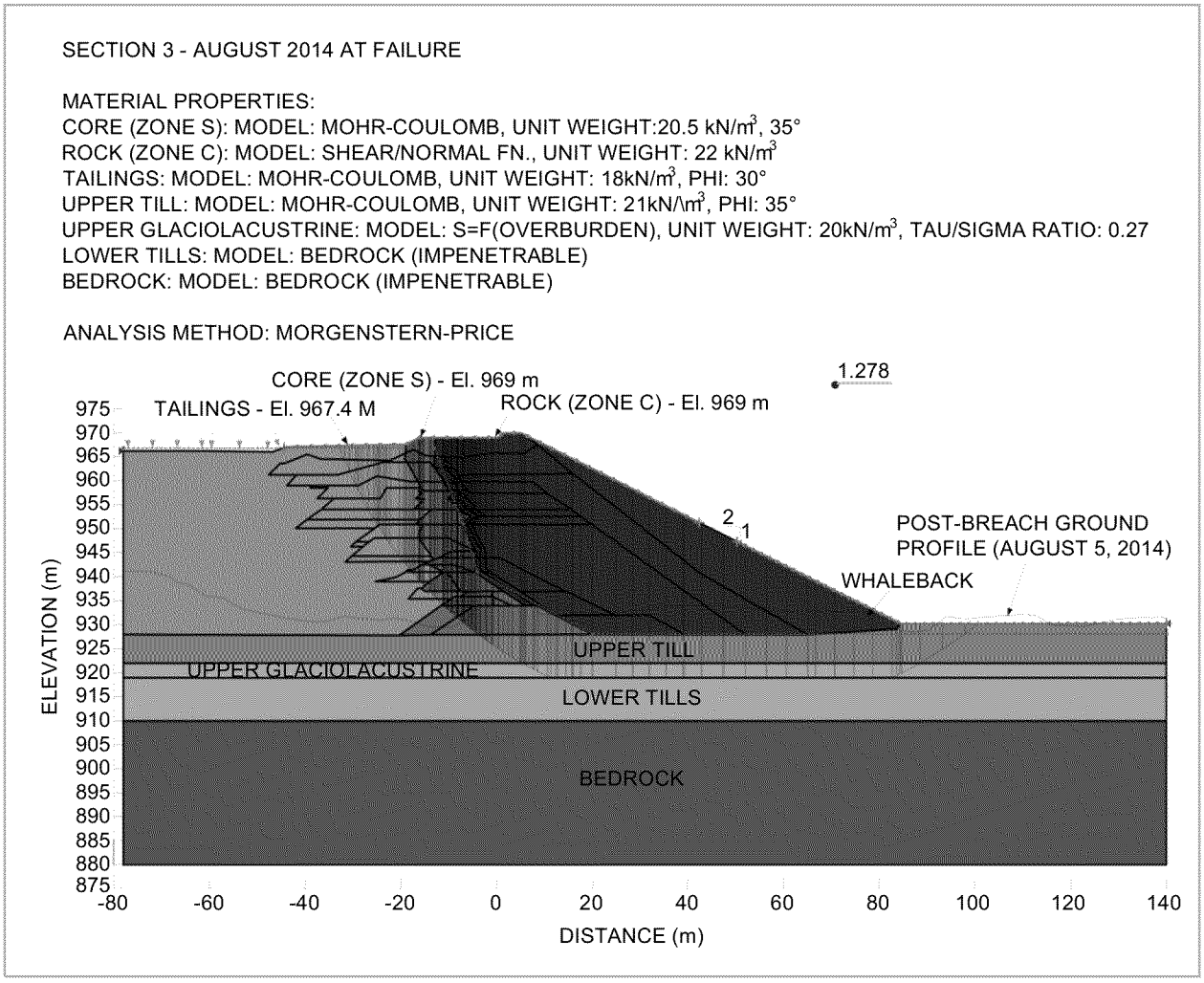
FIGURE 6.5.3: PANEL'S STABILITY ANALYSIS FOR 2H:1V SLOPE WITH WIDENED CREST (FS = 1.28)



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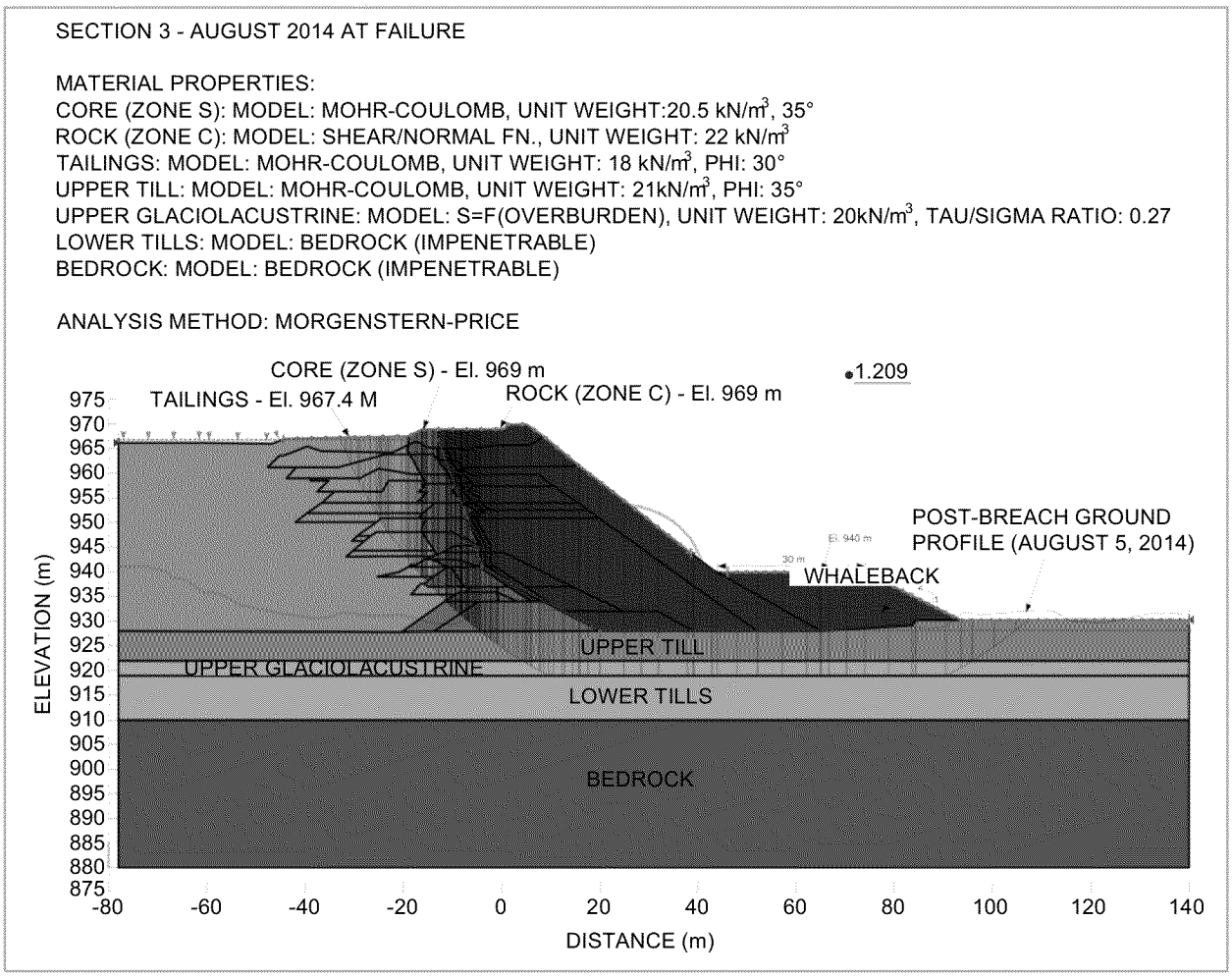
6.6 PREVENTION OF FAILURE

The Terms of Reference (TOR) authorize the Panel to comment on "what actions could have been taken to prevent this failure".

