DAM SAFETY GUIDELINES 2007

(2013 Edition)

CDA ACB

Canadian Dam Association
Association Canadienne des Barrages
www.cda.ca

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TECHNICAL BULLETIN:

Application of Dam Safety Guidelines to Mining Dams

(2019 Edition)

CDA ACB

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"Technical Support for Grassroots Public Interest Groups"

May 24, 2016

US Army Corps of Engineers
Keith Gordon, Project Manager
PO Box 6898
JBER, Alaska, 99506-0898
POA.donlingoldeis@usace.army.mil

Re: Donlin draft EIS, public comments

Dear Keith:

The Center for Science in Public Participation provides technical advice to public interest groups, nongovernmental organizations, regulatory agencies, mining companies, and indigenous communities on the environmental impacts of mining. CSP2 specializes in hard rock mining, especially with those issues related to water quality impacts and reclamation bonding. This letter represents our comments regarding the Donlin draft EIS (DEIS).

Introduction

The Donlin mine, if approved, will be the largest mine in Alaska. Similar to other gold mines, the gold is bound with arsenic and antimony in the ore. Unique to Alaska, the gold is also bound with mercury sulfides, necessitating a process of heating ore under pressure to release the gold – and in doing so also liberate the mercury. Barrick, a 50% partner in Donlin Gold LLC, has experience in processing this type of ore and capturing mercury in Nevada – however, those mines were not adjacent to wetland habitat. Additionally, mine ownership frequently changes hands. This is important to consider in the operation of mercury-capture equipment and in maintaining a facility that will need to pump and treat water in perpetuity.

In addition to the mine footprint, risks spread across an almost unimaginable breadth of landscape – over 300 miles of pipeline corridor east-west from Cook Inlet across the Alaska Range, and 200 miles of river transport north-south through a wildlife refuge and along one of the most important subsistence rivers in Alaska.

In addition to chemical risks at the mine site, pipeline, and barge route, there are physical risks associated with the tailings dam and financial risks.

The scale of infrastructure and ore processing, and the unique character of the ore, require a thoughtful environmental analysis process. It would not be unreasonable for the process to take substantially longer than previous mine proposals in order to best analyze chemical, physical, and financial impacts and alternatives.

Key Findings

- There is not enough information to compare the impacts of Alternative 2 (proposed by the mine proponent) and Alternative 4 (Birch Tree Crossing – an alternative with a shorter barge transport route but longer road). In particular there is not enough information to compare the impacts on fish, wildlife, wetlands, and subsistence.

In order to build the trust fund to $73 million dollars at closure, Donlin would make annual contributions of approximately $2.3 million per year into the trust fund during Project construction and operations.

First, a 200-year time period for analysis of the net present value calculation is adequate only if the net interest rate on the money in the long-term trust fund is typically higher than most public institutions can earn because of risk-avoidance requirements. The interest rate assumed is not disclosed in Appendix A.

Second, to underwrite the trust fund, an annual $2.3 million contribution is proposed. However, if the mine were to go into bankruptcy after several years of operation, the trust fund would likely not be large enough to cover the now-perpetual costs of treating water that have been incurred by early mine operation. How large is this amount and is the public now liable for this difference? Why wasn't a financial assurance required to cover the difference until the mine contributions to the post-closure trust fund are large enough to cover the financial obligation?

These are several, but not nearly all, of the issues that can be easily discussed at this stage of the mine analysis, and there is no practical reason why they shouldn't be open to public discussion now.

- **Recommendation: Provide a detailed analysis of the financial assurance, including estimated operational costs, estimated closure and long-term costs, and interest rates.**

Spill Scenarios

Partial Tailings Dam Failure

The tailings dam failure modeling scenario chosen for the DEIS only assumes a spill of 2.6 million cubic yards of tailings (2 million m^3) (DEIS 3.24.2.5.9). The capacity of the tailings storage facility is 568 million metric tonnes, which translates into approximately 355 million cubic yards.[1] Using this conversion factor, the 2.6 million cubic yards represents 0.73% release of tailings.

In a typical catastrophic rupture of a tailings impoundment, approximately 20% of the tailings are released from the impoundment.[2] The mitigation of dam design does not remove from the proponent the need to analyze the environmental impacts should there be a tailings facility accident. First the impact needs to be assessed, then the mitigation needs to be proposed. There can be no assurance that the original dam design will be followed as new lifts are added over the years, nor that the current water management plans to reduce water volume in the TSF will be followed throughout mine life and throughout any potential mine expansion. For example, plans currently call for the area under the dam foundation to be excavated to bedrock – but there can be no guarantee that this will be followed through when lifts are added. Therefore, for EIS analyses, a failure of the impoundment at maximum capacity should be assumed. There is no justification given for the assumption of a partial tailings dam failure.

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[1] Assume 1.6 metric tonnes per cubic meter (~100 pounds per cubic foot) for tailings at closure.

[2] Floods from tailings dam failures, M. Rico, G. Benito, A. D´ıez-Herrero, Journal of Hazardous Materials, 2008, Figure 4, p. 83.

A more substantial failure than the modeled 2.6 million cubic yards has implications for exceptionally high environmental damage: scour, erosion, deposition of tailings along a long stretch of Crooked Creek with resulting long term water quality degradation and habitat loss, potential blockage to tributaries to Crooked Creek (Getmuna, Bell, etc.) that have high fish populations, etc. Such an event would cause much greater impact to fish and aquatic resources than the current assessment of loss to "relatively few spawning redds" (DEIS p 3.24-156).

A larger spill also has implications for human risk. The Emergency Response section for a tailings dam failure focuses entirely on earthmoving equipment (e.g.):

> *This area is not currently being mined; therefore, no plan or capacity for response is presently available for this area. New plans and response capacities would be required for the proposed project, which would be detailed in the EAP required under ADNR dam safety permitting (Section 3.24.1.5). These would involve the extensive use of excavation and earthmoving equipment from the mine itself.* (DEIS p 3.24-11)

Modeling a 0.73% release estimates that released water would reach Crooked Creek within a day, and raise the creek by one foot (Table 3.24-10); a greater release could reach the village much sooner and raise the creek much higher. To understand the times and depths, and therefore appropriate emergency actions for human health and safety, would require modeling. Should there be greater risk than is currently estimated, the Emergency Action Plan (EAP), which is not available for review, should require a communication and alert system to be in place that is sufficient to warn people in Crooked Creek and boaters on the Kuskokwim near Crooked Creek of the potential need to move out of the area.

DSTF Operating Pond Spill

Although a Dry Stack Tailings Facility (DSTF) is provided as an alternative to the proposed mine plan (indeed, it is the ONLY mine plan alternative), there is no assessment of the potential impact of a failure of the DSTF operating pond. Although one section of the DEIS says

> "*Under Alternative 5A, the volumes of water and slurry stored behind the tailings main dam during the operational period would be lower relative to Alternative 2 (DEIS p 3.7-194)*",

another section says the DSTF operating pond would be approximately 131,500 acre-feet (42.8 billion gallons) (DEIS Figure 2.3-43), significantly **larger** than the TSF pond of 24,000 acre-feet (7.8 billion gallons) (Table 3.7-37 footnotes 5 and 6). If the sentence in italics above refers to water entrained in the tailings, not water in the operating pond, which would be behind a dam, this should be clarified.

Presumably the water quality would be similar to the TSF pond, although that has not been modeled (DEIS p 3.7-192).

A discussion of the relative risks of a potential failure of the TSF dam "water only release" to the DSTF pond would better allow reviewers to assess the potential risks. Is the DSTF dam built all at once, or in stages like the TSF dam? What are the potential failure modes for the DSTF operating pond? Just as the TSF spill scenario needs to be redone with a realistic volume failure, certainly something much higher

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CSP²

MEMORANDUM

Date: May 5, 2022

To: Earthjustice

From: David M. Chambers

Re: Response to BGC Engineering – Temperature of Treated Effluent

I have 40 years of experience in mineral exploration and development – 15 years of technical and management experience in the mineral exploration industry, and for the past 30+ years I have served as an advisor on the environmental effects of mining projects both nationally and internationally. I have a Professional Engineering Degree in physics from the Colorado School of Mines, a Master of Science Degree in geophysics from the University of California at Berkeley, and am a registered professional geophysicist in California (# GP 972). I received my Ph.D. in environmental planning from Berkeley. My recent research focuses on tailings dam failures, and the intersection of science and technology with public policy and natural resource management.

I have been asked by Earthjustice to comment on the applicability of some of the water treatment procedures proposed by BGC to mitigate the increases in water temperature that typically accompany mining and ore processing at the Donlin Mine.

In its project memorandum of April 14, 2022, BGC Engineering asserts that "*Donlin Gold can control the temperature of the treated effluent by managing the quantity (i.e., flow) of the water sources that are fed to the WTP* [Water Treatment Plant]." BGC Engineering suggests measures such as using groundwater rather than surface water sources, cooling treated effluent, releasing impounded water from the Snow Gulch Dam, adding groundwater from new wells outside the mine area, and assessing options to reduce the loss of water from Crooked Creek's hyporheic zone due to the dewatering wells.

Treating water, and consistently meeting compliance limits, is always a challenge. There are always excursions in the output from a water treatment plant, and the goal is insure there is enough margin between the actual output level and the compliance limit so that a violation does not occur.

Donlin will be no exception. Construction and operation of the proposed mine would entail: pumping enough groundwater to dewater a mine pit over 1800 feet deep and covering some two square miles; destroying all of American Creek and most of Anaconda Creek through excavation, filling, and diversions; creating a freshwater reservoir in Snow Gulch; creating two contact water dams in the waste rock pile to collect highly contaminated runoff from about three billion tons of waste rock; operating a plant to process 59,000 tons/day of ore that will discharge 17,000 gallons/minute of tailings slurry (processed ore residuals mixed with approximately an equal volume of contaminated wastewater) into a 3.7-square-mile tailings storage facility; pumping 14,000 gallons/minute of water from the tailings storage back to the processing plant for re-use in the ore processing; and collecting contaminated seepage from the tailings storage facility through a seepage recovery system. (FEIS 2018).

The water from these various sources will be directed either to the ore processing plant for use in processing the ore or to the water treatment plant for discharge to Crooked Creek. The ore processing plant requires an enormous amount of water and is designed to use water from the Snow Gulch reservoir, the two contact water dams, the pit dewatering wells, the tailings storage facility, the seepage recovery

system, and the water treatment plant. The water treatment plant would treat water collected from the pit dewatering wells, the contact water dams, the tailings storage facility, and the seepage recovery system.

During normal operation about half of the water going through the water treatment plant will come from the dewatering wells. It is theoretically possible to increase this to approximately 80% of the treatment volume. (FEIS 2018). Because the well dewatering water is the lowest temperature water of all the sources for the water treatment plant, it is possible as BGC Engineering suggests, to increase the amount of well water going to the treatment plant to lower the temperature of the water treatment plant water. However, the implications associated with diverting more well dewatering water to the treatment plant are not just a simple temperature balance calculation.

First, the heat in the water must go somewhere. If it is not being discharged from the treatment plant, then it must go back into the mine water system, probably to the processing plant. This will gradually drive the water temperature of the remaining water higher, building up heat which must be accounted for the next time this water is headed for the treatment plant. This will make temperature control more difficult at exactly the time when temperature control is most critical.

Second, the dewatering well water has relatively less contamination than water from the TSF, seepage collection system, and other mine facility collection points (FEIS 2018). It should also be noted that temperature is not among the factors predicted in the many water quality prediction tables in the Final EIS (e.g. dewatering wells, TSF, seepage return system, etc. water), which do contain predictions for metals and other constituents. Using more dewatering well water to lower the temperature of the water treatment plant discharge will cycle the contaminants normally removed in the treatment plant back through the process facility. This could impact pH control, as well as lead to metal ion interference, in the processing plant. While this is unlikely to cause severe processing problems, it could affect the efficiency of the processing, and complicate control of the milling circuit. Maximizing gold recovery is the main objective of the processing plant, and the operation of everything else on the minesite will be focused to maximize gold recovery in the mill, including the water treatment plant. The additional gold recovery will easily pay the fines for a few temperature excursions at the water treatment plant.

Historically at most mines, there hasn't been much emphasis on temperature control when managing water treatment plant operation. The emphasis is typically on the level of metals in the discharge. I know of no examples of a mine where water has been redirected for stream temperature control, as BGC Engineering proposes. Nor does it appear that Donlin has conducted any studies to evaluate the feasibility of this proposal. BGC Engineering's mitigation proposals are all theoretical, and moving something from theory, to lab demonstrations, then into practical field application has historically been problematic for the mining industry.

Sincerely;

David M. Chambers, Ph.D., P.Geop

References

BGC 2022. Review of BGC's Crooked Creek Stream Temperature Analysis – Response, BGC Engineering, April 14, 2022

FEIS 2018. Donlin Gold Project Final Environmental Impact Statement, US Army Corps of Engineers, April 2018

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Richard L. Darden
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JBER, AK 99506-0898

January 25, 2017

Subject: Follow up on Donlin Technical Working Group meetings, December 2016

Dear Mr. Darden;

The Chuathbaluk Traditional Council has read and approved the attached comments written by Kendra Zamzow, and David Chambers, on behalf of Chuathbaluk as a follow up to the Donlin Technical Working Group meetings in December 2016. We anticipate that these will be reviewed and incorporated into the Alternatives as appropriate.

If you have any questions or concerns regarding our request and data gap concerns, please feel free to contact the Chuathbaluk Traditional Council at (907) 467-4313 or via email at ctc.patriciayaska@gmail.com

Sincerely,

Patricia Yaska
Brownfield Tribal Response Program Coordinator

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"Technical Support for Grassroots Public Interest Groups"

MEMORANDUM Date: December 23, 2016

From: David M. Chambers

To: Corps/AECOM

Re: Donlin Technical Meeting on Mine Water and Tailings Storage Facility

During the meeting on Tuesday, December 13, 2016, there was a short discussion on the potential use of blanket or other drain-designs to drain the tailings in the impoundment, as per the recommendations of the Mt Polley Expert Panel.

During that discussion a comment was made by either the Army Corps Subject Matter Expert, or a consultant (I am not able to identify the individual), that 'tailings always remain saturated.' The expert was then asked about tailings impoundments in arid areas like Arizona and New Mexico, and his response was that those impoundments are dewatered by 'suction created by surface evaporation.'

There is quite a bit of literature detailing the success of drains for controlling the phreatic level in tailings dams using toe drains of several designs, and of the success of dewatering the entire tailings mass itself – primarily for uranium tailings.

A search for references to evaporative dewatering of tailings impoundments did not turn up any definitive articles on dewatering an entire impoundment, only reference to dewatering rates due to evaporation in the upper meter of tailings, and references to using thin-layer deposition or the addition of flocculants to increase evaporation. None of these techniques are documented as being used in arid areas to dewater tailings impoundments. There is documentation of extensive sulfate plumes in groundwater downgradient of copper tailings impoundments in arid areas, proof that interstitial water is entering (i.e. draining) into groundwater in significant amounts.

Existing literature supports the concept that tailings can be drained by drain layers, especially since this concept is essential to controlling the phreatic zone for tailings dams.

The Army Corps should ask for references that support the statement that 'tailings always remain saturated' as purported in the December 13 discussion, since the failure to consider draining the tailings post-closure depends on this assumption/assertion.

I would be happy to have a discussion with the subject matter expert/consultant about the recommendations of the Mt Polley Panel, and their potential for implementation at the Donlin tailings impoundment.

Sincerely;

David M Chambers, Ph.D., P. Geop.

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December 18, 2016

Chuathbaluk Tribal Administration
#1 Teen Center Trail
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Re: Follow up on Donlin Technical Working Group meetings, December 2016

Dear Patricia and Tracy:

I would like to recap here the key issues that appear to remain unresolved after the technical working group (TWG) meetings of December 12-16. I think it would be useful if you could combine these comments with comments of your own from the Barging TWGs and send to the Army Corps of Engineers as a follow up to the meetings. It might be helpful if our thoughts were laid out as

- Unresolved concerns that require additional field work or modeling. For these, we can request RFAIs (official "request for additional information")
- Unresolved concerns that require clarification in the next draft (or final) EIS

My key concerns revolve around

- The toxicity of pit lake surface water to wildlife, especially migratory waterfowl. This is affected by the volume of contaminated water from the WRF, the volume of clean surface and groundwater, and how they mix.
- The potential for pit lake water at depth to move out of the pit and transport contaminants.

Following is a list of RFAIs and requests for "clarification and context", followed by a more detailed discussion.

Please do share any of my memos with the traditional council. As you know, my goal is to ensure that all risks have been adequately identified and mitigated to the extent possible, and to ensure the Chuathbaluk Traditional Council has good information on which to base any future decisions or input they would like to provide in the process.

Regards,

Kendra Zamzow

Kendra Zamzow, PhD

RFAIs

This is a list of RFAIs we are requesting. The context for them follows in the bulk of the letter.

Waste rock covers

RFAI: How would placing an impermeable cap over PAG cells compromise the integrity of the WRF? How would placing an impermeable cap over the entire WRF compromise it?

RFAI: If an impermeable cap was placed on PAG cells in the WRF or on the entire WRF, would pit lake overturn occur sooner? Would pit lake water be "less bad" than with the designed colluvium cap? How would this affect water treatment plant design or capacity? Could it lead to decommissioning of the water treatment plant?

RFAI: In an early closure scenario, could an impermeable cap on PAG cells or the entire WRF eventually eliminate the WRF seepage into the pit lake allow the pit lake water to "clean up" enough (through clean freshwater inputs) that the water treatment plant could be closed? If so, provide an estimate of the number of years until the plant could be closed if the mine ended operations after 5 years, 10 years, 15 years. Please compare the cost of an impermeable liner over the full WRF to the cost of water treatment over these time periods.

Pit lake ecotoxicity

RFAI: Determine the toxicity of overturn pit lake water to wildlife, including waterfowl.

Groundwater hydrology

RFAI: Provide information on the feasibility of utilizing deep exploratory holes to determine the existence or non-existence of regional groundwater flow.

RFAI: Provide suggestions on other methods of collecting solid data that would inform the question of and models of regional groundwater flow.

Water treatment

RFAI: Please provide case studies of mines using xeolite to remove arsenic at similar scales.

RFAI: Provide water quality for the DSTF operating pond, and apply that to a "water only" spill release scenario for Alternative 5A.

RFAI: Please explain what the difficulties are, what technology exists, and limitations for treating DSTF operating pond and pit lake water, such as the volume that can be treated and discharged and placement of waste that cannot be discharged.

Mercury

RFAI: Please ensure soil and sediment samples utilized to determine mercury methylation are proportionally representative of the landscape to ensure there has not been any sampling bias.

RFAI: Perform laboratory tests with sediment, applying future wastewater effluent simulations under a range of temperatures and dissolved organic carbon concentrations.

RFAI: Perform the same tests listed above with the simulated tailings.

RFAI: Determine the Hg(II) content of porewater in sediment.

RFAI: Adjust the fugitive gas emissions model to account for the percent of time with high solar radiation.

Clarification and context

These are items that we do not believe need an RFAI, but which deserve clarification or better description of context in the FEIS.

Clarification: Should a range of hydraulic conductivities be applied to determine WRF seepage rates and volume?

Context: If regional groundwater flow is identified, discussions of pit lake stratification, pit lake ecotoxicology, and the water treatment plant will need to be updated.

Context: If it is determined that the pit will not maintain hydrologic conductivity, this may require a new management plan for waste rock intended for backfill.

Context: If bedrock conductivity is higher than expected, will this have implications for desiccation of wetlands?

Context: In the event that high flow is encountered at depth while mining, what would an extra 500 m^3/hr or 1,000 m^3/hr look like when added to the contact water pond or other storage areas?
Context: Post-closure scenarios for Alternatives 2 and 5A should include cost and design for waste from the water treatment plant that cannot be discharged.

Introduction to concerns

Three features will remain on the landscape forever: the tailings facility (with the permanent risk of tailings liquefaction if the dam fails at any time in the future), the waste rock facility (which will leach arsenic, selenium, and other contaminants forever, if rain and snow are allowed to infiltrate), and the pit lake (which will receive the contaminated waste rock seepage).

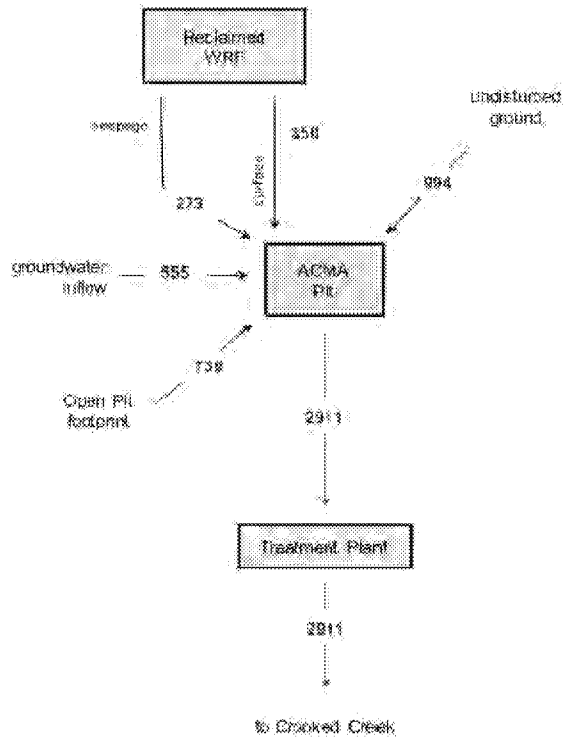


Figure 3.5-28 of DEIS. Flows (blue numbers) are in gallons per minute (gpm) expected in Years 52-200 of closure. Red arrows denote pumping routes; however, the route for "seepage" from the WRF will be a mix of gravity flow and pumping and perhaps should be marked with a red arrow.

While there is an alternative to assess for tailings options, there is no alternative that eliminates the pit lake. It is a certainty. The only permanent inputs into the pit lake are the waste rock facility (WRF) seepage and clean runoff water/precipitation (Figure 3.6-9). The tailings facility (TSF) is expected to stop contributing after the 30-60 year draindown period.[1] Groundwater may move into the pit in quantity (Fig. 3.5-28), but there is currently a lack of data supporting the conceptual model describing over 500 gpm groundwater flowing into the pit and no groundwater flowing out.

The environmental risks that require analysis under NEPA are

- The toxicity of pit lake surface water to wildlife, especially migratory waterfowl. This is affected by the volume of contaminated water from the WRF, the volume of clean surface and groundwater, and how they mix.
- The potential for pit lake water at depth to move out of the pit and transport contaminants.

Pit lake water quality

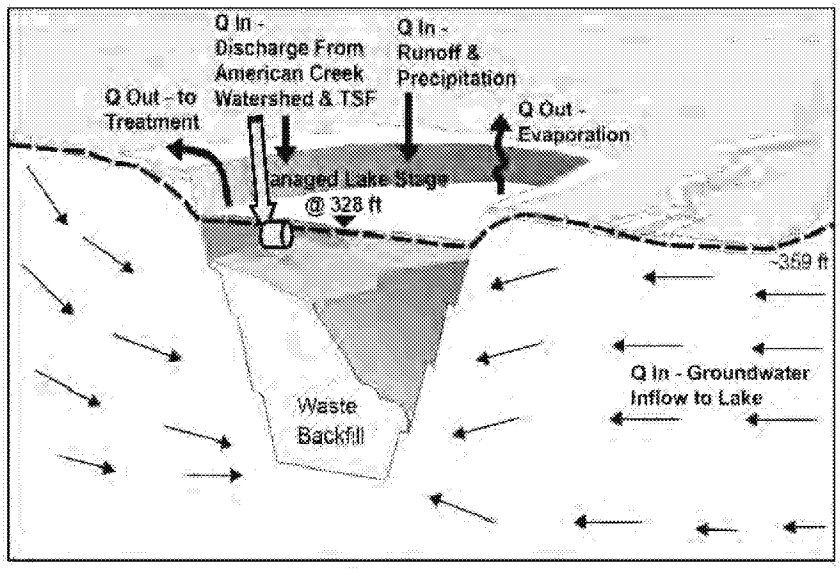
Waste rock seepage – very high in total dissolved solids, arsenic, and other contaminants, will enter a rock drain under the WRF and flow towards the pit. At the pit rim, it will be pumped to the bottom of the pit; presumably it will be pumped to the depth immediately above the waste rock backfill, rather than 1,800 feet down to the actual pit bottom. Freshwater inputs will float on this saline seepage water; this

[1] There is expected to be about 400 gpm clean groundwater flow (Fig. 3.5-28 and p 3.6-38, DEIS) to dilute the 18 gpm allowed to seep through the TSF liner, and therefore any water that infiltrates and percolates through the TSF cover is not expected to be poor quality.

stratification is a key part of the mine "design for closure" and a key argument to why the WRF should not be lined or provided with an impermeable cover.

This "less bad" surface water is the water quality utilized to determine if the pit lake water would be toxic to wildlife, and to design the water treatment plant.

This is insufficient. The bad water on the bottom of the pit lake *will* eventually mix throughout the lake. The effect of this mixture on wildlife, and inputs that contribute to mixed lake water quality need to be assessed. Cooperating agencies should not trivialize this issue simply because it may not occur for 100-200 years after closure. While the mining company will be long gone, the people and wildlife will remain and fewer mitigation options may be available.



After Pit Lake is Full

Adapted from Fig. 3.6-9 DEIS. The figure above shows the water inflows to the pit after closure. Added is a possible pumping discharge route for waste rock seepage (color). The tailings facility (TSF) is not expected to contribute water to the pit lake after the lake is full, and should be removed from the image.

WRF cover and pit lake water quality

The type of cover on the WRF influences the volume of bad water seepage that enters the pit. It also influences the year at which the pit lake will turn over (mixing bad saline bottom water with upper freshwater). A less permeable cover will lead to less bad water to the pit and a faster time to turnover.

The cover for the waste rock facility is designed as 3 feet of "low conductivity" (10^{-7} m/s) colluvium topped by vegetation. This will allow precipitation (rain, snowmelt) to enter into the waste rock. Water will be entrained in the waste rock facility before the cover is placed, and will continue to enter the facility, at a lower rate, after the cover is placed. Entrained and infiltrating water will percolate through the WRF into the underdrain and on to the pit. The permeable colluvium cap on the WRF ensures that water will percolate through the WRF in perpetuity and will seep into the pit lake in perpetuity.

Colluvium, which is uniformly given a hydraulic conductivity of 10^{-7} m/s in the DEIS, plays heavily into the WRF design. It was used to describe the conductivity of the 5-10 m of natural material under the WRF, the material that "encapsulates" PAG cells within the WRF, and the cover that will be placed on the WRF.

- Request for clarification: Even at depth, bedrock has a range of 10^{-6} m/s to 10^{-9} m/s. Shouldn't this range be applied to hydrology related to WRF covers? This could inform the seepage volume from the WRF, pit lake water quality, and the time to turnover.

PAG cells are expected to provide the worst water quality in the seepage, but make up a relatively small part of the volume of the total WRF. Most waste rock will by NAG, some of which will leach arsenic and some of which will not. Placing an impermeable cap on the PAG cells within the WRF or over the full WRF would limit oxygen moving into the facility (which would reduce reactions converting PAG rock sulfides to sulfuric acid/acid drainage) and reduce or eliminate water entering the PAG cells or WRF. We are told this would compromise the strength of the facility.

- RFAI: How would placing an impermeable cap over PAG cells compromise the integrity of the WRF?

- RFAI: How would placing an impermeable cap over the entire WRF compromise it? Or is the decision to go with an impermeable cap one of budget rather than geophysics?

The type of cap that covers the PAG cells and WRF affects pit lake water chemistry and potentially the point at which the water treatment plant needs to be redesigned to treat very bad water or the point at which a water treatment plant could be decommissioned entirely. It is critical to understand these points in order to balance long term cost and risk (water treatment) and short term cost (impermeable caps).

There is no reason to expect WRF seepage water chemistry to improve over time. When water levels flux with draindown and precipitation inputs, they create "wetting/drying" cycles that are particularly effective in causing metal leaching and mobilization.

- Add to FEIS: There are implications for the cost and design of a water treatment plant that is able to fully treat overturn water. If this requires reverse osmosis units, these themselves have solid and brine waste products. Post closure, the brine cannot be sent through the processing plant. Disposal of these waste products needs to be part of the full post-closure scenarios considered for Alternative 2 and Alternative 5A.

- RFAI: If an impermeable cap was placed on PAG cells,
  - Would overturn occur sooner? Would the chemistry of pit lake overturn water be "less bad" without PAG cell seepage? Would this make it easier for a water plant to treat?
  - Could a water treatment plant be fully decommissioned, and if so, at approximately what point in time (given inputs from fresh water, NAG WRF seepage, pit wall sloughing)?

- RFAI: If an impermeable cap was placed on the WRF,
  - Would overturn occur sooner (due to less TDS water entering the pit)? What are the implications for water treatment?
  - Is there a point at which the water treatment plant to be decommissioned entirely?

WRF cover and ecotoxicity of pit lake water

The models for potential toxicity of pit lake water only considered the scenario in which the fresher water was at the pit lake surface and the worst water was isolated below. We know that under the current design the bad water *will* eventually mix throughout the pit lake. The lack of an assessment of ecotoxicity after pit lake overturn is a serious data gap. The pit lake water at the point of overturn may not be the same as the Year 99 "complete mixing" scenario, as the pit lake may have a greater percentage of WRF seepage and less freshwater, resulting in potentially worse water than the Year 99 mix estimates.

- RFAI: Determine the toxicity of overturned pit lake water to waterfowl. For example, ecotoxicology was determined using arsenic at 114 ug/L (Lorax 2015 Table 3-1), but in an overturn scenario arsenic in pit lake surface water will be around 2.4 mg/L (Lori Filipek comment during TWG meeting). Discuss the potential ecological, technical, and cost impacts of mitigation options (e.g. drawing water from the bottom of the pit for treatment, etc.)

- For mitigation: If an impermeable cap was placed on the PAG cells, how would this change ecotoxicity?

- For mitigation: If an impermeable cap were placed on the WRF, how would this change ecotoxicity?

Early closure – cost of caps versus water treatment

We also need to keep in mind that water treatment will need to go forward, potentially in perpetuity, even if the mine only operates for a few years. Early closure, if permanent, is a particularly concerning scenario in that the water treatment plant will need to operate, possibly in perpetuity, but the mining company may have only paid into the fund for operations for a few years.

An early closure mitigation should consider an impermeable cap on any portion of PAG cells that have not already been covered by colluvium and non-acid generating (NAG) rock, and an impermeable cap on the full WRF. This would reduce the number of years that water flows out of the WRF into the pit lake.

- RFAI: In an early closure scenario, would eventually eliminating the WRF seepage into the pit lake allow the pit lake water to "clean up" enough (through clean freshwater inputs) that the water treatment plant could be closed? If so, provide an estimate of the number of years until the plant could be closed if the mine ended operations after 5 years, 10 years, 15 years. Please compare the cost of an impermeable liner over the full WRF to the cost of water treatment over these time periods.

A less expensive option to an impermeable liner over the full WRF would be to place the planned colluvium liner as a WRF cap but encapsulate the PAG cells in impermeable material.

- RFAI: In an early closure scenario, would eliminating seepage from the PAG cells alone be enough to allow the pit lake water to "clean up" eventually, or would arsenic leaching from NAG rocks continue to be so high that, along with contributions from the pit wall sloughing, freshwater inputs (clean runoff, precipitation, snowmelt) would not be enough to dilute the poor water and

the pit lake would need water treatment in perpetuity? If decommissioning the water treatment plant is possible, provide an estimate of the number of years until the plant could be closed if the mine ended operations after 5 years, 10 years, 15 years. Please compare the cost of an impermeable liner over PAG cells to the cost of water treatment over these time periods.

Hydrology and the pit lake

There remain concerns as to whether a regional groundwater flow exists that could intersect the pit and whether bedrock groundwater will flow towards the pit at all depths after the pit has filled. These have implications for pit lake de-stratification, water quality, and transport of pit water contamination.