Looking specificallyat the failure as documented in section 5 4, it was deemed desirable to increase the target FS to 1 . 5since the TSF was operating more or less continually at full capacity No significantprogress to this end was made in Stage 9 before failure occurred BGC's design report for Stage 10, issued on July 25, 2014, indicated the buttress required to meet the new design objectives that they identified Had it been in place as shown on **Figure 6.6.1**, the FS would have been 1 2 and the failure would have been prevented.

FIGURE 6.6.1: PANEL STABILITY ANALYSIS FOR BGC BUTTRESS ON STAGE 9



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7 | Management Practices

The Panel is cognizant that management practices have had a significantinfluenceon the design, construction and operation of the tailings storage facility (TSF) .For example, the Panel has already drawn attention to water balance protocols and the growth of water inventory in the TSF due to the timing associated with the implementation of water treatment and discharge It has pointed out that the recurrent adoption of a 1 3H:1V downstream slope for the Perimeter Embankment may have been due to limited material availability or other aspects related to mine planning .The details are not clear .What is clear is that multiple changes were made in the section of the dam in response to the limited time horizons adopted in mine and water planning .

The Panel has been advised that Mount Polley Mining Corporation (MPMC) were in the midst of becoming Mining Association of Canada (MAC) compliant and that tailings management issues were reported to the Board of Directors It has not identified any flaws in this reporting structure .

However, in conducting its inquiry, the Panel limited itself to relying on interviews and on the documents that it received from the various stakeholders, which were sufficient to determine root cause of the breach The Panel did not conduct its process according to formal legal procedures .To do so would have extended the length of this investigation and would have entered into an assessment of roles and responsibilities, which is beyond the Panel's authorization As a result, the Panel is not able to offer an adequate assessment of the role of management and oversight in its contribution to the cause of the failure In particular, the Panel has not explored the relationship between the designers and owner, contractual or otherwise .Accordingly, the Panel is unable to ascertain the circumstances that contributed to key decisions.

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8 | Regulatory Oversight

8.1 ROLES AND RESPONSIBILITIES

This section describes the regulatory roles and responsibilities for impoundments and diversions at mines in B C A Memorandum of Understanding (MOU) is in place between the Ministry of Energy and Mines (MEM), the Ministry of Forests, Lands and Natural Resource Operations (MFLNRO) and the Ministry of the Environment (MoE) to clarify the regulation of these facilities .This MOU and other documents related to Mine Tailings are available on the Geotechnical page of the MEM website:

http://www empr gov bc ca/MINING/PERMITTING-RECLAMATION/GEOTECH/Pages/default aspx

The MOU clearly places the responsibility for the engineering aspects of the Mount Polley tailings storage facility (TSF), seepage collection ponds and diversions on the shoulders of MEM, while the water quality of any discharges is the responsibility of MoE .Two permits are in place for the TSF and associated facilities: Permit M-200 from MEM and Permit 11678 from MoE .

MEM permits are issued by the Chief Inspector of Mines of B C .The Manager of Geotechnical Engineering and the Manager Environmental report to the Deputy Chief Inspector of Mines, Permitting .The Manager Geotechnical Engineering has a staff of two geotechnical engineers and one reclamation specialist, while the Manager Environmental has a staffof three geoscientists .This staffof eight is responsible for inspection of operating mines and permitting of new mines in B C Apart from TSF-related activities, they also have regulatory responsibility for open pits, underground workings, and mined rock and overburden piles .The Geotechnical Manager and staff also participate in secondary activities including the Canadian Dam Association (CDA) Regulatory Committee and coordination with the Association of Professional Engineers and Geoscientists of British Columbia (APEGBC) in development of the *Professional Practice Guidelines for Dam Safety Reviews* for mining dams in B C .[1] The latter publication is available on the above-mentioned website.

The ongoing activities of the geotechnical staffinclude:

- Review of geotechnical aspects of proposed mining projects in the Environmental Assessment process.
- Review of geotechnical aspects of *Mines Act* Permit applications during the approval and permit conditions development process .
- Review of permit amendment applications for dam raises, mine expansions, etc .
- Geotechnical site inspections of operating and closed mines.
- Review of geotechnical reports submitted under the Code, including annual dam safety inspections for mining dams and diversions .

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8 | Regulatory Oversight

Filling the positions at MEM has been challenging at times .The present Manager of Geotechnical Engineering joined MEM in October 2011 following a period of over 3 years when the position was open A senior geotechnical position was made redundant in 2003, but a new geotechnical inspector position was created in 2007 .This position was also vacant for about 2 years until filledin September 2012 A third position was posted in May 2014 and filledin early October 2014 .To attract qualifiedpersonnel, MEM has to compete with industry salaries, which is a challenge, especially during a booming mining cycle .To help accomplish these tasks, MEM has appointed four consulting professional engineers as Contract Inspectors to inspect tailings dams and other mining facilities .

An annual inspection schedule is developed for all the inspectors .The target is to inspect about 30 mines on an annual basis .Mount Polley is one of these mines .

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8.2 REGULATORY INTERACTIONS RELATED TO MOUNT POLLEY MINING CORPORATION (MPMC) TAILINGS STORAGE FACILITY (TSF)

Table 8.2.1 lists the dates of the geotechnical inspections completed at Mount Polley from 1995 to 2014 Annual inspections were completed during the Phase 1 operations and were resumed after start-up of Phase 2 operations until 2008 .There were no geotechnical inspections during 2009, 2010 and 2011, which is the same period as the vacancy of the Geotechnical Manager's position .

TABLE 8.2.1: GEOTECHNICAL INSPECTIONS AT MOUNT POLLEY

DATE OF INSPECTION	TYPE OF INSPECTION PERFORMED	INSPECTOR
Sept 20, 1995	Geotechnical	G .Headley
Oct 19, 1995	Geotechnical	G .Headley
Oct 19, 1995	Geotechnical	C . Brawner
July 9 and 13, 1996	Geotechnical	G .Headley
Aug 26, 1996	Geotechnical	G .Headley
Sep 27–28, 1996	Geotechnical	G .Headley
May 27, 1997	Geotechnical	G .Headley
Jun 4, 1998	Geotechnical	G .Headley
Jun 17, 1999	Geotechnical	G .Headley
Aug 17, 2000	Geotechnical	G .Headley
April 25, 2001	Geotechnical	C .Carr
Feb 3, 2005	Geotechnical	C .Carr
Oct 13, 2005	Geotechnical	N .Rose
Aug 30, 2006	Geotechnical	N .Rose
July 31, 2007	Geotechnical	N .Rose
Jun 7, 2008	Geotechnical	D . Apel
Apr 12, 2012	Geotechnical – site visit	G .Warnock
Sept 24, 2012	Geotechnical	M .Cullen
Sept 13, 2013	Geotechnical	M .Cullen
Dec 4, 2014	Geotechnical	M .Cullen

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Most of the inspection reports did not identify any concerns with the TSF, except in the following cases Based on the inspection of April 25, 2001 the inspector observed: *"The Ministry would strongly support the installation of two slope inclinometers at the downstream toe buttress to monitor potential dam and/or foundation movement. The slope inclinometers should extend through the underlying glaciolacustrine sediments."* [2] MPMC responded that this matter was forwarded to Knight Piésold (KP) .[3] These inclinometers were installed in July 2001 (refer to Appendix F).