Does regional groundwater flow exist that could intercept the pit?
The concept that groundwater will flow towards the pit at closure, even when the pit is filled with water (leaving 33 feet of freeboard between the lake and the pit rim) is based on data collected almost entirely in the upper 400 feet of the geology. The model was developed without any hydrologic data from depth.

First, deep wells should have been drilled to collect this data. At the Pebble exploration site, over 20 wells between 1,000 and 5,700 feet deep were drilled for monitoring and study purposes.[2]

Is it possible to determine the presence or absence of regional flow without drilling new, very deep wells? There must be exploratory drill holes down to the suggested 1,800' depth of the pit, and probably somewhat deeper than that. Drill logs would show the type of geologic material at depth and potentially whether groundwater was encountered. These holes, if closed, would be expected to have cement in the alluvial material, to prevent a connection from groundwater to the surface; however, nearly all the depth (in bedrock) is probably not cemented. It could be relatively inexpensive to drill through the upper cement and conduct hydrologic testing.

- RFAI: Provide information on the feasibility of utilizing deep exploratory holes to determine the existence or non-existence of regional groundwater flow.

- RFAI: Provide suggestions on other methods of collecting solid data that would inform the question of and models of regional groundwater flow.

Regional groundwater flow as a factor in pit lake water
If groundwater does intersect and move in and out of the pit, this has serious implications for the assumption that pit lake water will remain stratified for at least 100 years. The assumption is based on models that feed high TDS waste rock facility drainage into the pit; if this high TDS water is intersected by fresh groundwater, stratification will be affected, with implications for the design of the wastewater treatment plant and the disposal of waste (for example, from the reverse osmosis waste). Additional groundwater inputs could also provide more dilution.

The following provide context to emphasize the importance of understanding groundwater hydrology.

---

[2] DNR 2016 PLP Borehole Status spreadsheet

- If regional groundwater flow is identified, the pit lake stratification modeling will need to be adjusted.

- If pit lake stratification modeling is adjusted, a complementary adjustment of pit lake ecotoxicology, particularly for waterfowl, needs to be conducted.

- If regional groundwater flow is identified, a discussion of the water treatment plant will need to be updated. This should be done for Alternative 2 (TSF option) and Alternative 5A (Dry Stack Tailings Facility option). It will need to discuss design features such as the type and volume of water to be treated, and disposal of water treatment waste that cannot be discharged to creeks.

Pit lake water quality mitigation
Whether or not there is regional flow, there is possibility that water will not remain in the pit at all depths. Determining the depth at which flow leaves the pit, if it leaves, and the freeboard required to maintain a hydrologic gradient towards the pit, may be important in understanding where backfill can be placed.

WRF seepage will contribute poor water, as discussed above, but backfill waste rock could contribute significantly to poor water quality if a water cover is not maintained over it.

Waste rock from the ACMA pit will go to the WRF, except PAG 7 material will be stockpiled and placed as backfill in the pit in Year 22. All waste rock from the Lewis pit will be backfilled into the ACMA pit. Backfill must be covered with a water cover if it contains PAG material. If the pit lake needs to be kept at, say 500 feet below the rim of the pit, instead of the currently planned 33 feet of freeboard, in order to maintain hydrologic containment, then potentially less Lewis or PAG 7 ACMA waste rock will be able to be placed in the pit.

This is a situation in which there is time to develop an adaptive management plan. Dewatering wells will provide the necessary hydrologic data during mining of the ACMA pit, in time to determine whether PAG 7 should be encapsulated in the WRF with the other PAG and/or whether Lewis pit waste rock needs to be stored on the surface.

I offer this not as an RFAI, but again as a point to illustrate how important it is to determine hydrologic containment at the pit. If a significant amount of waste rock cannot be backfilled into the pit, this will add quite a bit of expense at the latter end of mine life.

Rock conductivity and wetlands
If conductivity is higher than expected, more dewatering would need to occur. Is it possible that this could cause more wetlands to dry up than currently expected? If so, are there implications for mitigation?

Water treatment

Treatment during operations
The water treatment plant is designed for a maximum of 1,500 m^3/hr inflow. It is assumed that if rock conductivity, which drives the volume of pit dewatering water, is higher than anticipated, operators will "know fairly quickly" and be able to adapt the water treatment plant. However, this assumes that conductivity declines with depth. This underscores the importance of Sue Braumiller's comments on understanding the conductivity at depth before operations begin.

As noted in the meeting, the volume you can pump is one ceiling, the volume you can store is another.

- For impact analysis: In the event that high flow is encountered at depth, what does an extra 500 m^3/hr or 1,000 m^3/hr look like when added to the contact water pond or other storage areas? For how many days, weeks, months can this occur before there is no more storage, under high and low precipitation scenarios?

Per the water treatment plant design of using zeolites (synthetic greensand) as a key part of the process to remove arsenic and manganese,

- RFAI: Please provide case studies of mines that use the technology for these elements at similar scales. This is necessary to ensure that current technology is being applied.

Treatment post closure
My impression is that the Dry Stack Tailings Facility operating pond will have TDS high enough that it will be difficult for it to be treated at the water treatment plant, and instead will be stored until the end of mine life and drained into the pit. However, at some point when the pit lake overturns, there will also be high TDS. This suggests that pit lake overturn water could be difficult to treat.

- RFAI: Provide water quality for the DSTF operating pond, and apply that to a "water only" spill release scenario for Alternative 5A. This is necessary to compare Alternatives 2 and 5A.

- RFAI: Please explain what the difficulties are, what technology exists, and limitations for treating DSTF operating pond and pit lake water, such as the volume that can be treated and discharged and placement of waste that cannot be discharged.

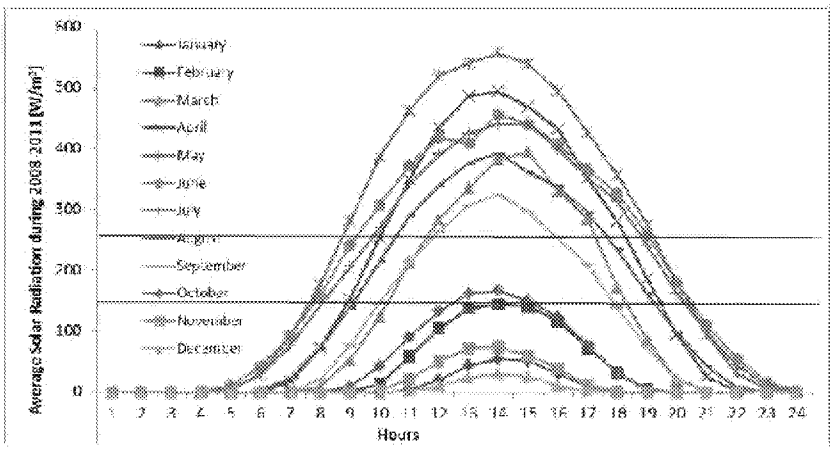
Mercury

Assumptions on solar radiation
The majority of mercury in the gas phase will be released from the processing plant, but the second highest source will be the tailings facility, particularly in the later stages when the facility is large.

> *"....gaseous Hg emissions from four fugitive source categories at Donlin (Tailings Storage Facility (TSF), waste rock facility, ore stockpile and open pit) were estimated using methods similar to the Eckley studies but accounting for Donlin-specific data where feasible to account for* ***differences in solar radiation****, air temperature and geochemistry/Hg content between Donlin and the Nevada mines."* (Environ 2014c) (emphasis added)

Solar radiation on site is expected to be low 72% of the time, middle range 8% of the time, and high 20% of the time (Environ 2014c, Figure 3-5 and pgs 20-21) (bars added to separate low, medium, and high solar radiation levels).

Although the Donlin area receives a range of solar radiation, only "low" and "middle" radiation were used to calculate fugitive gas emissions.



Adapted from Fig. 3-5, DEIS. The figure shows the average solar radiation by month at the Donlin Camp site. The two red lines have been added to indicate the cut off for the designations of "low" and "middle" solar radiation. Data from above the second line was not included in equations for calculating fugitive mercury gas emissions from mine site facilities.

> *"We estimated beach Hg fluxes by applying the linear regressions equations developed for the* ***low and middle solar regimes*** *to the Donlin solids Hg concentration as shown in Table 3-4. The equations developed are shown below, where f is the log(Hg flux) and c is log(Hg concentration)."* (Environ 2014c) (emphasis added)

Low Solar: $f = 0.604\ c + 3.238$ Mid Solar: $f = 0.542\ c + 4.36$

Table 3-4. Tailings beach mercury flux.

Beach Hg concentration (µg/g)	Log (Beach Hg concentration)	Log (Hg Flux in Low Solar Range)	Hg Flux in Low Solar Range (ng/m²-day)	Log (Hg Flux in Middle Solar Range)	Hg Flux in Middle Solar Range (ng/m²-day)
0.7	-0.15	3.34	1,396	4.28	18,902

* Values rounded off

The difference between the fugitive gas emissions that could be released under low and high radiation for the tailings facility are striking (Environ 2014c, Table 3-4 above).

- RFAI: Adjust the fugitive gas emissions model to account for the percent of time with high solar radiation.

Table 3-5. Monthly tailings beach Hg fluxes

Month	Daily Mean Solar Radiation at American Ridge (W/m²)	Solar Radiation Range	Tailings Beach Hg Flux (ng/m²-day)
January	8.9	Low	0
February	34.4	Low	0
March	111.8	Low	0
April	170.8	Medium	18,902
May	227.1	Medium	18,902
June	194.7	Medium	18,902
July	182.8	Medium	18,902
August	141.1	Medium	18,902
September	97.8	Low	1,396
October	41.1	Low	1,396
November	13.8	Low	0
December	4.3	Low	0

Potential for methylation

There remain a number of concerns about the degree to which mercury will impact the environment. I disagree that it is a "conservative assumption" to assume 100% of 1% of total mercury will methylate. Specifically

- Data does not support an assumption that the area will not support sulfate reducing bacteria (SRBs). The conclusion from the assumption is that only 1% of the total mercury will methylate.

- The Arcadis 2014 study did not appear to collect representative soil samples; there is a lack of samples from high sulfate areas (which would be more likely to support SRBs). This leads to potentially underestimating methylation rates.

- There is no consideration for how methylation rates could reasonably change in the future, due to exposure to fresh mercury particulates which methylate more easily than legacy cinnabar, or inputs that could stimulate SRB populations (additional sulfate release from the water treatment plant, lowered creek flow that could create anoxic and low flow areas, increased permafrost thaw that could provide fresh dissolved organic carbon).

If indeed more total mercury methylates, the impact analysis is inaccurate and further mitigations, such as reducing sulfate release from the wastewater treatment plant, may need to be discussed.

I would suggest collection of additional data that would provide better information for assessing impacts.

- RFAI: Please ensure soil and sediment samples utilized to determine mercury methylation are proportionally representative of the landscape to ensure there has not been any sampling bias. Soil should be collected from sites that are mineralized and unmineralized, high in sulfate and low in sulfate, high in organic material and low in organic material in proportions representative of the landscape. Sediment should be collected proportionally from areas of high and low oxygen (anoxic low flow/pool areas and higher flow oxygenated riffles, anoxic mucky bottoms and oxygenated gravel/cobble bottoms), as well as areas that are mineralized and unmineralized, high and low in sulfate, and high and low in organic material.

- RFAI: Perform laboratory tests with sediment, applying future wastewater effluent simulations under a range of temperatures and dissolved organic carbon concentrations. This will provide information on methylation potential. For example, mercury can be methylated by sulfate reducers, iron reducers, or methanogens all of which will be stimulated or repressed under different conditions.

- RFAI: Perform the same tests listed above with the simulated tailings that have been made for humidity cell and other tests. This will provide information on how dust consisting of tailings could act on the landscape.

RFAI: Determine the Hg(II) content of porewater in sediment. This can be done through sequential extraction or through a tin reduction method developed by USGS, Menlo Park. Brooks Rand Laboratories should be familiar with the process.

Adapting to Climate Change in the Middle Kuskokwim:

A Collaborative Effort by the Communities of Lower Kalskag, Upper Kalskag, Aniak, Chuathbaluk, Napaimute, Crooked Creek, Georgetown, Red Devil, Sleetmute, and Stony River

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Climate projection maps created by the Alaska Climate Adaptation Science Center

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Boats on Stony River.
Photo by Elizabeth Willis

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Introduction

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In 2018, the Georgetown Tribal Council received a Bureau of Indian Affairs Tribal Resiliency Program Grant to create a climate vulnerability assessment and adaptation plan for the Middle Kuskokwim region. The Alaska Native Tribal Health Consortium (ANTHC) was contracted to facilitate the climate change adaptation planning process, and develop the final climate change vulnerability assessment and adaptation plan in collaboration with the communities of Lower Kalskag, Upper Kalskag, Aniak, Chuathbaluk, Napaimute, Crooked Creek, Georgetown, Red Devil, Sleetmute, and Stony River.

The observations of environmental change in the Middle Kuskokwim are the foundation of the adaptation strategies outlined in the Middle Kuskokwim Climate Change Adaptation Plan. Middle Kuskokwim residents prioritized the types of environmental change that need to be addressed, and developed five adaption priority areas with associated goals. The Middle Kuskokwim adaptation goals focus on maintaining cultural traditions, ensuring the health and safety of the residents, and continuing a tradition of stewardship toward the land and animals in the region.

The following document includes the climate change vulnerability assessment, and the priority areas for adaptation that were identified by Middle Kuskokwim residents. The vulnerability assessment describes changes to the air, water, land, plants, animals, and people, all inextricably connected. The assessment is based on the observations and comments from the people whose relationship with the lands extend back to time immemorial. Additional information has been integrated from the Alaska Climate Adaptation Science Center, other available agency reports, and observations posted to the Local Environmental Observer (LEO) Network.

Kuskokwim River summer and winter
Photos by Harvey Hoffman

Fireweed
Photo by Patty Yaska

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Region

The Kuskokwim River flows southwest for 540 miles, from the headwaters in the Alaska Range and Kuskokwim Mountains, and drains in to the Bering Sea. As the river moves, it is fed by swift glacial rivers draining from the Alaska Range and clear streams from the Kuskokwim Mountains. The Kuskokwim River basin encompasses 50,000 square miles, and transitions from a mountainous landscape in the east, becoming dotted and streaked by innumerable lakes, streams, and sloughs in the western flats (Brown, 1985). Below the surface of the ground, the Middle Kuskokwim region is mineral rich. The quicksilver mineral cinnabar, along with gold and tungsten, are abundant. These deposits have drawn explorers and miners to the region, shaping the history of Middle Kuskokwim since the early 1900s. Deposits of copper, antimony, silver, tin, and molybdenum also occur, although these have not been commercially mined (Cady et al., 1955).

The vegetation changes based on the moisture content of the soil (United States Forest Service). Higher elevations are dominated by white spruce and birch trees, thickets of willow and alder, and ferns, mosses, and lichens in the undergrowth. Moose, caribou, black bears, and wolverines roam the uplands, while small mammals such as beaver, fox, marten, muskrat, land otter, lynx, weasel, and hare can be found across the region. Farther down river, spruce and birch trees thin and are confined to the riverbanks, interspersed by willow and alders. Nearing the Yukon-Kuskokwim Delta, the soil is moisture heavy and lies above discontinuous, but widespread permafrost. In these poorly drained areas, grasses, sedges, mosses, lichens, scrub willow and alder dominate (Brown, 1985). Migratory waterfowl pass through the delta annually, feeding on the abundant blackfish, whitefish, sheefish, rainbow trout, Arctic char, and Dolly Varden as they travel. All five species of salmon migrate up the Kuskokwim to meet subsistence fishers in each community along the way.

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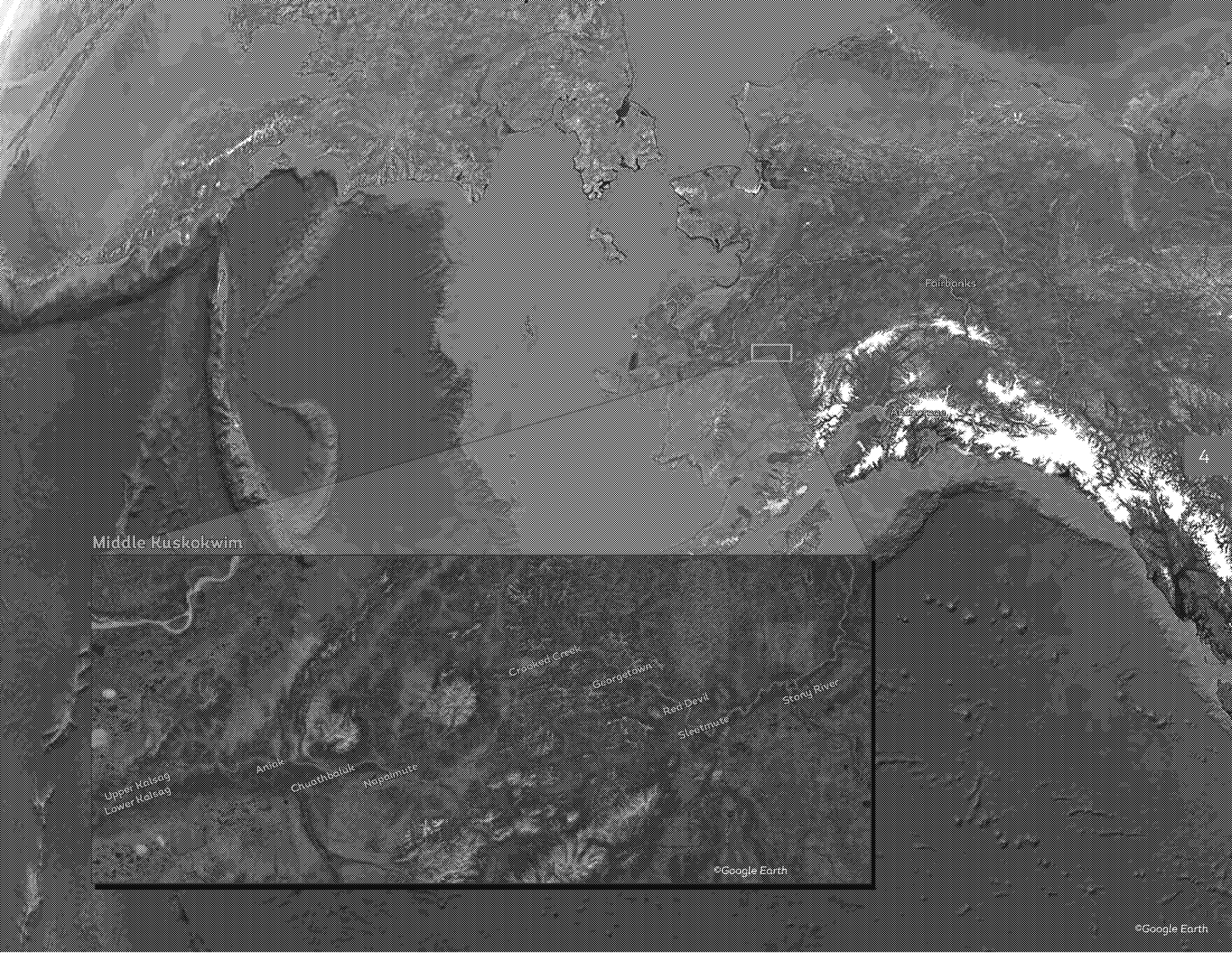
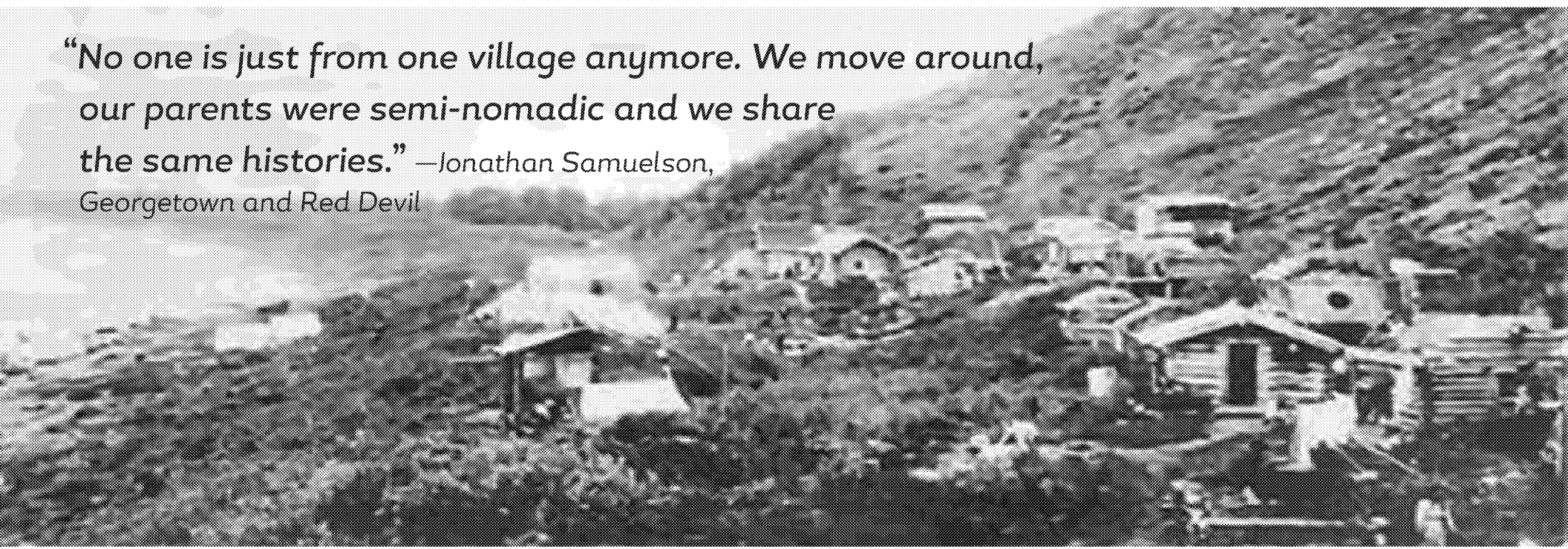

Fairbanks
Middle Kuskokwim
Crooked Creek
Georgetown
Red Dog
Stony River
Sleetmute
Aniak
Chuathbaluk
Napaimute
Upper Kalskag
Lower Kalskag
©Google Earth
©Google Earth

Communities

The Kuskokwim region is often geographically broken in to three sub-regions imposed on Yup'ik and Athabascan traditional homelands. The Lower Kuskokwim region includes the present day communities of Kwethluk, Napaskiak, Napakiak, Kasigluk, Oscarville, Nunapitchuk, Tuntutuliak, Tuluksak, Atmauthluak, Akiak, Akiachak, and Eek. The Middle Kuskokwim communities of Lower Kalskag, Upper Kalskag, Aniak, Chuathbaluk, Napaimute, Crooked Creek, Georgetown, Sleetmute, Stony River and Red Devil. The Upper Kuskokwim includes the communities of Takotna, McGrath, Medfra, and Nikolai.

The 10 Middle Kuskokwim communities are home to over 1,400 people who actively hunt, fish, and gather traditional foods. Each community has a different combination of infrastructure, economies, and services that work together to meet the needs of residents.

In the Middle Kuskokwim, there are no roads. Communities are connected primarily by the air and by river during the summer, and by the ice road and marked snowmachine trails in the winter. When the Kuskokwim River freezes during winter, village transportation crews work together to monitor ice conditions, plow and maintain the road, and mark open water. During the winter of 2017-2018, the ice road extended 250 miles from Kasigluk to Bethel to Crooked Creek. The ice road provides a much more affordable travel option, allowing people to get together for community events, sports, meals, and shopping (DeMarban, 2019).



"No one is just from one village anymore. We move around, our parents were semi-nomadic and we share the same histories." —*Jonathan Samuelson, Georgetown and Red Devil*

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Ayumqerryaraq – Lower Kalskag

Central Yup'ik

A distance of 95 river miles from Bethel, Lower Kalskag and Upper Kalskag sit on the north bank of the Kuskokwim River. Prior to European settlement, the area of the Kalskag communities was used as a Yup'ik seasonal fish camp called Kessiglik. Kalskag began as one community, but exists today as two communities connected by a 4-mile dirt road. Residents share many of the same resources, but each community maintains their own separate governing entities.

The City of Lower Kalskag became incorporated in 1969, following the construction of St. Seraphim Russian Orthodox Chapel in 1940, a school built in 1959, a post office in 1962, a sawmill in 1965, and a power plant in 1969. Lower Kalskag is co-governed by the City and the Village of Lower Kalskag, and is currently home to approximately 275 residents ((e) Alaska Community Database Online). Most homes, the school, and the clinic have either piped water and sewer utilizing a community well, or individual septic systems. Electricity is provided by the Alaska Village Electric Cooperative. Healthcare is available at the Crimet Phillips Sr. Clinic ((e) Alaska Community Database Online).

Kessigliq – Upper Kalskag

Central Yup'ik

Upper Kalskag was first settled in 1898 by the Kameroff family. The community grew in 1932 with the construction of a BIA government school that drew in surrounding residents. Soon after, a general store, post office, barge company, and a reindeer herding practice followed. In the 1930's, Russian Orthodox residents of Kalskag left the predominantly Roman Catholic community, and constructed residences in what is now Lower Kalskag. Today, Upper Kalskag is co-governed by the City and Village of Kalskag, and is home to 227 residents ((j) Alaska Community Database Online).

In Upper Kalskag, a piped gravity sewage system serves over 60 households and facilities, augmenting the individual well and septic systems that were established for most homes in 1997 (The Kuskokwim Corporation). Upper Kalskag receives electricity from the Alaska Village Electric Cooperative. Healthcare is available at the Catherine Alexie Health Clinic (The Kuskokwim Corporation). Delivery services are provided by barge and airplane. During the summer, fuel and supplies arrive on the barge. Daily air service, utilizing a state-owned airstrip, transports additional goods, people, and the mail. Additional trails are marked in the winter, directing people to Aniak and Russian Mission ((j) Alaska Community Database Online).

Historic photo provided by Dan Gillikin

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Anyaraq – Aniak

Central Yup'ik: "The Place Where it Comes Out"
(referring to the mouth of the Aniak River)

Aniak is on the south bank of the Kuskokwim River, 25 river miles from Kalskag. In 1832, Russian fur traders built Lukeen's Fort at the confluence of the Kuskokwim and Aniak rivers. It was destroyed, and replaced by Kolmakof's Redoubt a few miles downriver from Sleetmute (Cady et al., 1955) where a mercury deposit was discovered (Kurtak et al., 2010). In 1908, gold was discovered, and later silver, copper, and other minerals (The Kuskokwim Corporation, Cady et al., 1955). A store and post office opened in 1914, a territorial school in 1936, and an airstrip was built in 1939. At one point in history, Yup'ik families left the Aniak area, but returned when Willie Pete and Sam Simeon returned with their families (The Kuskokwim Corporation). The gold rush brought additional prospectors, new infrastructure, and an increased population. Aniak is co-governed by the City of Aniak, which was incorporated in 1972, and the Aniak Traditional Council.

Aniak is the largest community in the Middle Kuskokwim, home to 485 residents ((a) Alaska Community Database Online), and serves as the regional hub, offering groceries from three stores and a sub-regional clinic.

The majority of homes receive water from either individual wells, or a more recently constructed central well, and are served by piped sewer. Although some homes still have individual septic, drainage is a problem because of underlying permafrost. Plans are in place to transition all homes to piped sewer. Electricity is provided by privately-owned Aniak Light and Power. The Clara Morgan Sub-Regional Clinic provides a wide range of physical, mental, and emergency health care services (The Kuskokwim Corporation). The barge arrives in the summer with goods, but transportation and cargo is also available through air service. A state-owned, lighted, asphalt runway is able to accommodate larger commercial and charter planes.

Aniak
Photo by Harvey Hoffman

ED_013708_00000184-00180

Curarpalek – Chuathbaluk

Central Yup'ik: "Hills where Big Blueberries Grow" or "Provided with Big Blueberries"

On the north bank of the river, 11 river miles from Aniak and with the Kilbuck-Kuskokwim Mountains in view, is Chuathbaluk. The area was long used by Deg Xit'an people as a fish camp. In 1894, the St. Sergius Mission was built by the Russian Orthodox Church, and residents from the downriver community of Kukuktuk took up residence there. After an influenza epidemic in 1900, the site was deserted, except for the services that were still held at the mission. Residents from Crow Village, Aniak and Crooked Creek moved to Chuathbaluk in the early 1950's after the church was rebuilt. In the 1960's a state school opened, and the City became incorporated in 1975, now co-governing the community with Chuathbaluk Traditional Council (The Kuskokwim Corporation).

Approximately 111 people live in Chuathbaluk ((b) Alaska Community Database Online). Homes in Chuathbaluk receive piped water from a community well, and electricity is provided by the Middle Kuskokwim Electric Cooperative. North of the community is a state-owned airstrip that provides scheduled air service year round, supplemented by winter travel on the ice road after the river freezes ((b) Alaska Community Database Online).

Kuskokwim River
Photo by Patty Yaska

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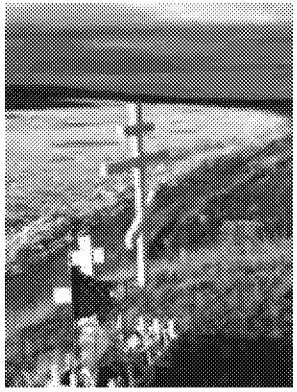
Napaimute

Central Yup'ik: "Spruce Tree Village" or "Forest People"

Moving 20 river miles up the Kuskokwim from Chuathbaluk, Napaimute sits on the north bank of the river. At one time, the area of Napaimute was called "Hoffman's," after George Hoffman who established a trading post in 1906. The population established around the trading post grew. Two schools were constructed between 1920 and 1926, but by the early 1950's, many residents had moved elsewhere as mining, fur, and reindeer herding declined. Despite the out-migration, Napaimute holds significant importance as an ancestral home for many people. In 1994, the Native Village of Napaimute (NVN) received federal recognition as one of Alaska's Native Tribes. Over the years, tribal membership has grown, as have efforts to revitalize the community. Although there is currently one year-round resident, the Napaimute Traditional Council has begun to build community infrastructure, including a council-owned airstrip, community building, tribal office, and rental cabins. NVN also provides fuel service, runs a small store, and operates a sawmill (Native Village of Napaimute). In the summer, mail and supplies are delivered by barge ((f) Alaska Community Database Online).



Freeze up, Napiamute
Photo by Dan Gillikin

Blueberries
Photo by Elizabeth Willis

Qipcarpak - Crooked Creek

Central Yup'ik

Around several bends in the river, Crooked Creek appears on the north bank of the river, 35 river miles from Napimute. The area has been known as "Kvikchagpak," Yup'ik for "great bend," and as "Khottylno," Deg Xinag for "sharp turn." Historically used as a fish camp by residents of Kwigiumpainukamuit, permanent infrastructure was built to service the Flat and Iditarod mining camps, an industry which continued to influence life in the village until the 1980s. In 1914, a trading post built by Denis Parent established the "upper village," some distance away from homes in the "lower village." Those area distinctions are still used today. The community is governed solely by the Native Village of Crooked Creek, as there is no incorporated city. The 94 residents of Crooked Creek ((d) Alaska Community Database Online) haul water from a central well and washeteria, although the school and store have individual wells. Electricity is provided by the Middle Kuskokwim Electric Cooperative (The Kuskokwim Corporation). Health care is available at the Crooked Creek Health Clinic. Air service is provided during the weekdays utilizing a state-owned airstrip, and cargo is delivered by barge and skiff in the summer ((d) Alaska Community Database Online).

Crooked Creek
Photo by Rebecca Wilmarth

Georgetown

Following the Kuskokwim upriver from Crooked Creek as it bends to the southeast, is Georgetown. Prior to the discovery of gold in 1909, the area was known as Keledzhichagat and was used as a fish camp by the residents of nearby Kwigiumpainukamiut. The community of Georgetown was named after three traders, George Hoffman, George Fredericks, and George Morgon, who established a community of 300 prospectors near the confluence of the Kuskokwim and George rivers. In 1911, a fire destroyed the majority of structures. The community relocated to the east side of the George River, and a school was constructed in 1965, but only operated for five years as the mining industry declined ((a) Koopman, 2017, (d) Alaska Community Database Online).

Georgetown Tribal Council (GTC) maintains good working relationships with the neighboring communities, and is in the process of planning a new settlement on the south bank of the Kuskokwim. There are no permanent residents currently living in Georgetown, however GTC envisions a future with homes, seasonal cabins, and a community center that will provide space for people to gather and engage in traditional and subsistence activities. Georgetown community leadership is young, and energetic, actively utilizing knowledge from Georgetown Elders to help plan for the future.

Georgetown
Photo by Rebecca Wilmarth

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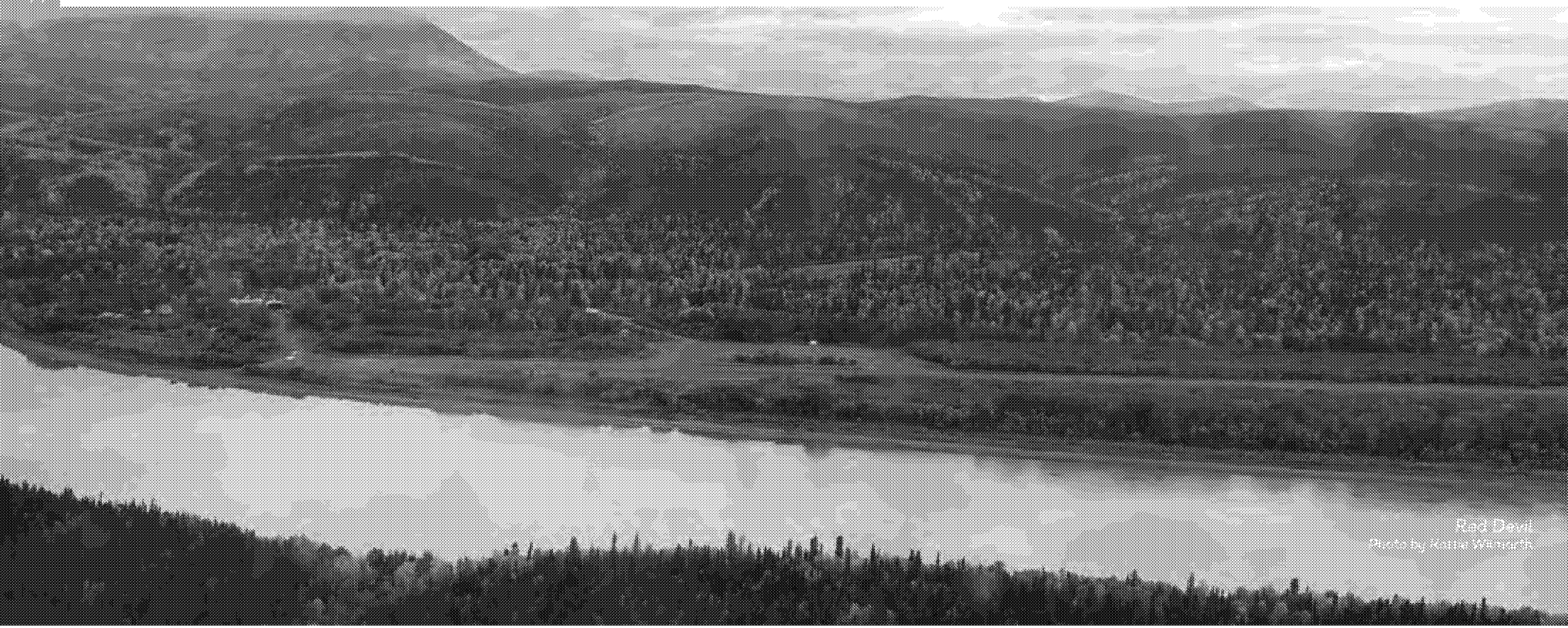
Red Devil

Named after the Red Devil Mine, operating from 1921-1971

Sixteen miles southwest of Georgetown, Red Devil spans both banks of the Kuskokwim River. In 1921, mercury was discovered in the Kilbuck-Kuskokwim Mountains, and by 1933 the Red Devil Mine was in full operation. In 1957, a post office opened, followed by a school in 1958. After the mine closed operations in 1971, residence in the community declined and the school was closed in 2009. The 16 current residents ((g) Alaska Community Database Online) are working to revive the Red Devil tribal council and develop a city government that could provide access to funds for additional community development.

Four homes in Red Devil are fully plumbed and connected to individual wells, while residents of the remaining 13 homes haul water from the still-accessible school well. Electricity is provided by the Middle Kuskokwim Electric Cooperative. A state-owned airstrip is still maintained by community members. There is currently no clinic in Red Devil, but community members hope to purchase the school building from the state, and open a community center and clinic (Shallenberger, 2019).



Red Devil
Photo by Arthur Wheeler

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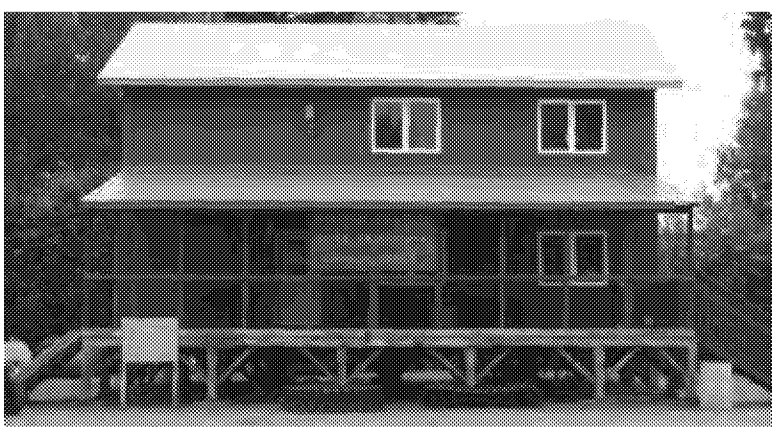
Cellitemiut – Sleetmute

Central Yup'ik: "Whetstone Village" or "Whetstone People"

On the east bank of the river, 20 river miles upriver from Red Devil is the community of Sleetmute. Prior to Russian exploration, the community was originally established by Deg Xit'an people. In 1906, a trading post was built, followed by a school in 1921 and a post office in 1923. There is no city government, and the community of 86 residents ((h) Alaska Community Database Online) is governed by the Sleetmute Traditional Council (The Kuskokwim Corporation).

Water is provided to each house by a hand-pumped gravity storage tank, connected to either the central well, or individual household wells. Electricity is provided by the Middle Kuskokwim Electric Cooperative, and health care is available at the Sleemute Clinic (The Kuskokwim Corporation). Barges deliver goods and provide transportation in the summer, along with air service utilizing a state-owned airstrip.



Gidighuyghatno' Xidochagg Qay - Stony River

Deg Xinag

An additional 20 river miles up the Kuskokwim River, the community of Stony River sits on an island that borders the north bank. Stony River was originally the site of a trading post until the 1960's, when construction of a school drew families from the surrounding area. Stony River is unincorporated, and governance for the 42 residents ((l) Alaska Community Database Online) is provided by the Village of Stony River (The Kuskokwim Corporation). There are regular community-wide activities for litter prevention, yard clean up, and road maintenance that bring the community together and improves community health.

Homes are not plumbed in Stony River, but water is provided by individual household wells and a washeteria. Electricity is provided by the Middle Kuskokwim Electric Cooperative and health care is provided by the Stony River Clinic (The Kuskokwim Corporation). Weekday air service is provided using a state-owned airstrip, and the barge delivers cargo and fuel during the summer ((l) Alaska Community Database Online).

Stony River council building with new roof.
Photo by Elizabeth Willis

ED_013708_00000184-00185

Changing Climate

ED_013708_00000184-00186

Climate Summary Points:

- Annual temperatures are projected to rise between 5.8° F and 8° F depending on the time frame and emissions scenario.
- Winter temperatures are projected to rise between 4° F and 12° F depending on the time frame and emissions scenario.
- Average annual precipitation is expected to increase, and the increase is expected to be larger than historical variability in all seasons.
- During the winter, the majority of precipitation will still fall as snow rather than rain. However, closer to the coast, snow will fall later in the year and melt earlier.

"We had early break-up, early melts, more rain than last few summers, few bumble bees, early ducks and geese, and more dandelions."

—Barbara Askoak, Lower Kalskag.
LEO Network Post, 2016

The climate of western Alaska is considered transitional, influenced by both maritime and continental characteristics. Maritime climate in Alaska is influenced by the Bering Sea, and the fluctuation of sea ice coverage. Continental climate is influenced less by the ocean, and more by the geographic features affecting storm tracks. For the Middle Kuskokwim, these influences have historically led to long, cold, winters and shorter summers.

Average annual temperatures in the Middle Kuskokwim are changing, becoming warmer. Average annual temperatures in the period before rapid warming (calculated between 1961 and 1990) range from 23-28.4 degrees Fahrenheit. In the summer, temperatures have historically ranged from 46.4 – 51.8 degrees Fahrenheit, transitioning to -4-4.1 degrees Fahrenheit in the winter ((b) Koopman, 2017). Between 1970 and 2019, the average temperature rose 1 degree per decade. During 2017 and 2019, the average annual temperate was above freezing for the first time on record (Markon et al., 2018). Average annual precipitation in the Middle Kuskokwim (calculated between 1961 and 1990) ranges between 14.6 and 16.5 inches. The majority of precipitation occurs from May to September, when an average of 9.4 and 12.1 inches falls. In the winter months, an average of 3.5-5 inches of precipitation falls as snow ((b) Koopman, 2017).

Fire, Stony River
Photo by Elizabeth Willis

ED_013708_00000184-00187

Residents of the Middle Kuskokwim communities are already observing the impacts of a warming climate. The weather changes more quickly than it has in the past, and is challenging to predict, but overall, residents agree that annual temperatures are rising. Temperatures are warmer during every season, making the winters warm and the summer hot. During warm winters, snow will fall as rain and it takes longer for adequate snow cover to form. Warm winters require less wood for home heating, but when conditions are colder, changing ice and snow conditions make it difficult for people to travel to gather firewood. More precipitation is falling as rain on top of the snow, causing widespread ice. After a winter with low snow, the water levels in the river are observed to be lower, especially when the spring, summer, and fall months are warmer than usual.

Child drives through snow melt February 2019, Aniak.
Photo by Dave Cannon

ED_013708_00000184-00188

Projections for temperature and precipitation, and all following climate projections, were created by the Scenarios Network for Arctic and Alaska Planning (SNAP) and provided with interpretations by the Alaska Climate Adaptation Science Center. These projections are dependent on future emissions scenarios called Representative Concentration Pathways (RCPs). These scenarios demonstrate what the future climate may look like if emissions of carbon dioxide and other greenhouse gases were reduced (lower emissions scenario) on a global scale and result in less warming (RCP 4.5), and the current emissions scenario resulting in more warming (RCP 8.5 or higher emissions scenario).

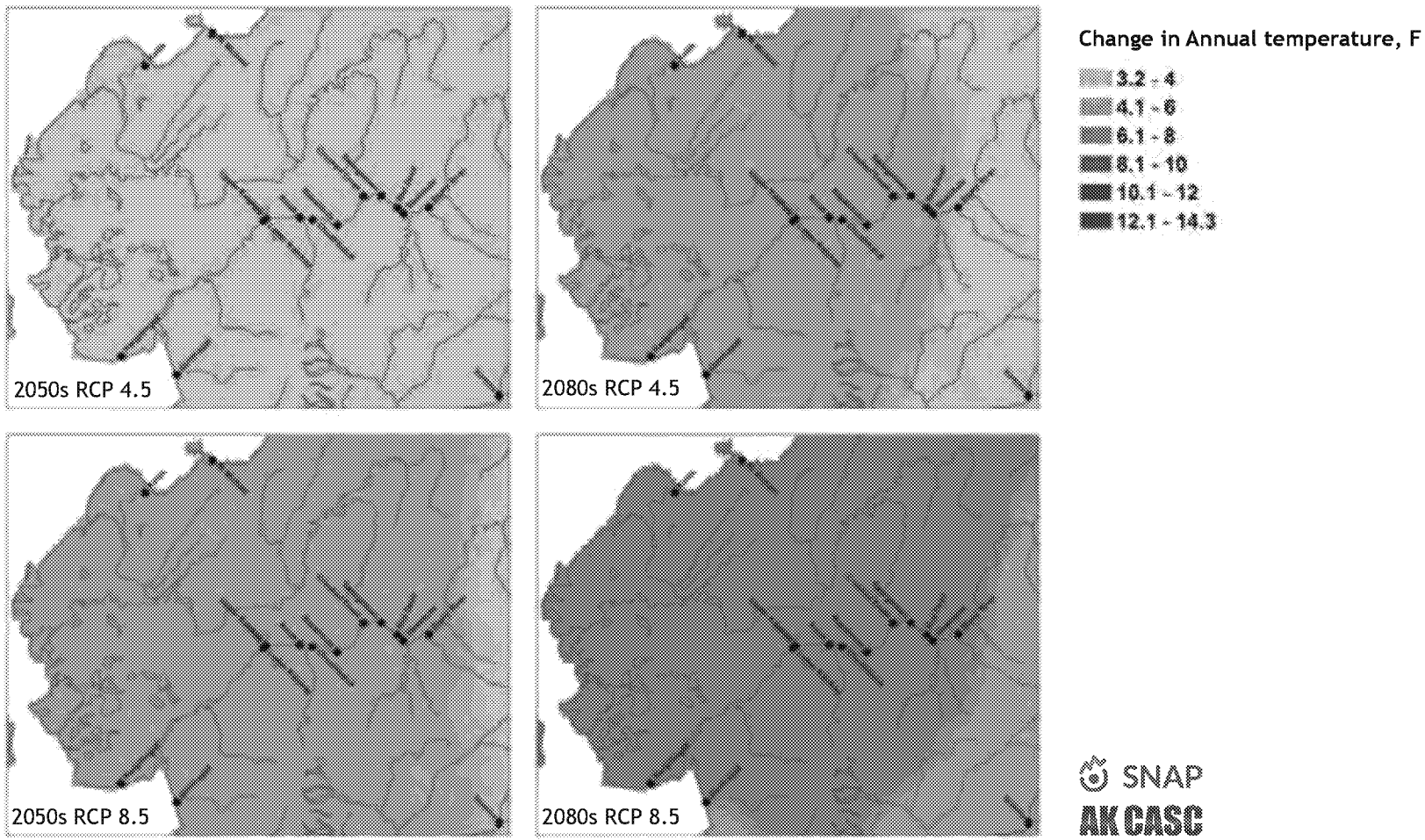
In Alaska, five models that combine historical weather data and future global climate are used to estimate local future temperature and precipitation. The information in this report is an average of those five models. These models are compared to averages calculated between 1970 and 1999 and are represented in degrees Fahrenheit (shown as °F).

River willows
Photo by Mary Peltola

ED_013708_00000184-00189

Under a lower emissions scenario (RCP 4.5), annual temperatures are projected to rise between 3.2 and 4° F above average between 2040 and 2069. Between 2070 and 2099, annual temperatures are projected to rise 4-6° F. Under a high emissions scenario (RCP 8.5), annual temperatures are projected to rise between 4.1 and 6°F above average during the years 2040 to 2069. Between 2070 and 2099, annual temperatures are projected to rise between 6.1-8°F.

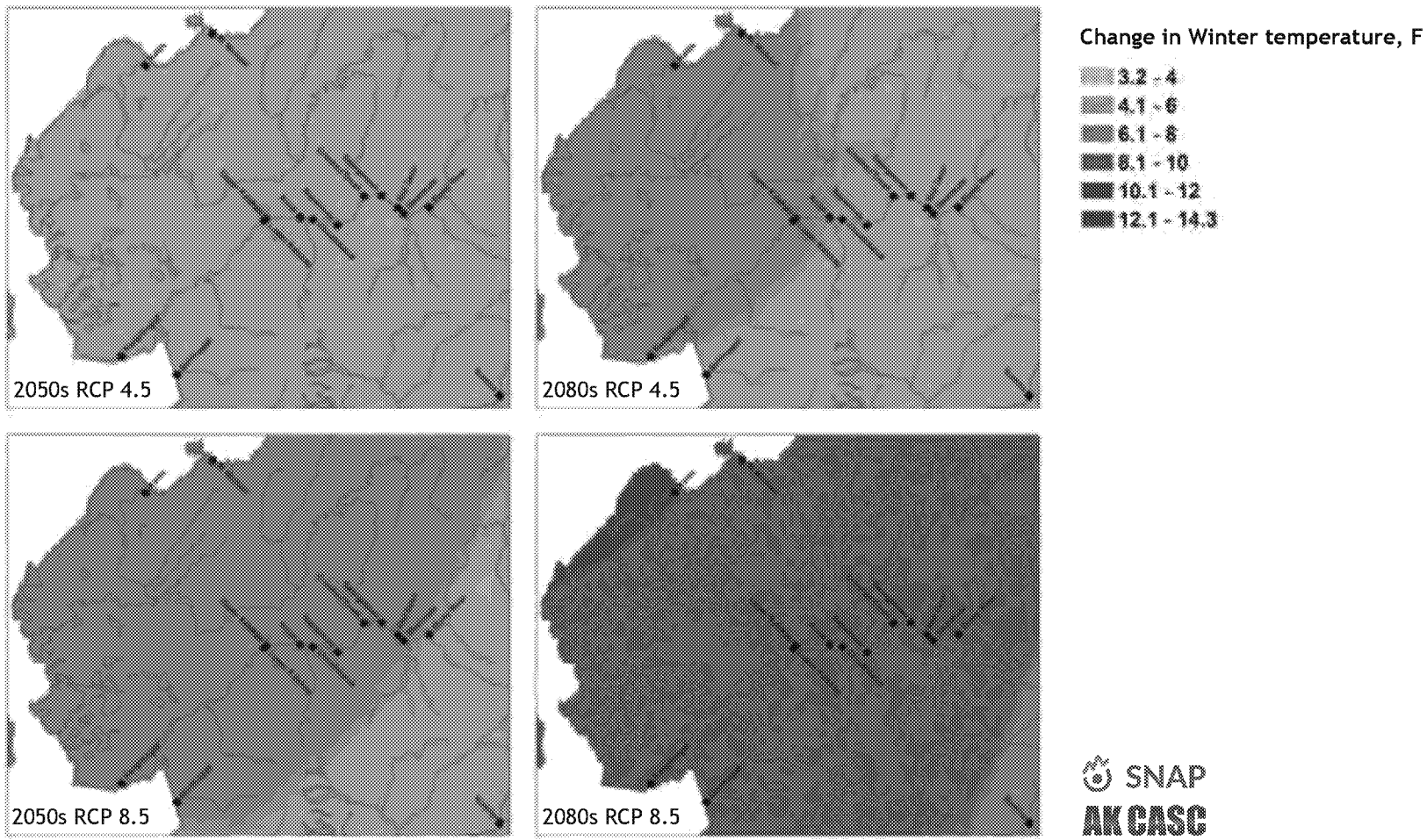
Figure 1: Change in Annual Average Temperature over the Yukon-Kuskokwim Delta



Walsh et al., 2018

Winter temperatures will warm more drastically than summer temperatures. Under a lower emissions scenario (RCP 4.5), winter temperatures are projected to rise between 4-6° F above average between 2040 and 2069. Closer to the coast, winter temperatures are expected to rise 6.1-8° F during the years 2070-2099. Under a high emissions scenario (RCP 8.5), winter temperatures are projected to rise between 6.1 and 8°F above average during the years 2040 to 2069. Between 2070 and 2099, winter temperatures are projected to rise between 8.1 and 12°F.

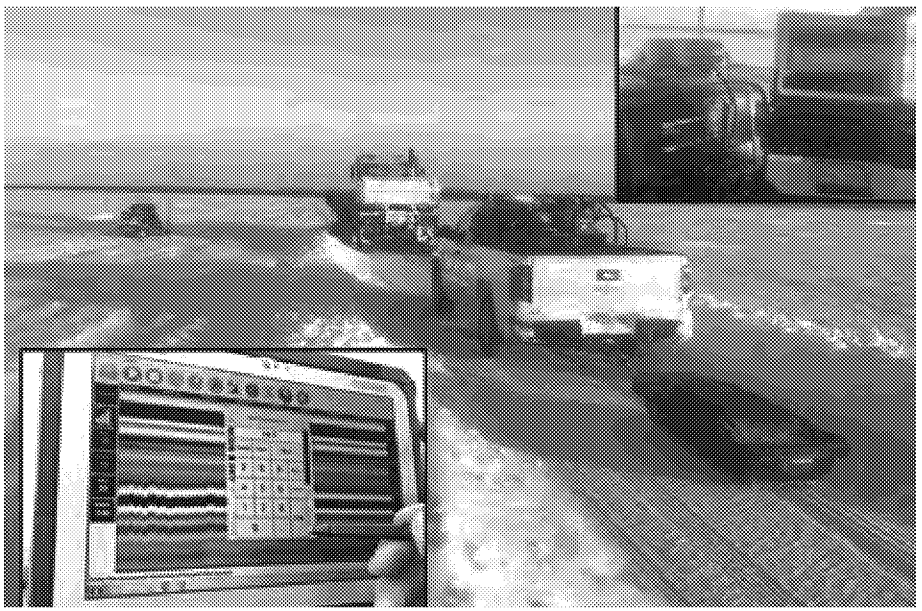
Figure 2: Change in Winter Average Temperature over the Yukon-Kuskokwim Delta



Walsh et al., 2018

The ice road is an important link between communities that provides a more cost effective method of travel compared to flying. Warmer temperatures make travel on the ice road dangerous during the winter. Ice conditions are becoming unpredictable, and in places are forming as "needle ice" or thawing and refreezing in ways that appear safe but are not. In recent years, residents have noticed that the lower river near the coast has broken up earlier.

Ice road, overland trail
Photo courtesy of the Native Village of Napaimute



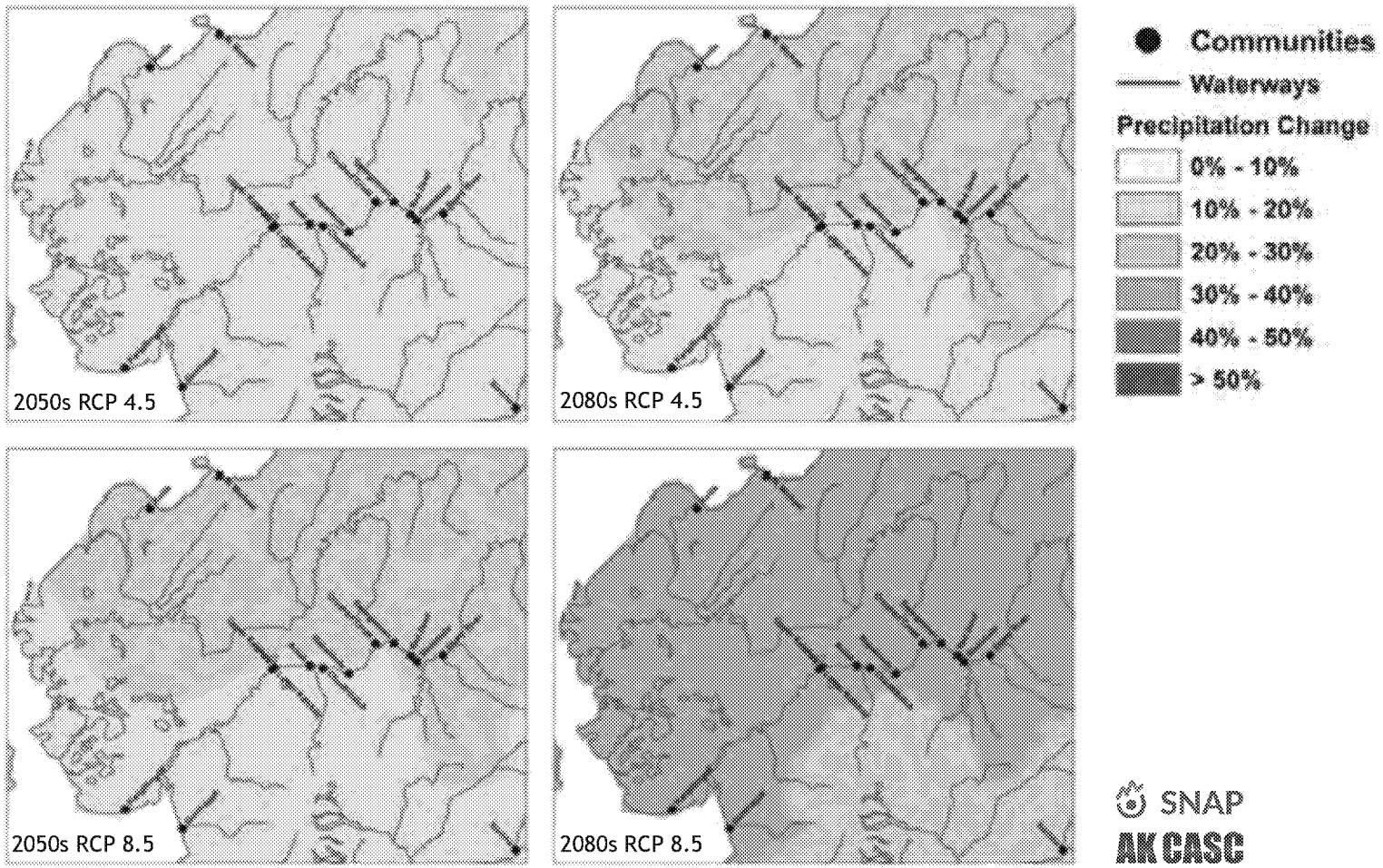
Ice road, ice monitor
Photo courtesy of the Native Village of Napaimute

Overland ice road
Photo courtesy of the Native Village of Noorvik

ED_013708_00000184-00193

Overall, annual precipitation is expected to increase in the region. However, each year is different and there will be some years with wetter summers, and some with drier summers. A modest increase in precipitation, combined with a greater increase in temperature, will likely leave less water in the soil and lead to drier conditions.

Figure 3: Change in Average Precipitation over the Yukon-Kuskokwim Delta

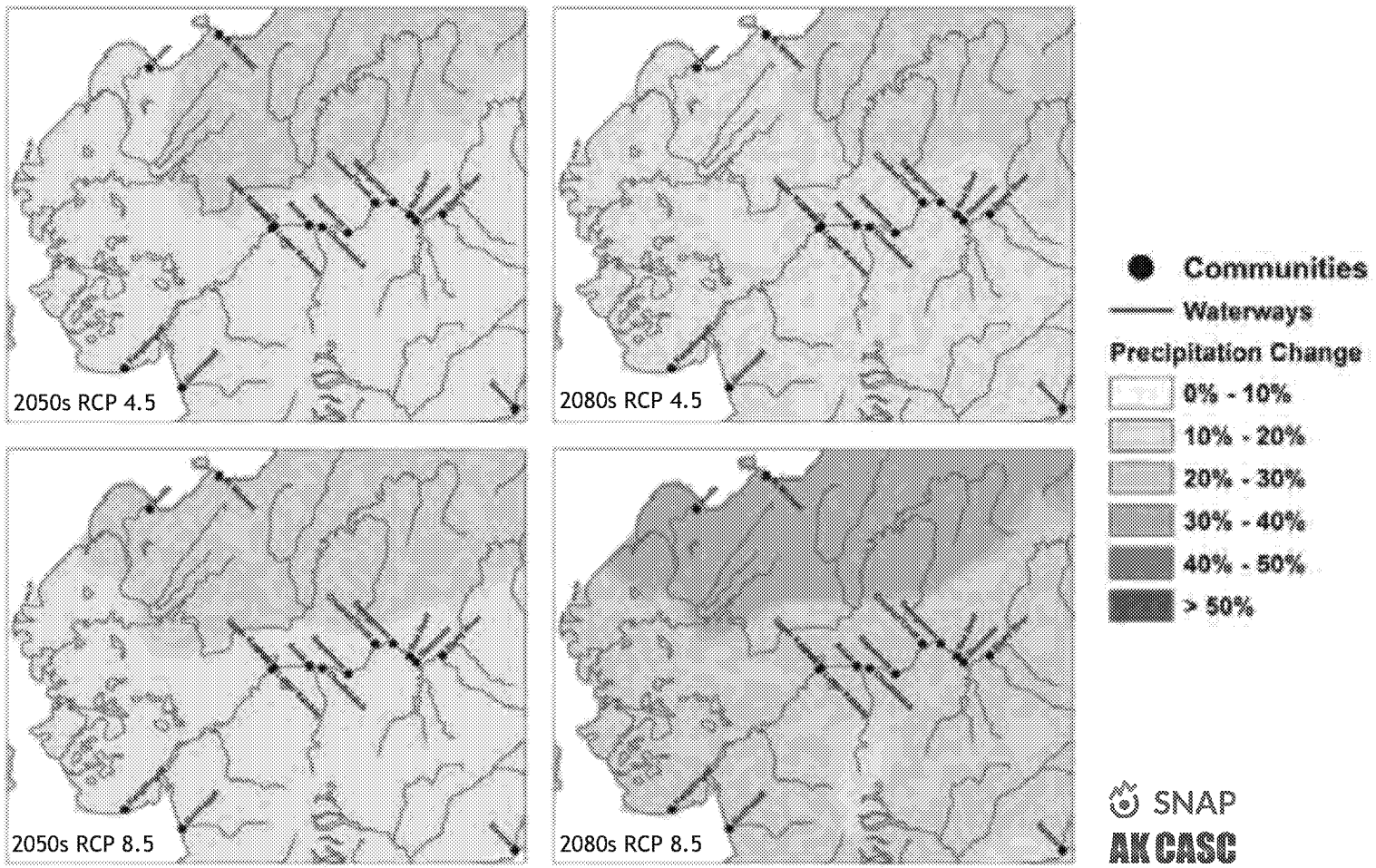


Walsh et al., 2018

ED_013708_00000184-00194

Under a low emissions scenario, annual precipitation is projected to increase by 10%-20% during the years 2040-2069 and increase 20%-30% between 2070 and 2099. Under a higher emissions scenario, precipitation is projected to increase by 20%-30% between 2040 and 2069 and by 30%-40% between 2070 and 2099.

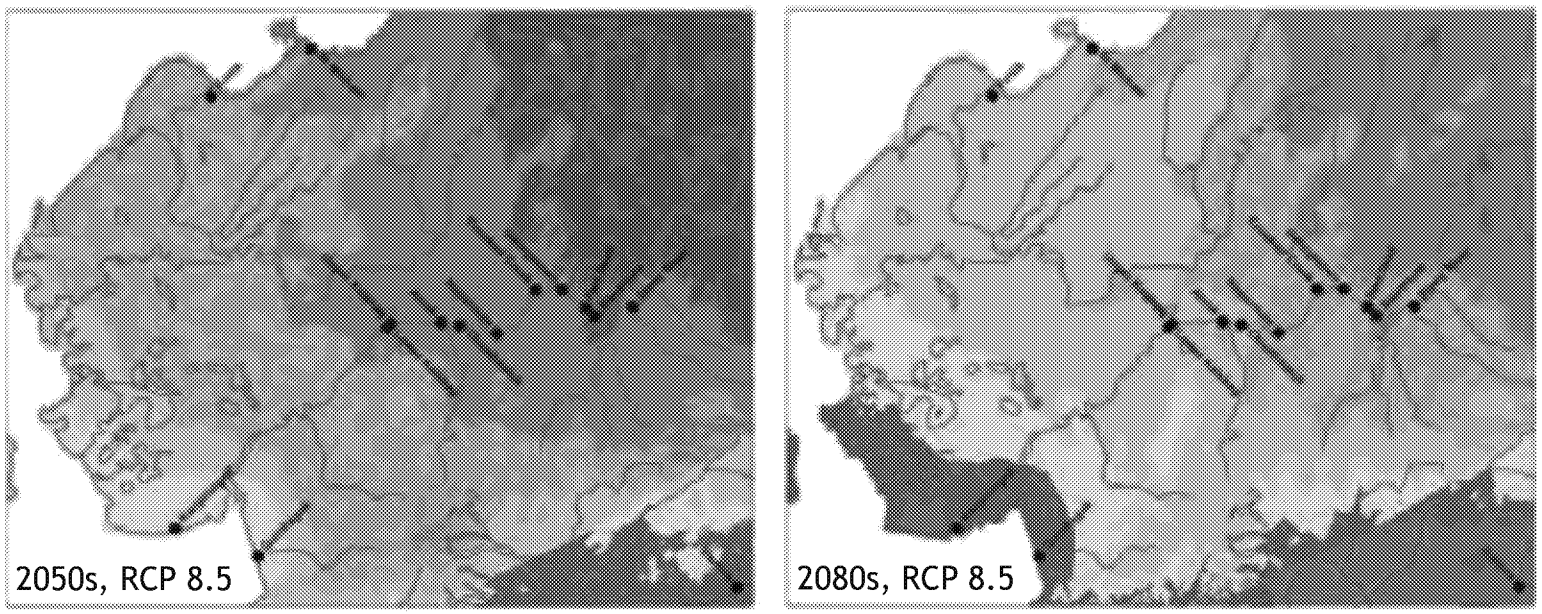
Figure 4: Change in Summer Average Precipitation over the Yukon-Kuskokwim Delta



Walsh et al., 2018

Despite changing temperatures, runoff in the Middle Kuskokwim watershed is expected to still be dominated by snowmelt rather than rain. However, the amount of precipitation that falls as snow during October to March is expected to decrease. Snow cover is expected later in the year, and is expected to melt earlier. Between 2040 and 2099 in both emissions scenarios, the coastal areas south of the Middle Kuskokwim are expected to see more rain during the winter months, and are projected to experience longer snow-free periods.