On October 13, 2005,[4] narrow beach widths were observed on the southwest side of the pond .On August 30, 2006,[5] wide beach widths were observed and MEM requested a specificspecificationfor beach width .MPMC responded, quoting KP:[6] *"The tailings embankments have been designed to remain stable for any condition and therefore there is not a 'requirement' for a minimum beach width in terms of embankment performance."*

On July 31, 2007,[7] the inspection found two concerns that were Departures from Approval First, Zone S material contained particles as large as 12 inches, which had to be removed to satisfy the specificationof 4 inches .In addition, there was no beach in the vicinity of the southeast corner and MPMC was told that the beach must be re-established and that more frequent monitoring of the piezometers must be conducted in that area.

While the examples above illustrate the role of the Regulator in matters of construction and performance, the Regulator also reviewed design .The following design-related issues were brought up by the Regulator:

- The shear strength associated with the lacustrine materials in the well log GW96-1A.[8]
- Testing on residual strength .[9, 10]
- Need to migrate factor of safety (FS) from 13 to 1 5 .[11]

In each case, the Engineer of Record (EOR) responded to the inquiries and these instances illustrate the limited ability of the Regulator to influence the design issues.

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8.3 PANEL ASSESSMENT

The roles and responsibilities of the Ministry of Energy and Mines (MEM) to regulate impoundments and diversions at mines are well definedand agreed upon with other Ministries .Within MEM, the roles and responsibilities of the geotechnical engineering group responsible for regulating the design, construction and operational aspects of TSFs are also clearly defined .This small group of professionals covers a large portfolio of existing facilities, permitting of new facilities and environmental assessments for proposed projects.

The Panel findsthat the MEM Geotechnical Staffand the Contract Inspectors are well qualifiedto perform their responsibilities.The team is well organized and has clear targets and schedules for annual inspections .The Panel considers the technical qualificationsof the MEM Geotechnical Staffas among the best that it has encountered among agencies with similar duties .

MEM geotechnical engineers addressed significantissues during the reviews and inspections of the Mount Polley TSF.They had insightful questions for the designers at many instances during their review of the design documents, as noted above .The EOR responded to these questions based on their observations and understanding of site conditions .The EOR is responsible for the overall performance of the structure as well as the interpretation of site conditions .The Regulator has to rely on the expertise and the professionalism of the EOR as the Regulator is not the designer .

Despite having a strong regulatory process and personnel, the Perimeter Embankment of the Mount Polley TSF still failed As indicated in earlier sections, it was a sudden failure without precursors Additional inspections of the TSF would not have prevented the failure .

However, the question remains as to the expectations from the Regulator in the future .The relationship between the Regulator and the EOR can result in differentopinions being expressed that are not easy to resolve without independent input .In such circumstances, independent external advice could be sought as further described in section 9 0 .There is a differencebetween regulating construction and regulating design after it has been approved .The Regulator by observation and experience has the capacity to regulate construction but does not have the capacity to modify the design Regulators are not normally recruited with specificdam design experience and are limited by statute in their capacity to take on design responsibilities. This role resides with the EOR

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It is difficulto review the adequacy of a constructed facility without having limits of measurable indicators that defineits performance .Measurable indicators of safe and orderly design and construction are needed for all existing and future tailings facilities that can be monitored and interpreted to evaluate this performance Section 9 0 provides further elaboration of Quantitative Performance Objectives (QPOs) as a means of accomplishing this.

ENDNOTES

1) Panel Interview, 12/12/14.
2) MP00170
3) MP00218
4) MP00174
5) MP00175
6) MP00216
7) MP00177
8) MO00137
9) MP00139
10) MO00222
11) MP00187

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9 | Where Do We Go From Here?

9.1 PERFORMANCE OF B.C. TAILINGS DAMS

Central to the Panel's Terms of Reference (Appendix A) is to recommend actions for preventing future tailings dam failures:

" . *the Panel may make recommendations to government on actions that could be taken to ensure that a similar failure does not occur at other mine sites in B.C."*

Fulfillingthis mandate starts by considering the tailings dams that currently exist in the province In particular, this involves how many there are and how they have performed Appendix I describes the Panel's effortsin this respect . It found that there are currently 123 active tailings dams, those that contain surface water in their impoundments along with tailings .

Active tailings dams were tracked through the years from Ministry of Energy and Mines (MEM) records In the 46-year period since 1969, there was a total of 4,095 years of active operation and 7 failures, where failure is considered to be breach of the dam resulting in release of tailings and/or water.This corresponds to a failure frequency of 1.7×10^{-3} per dam per year.In other words, statistically there is approximately a 1-in-600 chance of a tailings dam failure in any given year, based on historical performance over the period of record.

While these numbers may seem small, their implications are not . If the inventory of active tailings dams in the province remains unchanged, and performance in the future reflectsthat in the past, then on average there will be two failures every 10 years and six every 30 In the face of these prospects, the Panel firmly rejects any notion that business as usual can continue.

The Panel firmly rejects any notion that business as usual can continue.

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9.2 GETTING TO ZERO

In risk-based dam safety practice for conventional water dams, some particular level of tolerable risk is often specifiedthat, in turn, implies some tolerable failure rate .The Panel does not accept the concept of a tolerable failure rate for tailings dams .To do so, no matter how small, would institutionalize failure .First Nations will not accept this, the public will not permit it, government will not allow it, and the mining industry will not survive it.

Clearly, improvements to current practice provide an essential starting point on the path to zero failures But the Panel's evaluation of portfolio risk shows that incremental changes will not be sufficient to achieve this objective.

Appendix I explains why .Ultimately, the problem stems from how many active tailings dams there are in the province .To ensure against future failures for all of them would require roughly a hundredfold reduction or more in the current failure frequency While advances in practices, procedures and policies are imperative, the Panel does not expect these measures by themselves to achieve this degree of improvement . The path to zero needs an added dimension, and that dimension is technology.

The path to zero needs an added dimension, and that dimension is technology.

Tailings dams are complex systems that have evolved over the years They are also unforgiving systems, in terms of the number of things that have to go right .Their reliability is contingent on consistently flawlessexecution in planning, in subsurface investigation, in analysis and design, in construction quality, in operational diligence, in monitoring, in regulatory actions, and in risk management at every level All of these activities are subject to human error .

Human error is often, if not always, found to play a key role in technological failures .And human error will always be with us, as much as we might wish it to be otherwise .This is why failures invariably bring about improvements in technology that help compensate for human error .In perhaps the most notorious containment failure, double-hulled tankers were mandated after the *Exxon Valdez* oil spill .Similarly, improvements to rail tank cars are being adopted in the wake of the Lac-Mégantic tragedy .But tailings dams have no such redundancies Without exception, dam breaches produce tailings releases This is why best practices can only go so far in improving the safety of tailings technology that has not fundamentally changed in the past hundred years .

Failures invariably bring about improvements in technology that help compensate for human error.

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9 | Where Do We Go From Here?

Improving technology to ensure against failures requires eliminating water both on and in the tailings: water on the surface, and water contained in the interparticle voids Only this can provide the kind of failsafe redundancy that prevents releases no matter what In terms of portfolio risk, Appendix I shows that this works by reducing the inventory of active tailings dams subject to failure in the firstplace Simply put, dam failures are reduced by reducing the number of dams that can fail.

Thus, the path to zero leads to best practices, then continues on to best technology.