Figure 5: Change in Snow Dominance over the Yukon-Kuskokwim Delta



Littell et al., 2018

Communities
Waterways
Oct-Mar Prec as Snow, %

0 - 10
10 - 20
20 - 30
30 - 40
40 - 50
50 - 60
60 - 70
70 - 80
80 - 90
90 - 100

5 model means for the region

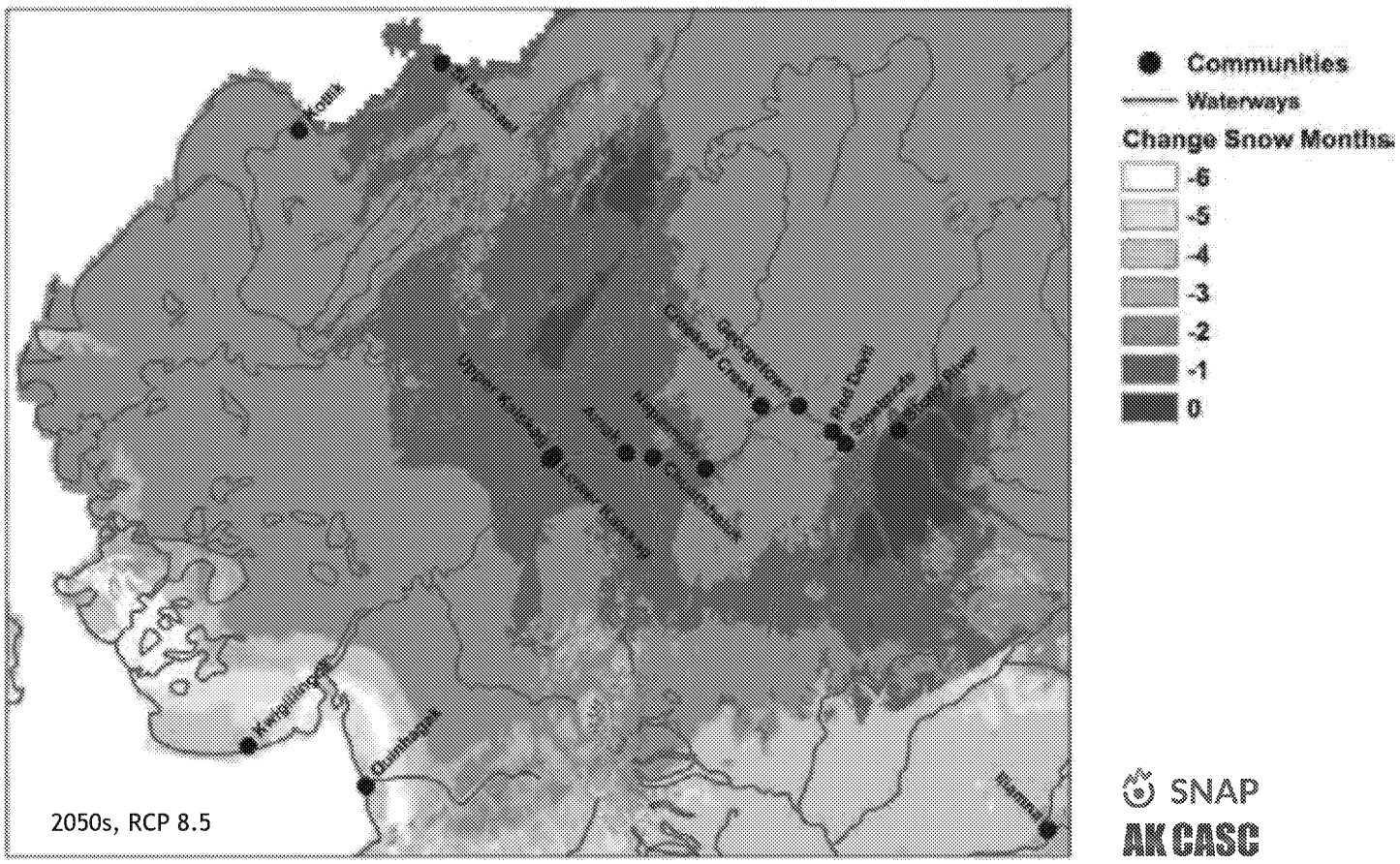
2040 - 2069, RCP 4.5: 79
2040 - 2069, RCP 8.5: 77
2070 - 2099, RCP 4.5: 75
2070 - 2099, RCP 8.5: 64

SNAP
AK CASC

ED_013708_00000184-00196

Snow is an important factor in overland travel during the winter. Travel in to the mountains is a common activity during the winter. When there is not enough snow, people cannot travel out on snowmachines. Additionally, successful trapping seasons are dependent on snow cover. Trapping provides an opportunity for people to get outside during winter, and is a source of income in the region. Under a warmer emissions scenario (RCP 8.5), most of the region will lose 1 to 2 months of reliable snow cover. During these months, of the days when precipitation falls, 7 out of 10 days will have snowfall and 3 of 10 will be rain or mixed rain and snow.

Figure 6: Change in Number of Months with Reliable Snow Cover Between 2040-2069



Littell et al., 2018

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Changing Environment

ED_013708_00000184-00198

River

Climate Summary Points:

- The river is freezing later, and breaking up earlier. Ice conditions throughout the winter are becoming more variable.
- Under a high emissions scenario, reductions in the amount of water contained in the April 1st snowpack is projected to be reduced by up to 10% between 2040-2069 and 10%-20% between 2070-2099.

"The river is our biggest resource. We alter our lives around the freeze and thaw."

—Elizabeth Willis, Stony River

Photo courtesy of the Native Village of Napaimute

River ice, Stony River
Photo by Elizabeth Willis

River Ice

Warming temperatures are already having a noticeable impact on the quality of ice along the Kuskokwim ice road. Historically, the river begins to freeze in early October, and break-up occurs in May. Many residents of the Middle Kuskokwim note that the Kuskokwim River is freezing later than usual, experiencing mid-winter thaw and re-freeze, and breaking up earlier. In some areas, the river no longer freezes completely. In a LEO Network post from Chuathbaluk submitted on April 17th, 2016, Patricia Yaska wrote that the river ice near the community went out earlier than usual following an extremely warm winter (Yaska, 2016). Longer ice-free periods on the river are allowing residents to travel by boat earlier in the spring, and later in the fall. In 2017, Patricia posted to the LEO Network again, saying that 2017 was the second year in a row that people were able to travel the Kuskokwim River by skiff in November (Yaska, 2017).

Mid-winter thaws may lead to flooding in some areas as the water pools on top of the ice before re-freezing. Eroding riverbanks has brought the floodwaters closer to infrastructure in some communities ((a) United States Army Corps of Engineers). In a LEO Network post submitted from Lower Kalskag in early May of 2012, John Parka writes that the ice began to move on May 7th, but stopped and water levels began to rise, causing residents to worry about the safety of the dumpsite, sewage lagoon, and personal property (Parka, 2012).

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"I remember growing up in Chuathbaluk, and in Aniak, and by the end of October, and by Thanksgiving, we were traveling between the two villages (Aniak & Chuathbaluk) on the "ice road". This day and age, we cannot do that. We are still traveling to Aniak for groceries with a boat, in an ice-free river."

—Patricia Yaska, Chuathbaluk. LEO Network, 2017.

Photo courtesy of the Native Village of Napaimute

Bad ice conditions at Stony River
Photo by Elizabeth Willis

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The importance of the Kuskokwim River ice road to the region cannot be understated. It provides a cost effective travel option during the winter. However, changes in freeze/thaw timing, depth of ice, and frequency of open water, increase the risk of accidents and injury during travel. Traditional paths along the ice have changed, and trails are marked in different areas than what is usual based on where the ice is the most stable. In uncertain conditions, it takes longer to travel using the ice road, and travel delays can impact activities such as traveling for work, gathering wood, shopping, traveling to see family, or to visit a health facility. The ability to travel safely is important for maintaining relationships between people, families, and communities in the region.

Village transportation crews, and Bethel Search and Rescue, are actively adapting to changing conditions and working to provide residents with the information they need to travel safely. River conditions are surveyed using ice radar and aerial imagery from drones. Transportation crews take ice core samples at regular intervals along the ice road, and use trail markers and willow limbs to mark dangerous areas in the ice. Updates on current conditions are distributed in the Bethel Search and Rescue River Reports. These reports are widely distributed to residents through radio and social media, and are also shared with scientists at the NOAA River Forecast Center and the Alaska Center for Climate Assessment and Policy at the University of Alaska Fairbanks.

Bad ice conditions at Stony River
Photo by Elizabeth Willis

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River Water

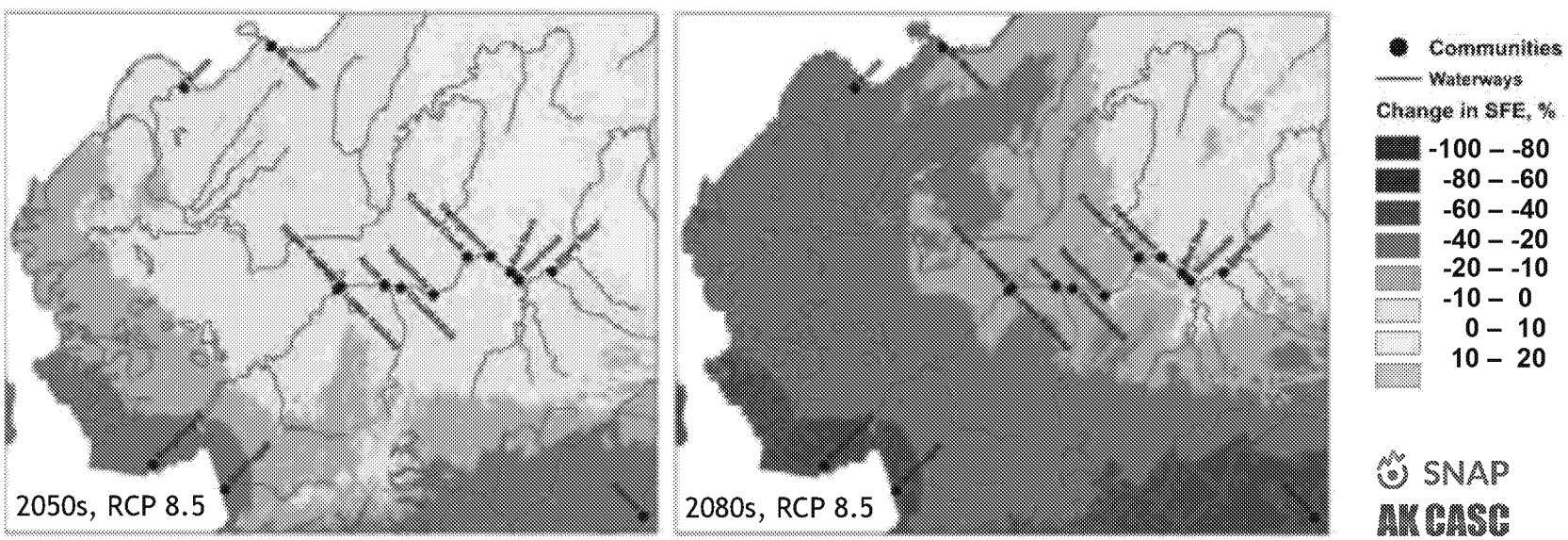
The Kuskokwim River provides food, water, and transportation for communities in the region. Healthy water quality and adequate water levels are important to maintaining that quality of life. The Middle Kuskokwim is considered "snow dominant", which means that the majority of precipitation falls as snow rather than rain during the winter. The Middle Kuskokwim region is projected to remain snow dominant, but in future climate scenarios, less precipitation is projected to be contained in the April 1st snowpack. The amount of snow still on the ground on April 1st can provide an estimate of how much water will melt from the snow, feeding the rivers, lakes, and groundwater as seasonal temperatures warm.

Bank erosion
Photo by Elizabeth Willis

Erosion covered by vegetation, Bethel
Photo by Mary Peltola

Under both low (RCP 4.5) and high (8.5 RCP) emissions scenarios, the amount of water in the April 1st snowpack decreases closer to the coast, where less snow is projected to fall in the future. Under a low emissions scenario, some areas may show an increase in the amount of water contained in the snowpack because of an increase in the amount of precipitation. Under a high emissions scenario, the amount of water in the April 1st snowpack is reduced for much of the Middle Kuskokwim region. During 2070-2099, reductions of 20-60% are projected near the coast, and reductions of 10-20% are expected near the Middle Kuskokwim communities.

Figure 7: Change in the Amount of Water Entrained in April 1st Snowpack over the Yukon-Kuskokwim Delta



Littell et al., 2018

Residents of the Middle Kuskokwim are seeing connections between changing snowpack and the health of salmon runs. There are many factors that impact the abundance of salmon, but the potential for change in river flow and river water temperatures are of particular concern to residents. The Kuskokwim River is an important salmon migration corridor, while the gravel beds in smaller streams and tributaries provide important spawning and rearing habitat. Residents have observed that some smaller streams have dried up, and can no longer support spawning salmon. Young salmon depend on riverbank vegetation to rest and avoid predators, but some salmon streams in the region have also become completely grown in as the water flow is reduced over time. Cold river water is an important cue for king (Chinook) salmon to begin running upriver (Sauter et al., 2001). Residents are concerned that changes in the timing of breakup and snowmelt might cause the fish to miss this cue, leading to smaller runs. Increasing air temperatures during the summer cause the river water temperature to fluctuate and create additional pressure on fish species. Warm water holds less oxygen for fish, and can also allow parasites and water-borne diseases, to thrive.

The amount of water that flows in to the Kuskokwim River also impacts the ability of residents to travel between communities. During the summer, travel by boat is more cost effective than travel by plane or ATV, but low water levels can make travel by boat difficult.

In May, after the ice breaks up and the river begins to thaw, the daily river discharge (the volume of water that flows through the Kuskokwim River channel) increases. The daily river discharge decreases slightly in June, remains steady until the rains come in August and September, and the river begins to freeze in October ((b) United States Army Corps of Engineers). Changes in river discharge due to snowmelt typically do not occur past July 1st. Average river water flows, measured between July 1st and September 30th at Crooked Creek, show a detectable decline between 1952 and 2015.

Shallow water in the rivers and tributaries prevents people from traveling up to camps, which have great cultural and emotional importance. When the river levels are low, the barge carrying fuel cannot reach some communities. This drives up the price of an already expensive commodity.

Several communities along the Middle Kuskokwim experience riverbank erosion, which increases the amount of sediment and debris in the river, and increase the risk of grounding even when the river discharge is strong enough to support barge travel ((b) United States Army Corps of Engineers).

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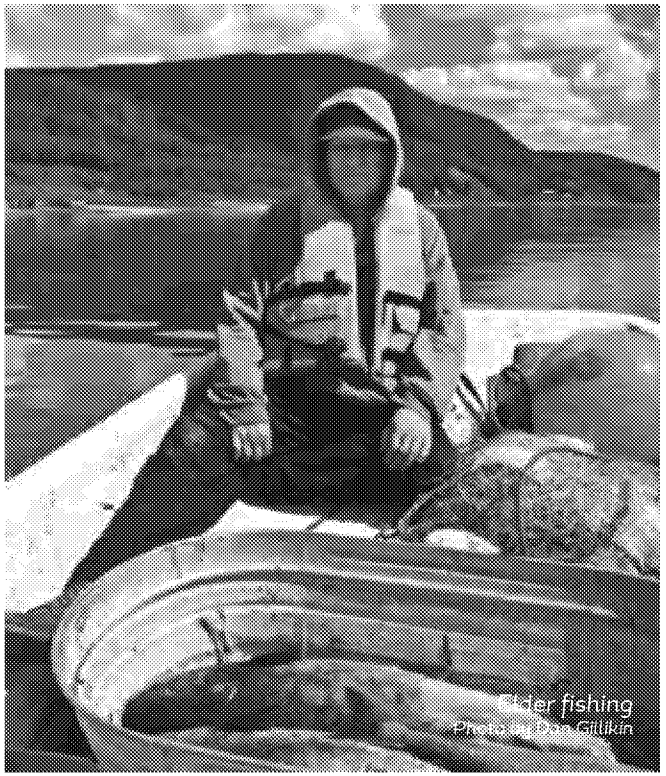
Red Devil
Photo by Kattie Wilmarth

Residents of the Middle Kuskokwim are also seeing connections between changing snowpack and the health of salmon runs. There are many factors that impact the abundance of salmon, but cold river water is an important cue for Chinook salmon to begin running upriver (Sauter et al., 2001). Residents are concerned that changes in breakup timing and water temperature might make the fish miss this cue, leading to smaller runs. Water temperatures are fluctuating, which impacts salmon health. Warm water holds less oxygen for fish, and can also allow parasites and water-borne diseases, to thrive.

Middle Kuskokwim communities have partnered to monitor water quality. Water quality monitoring is important to understand changes in the mineral content of river water. In the Middle Kuskokwim region, the soil contains naturally occurring mercury, antimony, gold, silver, and polymetallic deposits (Matz et al., 2017) which may flow in to the water due to erosion, permafrost thaw, mining, and mobilization of methylmercury from wildfire (Taylor, 2007, Kelly et al., 2006). These deposits naturally flow in to the water as the river banks erode, but tailings from previous mining operations may also increase contaminant levels in the water. Tailings from Red Devil mine, containing mercury, arsenic and

Water quality testing, July 2015, Aniak
Photo by Harvey Hoffman



Elder fishing
Photo by Dan Gillikin

antimony, were found to be leaching in to Red Devil Creek after the Red Devil mine closed in 1971. The Bureau of Land Management provided a temporary solution by re-grading the largest tailing piles and building a retention basin in Red Devil Creek, and is expected to develop a permanent method of stabilizing the site (Bureau of Land Management, Shallenbarger, 2019). However, concerns about water quality are heightened due to the proposed Donlin Gold Mine near Crooked Creek, and due to the increased rate of river bank erosion due to permafrost thaw.

In particular, mercury has the potential to concentrate in fish used for subsistence, which may then be transferred to the people who eat the fish. In certain amounts, mercury can present a health risk (Rossover et al, 2016). To date, the Alaska Department of Health and Social Services (DHSS) have not found any cases of unsafe mercury exposures that are the result of consuming Alaska fish. However, measurements of mercury levels found in pike and burbot (lush) from the Middle Kuskokwim were used by DHSS to create region-specific consumption guidelines. DHSS advises

women who are, or may become, pregnant, to eat smaller, younger, fish. These fish generally have lower mercury levels (Kossover et al., 2016). Otherwise, the cultural importance, and nutrition, of subsistence foods in Alaska is greater than that of store-bought foods, and consumption should still be encouraged.

Residents of Upper and Lower Kalskag, Aniak, Napaimute, collect surface water samples to monitor changes in temperature and pH (how acidic/basic the water is). Residents of Chuathbaluk sample surface water to monitor changes in Volatile Organic Compounds[1] (VOCs), Semi-Volatile Organic Compounds[2] (SVOC), and nitrates[3] in addition to monitoring pH and temperature. Sites at Georgetown sample for VOCs, SVOCs, temperature, pH and metals. Sleetmute samples for pH and nitrates, as well as for alkalinity[4], salinity[5], and turbidity[6]. The last monitoring site is at Telida, where samples are taken to monitor temperature, pH, turbidity, conductivity[7], metals, and nitrates. Between 2012 and 2017, water temperatures reached 59°F during peak salmon run months of May – August. Metals were also detected in concentrations higher than the Alaska Department of Environmental Conservation standards. These measurements provide important baseline information as the environment changes. Long term monitoring will help determine what impact these changes have on the health of the Kuskokwim River ecosystem (Witte). Results of water quality testing can be found in the online Kuskokwim Tribal Baseline Water Quality Data GIS database, maintained by Georgetown Tribal Council.

Lush Fishing
Photo by Megan Leary

1 Volatile Organic Compounds (VOCs) are chemicals that can dissolve in water or vaporize in the air. They are found in petroleum products such as gasoline or diesel fuel, as well as paints and solvents (USGS).

2 Semi-Volatile Organic Compounds (SVOCs) are found in many of the same products as VOCs, but are more persistent, meaning they are more difficult to remove from the environment.

3 Nitrates are a form of nitrogen and can be found in wastewater treatment plants, failing septic systems, and industrial discharge. Nitrates are an essential nutrient for plants, but in excess can affect fish and animal health (EPA).

4 Alkalinity of water is dependent on the presence of other chemicals that either allow, or do not allow, water to neutralize acids and bases and maintain a stable pH (USGS).

5 Salinity is a measure of how much salt is in the water.

6 Turbidity is a measure of how much sediment is in the water.

7 Conductivity is a measure of inorganic dissolved solids in the water that either allow, or do not allow, the water to pass an electrical current (EPA)

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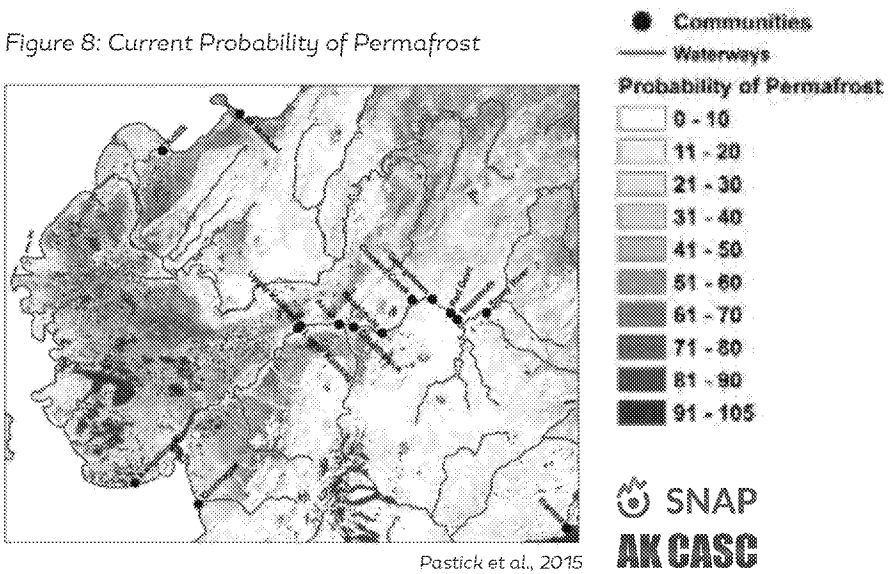
Landscape

Climate Summary Points:

- In Western Alaska, permafrost occurs closer to the coast and becomes discontinuous (more sporadic) inland. As temperatures warm, the Middle Kuskokwim is projected to be nearly free of permafrost between 2040 and 2099.
- A slight increase in the number of wildland fires is expected to occur by 2099. This increase may also lead to a slight increase in the rate of vegetation change, but the area is still expected to support spruce forest.

Figure 8: Current Probability of Permafrost



Pastick et al., 2015

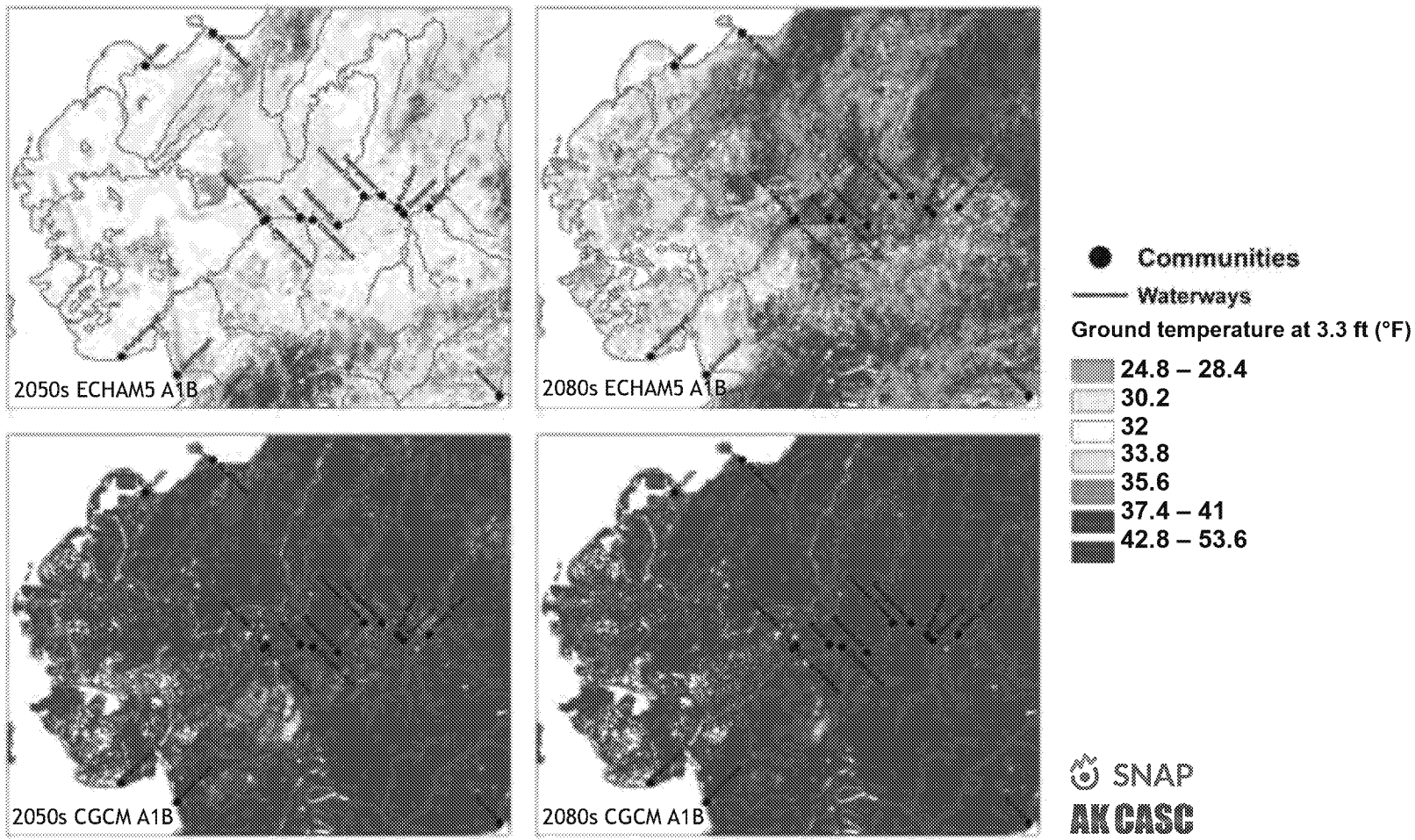
Permafrost Thaw

Many factors influence the distribution of permafrost in Alaska, including the climate, hydrology, vegetation, and geology. In Western Alaska, permafrost is more likely to be present closer to the coast, with discontinuous permafrost occurring farther inland. As temperatures warm, the distribution of permafrost is changing as thawing occurs. Thawing permafrost can lead to change in many different parts of the ecosystem, influencing the behavior and distribution of fish and wildlife. Landscape changes include soil subsidence and water movement that contribute to thermokarst terrain in the lowlands, and landslides and erosion in the uplands. Changes in soil temperature and moisture content may allow different plants to thrive, altering the distribution of dominant vegetation in that area. As permafrost thaws, nutrients stored in the frozen soil are released and flow in to the groundwater, eventually flowing in to rivers and lakes (Schuur and Mack, 2018).

Two models are used to project possible permafrost scenarios. MRI-CGCM3 and NCAR-CCSM4 are both climate models from the Coupled Model Intercomparison Project (CMIP5) generation of climate models used in the fifth Intergovernmental Panel on Climate Change assessment and have been found to perform well over the Arctic and Alaska (Walsh et al. 2017). The futures simulated by these models are considered equally likely, but CCSM4 projects warmer temperatures over much

of Alaska than CGCM3. The two scenarios can be used to understand a range of conditions when paired with different scenarios of future greenhouse gas concentrations such as those consistent with RCP 4.5 for moderate warming and RCP 8.5 for higher warming.

Figure 9: Change Annual Average Soil Temperature at 1 Meter Depth



Iafarov et al. 2013, Romanovsky and Marchenko 2013

In the Middle Kuskokwim region, communities along the river have documented the increase of arsenic, antimony and mercury in the river water as the permafrost thaws and the river banks erode (Matz etal., 2017). In some communities, such as Stony River, the eroding coast is coming closer to homes and other community infrastructure. Stony River residents are adapting to the erosion by using brush, shrub, and other vegetation to reduce soil exposure, educating community members about how cutting trees affects erosion, and continually monitoring river bank reduction and water levels.

Away from the river, permafrost is changing the landscape in other ways. Permafrost freeze and thaw causes the ground to heave. In some areas, this can shift houses, and damage roads. Road repair is expensive, but can also lead to vehicle damage or interruptions in road access if not addressed. Traveling across the land, residents have noticed that there are more landslides, especially between Bethel and Red Devil. In a LEO Network post from Chuathbaluk, submitted in June of 2014, Robert Hairell wrote that an ATV trail leading in to the Russian Mountains was eroding as the permafrost thawed. The trail was used by community members traveling to pick berries and go hunting (Hairell, 2014). Underground cellars are less common than in previous years, but are still used to store perishables, especially at camps. As permafrost thaws, and cellars are no longer an option, people have to make more frequent trips between camps and their community for perishable foods.

Changes in permafrost may also affect groundwater in the Middle Kuskokwim region. Frozen permafrost restricts groundwater movement, but as it thaws, standing water may soak in to the thawing soil. Middle Kuskokwim residents note that ponds and lakes, once used for hunting, have dried up, signaling possible thaw in those areas. Each community in the Middle Kuskokwim is served by either an individual household well or a community well. Changes in air temperature, the amount of water entrained in the April 1st snowpack, and permafrost thaw may also affect the movement of groundwater serving these wells.

Erosion, Stony River
Photo by Elizabeth Willis

Dust

In communities without paved roads, road dust is becoming a constant issue. Middle Kuskokwim residents remember when the air used to smell fresh in the spring, but now, there are more days when dust is a problem. During winters with less snow, the road becomes exposed and dries out, causing dust during a season when it isn't usually a problem. In the summers, road dust is a frequent concern as vehicles drive up and down the road. More people are experiencing allergies to road dust, and are sometimes more inclined to spend time inside where the air quality is better. Trees and other types of vegetation are important in dust control, but are often cleared as a method of wildfire control.

"When I was little, it used to be fresh. We could smell the leaves, and smell the air. There was not so much dust when I was small. We used to play all over. It so dusty now, we can't smell the freshness."

—Phyllis Evan, Lower Kalskag

Bank protection, Stony River
Photo by Elizabeth Willis

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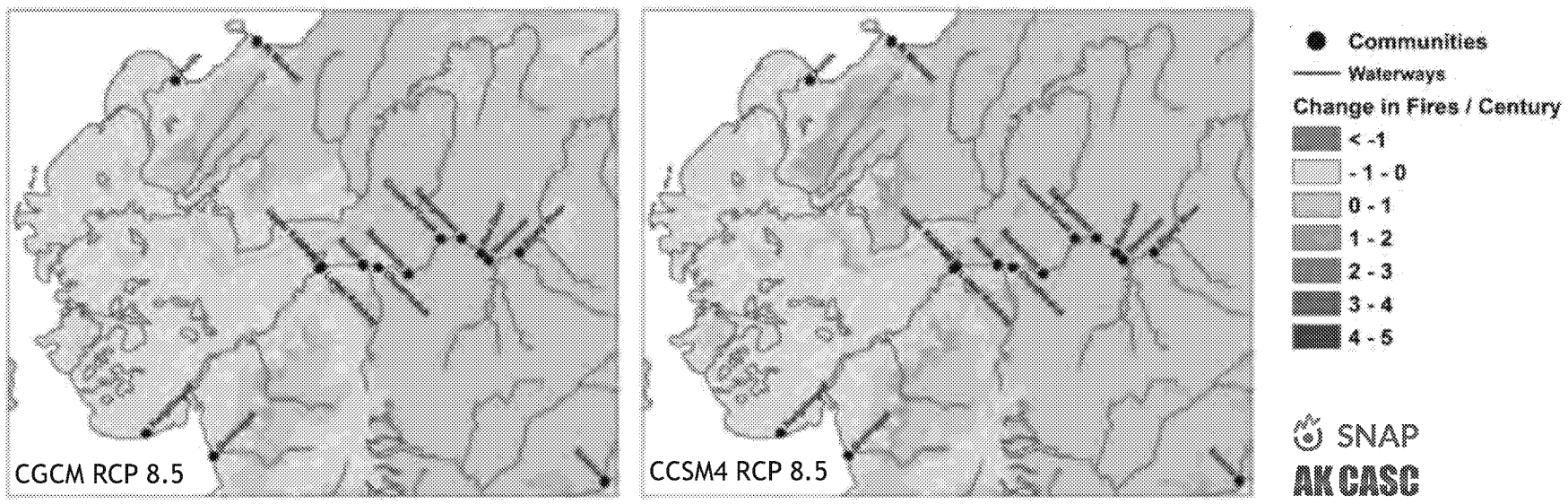
Wildfire

Middle Kuskokwim residents have experienced an increase in the number of wildfires, especially during dry years, and more that are caused by lightning strikes. Nearby wildfires may threaten some structures if the area is not cleared of vegetation that can fuel the fire. Wildfire smoke causes significant decreases in outdoor air quality. Elders, and others with respiratory problems, have difficulty breathing when the air is filled with smoke. Poor air quality due to wildfire smoke has occasionally prevented travel in and out of the area.

Figure 10: Change in the Number of Forest Fires per Century



Mann et al., 2012

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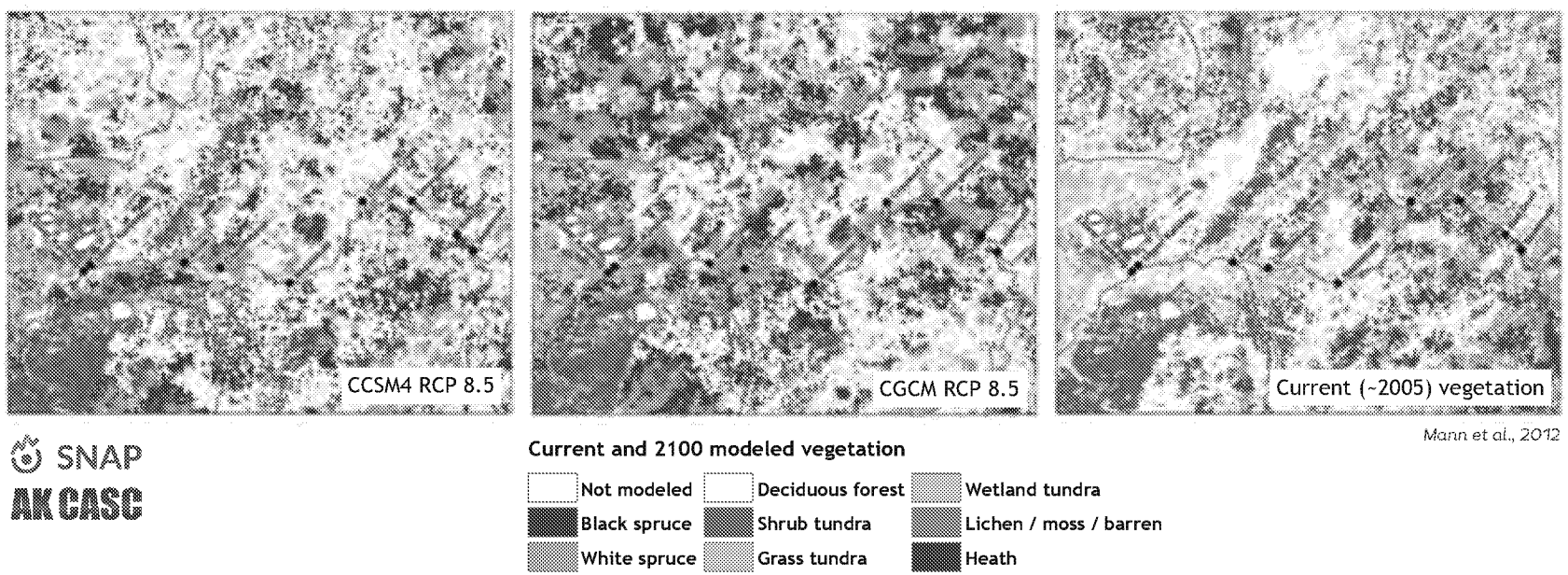
Fire is an important part of forest and tundra ecosystems and helps rejuvenate habitats, provides nutrients to the soil, and promotes vegetation diversity. However, warmer air temperatures are one factor in thunderstorm development and can increase the number of fires from lightning strike (Alaska Division of Forestry, 2019). Under both a lower (RCP 4.5) and higher (RCP 8.5) emissions scenario, the Middle Kuskokwim area will see a slight increase in the number of fires per century by 2099. The increase in fire activity may cause vegetation to change at a slightly higher rate, and lead to a gradual transition from spruce to deciduous forest in some areas.

Figure 11: Change in Dominant Vegetation per Century



Mann et al., 2012

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Sisters cutting fish
Photo by Megan Leary

Fishwheel
Photo by Megan Leary

Plants and Animals

The harvest of large and small land mammals, salmon and non-salmon fish, migratory waterfowl and game birds, as well as edible plants and berries is central to the livelihood and tradition of Middle Kuskokwim residents. Changes in temperature, precipitation, permafrost distribution, and the frequency of forest fires, among other species pressures, all impact the distribution and abundance of plants, animals, and fish that people depend on. Residents have observed changes in resource abundance and seasonal timing that affect when and how people harvest. Some hunting and gathering activities require people to travel farther from home, which means more time away from work and more money spent on fuel. Rather than spend more money on travel, some are opting to purchase more food from the local stores, which is less nutritious than traditional foods.

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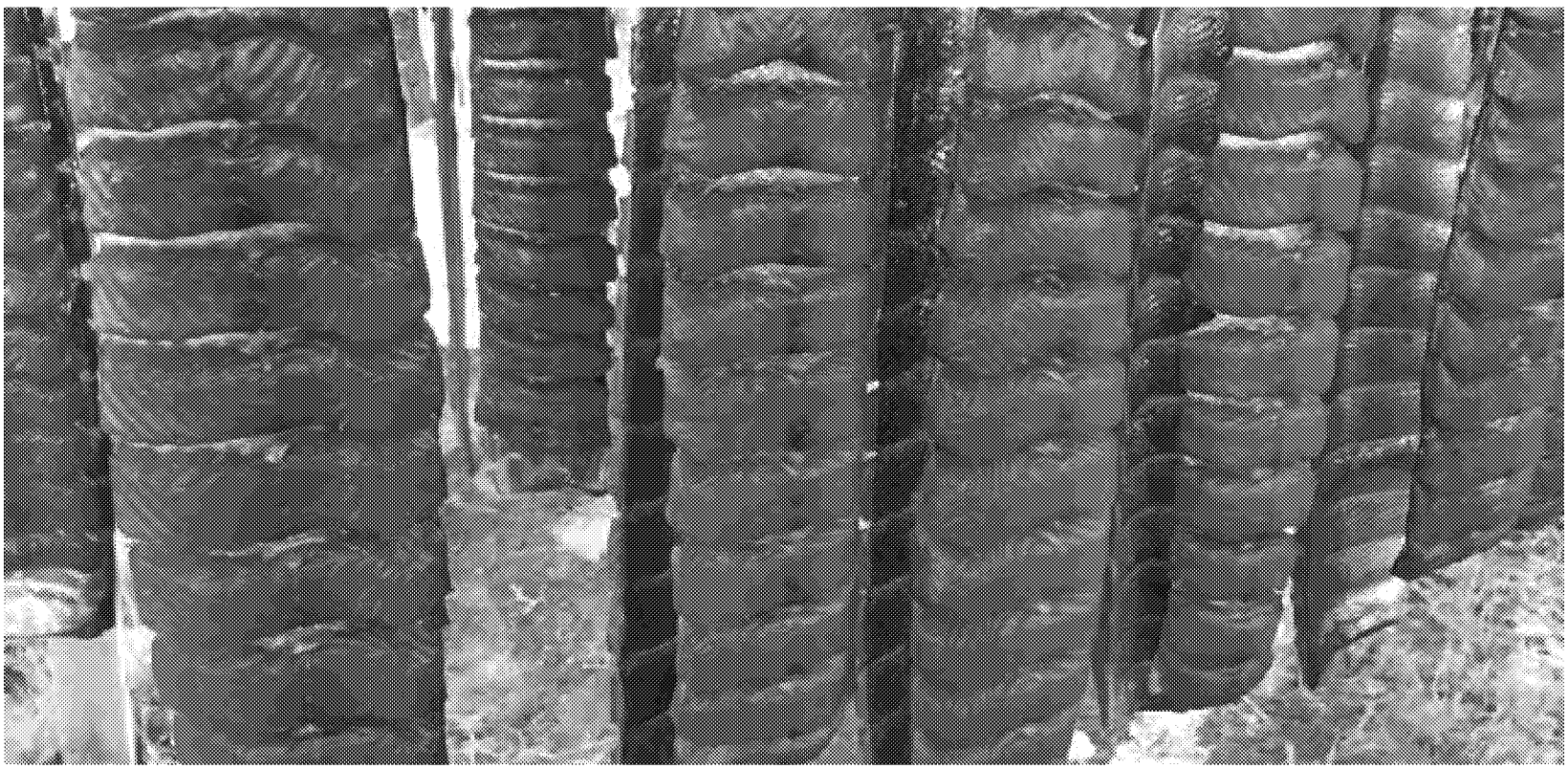
In 2009, the Alaska Department of Fish and Game (ADF&G) Division of Subsistence surveyed the communities of Aniak, Chuathbaluk, Crooked Creek, Lower Kalskag, Red Devil, Sleetmute, Stony River and Upper Kalskag, to understand contemporary harvest and use of subsistence resources. King (Chinook), dog (chum), and coho (silver) salmon made up 65% percent (by weight) of the regional subsistence harvest, followed by moose (11%) and other resources (24%) including non-salmon fish and beaver.

Salmon fishing is central to the history, culture, and lifestyle of the people who live along the Kuskokwim River. The health and abundance of salmon have the potential to be impacted by variables in both freshwater and ocean ecosystems, but residents of the Middle Kuskokwim have seen changes in the abundance of salmon that run up the river. People recalled times in years past, when one net catch full of king salmon would fill the boat. Now, people can no longer rely on adequate numbers of king salmon, and rely more



Drying slabs
Photo by Mary Peltola

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heavily on the harvest of other salmon species. When fishing primarily for king, the season used to be over before the Fourth of July, and people had time to attend community festivities and pick berries. However, dog, red (sockeye), and silver salmon run later in the season than king salmon, and are fished after the Fourth of July holiday. More rain falls after the holiday, and makes traditional practices of drying and smoking fish more challenging by increasing the risk of spoilage.

Concerns about the health of fish are related to concerns about water quality. Warmer waters stress the fish and allow more parasites and diseases to thrive, and residents say that more salmon are caught with internal worms, and physical abnormalities such as small bumps and growths. Warmer water also leads to low levels of dissolved oxygen, a phenomenon that was responsible for the deaths of pre-spawned dog and pink salmon across Alaska during the summer of 2019.

Salmon are also observed to be smaller. A common method of cutting fish to dry is called the "butterfly cut," or the "blanket cut," where the back bone is removed and two similar sized salmon are tied together, dried and smoked.

Some women are noticing that these cuts are not being used or taught with the smaller sized salmon.

Moose provide a significant amount of healthy meat to the Middle Kuskokwim communities, but changes in moose populations and health are concerning residents. At the time of the ADF&G Division of Subsistence survey, moose populations were below the Board of Game regulatory objectives due to low calf-to-cow ratios and low bull-to-cow ratios (Brown et al., 2009). Although moose populations have begun to recover in this area (Wells, 2014) some successful hunters find that harvested moose are skinnier than usual, or have worms in the meat. Hunts are also becoming more

Smelt fishing
Photo by Megan Leary

Megan Shelley at the fish table
Photo by Megan Leary

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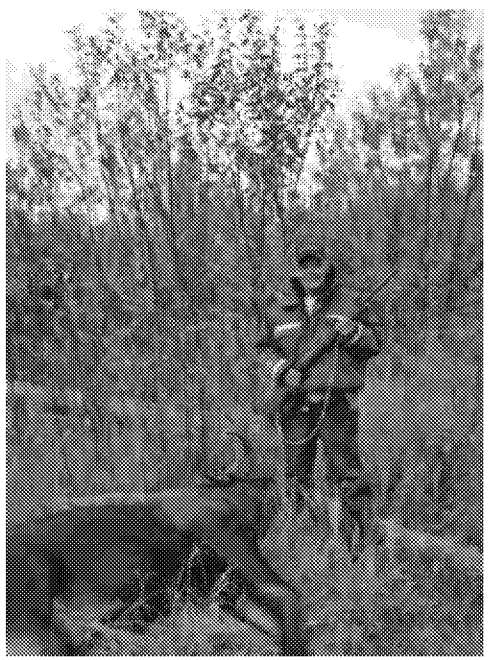
difficult as warm temperatures in September keep animals from moving around. Overall, more moose are observed moving downriver than has been usual in the past. This benefits some communities, but others struggle to travel so far.

Berries are an important cultural food source for people who live in the Middle Kuskokwim, but their distribution and abundance are fluctuating. The Middle Kuskokwim area is home to a variety of berries including kavlak or bear berries *(Arctostaphylos alpine)*, cingqullektaq or air berries *(Cornus suecica)*, tan'gerpiit or crowberries/blackberries *(Empetrum nigrum)*, uingiaraat or bog cranberry *(Oxycoccus microcarpus)*, mercuullugpiit or red currant *(Ribes triste)*, puyuraarat or wild raspberry/dward nagoonberry *(Rubus arcticus)*, atsalugpiaq or salmonberry/cloudberry *(Rubus chamaemorus)*, curat or blueberry *(Vaccinium uliginosum)*, kavirlit or low bush cranberry *(Vaccinium vitis-idaea)*, and agautaat or high bush cranberry *(Viburnum edule)*. When there is little rain and snow during the year, berries are observed to be less abundant. However, two years after a fire has burned through the area, berries will often be found in abundance, ripening earlier than usual when summer temperatures are warm. In other areas, places where berries used to grow are covered by trees and grasses. Warm temperatures lead to longer growing season for plants, and more people experience spring and summer allergies. In a LEO Network post submitted in April of 2016, Patricia Yaska describes seeing buds on the birch trees in Chuathbaluk, two months earlier than normal after a mild winter with little snow (Yaska, 2016).

Many plants have been traditionally used as medicines, to treat ailments such as boils, cuts and infections, as well as ease teething pain for babies. Although use of traditional plants have decreased over time, they are still important both culturally and for medical use. A new threat to traditional plants use is the emergence of invasive plants that are benefiting from warming temperatures. One example of this



Moose hunt
Photo by Verdene Morgan

Blueberry picking
Photo by Mary Peltola

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can be seen in the changing distribution of Caiggluk or wormwood *(Artemisia tilesii)* around Stony River. Traditionally, this plant is used for treating rashes, congestion, chest pain, and other ailments. Dandelions (genus *Taraxacum*) are now growing on the sides of roads, lawns, and in grass fields where Caiggluk used to grow in abundance. In the Middle Kuskokwim, other invasive plants such as splitlip hempnettle *(Galeopsis bifida)*, narrowleaf hawksbeard *(Crepis tectorum)* and yellow toadflax *(Linaria vulgaris)* have already become established in the region. Canada thistle *(Cirsium arvense)*, oxeye daisy *(Leucanthemum vulgare)*, spotted knapweed *(Centaurea biebersteinii)* and meadow hawkweed *(Hieracium caespitosum)* are all present in other Alaskan landscapes, and have the potential to establish themselves in the Middle Kuskokwim as well. Invasive aquatic plants such as elodea *(Elodea Canadensis)* and reed canary grass *(Phalaris arundinacea)* may also become a concern in lakes and streams ((b) Koopman, 2017).

As conditions continue to change and become unpredictable, residents have noticed a change in diets. The majority of food used to be provided by hunting, fishing and gathering. These foods used to be available all the time but are now reserved for special events. People are purchasing meat and shelf stable foods to augment subsistence diets. Shelf stable foods allow budgets to stretch farther, as fresh foods available in stores are often cost prohibitive. As diets have changed, residents have noticed an increase in symptoms of food allergies and intolerances. Residents raised concerns about dietary change and the potential implications for chronic diseases such cancer and diabetes, which may be related to changes in diet and exercise.

The price of butter
Photo by Mary Peltola

Fish soup
Photo by Mary Peltola

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46

Changing Communities

ED_013708_00000184-00220

"Activities feed our soul and with regulations that say you can't fish, it crushes our soul."

—Marce Simeon, Napaimute

Difficult and dangerous conditions, compounded by the high price of fuel, are preventing people from traveling for gatherings and subsistence activities. Traditional activities such as hunting, fishing, and steaming provided important opportunities for people to connect with each other and maintain healthy relationships. Even taking a steam or packing water, provided outlets for excess energy. Middle Kuskokwim residents notice fewer people engaging in outdoor activities, and instead people spend more time inside with their attention to phones and television.

Physical activity, and time spent on the land, is crucial for maintaining mental health and wellbeing. When conditions prevent people from traveling outside the village, it is more difficult to find healthy emotional outlets. Stress in individuals leads to stress in the broader community. Elders used to take children out camping and berry picking, and use that time to pass on traditional knowledge and values, and teach children to be respectful. Today, elders are frustrated because their knowledge is difficult to apply in a changing climate.

Time spent outside improves physical health as well as mental health. When people spend more time inside, seasonal colds and flus linger longer. There are more instances of walking pneumonia and other respiratory issues, which cause people to miss school and work.

" *As indigenous people we are designed very complex. Health and wellbeing depend on different things - physical, mental, spiritual health - everything is connected. What is ecological knowledge? Everything is inter-twined. When I think about health, what we need to be healthy, it is what everyone has said. It is unsafe to travel, we have to go farther or work harder and that is expensive. By design, we are meant to take care of each other. As young men, we are supposed to be providers. When we are not able to do that, it affects physical, mental and spiritual health. Loss of a diet is a loss of a role and that leads to unhealthy choices. We focus on physical health but we have a lot of connections and those are seen more as things change."*

—Jonathan Samuelson, Georgetown and Red Devil

Fish cutting contest
Photo by Harvey Hoffman

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Adapting to Change

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"Change has empowered our youth. I used to look around the room and be the youngest person there. But not anymore. Things are more unpredictable and a lot is new so young people are learning at the same time as our elders. It evens the playing field a little – it empowers them to contribute in new ways and inspires more self-confidence. Youth can use the new technology. In some ways, it can bring us back together."

—*Jonathan Samuelson, Georgetown*

The adaptation planning process had three stages. Residents of the Middle Kuskokwim communities met in February of 2019 to share observations about the types of environmental changes occurring in the region, and the impact those changes have on community health, travel, infrastructure, and the economy. Residents met again during August of 2019 to identify priority adaptation areas and develop adaptation goals and project ideas. Middle Kuskokwim residents gathered together for a third time in February 2020 to further discuss future projects and meet with potential agency partners.

Conversations about environmental change during the first adaptation planning meeting resulted in 66 statements of change categorized by topic area and impact. Topic areas included weather and temperature, river water quality and ice, landscape, plants and animals, and community life. Impact categories included physical health, mental wellbeing, activities and relationships, food security, travel, economy and infrastructure.

Tribal gathering
Photo by Harvey Hoffman

Summary of Observed Environmental Change

TEMPERATURE & PRECIPITATION	*Overall, annual temperatures and annual precipitation are increasing.* *Weather is becoming unpredictable, and disrupting traditional activities that are based on predicable patterns.*
RIVER ICE	*The Kuskokwim River is freezing later and thawing earlier. Where the river is frozen, there are more areas of unstable ice. Parts of the river do not freeze at all. Changing ice conditions make travel on the river ice more dangerous.*
RIVER WATER	*Water temperatures are warming. Warm water holds less oxygen for fish, and allows parasites and other diseases to thrive.*
PERMAFROST	*Permafrost thaw is causing the river banks to erode more rapidly. Eroding river banks have increased the amount of arsenic, antimony, and mercury in the river water.* *Permafrost thaw is heaving the ground. As the ground heaves, building foundations and roads are damaged.*
AIR QUALITY	*Reduced air quality from dust is becoming an issue year-round. In years with low snow cover, the exposed ground dries and more dust is created.* *There are more wildfires in years with less precipitation. Elders, and others with respiratory problems, have difficulty breathing when the air is filled with smoke.*
VEGETATION	*Invasive vegetation pushes out plants that are traditionally used for traditional medicines. Overall, the use of traditional medicine has decreased as plants become more difficult to find.*
FOOD SECURITY	*Health and abundance of salmon are changing. Changes in the abundance of king (Chinook) salmon cause more people to rely on sockeye salmon, which migrate later. Processing time overlaps with the rainy season, which increases the risk of spoilage. Salmon are smaller, and are more frequently caught with signs of disease and parasites.* *The abundance of berries fluctuates based on precipitation and wildfire. When there is little rain and snow during the year, the berries are less abundant. If there is a wildfire, the berries will become more abundant two years afterwards.* *Moose are changing their migration patterns, which may be affected by changes in temperature and vegetation distribution. More moose are moving downriver, which benefits some communities, but others have to travel longer.*
COMMUNITY LIFE	*Changing weather conditions impact the ability of people to engage in traditional activities.* *Traditional activities such as hunting, fishing, and steaming provided important opportunities for people to connect to each other, and are based on predictable weather and temperature patterns. When these activities are not possible, physical and mental health suffers.* *Diets have changed. The majority of food used to be provided by hunting, fishing and gathering. These foods used to be available all the time but are now reserved for special events, and there is a shift to more shelf stable foods and commercial meat.*

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During the second adaptation planning meeting, Middle Kuskokwim residents discussed what the ecosystem may look like in the future, and the intrinsic connections between individuals, communities and the landscape. With these discussions in mind, meeting attendees reviewed and revised the statements of change, topic areas, and impacts, then prioritized each statement of change as "high," "medium," or "low" priority for adaptation.

Impact Prioritization

HIGH	*A critical activity that should be the focus of energy and resources*
MEDIUM	*Makes a substantial contribution to adaptation goals; lower priority for resources*
LOW	*Makes a contribution to adaptation goals, and should be developed as resources or opportunities become available*

Kwethluk fish meeting
Photo by Mary Peltola

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Fish camp
Photo by Mary Peltola

From the sixty-six statements, eleven statements were identified as high priority by nine or more (70%) of the people who attended the second meeting, and were reviewed again by the group. These statements described changes to:

Weather and Temperature

- "Berries also depend on snowpack, and there are fewer berries in dryer years."
- "Warmer temperatures make travel on the river and ice road dangerous."

River Water Quality and Ice

- "Water temperatures are fluctuating, which impacts salmon health. Warm water holds less oxygen for fish, and can also allow parasites and fish diseases to thrive."

Landscape

- "There are more wildfires in dry years. Wildfire smoke led to the evacuation of elders and children in Aniak."
- "Elders, and others with respiratory problems, have difficulty breathing when the air is filled with smoke. "

Plants and Animals

- "Diets have changed. The majority of food used to be provided by hunting, fishing and gathering. These foods used to be available all the time but are now reserved for special events."
- "The salmon are smaller and less abundant."
- "Salmon are more frequently caught with physical abnormalities."

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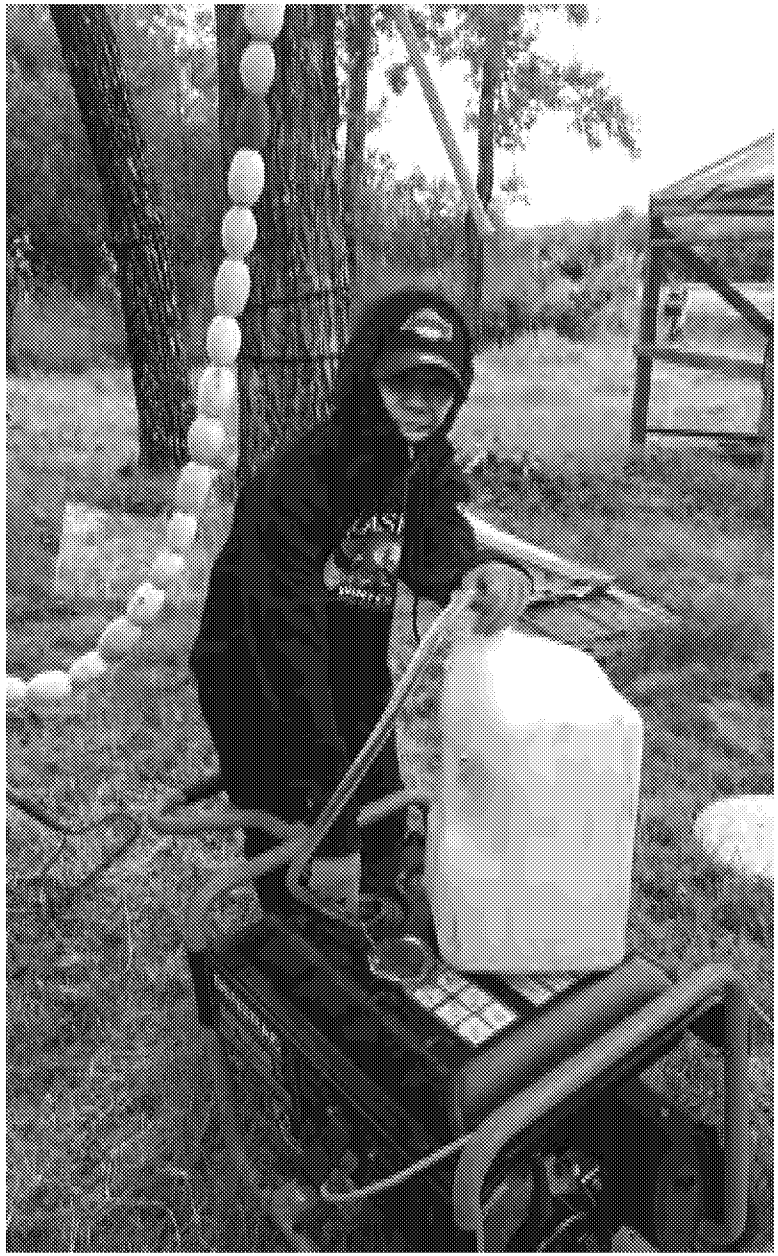
Community Life

- "People spend more time inside with their attention to phones and television. Emotional and mental health suffers from lack of physical activity."
- "Seasonal colds and flus linger longer, which may be related to people spending more time inside. Many people suffer from chronic diseases such as cancer and diabetes, which may be related to changes in diet and exercise."
- "The price of gas is expensive, making it expensive to travel for recreation and subsistence."

An additional statement, "*When the river levels are low, the barge carrying fuel cannot reach some communities. This drives up the price of an already expensive commodity,*" was added to the discussion by ANTHC staff. Adaptation strategies focused on alternative energy may also address aspects of the statements prioritized by the group.

As a group, workshop participants further explored each of the prioritized statements of change, identifying common themes and topic areas. Through discussion, the twelve statements were combined in to five adaptation focus areas. Each focus area was broken down in to specific goals, with project ideas, potential challenges and potential resources.



Gassing up generator
Photo by Mary Peltola

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Adaptation Priorities

Reconnecting Our People with the Natural World

Residents of the Middle Kuskokwim are observing changes to the land and water that affect traditional hunting, fishing and gathering activities. When people are not able to go out on the land, it is harder to learn traditions, values, and ways of understanding the landscape. Participating in community activities helps support physical activity by getting people out of the house and away from televisions and cell phones. These activities also build relationships between people, improving mental and emotional wellbeing.

Goal: Bring community members, including youth and elders, together in a series of activities to share skills, traditional knowledge, and values.

Fish
Photo by Verdene Morgan

Ensure Sustainable Populations of Fish, Game, and Vegetation to Increase the Availability of Traditional Foods

Changing environmental conditions are affecting the health of plants, animals, and fish, which people in the Middle Kuskokwim depend on. Traditional foods are an important part of community gatherings, and daily meals at home. Additionally, traditional foods provide more nutrition than store-bought foods.

To ensure that these resources are available for future generations, it is important to monitor the health of subsistence resources and understand what changes have been seen before and what changes are new. Residents of the Middle Kuskokwim are stewards to the land and the resources, and to continue this tradition, their knowledge and values need to be heard during regulatory decision making.

Goals:

- Amplify the voice of Middle Kuskokwim residents in fisheries related decisions.
- Build the confidence and skill in individuals to effectively communicate with regulatory agencies, journalists, and communities.
- Increase the number of Middle Kuskokwim residents trained as fish biologists and resource managers.
- Monitor the health of subsistence resources.

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Ensure Safe Ground Transportation

The Kuskokwim Ice Road is central to winter travel in the Middle Kuskokwim. As temperatures warm, the Kuskokwim River is freezing later than usual, experiencing mid-winter thaw and re-freeze, and breaking up earlier. Unpredictable ice conditions make winter travel over the frozen river dangerous and unreliable. Exploring other transportation methods will help provide safe, cost effective, alternatives when necessary.

Goals:

- Revitalize overland trails.
- Expand capacity for regular trail assessment and documentation.

Reduce the Impact of High Fuel Cost

As the rivers and landscape change, the timing of seasonal animal and fish migrations are changing as well. Middle Kuskokwim residents are spending more on fuel to access subsistence areas. Fuel is delivered to many of the Middle Kuskokwim by barge, but when the river is low or sand bars appear, the barge cannot make its delivery. In those instances, the cost of fuel increases. Partial reliance on renewable energy, and bulk fuel purchase, may allow residents to better accommodate fluctuations in fuel delivery and cost.

Goals:

- Reduce the cost of diesel and unleaded fuel through creation of a fuel consortia.
- Increase use of renewable energy.

Monitor Air Quality

The two primary causes of poor outdoor air quality in the Middle Kuskokwim region are wildfire smoke and road dust. While wildfire smoke is a seasonal issue, road dust is becoming a year-round problem as exposed areas of the ground dry without snow cover. Monitoring outdoor air conditions will allow Middle Kuskokwim residents to document air quality trends, and support adaptation activities like establishing clean rooms.

Maintaining indoor air quality is also important for a healthy living environment. As the landscape changes, disrupting some traditional activities, Middle Kuskokwim residents find themselves spending more time inside. Contagious colds and flus tend to linger when people spend more time inside, but a combination of indoor air quality improvements and increased participation in outdoor community events will help maintain community health.

Goals:

- Improve indoor air quality and reduce instances of respiratory illness.
- Improve localized monitoring of outdoor air to improve the health of those with sensitive respiratory systems.