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9.3 BEST AVAILABLE TAILINGS TECHNOLOGY

9.3.1 BAT PRINCIPLES

While best practices focus on the performance of the tailings dam, best available technology (BAT) concerns the tailings deposit itself .The goal of BAT for tailings management is to assure physical stability of the tailings deposit .This is achieved by preventing release of impoundment contents, independent of the integrity of any containment structures In accomplishing this objective, BAT has three components that derive from firstprinciples of soil mechanics:

1. **Eliminate surface water from the impoundment.**
2. **Promote unsaturated conditions in the tailings with drainage provisions.**
3. **Achieve dilatant conditions throughout the tailings deposit by compaction.**

The firstof these, eliminating surface water, not only precludes release of water itself, but also eliminates fluvial tailings transport mechanisms like those illustrated in Appendix C during the Mount Polley breach .The second, promoting unsaturated conditions by drainage, reduces the possibility for, and the quantity of, high-mobility flowsliderelease of tailings And the third, achieving dilatant conditions by compaction, further reduces flowslide potential by improving the properties of the tailings mass .Thus, underpinning these principles are multiple redundancies that provide defence in depth .

The Panel recognizes that eliminating water from the tailings deposit will not eliminate the need for storage of mine and processing water elsewhere But Mount Polley has shown the intrinsic hazards associated with dual-purpose impoundments storing both water and tailings The Panel considers that security can be more readily assured for conventional water dams that are designed and constructed for their own purpose and that preventing tailings release is the overriding imperative.

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9.3.2 BAT METHODS

The overarching goal of BAT is to reduce the number of tailings dams subject to failure. This can be achieved most directly by storing the majority of the tailings below ground—in mined-out pits for surface mining operations or as backfill for underground mines. Both methods require integrating tailings planning into mine planning. This has not been common practice in the industry to date, as the Mount Polley case has shown, and the synergies to be achieved are mostly unexplored. Apart from this, surface storage using filtered tailings technology is a prime candidate for BAT.

The overarching goal of BAT is to reduce the number of tailings dams subject to failure.

Demonstrated technology for producing and placing filtered tailings (sometimes termed "dry stack" tailings) is well-known in the industry. Its adoption and design practices are documented in the literature.[1, 2] Using various kinds of equipment, the water content of the tailings is reduced before they leave the mill. The specified degree of water removal can vary, but is sufficient to allow transport by truck or conveyor to the tailings facility and compaction. Compaction is necessary to prevent liquefaction flowslides that can and have occurred in loosely placed dewatered materials due to infiltration of ponded surface runoff. The Panel recognizes that creating dry tailings may increase the amount of water requiring treatment or storage.

Filtered tailings technology embodies all three BAT components described in section 9.3.1. Most commonly used in dry climates where economy in water consumption is important, it has also been adapted to cold regions.[3] This method has been used since start-up of the Greens Creek mine in Alaska under conditions not unlike coastal B.C.[4] The Greens Creek facility is shown in **Figure 9.1.1**.

Variations on this technology are easily envisioned, for example separation, dewatering, and gravity drainage of sand tailings by cycloning to reduce quantities requiring filtration dewatering. The Panel believes that additional enhancements are ripe for development if there is incentive to do so.

In some cases, clayey ore may pose difficulties in dewatering. And most filtered tailings operations to date have been relatively small. But some new operations will be producing filtered tailings at a rate of 68,000 tonnes per day—almost three times the production of Mount Polley—in facilities that will reach heights of 150 metres (m). As demonstrated by the Greens Creek case and others, there are no overriding technical impediments to more widespread adoption of filtered tailings technology.

There are no overriding technical impediments to more widespread adoption of filtered tailings technology.

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9 | Where Do We Go From Here?

FIGURE 9.1.1 FILTERED TAILINGS FACILITY, GREENS CREEK, ALASKA

The chief reason for the limited industry adoption of filtered tailings to date is economic. Comparisons of capital and operating costs alone invariably favour conventional methods. But this takes a limited view. Cost estimates for conventional tailings dams do not include the risk costs, either direct or indirect, associated with failure potential. The Mount Polley case underscores the magnitude of direct costs for cleanup, but indirect losses—notably in market capitalization—can be even larger.[5] Nor do standard costing procedures consider externalities, like added costs that accrue to the industry as a whole, some of them difficult or impossible to quantify. Full consideration of life cycle costs including closure, environmental liabilities, and other externalities will provide a more complete economic picture. While economic factors cannot be neglected, neither can they continue to pre-empt best technology.

While economic factors cannot be neglected, neither can they continue to pre-empt best technology.

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9.3.3 BAT FOR CLOSURE

Closure of tailings deposits is subject to two fundamental considerations: physical stability and chemical stability. Although the former is the object of the Panel's investigation, no treatment of tailings technology can ignore the latter. Matters related to physical and chemical stability reside in different domains and have developed independently, each with their own goals and methods. These two aspects converge in the context of BAT.

In short, the most serious chemical stability problem concerns tailings that contain sulfide minerals, particularly in metal and coal mining. In the presence of oxygen, these sulfides react to produce acid that then mobilizes a variety of metals in solution. There are a number of ways to arrest this reaction, and one is to saturate the tailings so that water replaces oxygen in the void spaces. This saturation is most conveniently achieved by maintaining water over the surface of the tailings. Hence, so-called water covers have sometimes been adopted for reactive tailings during operation and for closure.

It can be quickly recognized that water covers run counter to the BAT principles defined in section 9.3.1. But the Mount Polley failure shows why physical stability must remain foremost and cannot be compromised. Although the tailings released at Mount Polley were not highly reactive, it is sobering to contemplate the chemical effects had they been. No method for achieving chemical stability can succeed without first ensuring physical stability: chemical stability requires above all else that the tailings stay in one place.

Filtered tailings technology adopts a different approach to chemical stability. Rather than arresting the reaction, it retards the transport of reaction products. Seepage gradients are greatly diminished by eliminating surface water. This has a beneficial effect not only on sulfide reaction products; it also equally reduces transport of soluble constituents such as arsenic, sulfates and selenium, if present in the tailings.

Moreover, the technology for alternative dry covers is well advanced. Using different cover designs for different climatic conditions, soil covers placed over the tailings deposit further reduce infiltration, retard oxygen entry, or both. Cover placement and reclamation can proceed concurrently with operation, as shown in the foreground in **Figure 9.1.1** at Greens Creek.

Yet other technologies attack the chemical effects of sulfide minerals by removing them from the tailings. Doing so using conventional metallurgical processes has been shown to be technically and economically feasible.[6] These same techniques can be used, in effect, to manufacture clean tailings cover material free from sulfides.[7]

This shows that the physical stability objectives of BAT are not incompatible with chemical stability. A variety of complementary technologies are available for achieving both.

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9.3.4 BAT RECOMMENDATIONS

Implementation of BAT is best carried out using a phased approach that applies differently to tailings impoundments in various stages of their life cycle.

- **For existing tailings impoundments** .Constructing filteredtailings facilities on existing conventional impoundments poses several technical hurdles.Chief among them is undrained shear failure in the underlying saturated tailings, similar to what caused the Mount Polley incident.Attempting to retrofit existing conventional tailings impoundments is therefore not recommended, with reliance instead on best practices during their remaining active life .
- **For new tailings facilities** .BAT should be actively encouraged for new tailings facilities at existing and proposed mines .Safety attributes should be evaluated separately from economic considerations, and cost should not be the determining factor .
- **For closure** .BAT principles should be applied to closure of active impoundments so that they are progressively removed from the inventory by attrition.Where applicable, alternatives to water covers should be aggressively pursued .

As discussed in section 9 2, best technology is only one of the two components necessary for safety improvement . The complementary aspects of best practices are presented in the following sections.