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Conclusion

2019 Clean Up Green Up
Photo by Harvey Hoffman

Reliance on customary ways and continuous adaptation have traditionally made Kuskokwim communities resilient. By sharing stories of change, and developing adaptation priority areas, the Middle Kuskokwim communities have shown their commitment to creating a safe, sustainable future for generations to come.

Tug-of-war, Stony River
Photo by Elizabeth Willis

"Elders long ago were not rich with money, they were rich with knowledge about gathering resources and making it through winter."

—Nick Levi, Lower Kalskag

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Aniak session 2017
Photo by Byron Nikolai

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Appendix A

Climate Change and Health Matrix

TOPIC	DESCRIPTION	OBSERVED CHANGE	COMMUNITY IMPACTS
Weather	Temperature	Increase in year-round air temperature, especially during winter	Variability in river ice quality impacts travel on the ice road
	Precipitation	Variable snowfall amounts	Fewer opportunities to travel by snowmachine and participate in regional activities
		More rain during winter	Roads and walkways become covered in ice
Air	Air Quality	Exposed ground during winter leads to unseasonable road dust	Increased number of days during the year when outdoor air quality is poor Decrease in indoor air quality as people spend more time indoors
		Increase in frequency of wildfire	
		Increase in the duration of seasonal pollen events, and potential for new types of pollen events as vegetation changes	
Water	River Water Quality	Permafrost thaw is increasing the levels of arsenic, antimony, and mercury in river water	Concern about the bio-accumulation of mercury, and other metals, in pike and burbot (lush)
		River water temperatures are rising	Salmon are more frequently caught with signs of disease and parasites
	Groundwater	Permafrost thaw may change ground water movement	Combined with changing temperatures, precipitation, and amount of water entrained in the April 1st snowpack, wells may recharge at different rates
Land	Infrastructure	Permafrost freeze and thaw is heaving the ground	These frost heaves shift buildings and roads
		Permafrost thaw is contributing to river bank erosion	In some communities, erosion threatens community infrastructure
			Erosion increases the amount of sediment in the water, which may prevent barges and boats from traveling safely
Wildlife	Food Security	Moose are changing their movement patterns, which may be related to changes in temperature and vegetation distribution	Disruption of subsistence practice and nutritious food consumption
Vegetation	Traditional Medicine	Increasing abundance of invasive plants	Decrease in the abundance of native plants used for traditional medicine

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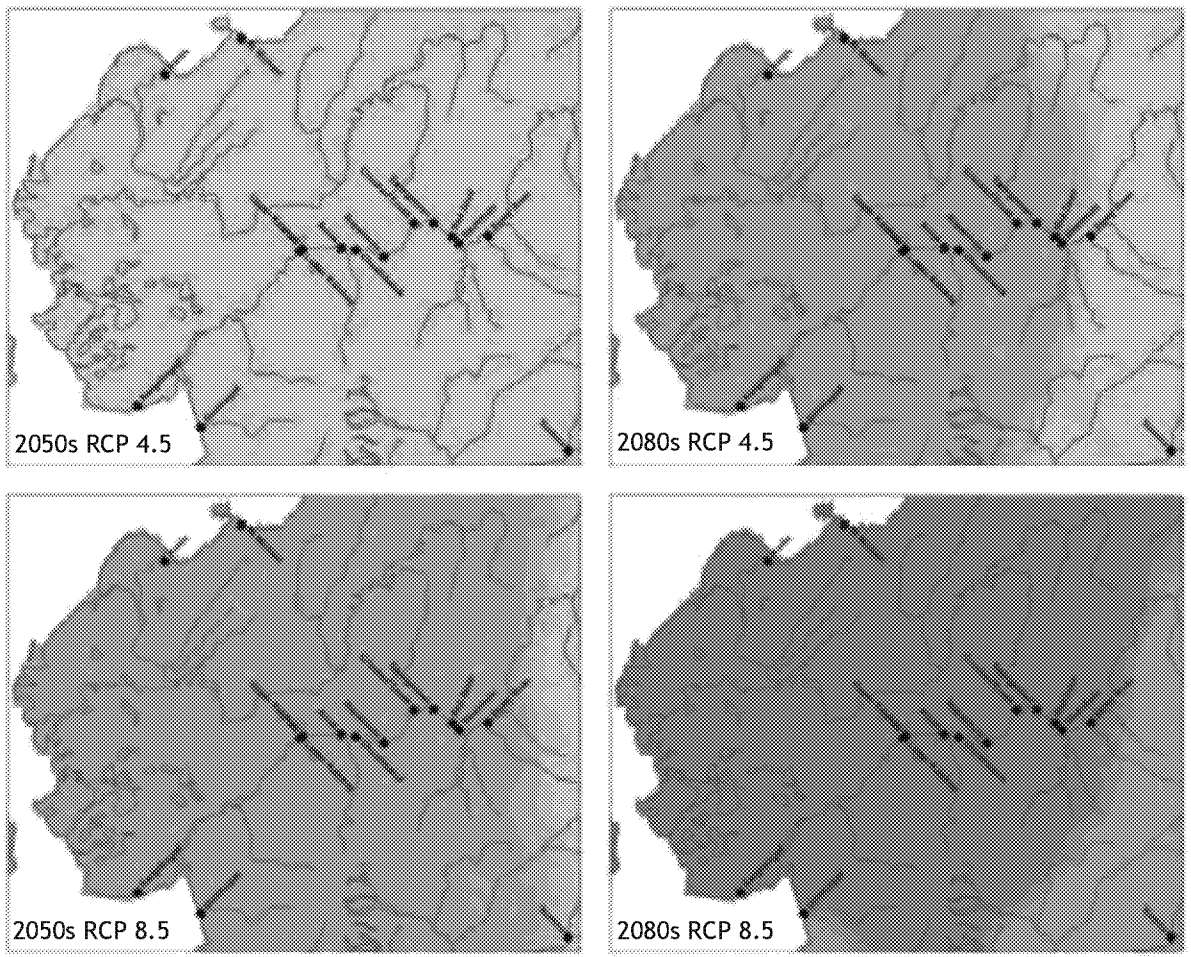
HEALTH CONCERNS	RECOMMENDATIONS
Poor ice conditions increase the risk for accidents during travel.	**Included in 2019 Plan:** Explore phone app to share ice road conditions **Included in 2019 plan:** Revitalize overland trails
Reduced physical activity and increased emotional stress	**Included in 2019 plan:** Bring community members together in a series of activities to share skills, traditional knowledge, and values
Increased risk for physical injury	**ANTHC Recommendation:** Start program to distribute ice cleats to community members, begin a community shuttle program
Respiratory health (sneezing, coughing, wheezing), headache, fatigue, and other associated symptoms	**Included in 2019 plan:** Monitor outdoor air quality **ANTHC Recommendation:** Create clean-rooms in each community, or create evacuation plan, for those with sensitive respiratory systems Implement speed limits to reduce road dust
According to the Alaska Department of Health and Social Services, too much mercury can harm the developing brain and nervous system of unborn babies and young children	**Included in 2019 plan:** Continue water quality monitoring and public notice of monitoring results **ANTHC Recommendation:**Follow the Alaska Department of Health and Social Services fish consumption guidelines for women who are, or who may become, pregnant
Salmon who show signs of illness or abnormality are not consumed, and present a threat to food security	**Included in 2019 plan:** Combine traditional knowledge and science to develop salmon health monitoring program
Middle Kuskokwim communities are served by well water. Changes in water availability may impact the ability of drinking water wells to provide enough water	**ANTHC Recommendation:** If water shortages occur or become a concern, use instruments, such as an electrical sounder, to monitor seasonal changes in water level Develop a plan to provide water to residents if shortages do occur
Damage or disruption of water and sanitary services may increase instance of illness and infection	**ANTHC Recommendation:** Document changes to infrastructure and roads using the LEO Network Identify areas impacted by thaw, and areas that are more resistant to thawing. Construct new infrastructure in resilient areas. Perform development, construction and maintenance in ways to preserve permafrost
Loss of homes and other community infrastructure	**ANTHC Recommendation:** Identify and relocate infrastructure that may be affected by riverbank erosion
Barges carrying fuel and other supplies may not be able to reach every community, which drives up the cost of fuel	**Included in 2019 plan:** Create a fuel consortia to reduce cost burden during fuel shortages, and increase use of renewable energy
Economic burden from the purchase of food from stores Market foods provide less nutrition	Included in 2019 plan: Combine traditional knowledge and science to monitor the health and distribution of subsistence resources
Decrease in the use of traditional medicines	**ANTHC Recommendation:** Develop eradication and re-vegetation program Included in 2019 plan: Combine traditional knowledge and science to monitor abundance of medicinal plants

Temperature – Annual (12 months) as well as four seasons (Spring – March to May; Summer – June to August; Autumn – September to November; Winter – December to February). These represent the change in degrees in surface air temperature, averaged over the year or three-month periods. The changes mapped are compared to the same months in the future projections from climate models.

Figure 1: Change in Annual Average Temperature over the Yukon-Kuskokwim Delta

Change in Annual temperature, F

- 3.2 - 4
- 4.1 - 6
- 6.1 - 8
- 8.1 - 10
- 10.1 - 12
- 12.1 - 14.3



These maps represent the change in annual average temperature (in F, relative to 1970-1999) for 5 climate models averaged together.

5 model means for the region

2040 - 2069, RCP 4.5: + 3.2
2040 - 2069, RCP 8.5: + 4.2
2070 - 2099, RCP 4.5: + 4.1
2070 - 2099, RCP 8.5: + 6.2

SNAP
AKCASC

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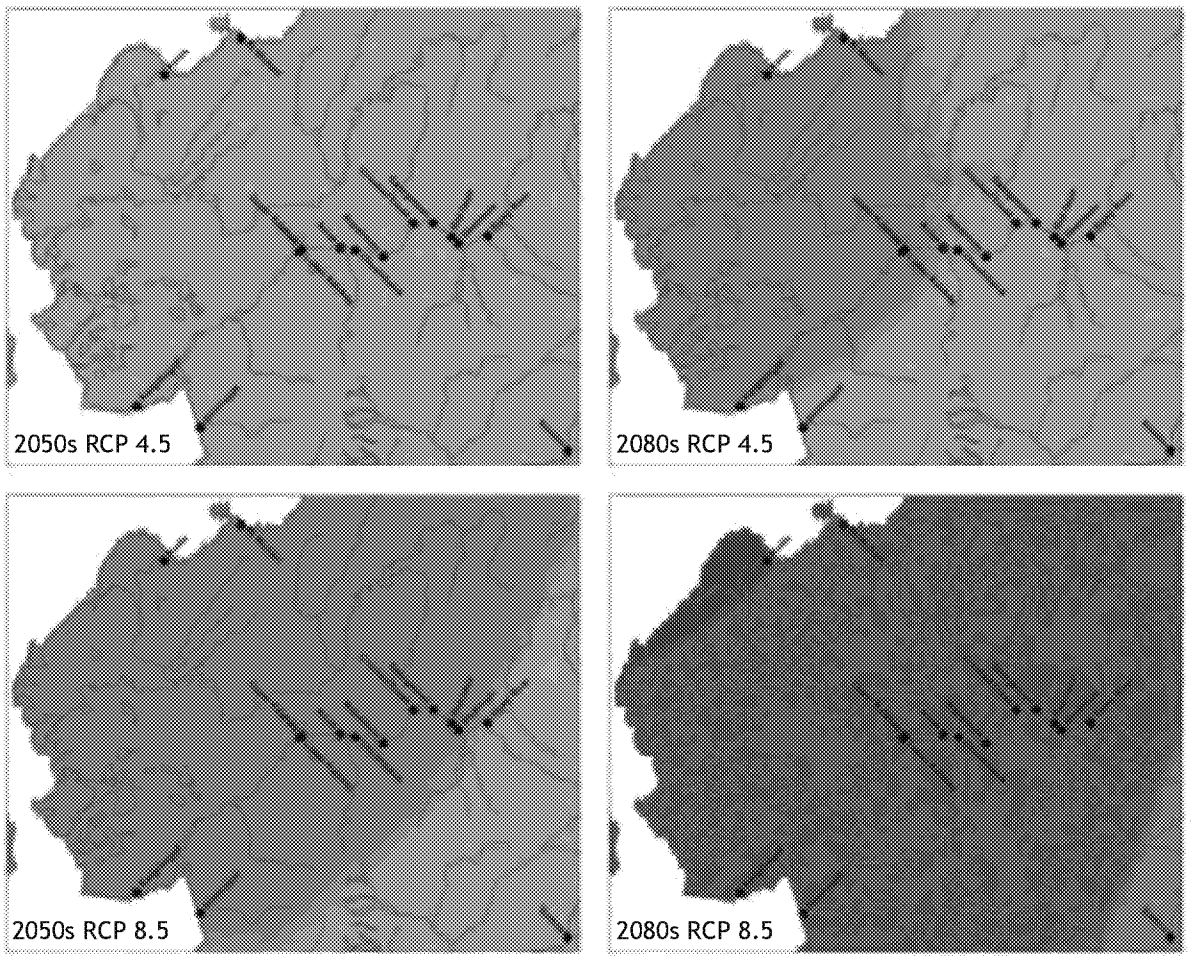
Figure 2: Change in Winter Average Temperature over the Yukon-Kuskokwim Delta

Change in Winter temperature, F

- 3.2 - 4
- 4.1 - 6
- 6.1 - 8
- 8.1 - 10
- 10.1 - 12
- 12.1 - 14.3



These maps represent the change in winter (December to February) average temperature (in F, relative to 1970-1999) for 5 climate models averaged together.

5 model means for the region

2040 - 2069, RCP 4.5: + 4.5
2040 - 2069, RCP 8.5: + 6.2
2070 - 2099, RCP 4.5: + 5.9
2070 - 2099, RCP 8.5: + 8.8

SNAP
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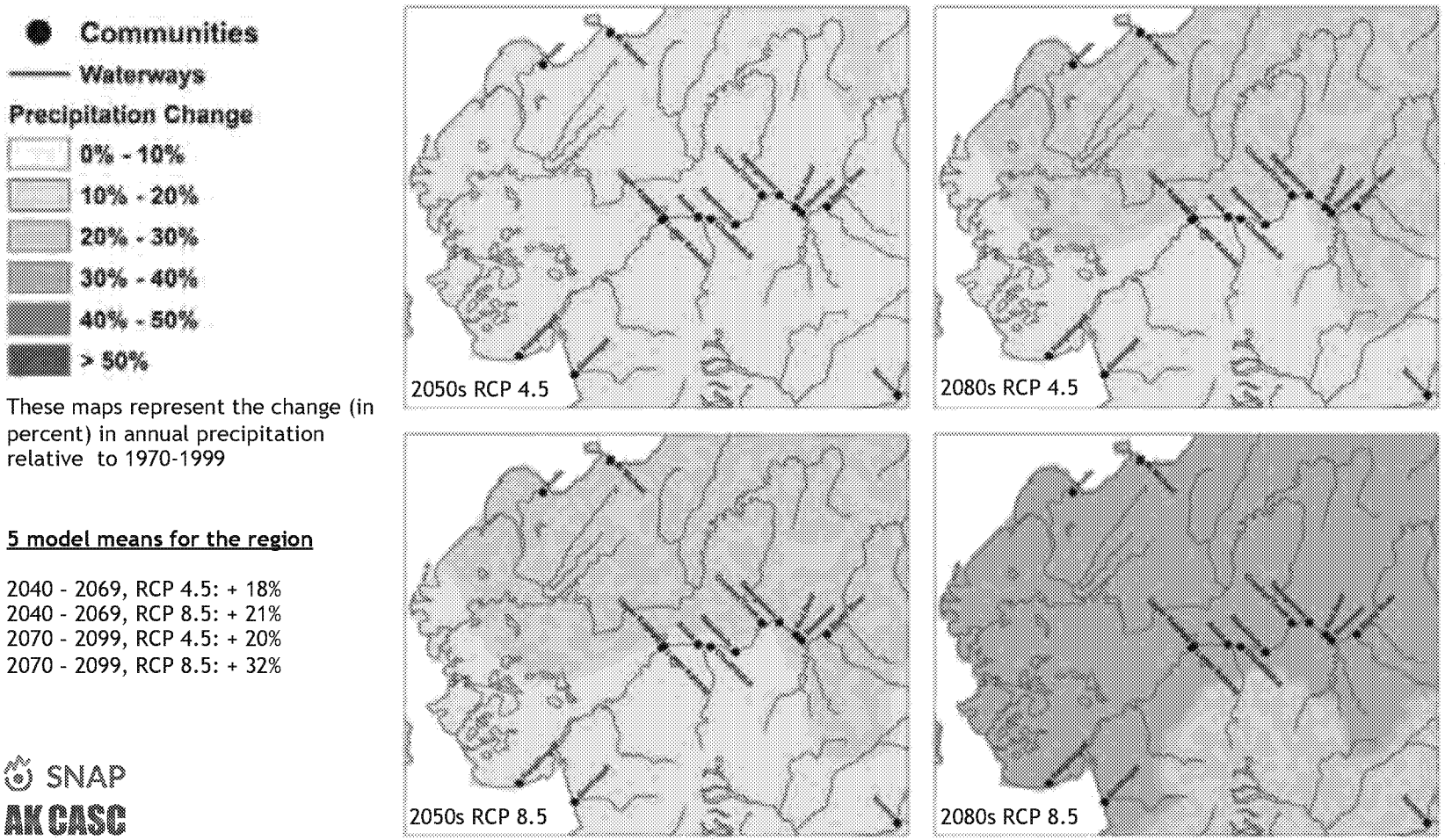
Precipitation – Annual (12 months) as well as four seasons (Spring – March to May; Summer – June to August; Autumn – September to November; Winter – December to February). These represent the percent change in total precipitation, averaged over the year or three-month periods. The changes mapped are compared to the same months in the future projections from climate models.

Figure 3: Change in Average Precipitation over the Yukon-Kuskokwim Delta



These maps represent the change (in percent) in annual precipitation relative to 1970-1999

5 model means for the region

2040 - 2069, RCP 4.5: + 18%
2040 - 2069, RCP 8.5: + 21%
2070 - 2099, RCP 4.5: + 20%
2070 - 2099, RCP 8.5: + 32%

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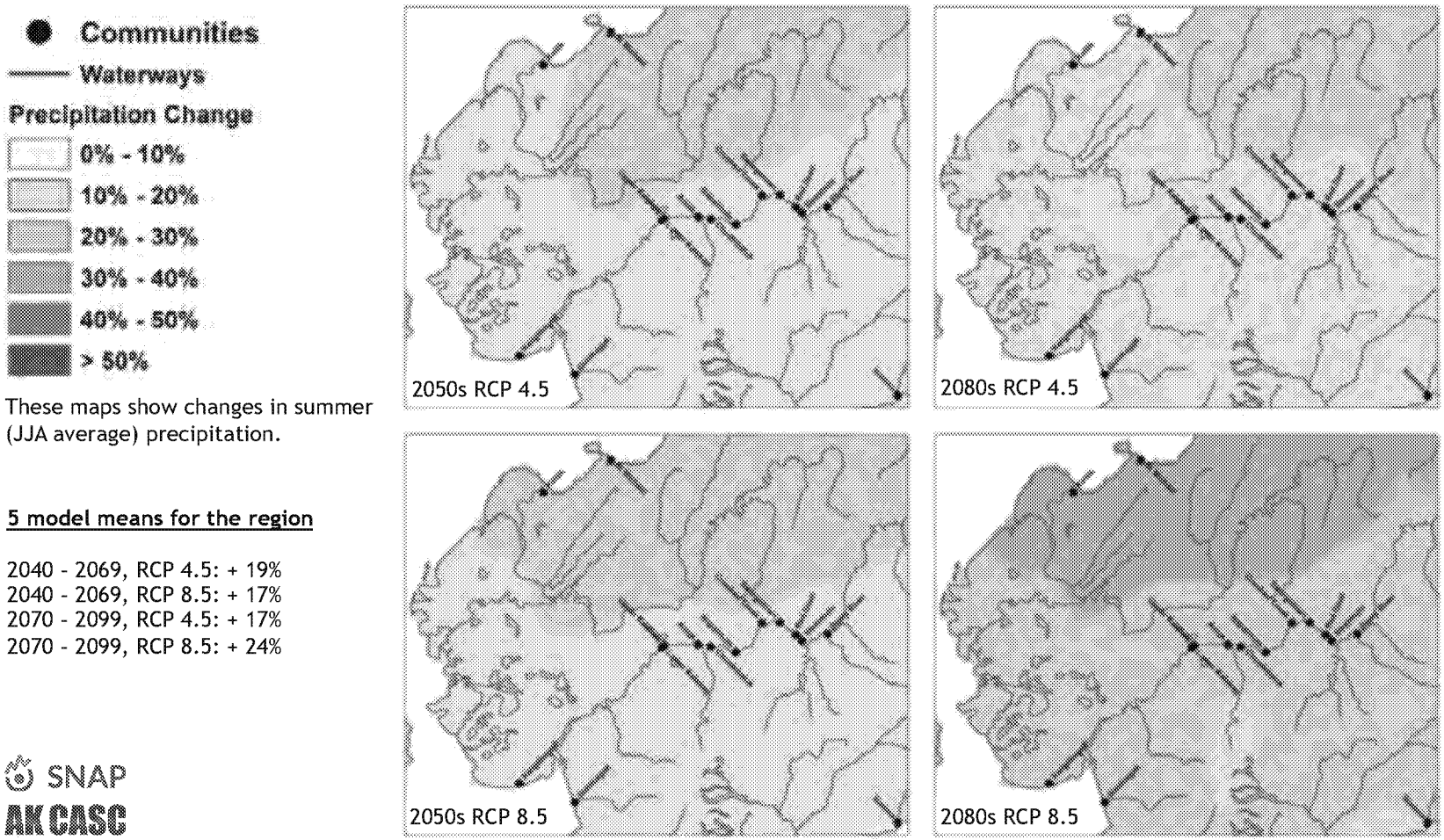
Figure 4: Change in Summer Average Precipitation over the Yukon-Kuskokwim Delta



These maps show changes in summer (JJA average) precipitation.

5 model means for the region

2040 - 2069, RCP 4.5: + 19%
2040 - 2069, RCP 8.5: + 17%
2070 - 2099, RCP 4.5: + 17%
2070 - 2099, RCP 8.5: + 24%

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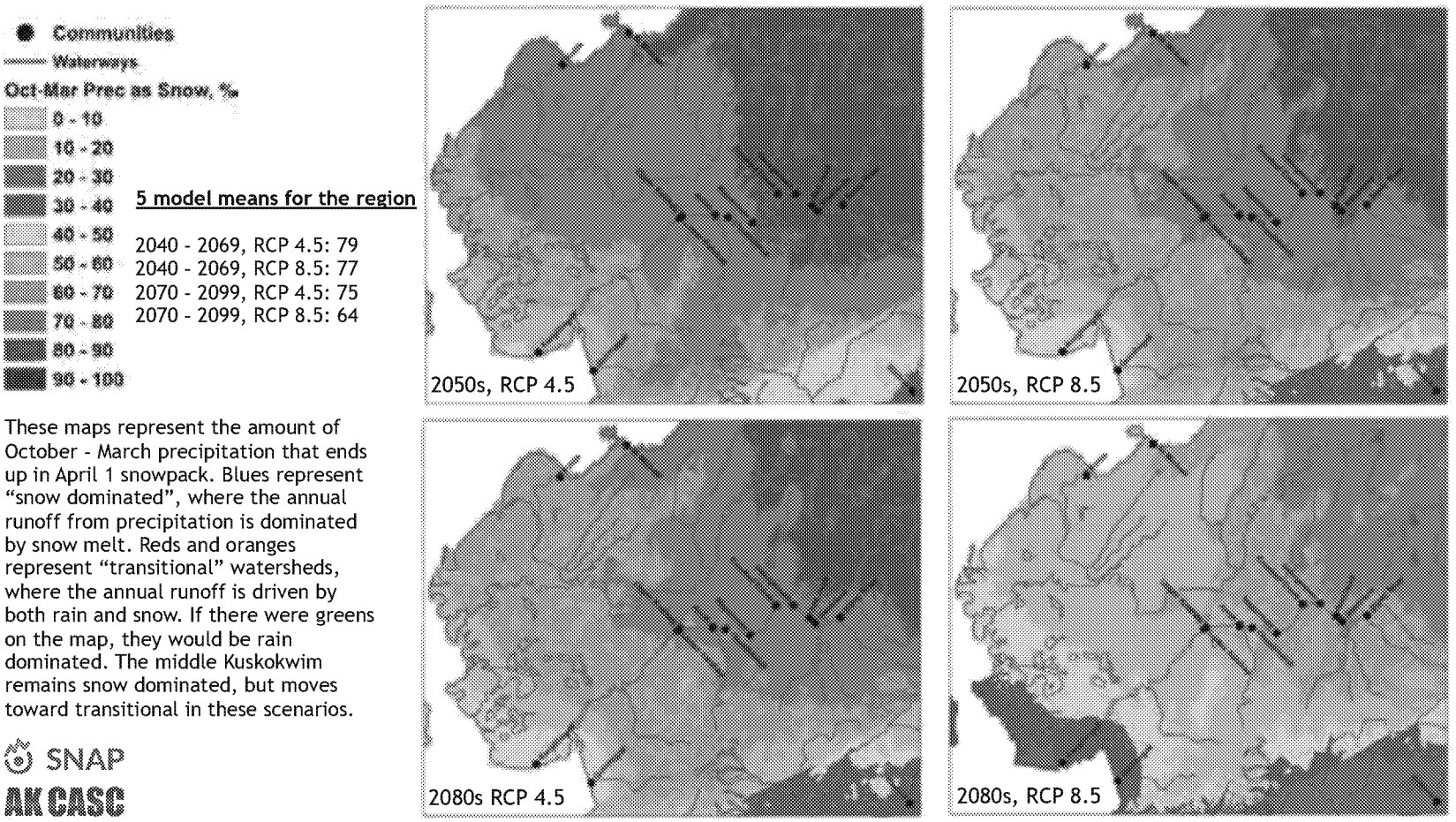
Snow index – October to March amount of total precipitation that is snowfall, measured By the amount of water it contains. These are displayed as a percent (a value of 55% would mean that 55% of the total precipitation falls as snow between October and March. 55% means that 55% of the precipitation was snow, while 45% was rain. Values greater than 40% are snow dominated; values between 10% and 39% are transitional; values between 0% and 9% are rain dominated.

Figure 5: Change in Snow Dominance over the Yukon-Kuskokwim Delta



These maps represent the amount of October - March precipitation that ends up in April 1 snowpack. Blues represent "snow dominated", where the annual runoff from precipitation is dominated by snow melt. Reds and oranges represent "transitional" watersheds, where the annual runoff is driven by both rain and snow. If there were greens on the map, they would be rain dominated. The middle Kuskokwim remains snow dominated, but moves toward transitional in these scenarios.

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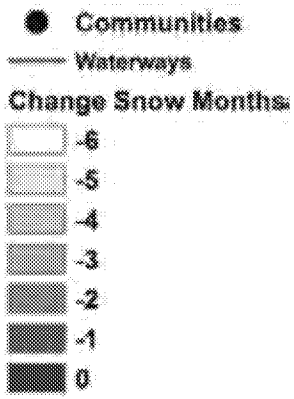
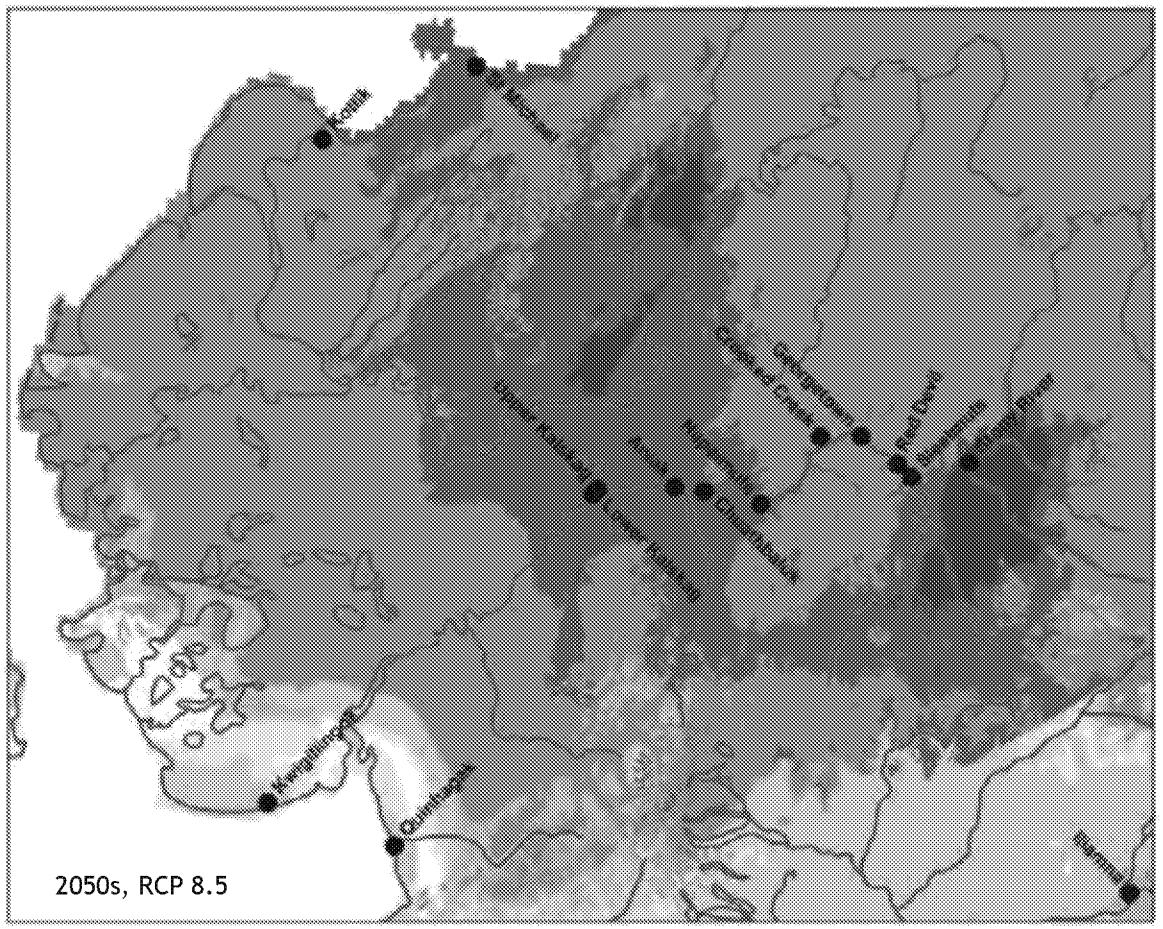
Change in months of reliable snow – For this map, a month with "reliable snow" was defined as a month where, on average, more than 70% of the precipitation arrived as snow. The historical (1970-1999) months of reliable snow were compared to the future (2040-2069) months of reliable snow for RCP 8.5 (higher emissions), and the change calculated as future minus historical.

Figure 6: Change in Number of Months with Reliable Snow Cover Between 2040-2069





This map shows the change in months of reliable snow, defined as 70% or more of the monthly precipitation arriving as snow. Some parts of the YK Delta loose as many as 5 or 6 months of reliable snow, suggesting a shift to mixed rain and snow in most or even all parts of the winter. The middle Kuskowkim loses 0 to two months depending on location.