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9.4 BEST APPLICABLE PRACTICES (BAP)

The safety of any dam, water or tailings, relies on multiple levels of defence. The Panel was disconcerted to find that, while the Mount Polley Tailings Dam failed because of an undetected weakness in the foundation, it could have failed by overtopping, which it almost did in May 2014. Or it could have failed by internal erosion, for which some evidence was discovered. Clearly, multiple failure modes were in progress, and they differed mainly in how far they had progressed down their respective failure pathways.

Accordingly, recommendations for future BAP require considerations that go beyond stability calculations. It is important that safety be enhanced by providing for robust outcomes in dam design, construction and operations. As discussed below, this has implications for corporate responsibility, enhanced regulatory capacity, expanded technical review, and improvements in professional practice.

It is important that safety be enhanced by providing for robust outcomes in dam design, construction and operations.

9.4.1 CORPORATE GOVERNANCE

In response to several international tailings dam failure incidents in the 1990s, the Mining Association of Canada (MAC) established a task force in 1996 to promote safe, environmentally responsible management of tailings and mine waste. The task force concluded that the main priority should focus on improvement of tailings management, which resulted in the establishment of the MAC Tailings Working Group. The outcome of this initiative were several guides related to the management of tailings facilities; the development of operations, maintenance and surveillance manuals; and auditing and assessment of tailings management facilities.[8] The guides themselves are available from the MAC.[9] They are now embraced by the Towards Sustainable Mining (TSM) initiative launched by MAC in 2004.

Compliance with the TSM initiative is an element of BAP for the mining industry today. Accordingly, mining operations in B.C. proposing to operate a tailings storage facility (TSF) should either be required to be a member of MAC—ensuring adherence to the TSM—or be obliged to commit to an equivalent program, including the audit function. Tailings management is often not a core skill in many mining organizations. Embracing MAC's TSM initiative will ensure awareness of responsibilities at the highest corporate levels.

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At the same time, many in the industry have reacted to the Mount Polley failure with incredulity, asking how it could have happened with programs such as MAC's in place This serves as a reminder that these programs should not instill a sense of overconfidence and cannot themselves be seen as a substitute for more fundamental changes in technology .

9.4.2 CORPORATE TSF DESIGN RESPONSIBILITIES

In the experience of the Panel, TSF design studies submitted to Regulators are often lacking in detail regarding the factors that need to be considered in assuring safety of the facility This applies equally to appropriate tailings technology and to performance metrics for confirming orderly construction and operations .

At Mount Polley, the only quantitative performance objectives were those implied in its design criteria A list of potential failure modes was compiled in the 2006 Dam Safety Report, but these were generic and not tied to specific site conditions One of the lessons learned here is that future permit applications for TSFs must provide a more comprehensive assessment of potential geotechnical problems associated with the selected site In addition, BAT for both tailings storage and closure considerations also needs to be incorporated in such proposals.

The Panel is of the view that the inclusion of these considerations and the declaration of Quantitative Performance Objectives (QPOs) are best incorporated early in project commitment at the bankable feasibility level .QPOs are intended to constrain the type of ad hoc design practices that characterized Mount Polley and strengthen regulatory capacity .

The Panel would require a bankable feasibility study and related permit application to have considered all technical, environmental, social and economic aspects of the project Resolution of technical and environmental considerations would usually be supported by proven methods, although technology development studies would not be precluded if they have advanced far enough to warrant implementation in practice The bankable feasibility study would be of sufficient detail to support an investment decision that might have an accuracy of ±10%–15%.

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More explicitly, the bankable feasibility document would be required to contain the following:

1) A detailed evaluation of all potential failure modes associated with:

   - The geological conditions of the site
   - The uncertainties associated with this evaluation
   - The role of the Observational Method to manage residual risk
   - Mitigation measures in case worse than anticipated conditions are encountered.

   This evaluation should be updated and incorporated into MEM requirements for annual inspection and construction review .This is to ensure that the evaluation would become a living document maintained throughout the life of the facility .It should be sufficiently well documented to survive changes in mine personnel, mine ownership or Engineers of Record (EORs), and it should be referenced as part of the Operations Maintenance and Surveillance (OMS) manual .The Panel anticipates that as-built reports would provide the basic information recording departures from what had been anticipated .An ongoing compilation should be maintained by the EOR as a separate document.

2) Detailed cost analyses of BAT tailings and closure options, so that alternative means of achieving BAT can be understood and accommodated As discussed in section 9 3 2, this assessment should recognize that indirect and unquantifiable costs cannot be fully incorporated and hence the results of the cost analyses should not supersede BAT safety considerations.

3) A detailed declaration of QPOs, beyond those associated with regulatory compliance and ordinary design criteria .Examples of QPOs are numerical values and limits associated with:

   - Beach widths
   - Calibration of impoundment filling schedule
   - Water balance audits and calibration
   - Construction material availability and scheduling to ultimate height of structure
   - Instrumentation adequacy and reliability
   - Trigger levels for response to instrumentation
   - Performance data gathering, interpretation, and reporting intervals

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The Panel recognizes the need for a regulatory process that is responsive to changed conditions arising from market forces, reserves, regulatory revisions and technical issues It is envisaged that such changes can be accommodated by staged approval for construction, as occurs at present . However, the stage applications should honour the declared QPOs or present a basis for their modification .

The Panel recognizes the need for a regulatory process that is responsive to changed conditions arising from market forces, reserves, regulatory revisions and technical issues.

9.4.3 INDEPENDENT TAILINGS REVIEW BOARD (ITRB)

The appointment of ITRBs to provide third-party advice on the design, construction, operation and closure has become increasingly common and is recognized to provide value.[10] The World Bank and other lenders groups are requiring the formation of an ITRB . International Finance Corporation/World Bank guidance and operating principles OP4 01 and OPR 37 establish the requirement to review the development of tailings dam design, construction and initial dam filling Maintaining an ITRB through operations and closure will depend upon the scale and complexity of the facility Some large corporations retain a third-party review board for ongoing advice on tailings operations to complement their internal technical audit systems.

The appointment of ITRBs to provide third-party advice on the design, construction, operation and closure has become increasingly common and is recognized to provide value.

ITRBs are not unique to the mining industry They have a long history in water dam design and safety assessments . In British Columbia, BC Hydro has considerable experience with such Boards for safety assessment of both existing and new dam projects . In a mining context, an ITRB could be asked to provide opinions on the following:

- Whether the design, construction and operation of the TSF are consistent with satisfactory long-term performance .
- Whether design and construction have been performed in accordance with the Board's expectation of good practice .
- Whether safety and operation of the TSF conform to the Board's expectation of good practice .
- Whether there are weaknesses that would reasonably be expected to have a material adverse effect on the integrity of the TSF, human health, safety, and successful operation of the facility for its intended purpose.

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9 | Where Do We Go From Here?

Experience has shown that the effectiveness of an ITRB in specific circumstances depends on the following:

- That it not be used exclusively as a means for obtaining regulatory approval.
- That it not be used for transfer of corporate liability by requesting indemnification from Board members.
- That it be free from external influence or conflict of interest .
- That there be means to assure that its recommendations are acted upon .

No ITRB can function successfully without unqualifiedsupport and commitment at the highest corporate levels . While it is essential that the Board be organized by Mine Operations, it is equally essential that its reports go to senior corporate management and Regulators .To establish and strengthen credibility, Board reports should also be open to other stakeholders . An important mechanism for accountability in response to Board recommendations is the creation of an Action Log that reviews corporate response to Board recommendations at each successive meeting .

No ITRB can function successfully without unqualified support and commitment at the highest corporate levels.

It is evident that the establishment of Independent Tailings Review Boards is an element of BAP, and the Panel is of the view that they have a role in improving current practice But they should not be necessary for all tailings undertakings and MEM should consider, based on their current portfolio of operating and proposed TSFs, the conditions related to complexity and failure consequence that warrant an ITRB.

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9.4.4 MINISTRY OF ENERGY AND MINES (MEM)

As noted in section 7, the Panel was favourably impressed by the skill and commitment of MEM's geotechnical staffin carrying out their responsibilities .Nevertheless, it also considered what measures could be taken to improve regulatory operations .

With recent inspections of TSFs in the province in hand, the short-term need is to evaluate these facilities with respect to the following potential failure modes, in order of importance:

1. **Undrained shear failure** for dams with silt and clay foundation soils.
2. **Water balance adequacy,** including provisions and contingencies for wet years .
3. **Filter adequacy,** especially for dams containing broadly graded soils or mine waste.

The Regulator is not the designer.

One issue identifiedin section 8 0 is the ultimate reliance of the Regulator on the EOR to confirmthat the facility is safe and is operating as intended .The Regulator is not the designer, and this limits the degree of inquiry that is manageable .If Regulators were provided with more information in an ongoing manner, they would be better versed to engage the EOR .This is one of the benefitsof having declared QPOs that can be monitored, as discussed in section 9 4 2 .To this end, MEM should evaluate how to determine the QPOs associated with ongoing facilities and begin to apply them in practice.

Additionally, the Panel's compilation of the province's tailings dam inventory revealed limitations in MEM's capacity for information retrieval, especially for timely response to unexpected occurrences .Tailings dam data for each mine and each structure needs to be scanned electronically, compiled separately from permit files,and maintained in a readily accessible database .

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9.4.5 PROFESSIONAL PRACTICE

The Panel found it disconcerting that, notwithstanding the large number of experienced geotechnical engineers associated with the Mount Polley TSF, the overall adequacy of the site investigation and characterization of ground conditions beneath the Perimeter Embankment went unquestioned. This may reflecta regional issue, or possibly one of wider extent. Regardless, it calls for a concerted effortto improve professional practice in this area. The situation is reminiscent of the conditions that prevailed in B.C. that resulted in the Association of Professional Engineers and Geoscientists of British Columbia (APEGBC) Guidelines for *Legislated Landslide Assessment for Proposed Residential Developments in B.C.*.

In the view of the Panel, the fundamental need is to improve the geological, geomorphological, hydrogeological and possibly seismotectonic understanding of sites proposed for tailings dams in B.C. This improved understanding should account for the likely scale associated with variability so that site investigations can be planned with enhanced reliability.

APEGBC appears to be well-suited for this task.

9.4.6 CANADIAN DAM ASSOCIATION (CDA) GUIDELINES

From its inception in 1995, the Mount Polley TSF adopted a minimum factor of safety (FS) of 1.3 during operations and 1.5for closure. As chronicled in section 5.4, these FS criteria drove key decisions throughout the design process, and so the Panel is of the view that it would be helpful to comment on them.

CDA dam safety guidelines originally developed for water dams were subsequently adapted to tailings dams, with target factors of safety as indicated in **Table 9.4.1**.[11]

TABLE 9.4.1 TARGET FACTORS OF SAFETY FOR SLOPE STABILITY IN CONSTRUCTION, OPERATION AND TRANSITION PHASES – STATIC ASSESSMENT (AFTER CDA, 2014)

LOADING CONDITIONS	MINIMUM FACTOR OF SAFETY	SLOPE
During or at end of construction	>1.3 depending on risk assessment during construction	typically downstream
Long-term (steady state seepage, normal reservoir level)	1.5	downstream

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These 2014 guidelines vest responsibility for establishing appropriate FS criteria solely with the designer, subject to the designer's consideration of the following:

- The consequences of failure
- The loading conditions
- The strength parameters used

Hence, the CDA Guidelines are premised on proper evaluation of these factors But in the case of Mount Polley, this premise was flawed Few would argue that the failure consequences were anything less than catastrophic to those affected .The loading conditions did not account for the development of normally consolidated conditions in the foundation And the strength parameters neglected undrained shearing Furthermore, selection of FS criteria using risk analysis, as specifiedin **Table 9.4.1**, could not have succeeded because the operative failure mode went unrecognized .

Mount Polley illustrates that dam safety guidelines intended to be protective of public safety, environmental and cultural values cannot presume that the designer will act correctly in every case To do so defeats the purpose of FS criteria as a safety net In this, the CDA Guidelines are unable to achieve their intended purpose Neither is the Province well served, to the extent that MEM has incorporated compliance with these guidelines as a statutory requirement .[13]

The Panel considers that tailings dam guidelines and criteria tailored to conditions in B C .would more effectively meet the needs of the Province in protecting public safety .Those developed by the U S Army Corps of Engineers for water dams provide one example, among others, that might be used as a starting point .[12] This does not preclude adopting parts of the CDA Guidelines where appropriate as well as the CDA technical bulletin *Geotechnical Considerations for Dam Safety* .[14] The Panel anticipates that this will result in more prescriptive requirements for site investigation, failure mode recognition, selection of design properties, and specificationof factors of safety .

Tailings dam guidelines and criteria tailored to conditions in B.C. would more effectively meet the needs of the Province in protecting public safety.

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10 | Conclusions

Based on the activities described and interpretations advanced in the preceding sections of the report, the Panel has developed the findingssummarized below .

10.1 MECHANISM OF FAILURE

The breach of the Perimeter Embankment on August 4, 2014 was caused by shear failure of dam foundation materials when the loading imposed by the dam exceeded the capacity of these materials to sustain it.The failure occurred rapidly and without precursors .

Direct evidence of this failure mechanism is provided by an identifiedshear surface in surviving remnants of the dam core and by deformations consistent with shearing in a weaker glacially-deposited layer of silt and clay about 8–10 metres (m) below the original ground surface.This layer, its properties, and its extent received intense scrutiny during this investigation, and analyses using representative parameters provide indirect evidence that further supports this failure mechanism .

Deposited in a complex geologic environment, the weaker glaciolacustrine layer was localized to the breach area.It went undetected, in part because the subsurface investigations were not tailored to the degree of this complexity.But neither was it ever targeted for investigation because the nature of its strength behaviour was not appreciated .

Throughout, the design investigations took note of the stiff, dense character of foundation soils and used corresponding strength properties in stability analyses .But it was not recognized that this character would change, with a corresponding change in strength behaviour under the increased loading as the dam grew higher . Specifically,it was never recognized that the glaciolacustrine soils that were initially overconsolidated would become normally consolidated, requiring undrained shear strengths for stability analyses.This is the process that affected the weaker glaciolacustrine layer in the breach area that was not accounted for in the design of the dam .

Adding to the antecedent foundation conditions was the unprecedented steepness of the 1.3H:1V Perimeter Embankment slope.This was justifiedby design analyses without questioning its reasonableness .The higher Main Embankment had glaciolacustrine foundation soils with properties broadly comparable to those at the breach section.But here, the steep slopes were effectivelyflattenedby the addition of a buttress, which explains why the failure did not occur at the highest part of the dam .

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10.2 CONTRIBUTING FACTORS

10.2.1 LONG-TERM PLANNING

A lack of foresight in planning for dam raising contributed to the failure Successfully executing the raising plan required intimate coordination of impoundment water-level projections, production and transport of mine waste for raising, and seasonal constraints on construction This made the tailings dam contingent at the same time on the water balance, the Mine plan, and the weather But instead of projecting these interactions into the future, they were evaluated a year at a time, with dam raising often bordering on ad hoc and only responding to events as they occurred The effectswere twofold: a near overtopping failure in May of 2014, and restrictions on mine waste availability that produced the oversteepened slopes and deferred buttress expansion.