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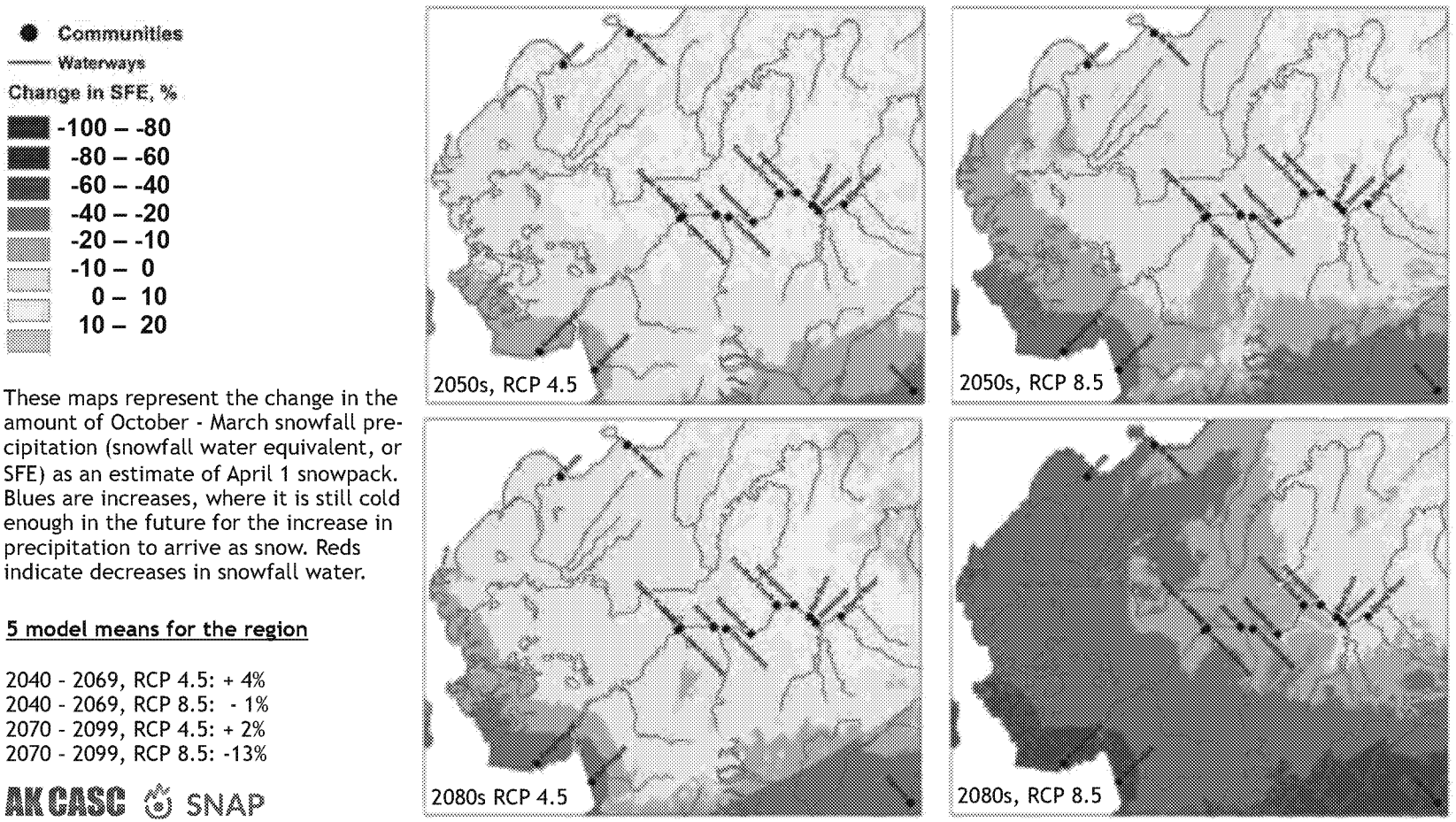
Snowfall, or snowfall water equivalent – October to March amount of snowfall, measured By the amount of water it contains. These represent the percent change in total snowfall. The changes mapped are compared to the same months in the historical projections from climate models.

Figure 7: Change in the Amount of Water Entrained in April 1st Snowpack over the Yukon-Kuskokwim Delta



These maps represent the change in the amount of October - March snowfall precipitation (snowfall water equivalent, or SFE) as an estimate of April 1 snowpack. Blues are increases, where it is still cold enough in the future for the increase in precipitation to arrive as snow. Reds indicate decreases in snowfall water.

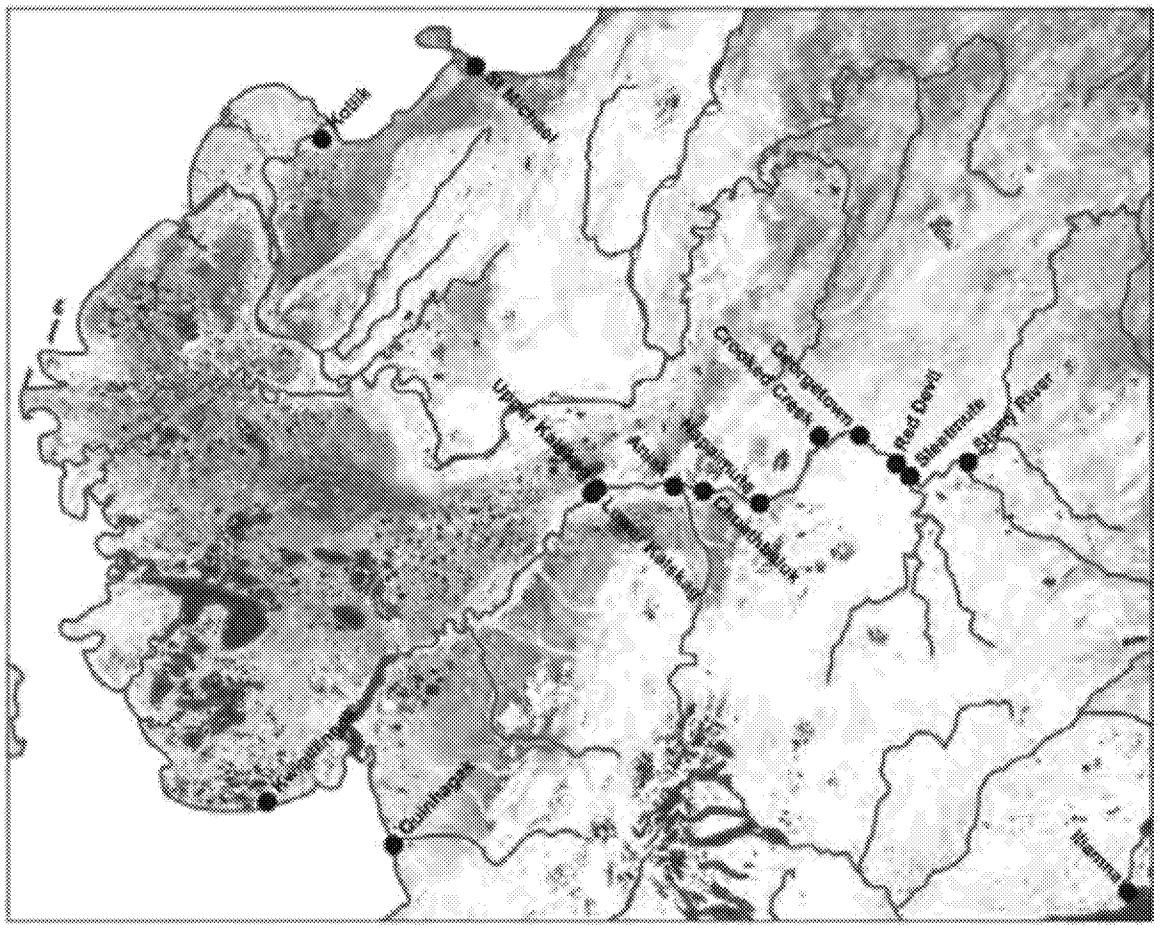
5 model means for the region

2040 - 2069, RCP 4.5: + 4%
2040 - 2069, RCP 8.5: - 1%
2070 - 2099, RCP 4.5: + 2%
2070 - 2099, RCP 8.5: -13%

AK CASC SNAP

Ground temperature at 1m (3.3ft) depth – Annual average ground temperature at 1 meter (3.3 feet) deep in the ground. This is an index of permafrost stability or thaw. The colder it is, the more likely permafrost is to persist. Near freezing (0C or 32F), the permafrost is more likely to thaw. Above freezing, it is unlikely to persist into the future.

Figure 8: Current Probability of Permafrost



Pastick et al. current probability of near-surface permafrost, modeled from landform, vegetation, and climate data. Dark blues indicate higher prevalence of likely permafrost; lighter colors suggest permafrost is unlikely or sporadic

SNAP
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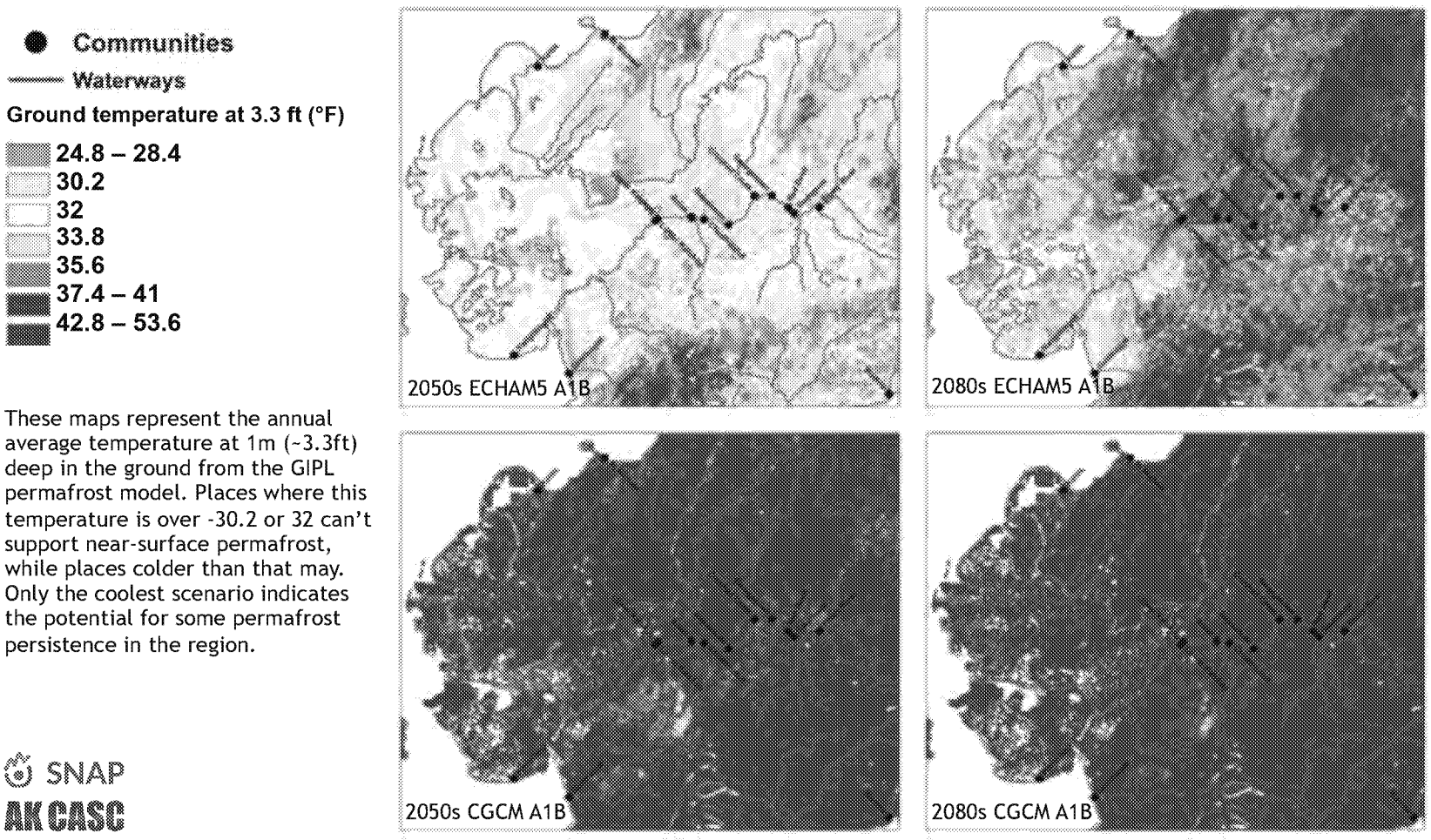
Current probability of permafrost – This map shows the current probability that the area has permafrost under it. Darker blue indicates a higher probability of permafrost.

Figure 9: Change Annual Average Soil Temperature at 1 Meter Depth



These maps represent the annual average temperature at 1m (~3.3ft) deep in the ground from the GIPL permafrost model. Places where this temperature is over -30.2 or 32 can't support near-surface permafrost, while places colder than that may. Only the coolest scenario indicates the potential for some permafrost persistence in the region.

SNAP
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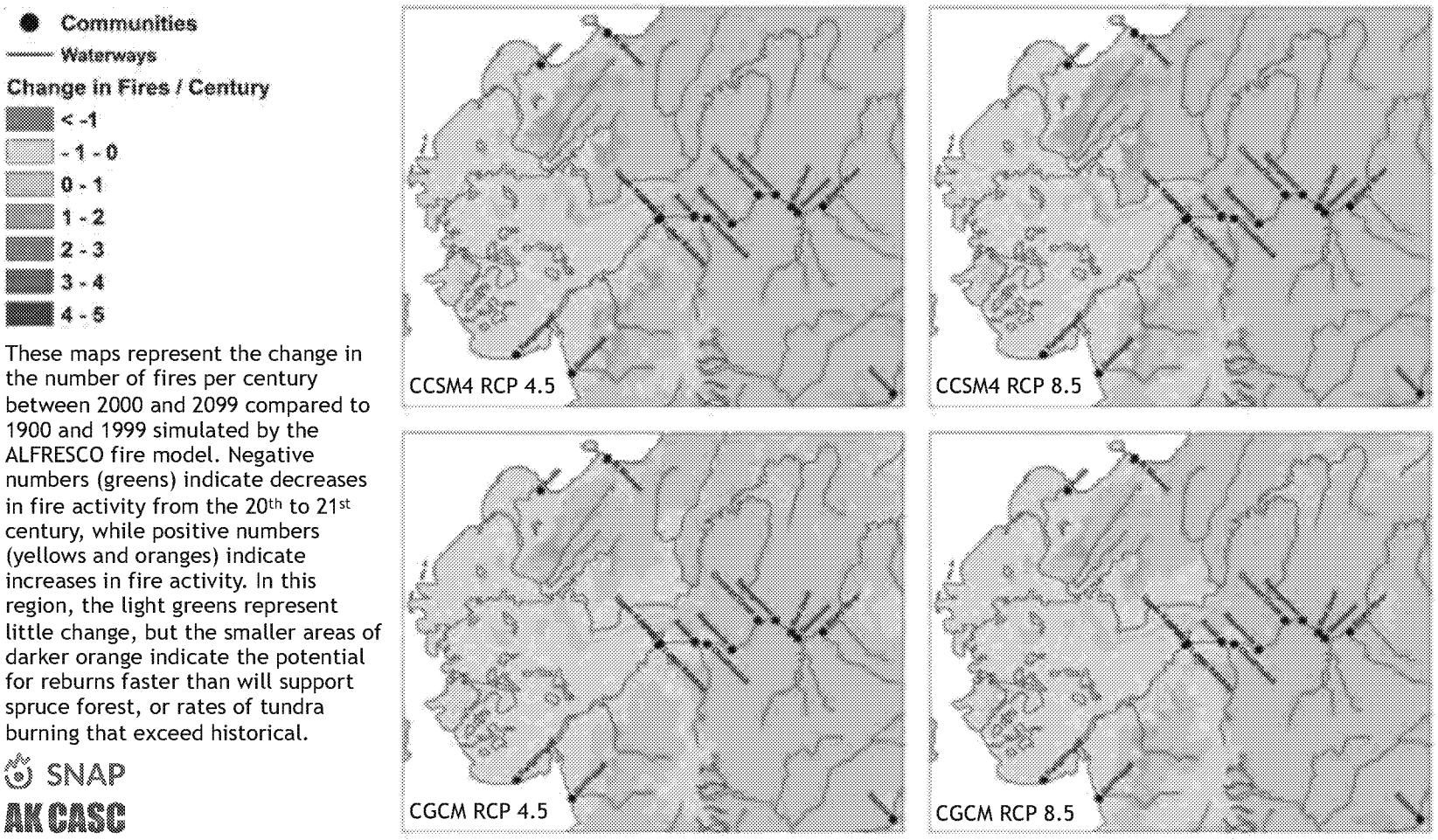
ED_013708_00000184-00246

Changes in fires per century – The times an area burned under simulated historical (1901 – 2000) conditions is compared to the number of times an area burned under simulated future (2001-2100) conditions. Numbers over 0 mean an increase in fire (e.g., 2 would mean a doubling of fire frequency); numbers less than 0 mean a decrease in fire.

Figure 10: Change in the Number of Forest Fires per Century



These maps represent the change in the number of fires per century between 2000 and 2099 compared to 1900 and 1999 simulated by the ALFRESCO fire model. Negative numbers (greens) indicate decreases in fire activity from the 20th to 21st century, while positive numbers (yellows and oranges) indicate increases in fire activity. In this region, the light greens represent little change, but the smaller areas of darker orange indicate the potential for reburns faster than will support spruce forest, or rates of tundra burning that exceed historical.

SNAP
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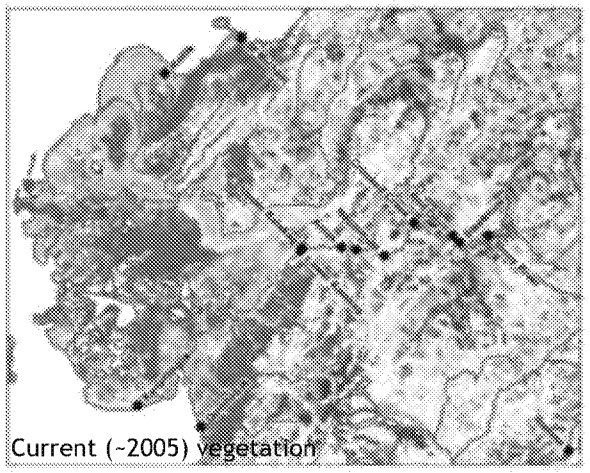
ED_013708_00000184-00247

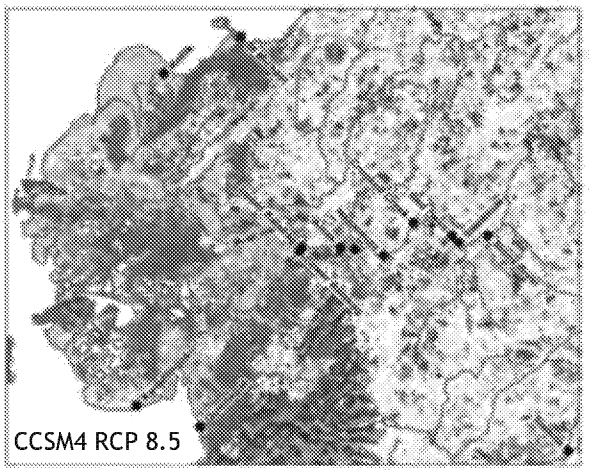
Changes in vegetation per century – The times the dominant vegetation in an area changed under simulated historical (1901 – 2000) conditions is compared to the number of times vegetation changes under simulated future (2001-2100) conditions. Numbers over 0 mean an increase in landscape change (e.g., 2 could mean a change from shrub tundra to spruce followed by a change to deciduous forest).

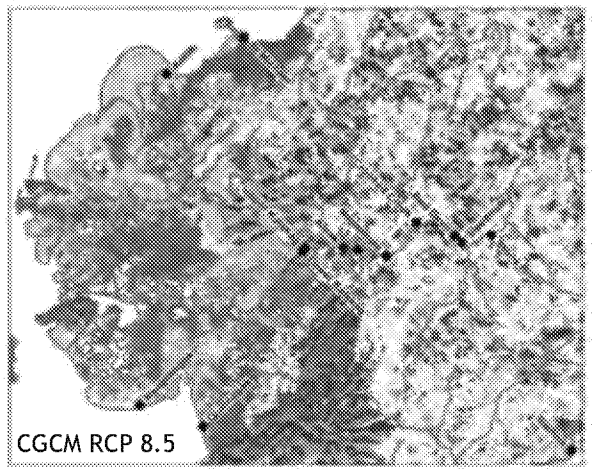
Figure 11a: Change in Dominant Vegetation per Century

Future vegetation changes simulated by the ALFRESCO vegetation model project spruce will establish in the southwest part of the region east of Quinhagak. Similar establishment occurs in both climate models in the middle Kuksokwim valley between Lower Kalskag and Napaimute. In the CGCM model, this establishment is also evident further upriver toward Sleetmute.

In much of the middle Kuskokwim, current spruce forests transition to deciduous forests as a result of the increase in fire activity. This change is more evident under the CCSM4 climate model than the CCSM4 climate model.







Current and 2100 modeled vegetation

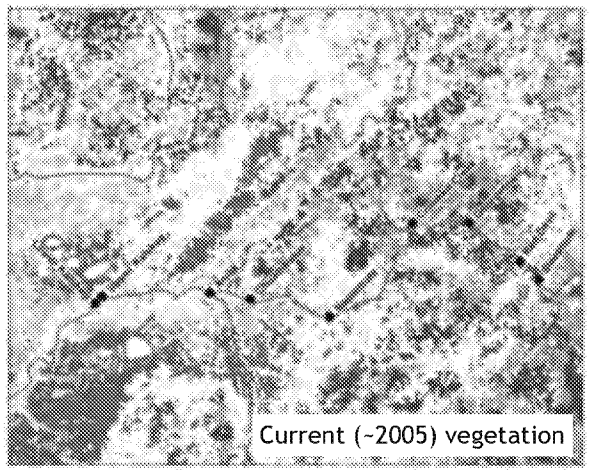
- Not modeled
- Black spruce
- White spruce
- Deciduous forest
- Shrub tundra
- Grass tundra
- Wetland tundra
- Lichen / moss / barren
- Heath

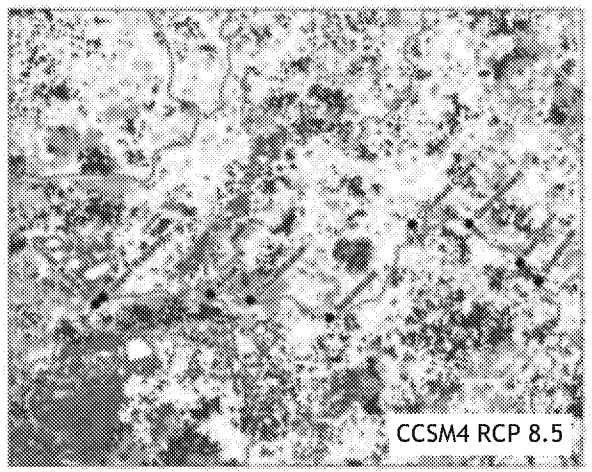
SNAP
AK CASC

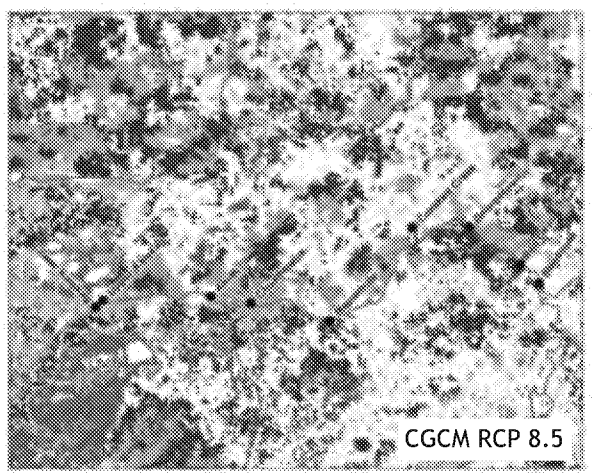
Figure 11b: Current Local Vegetation Compared to 2100 Modeled Vegetation

Future vegetation changes simulated by the ALFRESCO vegetation model project spruce will establish in the southwest part of the region east of Quinhagak. Similar establishment occurs in both climate models in the middle Kuksokwim valley between Lower Kalskag and Napaimute. In the CGCM model, this establishment is also evident further upriver toward and northeast of Sleetmute.

In much of the middle Kuskokwim region, current spruce forests transition to deciduous forests as a result of the increase in fire activity. This change is more evident under the CCSM4 climate model than the CCSM4 climate model.





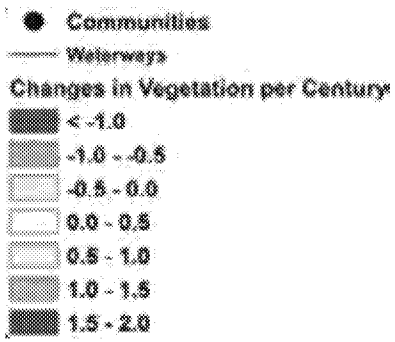


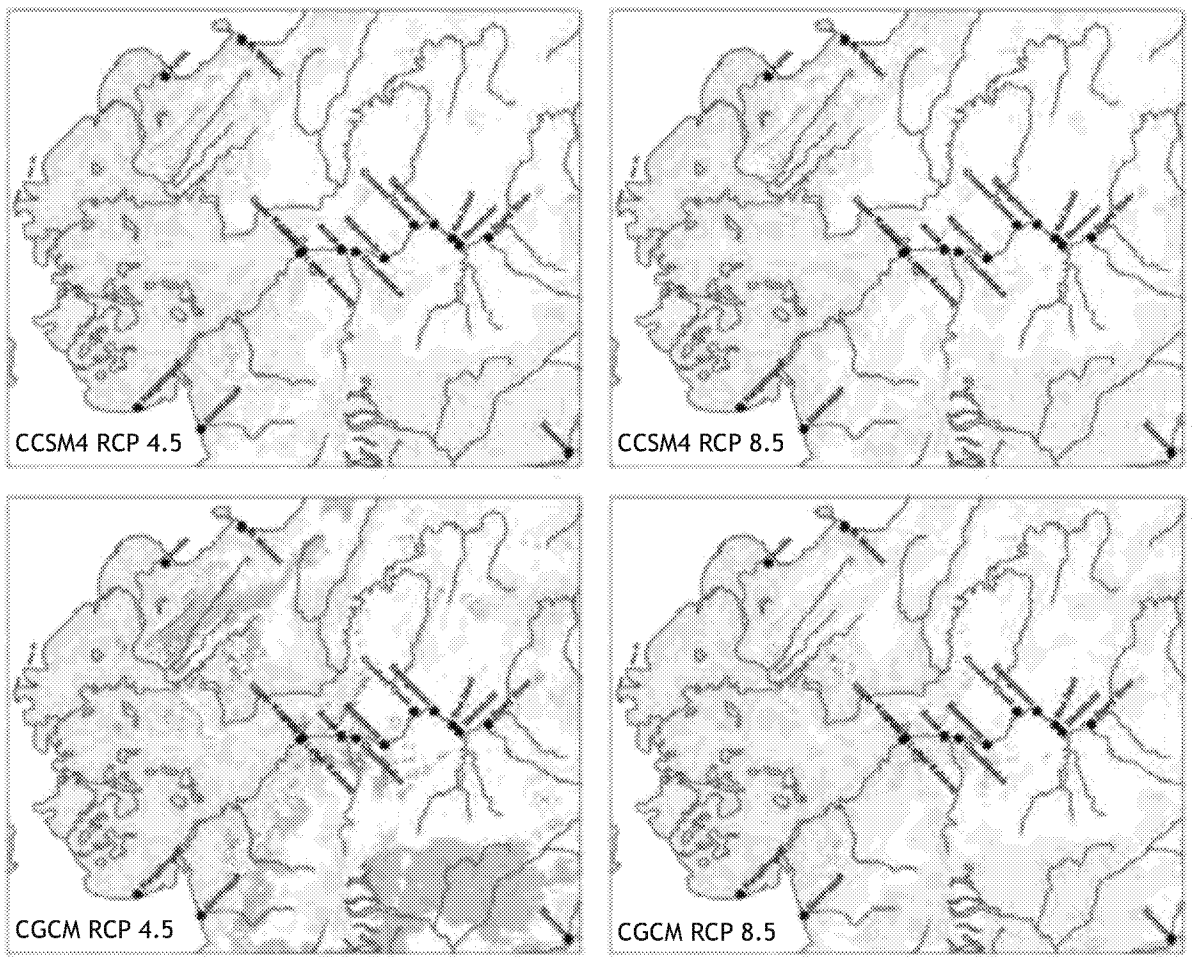
Current and 2100 modeled vegetation

- Not modeled
- Black spruce
- White spruce
- Deciduous forest
- Shrub tundra
- Grass tundra
- Wetland tundra
- Lichen / moss / barren
- Heath

SNAP
AK CASC

Figure 12: Changes in Vegetation per Century





These maps represent the number of changes in the dominant ecosystem vegetation per century between 2000 and 2099 compared to 1900 and 1999 simulated by the ALFRESCO fire model. Negative numbers (greens) indicate decreases in rate of change from the 20th to 21st century, while positive numbers (browns) indicate increases in ecosystem type changes. In this region, the light greens represent less change, but the smaller areas of darker brown indicate the potential for faster vegetation change than historical.

Weed whacking at fish camp
Photo by Mary Peltola

ED_013708_00000184-00251

Hoar frost
Photo by Patty Yoaku

We would like to express our appreciation to our partners in the tribal governments and tribal organizations in the Middle Kuskokwim Region for making this project possible.

United States Department of the Interior

U.S. FISH AND WILDLIFE SERVICE
Anchorage Fish and Wildlife Conservation Office
4700 BLM Road
Anchorage, Alaska 99507

IN REPLY REFER TO:
FWS/AFES/AFWCO

March 30, 2018

EMAILED TO:
Mr. Jamie Hyslop
Regulatory Division
Alaska District
United States Army Corps of Engineers
Joint Base Elmendorf-Richardson, Alaska 99506

Subject: Application for Department of the Army Permit, Donlin Gold Project

Dear Mr. Hyslop:

The U.S. Fish and Wildlife Service (Service) appreciates the opportunity to review and comment on the U.S. Army Corps of Engineers (Corps) permit application and compensatory mitigation plan for the Donlin Gold Mine Project POA-1995-120, received December 22, 2017. As currently proposed, the compensatory mitigation plan does not adequately mitigate for wetland impacts within the Kuskokwim River watershed. According to the 2008 Mitigation Rule, "the ultimate goal of a watershed approach is to maintain and improve the quality and quantity of aquatic resources within watersheds through strategic selection of compensatory mitigation sites" (33 CFR 332.3(c)(1)).

To address our concerns related to the adequacy of the compensatory mitigation plan, we provide the following recommendations.

1. The Service recommends using a watershed approach to site compensatory mitigation where it is most likely to replace lost functions and provide ecological benefits. We request the mitigation options already identified within the Kuskokwim watershed be reconsidered, prioritized, and more fully developed with assistance from the Corps, the Environmental Protection Agency (EPA), the Service, the State of Alaska, and land owners Calista, the Kuskokwim Corporation, and the Tyonek Native Corporation.
2. Due the extent of related infrastructure, which spans multiple watersheds and crosses hundreds of miles, we recommend multiple mitigation locations be considered with priority given to siting mitigation within hydrologic unit code (HUC) 8 watersheds.