10.2.2 OBSERVATIONAL METHOD

The Observational Method was adopted as a design philosophy, but misapplied For reasons not unrelated to planning shortcomings, instrumentation was relied upon to substitute for definitiveinput parameters and design projections But the Mount Polley dam was ill-suited to this approach, for both practical and strategic reasons . The steep slopes and constant construction activity on the Perimeter Embankment prevented installation of instruments at optimal locations More importantly, the instrumentation program was incapable of detecting critical conditions because, once again, the critical materials and their critical mode of undrained behaviour were not recognized .

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10.3 ROLE OF WATER

In light of its importance in planning and the near-overtopping incident, the role of water contained in the tailings storage facility (TSF) deserves special mention First of all, overtopping did not cause the breach of August 4, 2014 . However, the high water level acted in other ways that influenced both the failure and its effects.

High impoundment water levels were a major cause of chronic problems in maintaining a tailings beach around the perimeter of the dam At the breach section, water was in direct contact with the upstream zone of tailings fill when failure occurred This increased the piezometric level in the upstream zone above what it would have been had a wide tailings beach been present The Panel's analyses show that this had some influenceon dam stability, although it was not the dominant factor.

The high water level was the finallink in the chain of failure events Immediately before the failure, the water was about 2 3 m below the dam core The Panel's excavation of the failure surface showed that the crest dropped at least 3 3 m, which allowed overflowto begin and breaching to initiate Had the water level been even a metre lower and the tailings beach commensurately wider, this last link might have held until dawn the next morning, allowing timely intervention and potentially turning a fatal condition into something survivable.

Finally, the quantity of water had a great deal to do with the quantity of tailings released after the breach developed . It was water erosion that transported the bulk of the tailings, and these fluvialprocesses ended when the supply of water was exhausted Had there been less water to sustain them, the proportion of the tailings released from the TSF would have been less than the one-third that was actually lost.

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10.4 REGULATORY FACTORS

The Panel examined regulatory activities by the Ministry of Energy and Mines (MEM) in relation to the failure and whether differentactions on MEM's part might have prevented it In particular, the Panel's attention was drawn to the period from 2009 to 2011 when no government inspections of the Mount Polley dam were performed .The Panel concludes that this lack of inspection was immaterial to the failure because there were no precursors that could have been detected, even on the eve of the breach By definition,no amount of inspection can discover a hidden flaw .

The Panel also examined MEM's actions concerning factors that did have a material relationship to the failure . In this regard, MEM queried the designer about softer conditions in glaciolacustrine soils encountered in a groundwater well that were similar to those at the breach Its inspector issued a "Departure from Approval" notice concerning the absence of an adequate tailings beach .The inspector questioned the designer's factor of safety FS = 1 3 criterion, subsequently requiring its increase .The Panel found these actions to be appropriate and within the expected conduct of regulatory responsibilities .

It is not unreasonable to ask whether MEM could have acted sooner or more aggressively in these matters or even intervened in the design process, and perhaps this might have been warranted under the harsh illumination of hindsight .Yet the Panel considers that a bright line must be maintained between designer and Regulator .It is axiomatic that a Regulator cannot regulate its own activities Were it to usurp the role of the designer, it would also usurp its own role .

10.5 POSSIBLE FAILURE PREVENTION

In fulfillingits Terms of Reference, the Panel considered what actions could have been taken to prevent the failure . From a purely technical perspective, apart from rectifying the deficienciesreviewed here, there is one that stands out .

The design for the next raise of the dam had been submitted only days before the failure In it was a buttress that would have extended along the Perimeter Embankment, including the breach section Although this buttress was still not designed using the appropriate stratigraphy or undrained strengths, the Panel determined that had it been in place, the failure would have been averted .The solution would have been correct, even if for the wrong reasons .

In keeping with its Terms of Reference, the Panel has developed these conclusions on the basis of technical factors specificto the Mount Polley failure It must be left to others to determine how they might translate more broadly to legislative, administrative process, and policy areas.

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11 | Recommendations

Recognizing that the path to zero failures involves a combination of best available technology (BAT) and best applicable practices (BAP), the Panel recommends the following:

1) **To implement BAT using a phased approach:**
   - **a . For existing tailings impoundments** .Rely on best practices for the remaining active life.
   - **b . For new tailings facilities** .BAT should be actively encouraged for new tailings facilities at existing and proposed mines .
   - **c . For closure** BAT principles should be applied to closure of active impoundments so that they are progressively removed from the inventory by attrition .

   See section 9 3 .

2) **To improve corporate governance:**
   Corporations proposing to operate a tailings storage facility (TSF) should be required to be a member of the Mining Association of Canada (MAC) or be obliged to commit to an equivalent program for tailings management, including the audit function .

   See section 9 4 1 .

3) **To expand corporate design commitments:**
   Future permit applications for a new TSF should be based on a bankable feasibility that would have considered all technical, environmental, social and economic aspects of the project in sufficient detail to support an investment decision, which might have an accuracy of ±10%–15% More explicitly, it should contain the following:

   - **a .** A detailed evaluation of all potential failure modes and a management scheme for all residual risk.
   - **b .** Detailed cost/benefit analyses of BAT tailings and closure options so that economic effects can be understood, recognizing that the results of the cost/benefit analyses should not supersede BAT safety considerations.
   - **c .** A detailed declaration of Quantitative Performance Objectives (QPOs) .

   See section 9 4 2 .

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4) **To enhance validation of safety and regulation of all phases of a TSF:**

Increase utilization of Independent Tailings Review Boards .

See section 9.4.3 .

5) **To strengthen current regulatory operations:**

a . Utilize the recent inspections of TSFs in the province to ascertain whether they may be at risk due to the following potential failure modes and take appropriate actions:

i . Undrained shear failure of silt and clay foundations

ii . Water balance adequacy

iii . Filter adequacy

b . Utilize the concept of QPOs to improve Regulator evaluation of ongoing facilities .

See section 9.4.4 .

6) **To improve professional practice:**

Encourage the APEGBC to develop guidelines that would lead to improved site characterization for tailings dams with respect to the geological, geomorphological, hydrogeological and possibly seismotectonic characteristics.

See section 9.4.5 .

7) **To improve dam safety guidelines:**

Recognizing the limitations of the current Canadian Dam Association (CDA) Guidelines incorporated as a statutory requirement, develop improved guidelines that are tailored to the conditions encountered with TSFs in British Columbia and that emphasize protecting public safety.

See section 9.4.6 .

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12 | Postscript and Acknowledgements

The Panel has been acutely aware of its responsibilities in conducting this investigation .It set out to be thorough, focusing on the technical issues, and to report its findingsin an independent, open, transparent and timely manner It is content that it has fulfilledits mandate .To do so required the digestion of thousands of pages of technical documents; fieldinvestigations involving mapping, drilling and sampling; complex laboratory tests; various theoretical analyses; and consolidation of its findings,conclusions and recommendations in a manner intended to be accessible to a variety of stakeholders .The Panel could not have met its objectives without the assistance of a number of dedicated and skilled individuals .The Panel wishes to acknowledge this assistance here.

First, and possibly foremost, the Panel expresses its gratitude to Mr Kevin Richter, Assistant Deputy Minister, Ministry of Transportation and Infrastructure, who was appointed to lead the Secretariat for the investigation and his assistants, Stacy Scriver and Rupinder Prihar Mr Richter managed the business of the investigation with enormous skill, diplomacy and good grace .This allowed the Panel to focus on its main task and hence the Secretariat made a most valuable contribution to the collective effort .

The Panel retained Thurber Engineering Limited (Thurber) to undertake a wide variety of technical tasks acting under the direction of the Panel .These tasks involved site mapping, drilling and sampling, a wide suite of laboratory tests, a variety of analyses, and preparing material for inclusion in the report .The Thurber team was outstanding in its technical contributions and dedication to this assignment .The Panel was extremely pleased to work with such a skilled team that included the following:

- In Vancouver – David Regehr (Project Manager), Paul Wilson, Caleb Scott, Ben Singleton-Polster, Denny Ma, Andrea Lougheed, Paul Evans
- In Victoria – Stephen Bean, Warren Wunderlick, Suzanne Powell
- In Calgary – John Sobkowicz
- And others too numerous to mention

Deborah Lovett, QC, of Lovett & Westmacott was retained as legal advisor to the Panel and provided wise counsel throughout the period of the investigation.

Judith Brand provided senior editorial advice and Shawn Robins, Robins Communications, assisted the Panel in organizing its outreach activities .

While many have contributed to this report, the Panel retains sole responsibility for its content.

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13 | List of Abbreviations

ABBREVIATIONS

APEGBC: Association of Professional Engineers and Geoscientists of British Columbia
BAP: best applicable practices
BAT: best available technology
CDA: Canadian Dam Association
CPT: cone penetration test
CQA: Construction Quality Assurance
DSR: Dam Safety Review
DSS: direct simple shear
EOR: Engineer of Record
EPRI: Electric Power Research Institute
ESA: effective-stressanalysis
FOIPPA: *Freedom of Information and Protection of Privacy Act*
FS: factor of safety
GLU: Upper Glasciolacustrine Unit
GSA: grain size analyses
ITRB: Independent Tailings Review Board
KCB: Klohn Crippen Berger
KP: Knight Piésold
LiDAR: Light Detection And Ranging
LI: Liquidity Index
LPT: Large Penetration Testing
MAC: Mining Association of Canada
MEM: Ministry of Energy and Mines
MFLNRO: Ministry of Forests, Lands and Natural Resource Operations
MoE: Ministry of the Environment
MOU: Memorandum of Understanding
MPMC: Mount Polley Mining Corporation
OCR: overconsolidation ratio
OMS: Operations Maintenance and Surveillance
PMP: Probable Maximum Precipitation
QPO: Quantitative Performance Objective
RCPT: Resistivity Cone Penetration Test
SOL: setting out line
SPT: standard penetration test
Thurber: Thurber Engineering Limited
TSF: tailings storage facility
TSM: Towards Sustainable Mining
USA: undrained strength analysis
USBR: U S .Bureau of Reclamation
VST: vane shear test

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14 | Glossary of Technical Terms

GLOSSARY

Angle of repose: the maximum slope steepness that dry granular material can sustain

Anisotropy: directional differencesin properties, typically horizontal and vertical

Anticlinal structure: dome-shaped folding

Applied load: usually gravity stresses imposed by a structure; simplistically, its weight

Arcuate headscarps: semicircular and nearly perpendicular slopes delineating the upper end of a slope movement

Artesian pressure: water pressure sufficient to cause water to flow upwards out of the ground

Bankable feasibility study: a level of design sufficient for detailed cost estimates

Bathymetric survey: survey of underwater surfaces

Beach: a gently sloping surface of deposited tailings

Bedding: layering, commonly horizontal

Blow count: the number of drops of a heavy weight required to advance a sampler 30 cm into the ground

Buttress: a berm constructed at the bottom of a slope to increase its stability

Chimney drain: a zone of sand or gravel within a dam for collecting and conveying water

Coefficient of consolidation: a parameter used to calculate change of pore pressure with loading

Crest: the top of a dam or slope

Critical failure surface in stability analysis: the failure surface with the lowest factor of safety

Cycloning: separation of tailings into coarser and finer fractions

Dendritic drainages: branching stream channels

Dip direction: the direction in which a geologic structure slopes downward

Direct shear: type of test used to determine drained shear strength

Direct simple shear: type of test used to determine undrained shear strength

Downcutting: a natural process of excavation, usually by erosion

Downthrow: downward movement

Effectivestress : the stress experienced by soil particles after the known pore pressure is subtracted

Effective-stress strength: the strength of a soil expressed only in terms of the effective stress

En echelon scarps: parallel steep slopes produced by ground movement

Factor of safety: the ratio of available strength to the strength required for equilibrium; a measure of stability

Fines: fine particles smaller than visible with the naked eye, typically less than 0074 mm diameter

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14 | Glossary of Technical Terms

Flowslide: high-velocity earth movement; mudflow

Fluvial processes: processes caused by or associated with rivers or streams

Freeboard: reservoir capacity reserved for storage of flood inflows, including wave height

Grab samples: disturbed samples

Graben: downdropped block within the ground

Headscarp: steep slope at the upper end of a landslide

Hydraulic-cell deposition: controlled discharge of tailings into a small, confined area

Hydraulic fracturing: cracking of soil caused by water pressure

Inclinometer: a device for measuring horizontal subsurface movements

Internal erosion: subsurface transport of soil particles by water

Interparticle voids: open spaces between soil particles

Glaciofluvial: associated with or deposited in a glacial stream

Glaciolacustrine: associated with or deposited in a glacial lake

Lift lines: boundaries between successive layers of compacted fill

Loading: the imposition of stresses or weight; see applied load

Marker bed: a prominent layer of soil or rock used as a reference

Normally consolidated: a state or condition of soil that is experiencing pressures equal to or exceeding the pressures that it has experienced in the past

Oedometer test: a test for measuring compression of soil under load

Offtake: a drain or pipe that discharges flow

Orthophoto imagery: aerial photograph looking directly down on the terrain

Overconsolidation: a state or condition of soil produced by past stresses greater than those that currently exist

Overtopping: water flowing over the crest of a retaining dam or structure

Phreatic surface: water table

Piezometer: a device for measuring subsurface water pressure

Piping: see internal erosion

Pore pressure: the pressure of water that exists within the voids of a soil mass; see interparticle voids

Preconsolidation pressure: the maximum pressure experienced by the soil in its past

Pre-shearing: the process or condition of having been previously sheared

Relic erosional surface: ground surface remaining after previous erosion

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14 | Glossary of Technical Terms

Residual strength: strength of a soil after having been sheared; see also pre-shearing

Rills: small-scale gullies

Runup: the height of breaking waves on a slope

Sand tailings: coarser fraction of tailings

Scarp: a very steep, near-perpendicular slope at the head of a landslide; see also headscarp

Scour: erosion by surface water

Seepage flow: flow of subterranean water

Sentinel section: an instrumented section providing preliminary information; see also inclinometer, piezometer

Shear: a) the act or process of one surface sliding across another; b) a state of stress in the ground

Shell: a zone of material that supports the core of a dam

Slickenside: polished surface resulting from shearing

Slimes: finer fraction of tailings

Slump blocks: large masses subject to or transported by downslope movement

Stereopairs: aerial photographs producing a three-dimensional image

Stratigraphy: systematic or characteristic layering exhibited by soil or rock at a particular locale

Substrate: underlying soil

Survey monuments: fixed reference points for measuring relative movements

Tailings: finely ground rock particles remaining after extraction of valuable minerals

Tailings beach: see beach

Till: unsorted glacial sediment moved or deposited directly by the glacier

Tip resistance: the pressure measured at the tip of the cone during CPT testing

Toe: bottom of a slope

Triaxial test: type of test used here to determine drained and undrained strength

Undrained strength: the strength of a soil that incorporates the effect of pore pressures generated by shearing

Undrained strength ratio: the ratio of undrained strength to effective stress

Vane testing: an in situ test for measuring undrained strength of clays

Varving: thinly laminated layering

Water balance: an accounting of water inputs and outputs for determining water accumulation or deficit

Whaleback: a linear bulge or uplift

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