3. We recommend a combination of mitigation sites and methods be considered, including mitigation banks and in-lieu fee programs. After all local credits options have been considered and exhausted, then consideration should be given to existing banks and in-lieu fee programs outside their service areas. Consideration should be given to all "non-traditional mitigation" within the watershed as well, as identified in Table 7 of the compensatory mitigation plan (Donlin 2017).
4. We recommend planning efforts focus on restoring degraded wetlands and prioritizing those opportunities in areas of higher ecological value. To assist in that effort, please see the prioritization information available in the 2017 report by Great Land Trust, which prioritized areas within the Kuskokwim River watershed by ecological value (Hults and Geist 2017).
5. We recommend providing a clear rationale for calculating acres of wetlands impacted. Calculations for wetland acres impacted have differed greatly as the proposed project plans progressed, from 14,200 acres presented to the public in the Draft Environmental Impact Statement (DEIS), to 7,174 acres (3PPI 2014) presented by field studies in the wetland function assessment, to 3,415 acres presented by the project proponent, of which only 2,053 acres of permanent impacts and 29.7 miles of stream were identified for compensatory mitigation (Donlin 2017). We consider 7,174 acres, which were calculated using a professional wetland functional assessment, to be the most appropriate for determining acres of wetland impacted. See Enclosure 1 for detailed calculations.
6. Only fill in waters of the state listed as permanent loss were included in the calculation to determine the acreage for compensatory mitigation. We request the current calculation of acres impacted be expanded to include areas impacted by vegetation clearing, work areas, or temporary (cut and) fill activities.
7. We request temporal loss be considered for loss of wetland function during construction, operations, and restoration. The DEIS states that the mine site would impact about 9,000 acres, of which 6,641 acres of wetlands would be directly affected from cut and fill, with an additional 325 acres affected from vegetation clearing. Wetland functions in American and Anaconda Creeks would essentially be eliminated (Corps 2015, Table 2.3-44).
    - We recommend that acres of wetlands lost during construction, termed as "short-term temporary" in the compensatory mitigation plan, be calculated and considered for compensatory mitigation using an agreed upon ratio to account for temporal loss, such as the Alaska District's credit-debit methodology, which includes an adjustment for time lag (Corps 2016).
    - Acres termed as "long-term temporary" in the compensatory mitigation plan should be calculated as permanent acres for compensation. The hydrological system and associated wetlands would be permanently modified. Not only is the mine operation expected to last for 27 to 30 years, the pit lake will take 50 years to fill, and would be kept lower than the surrounding water table. Crooked Creek is a gaining stream that would be unlikely to have groundwater recharge to function as such after closing the mine operations.
8. We recommend stream buffers be applied to calculate for loss of stream function for affected streams. According to the compensatory mitigation plan, stream miles impacted are based on linear feet of streams, while areas of stream mitigation proposed includes areas of stream

area, buffers, and upland riparian areas, which means stream buffers were not calculated equally for debits and credits.

9. If preservation is considered, we recommend instruments used for long-term protection follow the guidelines set out in the 2008 Mitigation Rule (33 CFR 332.3(h)).
10. We recommend reevaluating wetland impacts along the pipeline to determine which acres are within the Chuitna watershed. Although mitigation in the Chuitna watershed is not a high priority for impacts occurring within the Kuskokwim watershed, we do support mitigation in this watershed as compensation for impacts to wetlands within the Chuitna watershed (e.g., impacts from the proposed pipeline). According to the wetland functional assessment, 2,161 acres of wetlands would be impacted along the pipeline (3PPI 2014). The compensatory mitigation plan proposes a total of 5,888 acres for preservation in the Chuitna watershed. This calculates to about a 2.7 to 1 ratio for preservation.
11. We recommend mitigation of mercury in the Kuskokwim River watershed should be considered a high priority for compensatory mitigation. Cumulative effects from past mining contribute to highly elevated concentrations of mercury in northern pike, which are used as a subsistence food source by Native Alaskans from surrounding villages in the Kuskokwim watershed (Matz et al. 2017).
12. We recommend remediation of historic placer mines in the George or Holitna watersheds should be considered for compensatory mitigation.

Thank you, we look forward to working with the Corps and the EPA to further discuss the proposed compensatory mitigation options. If you have any questions or need additional information, please contact Ms. Jennifer Spegon at (907) 271-27687 or jennifer_j_spegon@fws.gov.

Sincerely,

Douglass M. Cooper
Acting Field Supervisor

Literature Cited

Donlin Gold. 2017. Updated application for Department of the Army Permit; Donlin gold project POA-1995-120. December 20, 2017. pp. 590.

Hults A., M. Geist. 2017. Great Land Trust, Anchorage, Alaska. Prioritizing land for ecological value in the Kuskokwim watershed. Grant number F15AC00455. pp. 28.

Matz M., M. Varner, M. Albert, and K. Wuttig. 2017. Bureau of Land Management. Mercury, arsenic, and antimony in aquatic biota middle Kuskokwim River region, Alaska 2010-2014. Technical report number 61. pp. 59.

Three Parameters Plus, Inc. 2014. Draft wetland functional assessment; Donlin gold project. Version 2. Revision 1. June 2014. pp. 111.

U.S. Corps of Engineers. 2015. Donlin gold project; draft environmental impact statement. November 2015. pp. 3,162.

U.S. Corps of Engineers. 2016. Methodology for assessing functional gains and losses for permittee responsible compensatory mitigation and calculating compensatory mitigation credits and debits for third party mitigation providers in the Alaska District. April 29, 2016. pp. 11.

Enclosure 1. Calculations of Wetland Impacts (Refers to item 5 above)

- The 2014 Wetland Functional Assessment calculated a total of **7,174 acres** wetlands and waters of the state would be impacted (3PPI 2014):
  - 5,667 acres impacted from facilities (Table 1.1-1, pg. 1-2),
  - 1,507 acres of wetlands impacted along the pipeline (Table 1.1-2, pg. 1-6).

- The Draft Environmental Impact Statement calculated a total of **14,200 acres** of wetlands would be impacted (DEIS, Corps 2015):
  - 9,664 acres for the mine site, included direct impacts of 6,977 acres, 1,954 acres of indirect impacts, 541 acres of dewatered wetlands, and 192 acres of clearing vegetation in areas of permafrost (pg. 3.11-82),
  - 2,161 acres for the transportation portion, which includes transportation corridors, facility construction, operations, and maintenance of 412 acres plus 1,749 additional acres of wetlands impacted by dust (pg. 3.11-94),
  - 2,375 acres for the pipeline construction to include 35 acres of streams and 2,340 acres of wetlands (pg. 3.11-107)

- The revised permit application calculates a total of 3,414 acres and 29.7 steam miles, of which, only **2,053 acres** of permanent impacts and **29.7 miles of stream** were considered for compensatory mitigation (Donlin 2017, Table 22-1):
  - Permanent fill impacts of 2,053 acres wetlands and 29.7 miles of steam,
  - Temporary long-term of 823 acres, and
  - Temporary short-term of 538 acres.

Estimation of Tailings Dam Break Discharges

Arvind Dalpatram

USSD
Workshop on Dam Break Analysis
Applied to Tailings Dams
August 24-26, 2011

Klohn Crippen Berger
60 YEARS

USSD

Overview

- Dam break analyses for water storage dams
  - Relatively simple
  - Lots of guidance available in literature
  - Often covered by regulatory guidelines
  - Well established numeric modelling tools/software available

- Dam break analyses for tailings storage dams
  - More complex than water storage dams
  - Tailings more viscous than water, and not as free flowing
  - Not all tailings released from impoundment
  - Numeric modelling tools/software difficult to use or not reliable

Klohn Crippen Berger
60 YEARS

Overview

- Difference between water storage and tailings storage impoundments
- Use of methodology/tools for water storage dams

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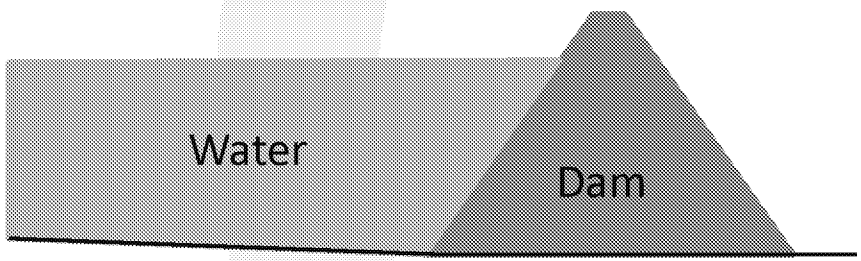
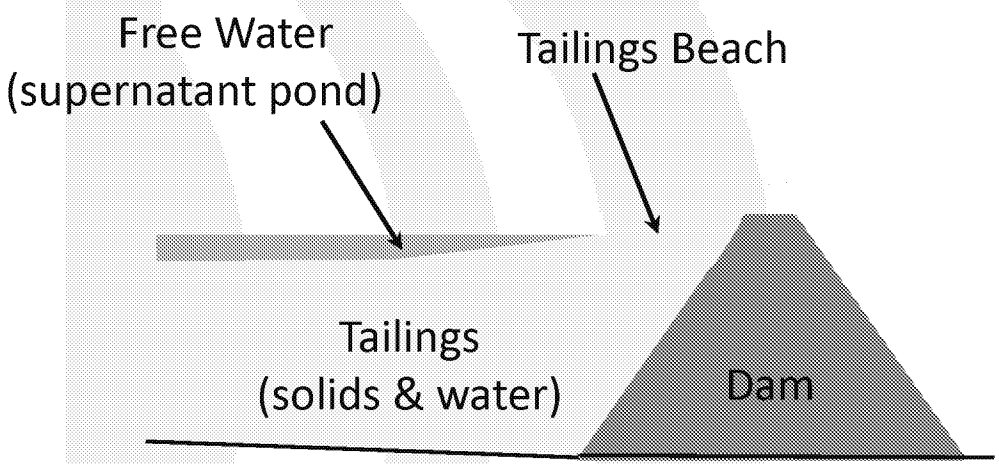
60 YEARS

Water and Tailings Storage Impoundments

Water Storage



Tailings Storage



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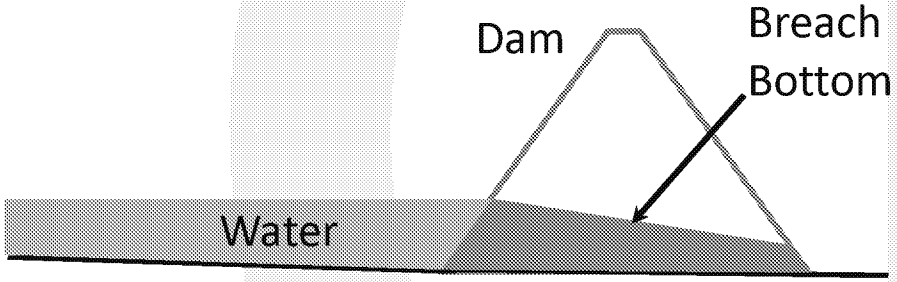
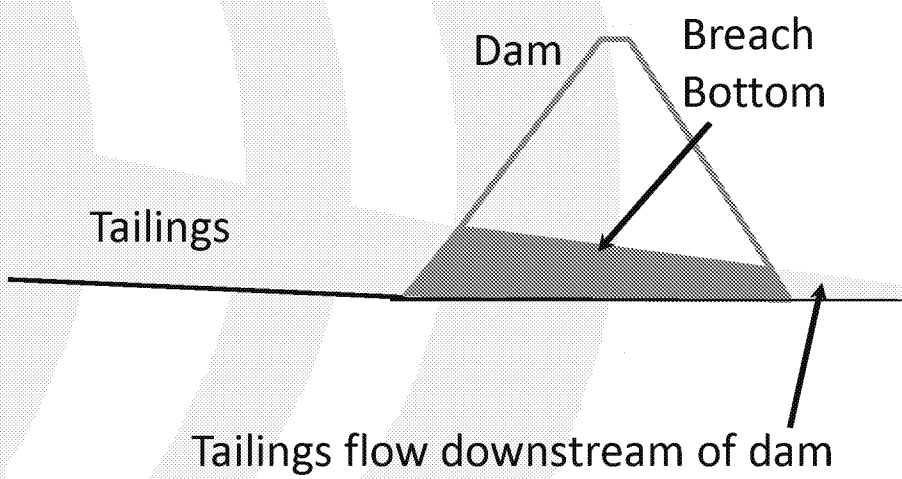
After Dam Breach

Water Storage



Tailings Storage



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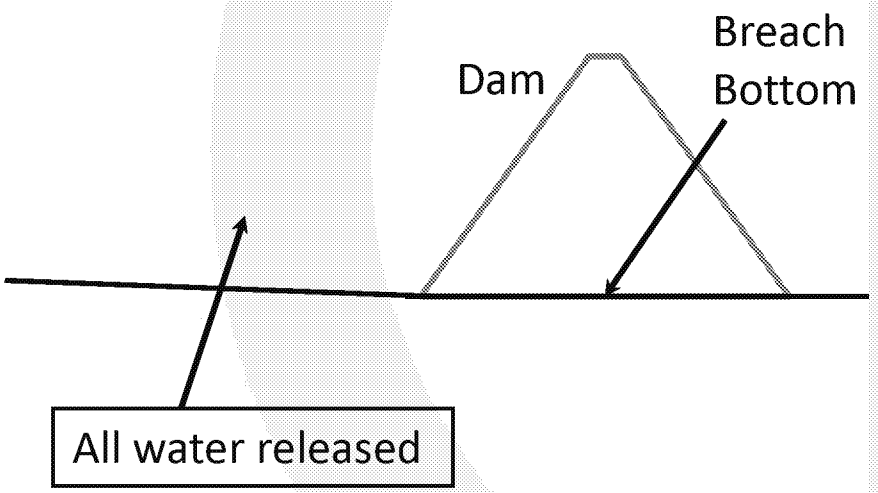
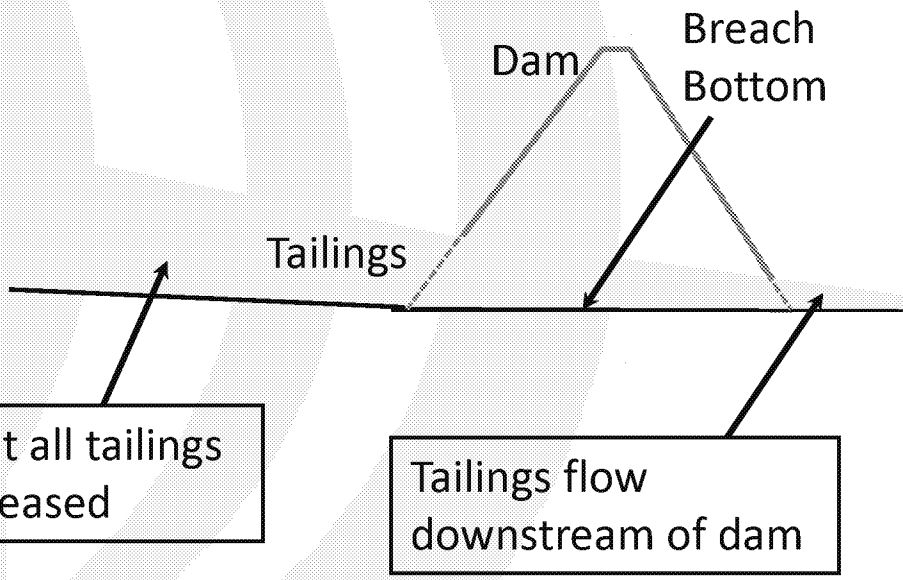
60 YEARS

Breach to Foundation Level

Water Storage



Tailings Storage



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60 YEARS

Volume of Tailings Released

Source	No. of Dams	Dam Heights	Tailings Released	
			Range	Average
Lucia (1981)	11	15m to 46m	14% to 100%	40%
USCOLD (1995)	16	20m to 61m	1% to 100%	29%
Garga and Khan (1995)	19	?	3% to 100%	28%
USCOLD (1995) and www.tailings.info	31	12m to 61m	1% to 100%	26%
M. Rico et al. (2007)	28	5m to 66m	3% to 100%	33%
Azam and Li (2010)	72	?	?	20%

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Volume of Tailings Released (M. Rico et al.)

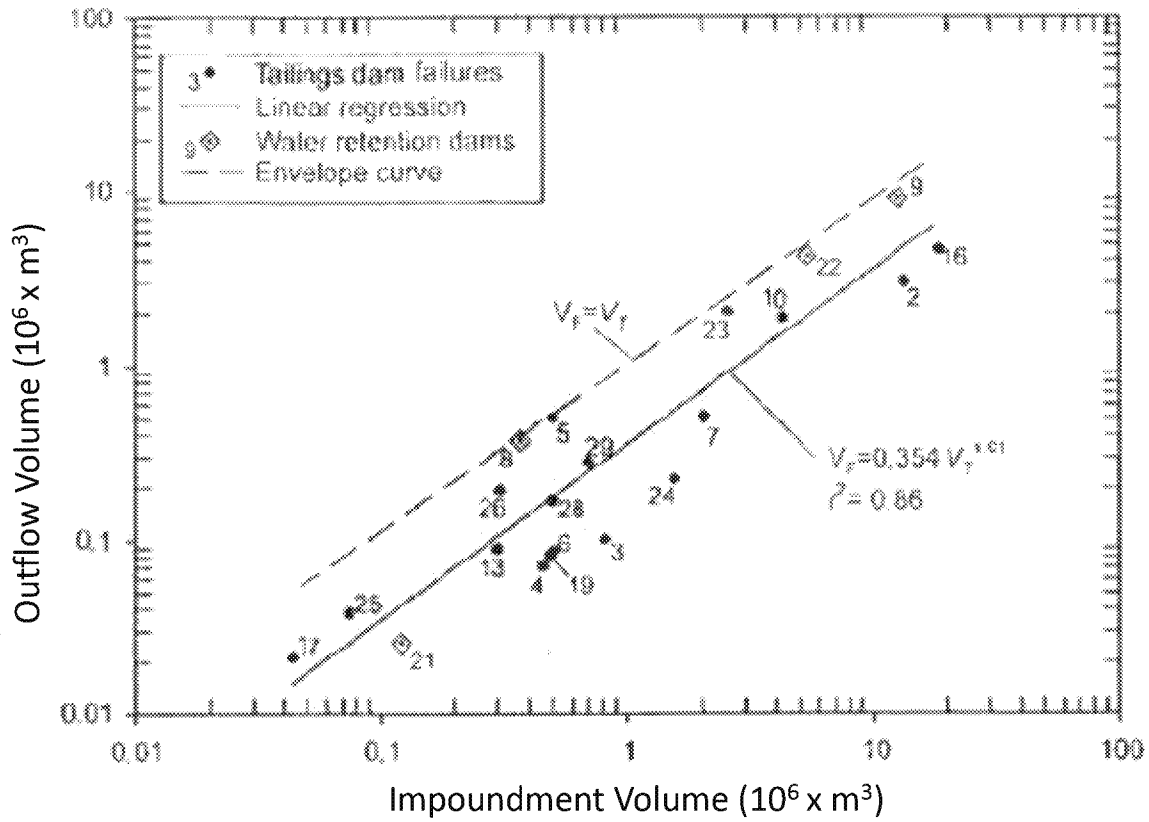

Fig. 4. Graph showing the tailings outflow volume from the tailings dam (V_F in $10^6 \times m^3$) vs. the volume of tailings stored at the dam (V_T in $10^6 \times m^3$) at the time of the incident.

Source: M. Rico et al. (2007)

$V_F = 0.354V_T^{1.01}$

Where:
V_F = Outflow volume
V_T = Stored volume

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Steps for Tailings Dam Break Analyses

- Establish dam break scenario
- Estimate volume of tailings released
- Review flows in downstream river and potential for transport of tailings
- Assume released tailings behave like water
- Estimate dam breach parameters
- Run numeric dam break and inundation model
- Carryout sensitivity analyses for estimated/assumed values

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Dam Break Scenarios

- "Sunny-day" Failure
  - Supernatant pond at max. normal operating level
  - Normal flows in river(s) downstream of the dam (e.g., average annual flow)
  - Caused by earthquake, seepage, foundation failure, etc.

- "Rainy-day" Failure
  - Flood-induced failure
  - Supernatant pond at design flood level, or higher
  - Flood flows in river(s) downstream of the dam (i.e., flows most likely to occur coincident with the breach event)
  - <u>More water</u> than sunny-day failure; more tailings mobilized

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Amount of Tailings Mobilized

- Impoundment Characteristics
  - Stage/storage curve
  - Shape of impoundment
- Water in the Impoundment
  - Free water above the tailings
  - Water retained within the tailings (i.e., water content)
- Flows in the rivers downstream of dam

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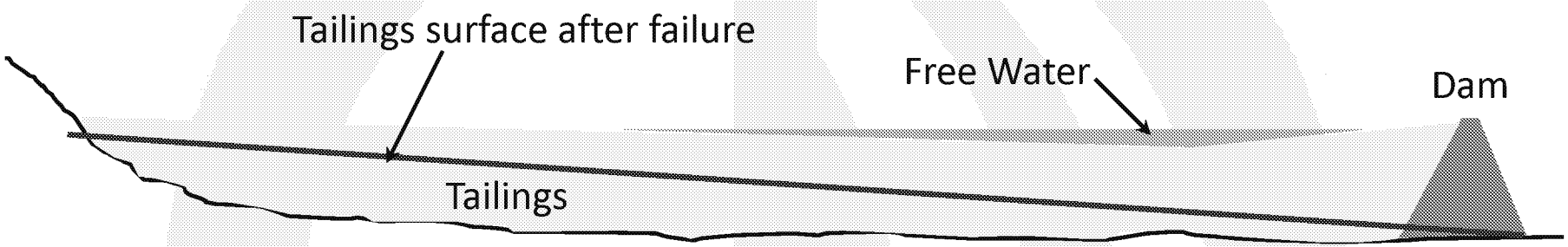
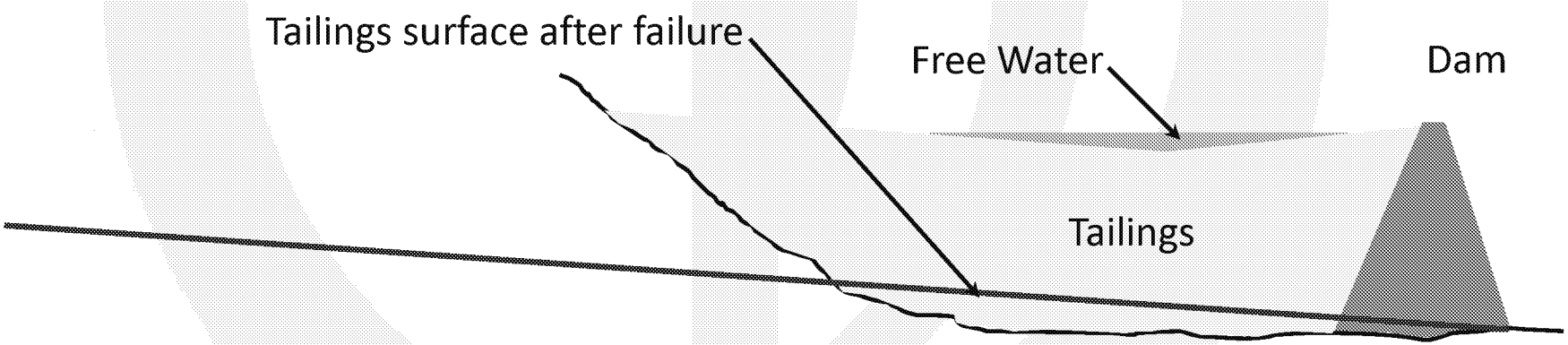
Impoundment Characteristics





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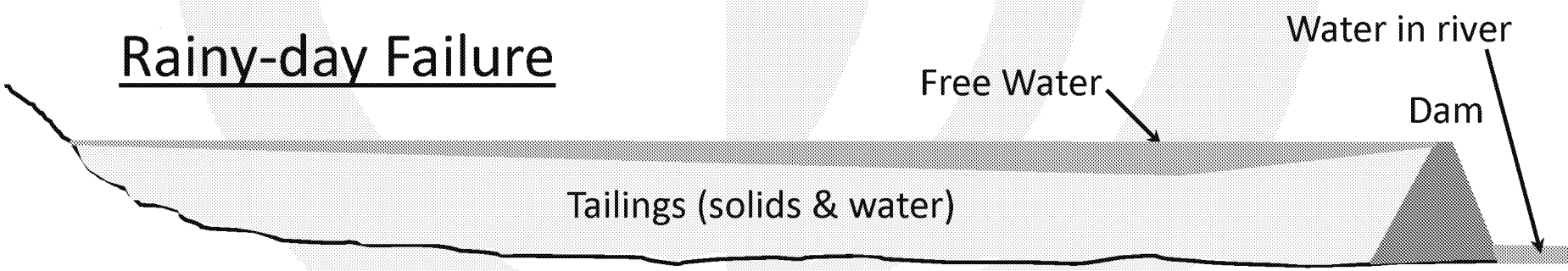
Water in the Impoundment and River



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Breach Parameters

- Breach Geometry
  - Breach depth
  - Breach width
  - Breach side slopes
- Breach Formation Time

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Dam Break and Inundation Modelling

- Conventional dam break and flood routing models

- Sensitivity analyses:
  - Assumed tailings release volume
  - Breach geometry
  - Breach formation time
  - etc.

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Garga, V.K. and Khan, M.A. (1995). Review and Comparison of a deterministic Model for estimating Flow Out Distance of Breached Tailings, report submitted to Resources Canada, Mining Research Laboratory.

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www.tailings.info

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Questions / Comments?

SECTION NUMBER	PAGE	ID	ORIGINAL LANGUAGE	PROPOSED LANGUAGE OR COMMENT	RESPONSE
Executive Summary	ES-1	TR	Groundwater around the Core Operating Area is not a source of drinking water.	We recommend the HHRA specify the area (acres) around the Core Operating Area that is not a source of drinking water. We have also made recommendations related to designing and operating the mine facilities in ways that minimize the impacts to groundwater and drinking water, and disclosing that information in the FEIS. Please see our comments on the PFEIS regarding protection of those resources.	Consistent with the SOW, the HHRA specifies the area within the Operating Area where groundwater impacts are anticipated, and that this area is not a current or proposed source of drinking water. See p. 3-3. The content of the FEIS is also beyond the scope of this HHRA.
Executive Summary	ES-1	TR LK	The HHRA calculated risks at the end of mine life (year 27), because the increase in constituent concentrations in the environment due to emissions from the proposed Project is expected to be highest at that time. After operations cease, Project emissions will diminish, and accordingly, evaluating potential exposure as of the end of operations represents a reasonable temporal boundary for maximum potential risk related to releases from the proposed Project.	EPA's hydrogeologists have indicated that groundwater may become contaminated during mining operations. Therefore, there may be additional risks to human health from groundwater after year 27. We recommend including an evaluation of groundwater risks after the end of mine life in the HHRA. We also recommend that the HHRA assess the health risks that might exist if water treatment or containment failed at any point in the process.	The introduction of the HHRA includes a discussion of temporal limitations. EPA's request to address potential and catastrophic failure scenarios are not addressed as this is outside the previously-described scope of the HHRA.
Executive Summary	ES-1, 1st ¶	LK		Under CERCLA, the potentially responsible parties (PRPs) are only responsible for site related risk. However, in this case, the HHRA should discuss the joint hazards from background AND site related chemical exposures (e.g. mercury, arsenic, antimony, etc.). All of the example chemicals of potential concern (COPC) are considered to have dose thresholds where adverse effects occur. The significance of incremental chemical exposures associated with Donlin's operation will be affected by background exposures to these chemicals and the total exposure from background and Donlin's operation.	The stated scope of the HHRA was to address incremental risks. Additive background + site related risks are shown in the resulting tables, which indicate no significant risk thresholds were exceeded as a result of additive exposure from project-related risk. However, Donlin is not responsible for hazards related to background risk.
Executive Summary Conceptual Model	ES-1, 1st ¶	LK		As stated above, we recommend that groundwater be included as an exposure medium. If it not going to be included, then the HHRA should provide a rationale for excluding groundwater from the health risk assessment.	Please see the responses above and the rationale provided on page 3-3 of the HHRA.
Executive Summary Conceptual Model	ES-1, 2nd ¶	LK		We recommend that the geographic scope of the HHRA should be expanded to include groundwater exposures/risks, as well risks posed by treatment and containment failures.	Please see the responses above and the rationale provided on page 3-3 of the HHRA.
Executive Summary Conceptual Model	ES-2	LK		We recommend that the Alaska Dept. of Fish and Game, Division of Subsistence (ADFG-DS) staff be engaged in developing game and fish consumption rates used in this document. It is possible to derive upper percentile consumption rates that are typically associated with reasonable maximum exposure. These derivations would require access to household level information that ADF&G-DS can access. We recommend that the HHRA include a discussion on the involvement of ADFG-DS in developing game and fish consumption rates and the level of information used in the assessment.	Consistent with data used in the DEIS, the HHRA relied on a robust subsistence population study of regional harvesting rates that was authored by ADFG. The HHRA explains how that information was used to develop consumption rates. The SOW specified that the HHRA would be completed with existing data. EPA's repeated requests to include new data, scenarios, references, and/or analytical methods are inconsistent with the SOW agreed upon between Donlin Gold and USACE. Since the HHRA achieves these agreed upon objectives, there is no reason to expand the scope of the analysis.
Executive Summary Exposure Point Conc.	ES-4, 1st ¶	LK		Using mean concentrations for EPCs based on modeling requires discussion as to how uncertainty in the mean will be addressed. We note that the reasonable maximum exposure (RME) typically uses the 95% UCL on the mean to account for uncertainty in EPCs. We recommend that this variance from RME derivation be identified. In addition, we recommend that the HHRA describe how uncertainty in	The rationale for mean EPCs is discussed in the HHRA (see p. 5-25). Additionally, the uncertainty section examined increases and decreases in EPCs relative to background (see p. 8-7). A modeled concentration cannot be used to derive a 95% UCL, and therefore the variance between the two statistics cannot be developed.

SECTION NUMBER	PAGE	ID	ORIGINAL LANGUAGE	PROPOSED LANGUAGE OR COMMENT	RESPONSE
				modeled concentrations would be considered.	
Executive Summary	ES-5	TR	The potential solubility of arsenic and antimony into surface water from sediments or soil runoff was assumed to be negligible, particularly after factoring the contribution of treated water from the water treatment plant, which will be at concentrations less than 0.005 mg/L (below water quality criteria). Therefore, future concentrations of arsenic and antimony in surface water were assumed to be unchanged from baseline concentrations.	We noted in our comments on the PFEIS, and reiterate here, that the drinking water MCL (maximum contaminant level) under the Safe Drinking Water Act for antimony is 0.006 mg/L It would be helpful to discuss background concentrations of arsenic and antimony in surface water and groundwater in the HHRA, as the discharge from Donlin mining operations will be added to the background concentrations. We recommend that there also be a discussion of what happens if the MCL for antimony and arsenic are exceeded due to mining operations.	The DEIS already discusses surface water concentrations compared to relevant regulatory levels. Both drinking water and groundwater were determined to be incomplete pathways in the HHRA; as such, this type of analysis, which is addressing consumption of surface/ground water, is not relevant.
Executive Summary Exposure Point Conc.	ES-5	LK	The potential solubility of arsenic and antimony into surface water from sediments or soil runoff was assumed to be negligible.	We recommend that this conclusion be substantiated in the HHRA. Given the high concentration of arsenic in the gold ore deposit and the background and ambient concentrations that may be present in water, we recommend additional information for agency decision makers and the public, as part of the NEPA process, that justifies the assumption of negligible potential solubility of arsenic and antimony into surface water.	EPA should review, as part of the NEPA process, the water resources management plan which describes control of runoff of mine drainage water and process water. Mine drainage water and excess precipitation in the TSF pond will not be allowed to discharge to the environment without treatment. Negligible increases in runoff rates from added arsenic and antimony due to project-related emissions were assumed based on the extremely low rate of dust deposits into the study area (1.80E-05 ug/m^3), particularly relative to baseline soil and sediment levels.
Executive Summary Exposure Point Conc.	ES-5	LK	The use of harvest rates to estimate consumption rates is an overestimate; the study indicates that people do not consume all of each animal harvested (e.g., often just the fish fillet is consumed, not the entire fish), and further, people may not necessarily consume the total amount of subsistence food harvested (e.g., primary subsistence providers frequently share with others who may reside in the area or in other distant communities).	ADFG-DS harvest rates are in terms of edible material, not raw resources. We recommend that the HHRA also use the approach advocated for development of upper percentile consumption rates developed by ADFG- DS. SEE: http://www.adfg.alaska.gov/techpap/tp261.pdf. This approach accounts for resource sharing. As mentioned previously, we recommend that the ADFG-DS be consulted regarding the use and interpretation of their data in this document supporting the NEPA process and decision making regarding the proposed gold mine project.	ADFG-DS harvest rates were not used to develop consumption rates for the HHRA. The study used in the HHRA (Brown et al. 2012) to presents harvested rates as whole materials, not that which is consumed (see: http://www.adfg.alaska.gov/techpap/TP396.pdf). This is further discussed in the HHRA (See ES and p. 5-38).
Executive Summary Risk Results	ES-6	LK		We recommend that the mercury hazards be assessed using the EPA reference dose (RfD), not a no observable effects level (NOAEL). The NOAEL doesn't incorporate safety factors. A health protective estimate of toxicity should be used to ensure that the mercury hazards to public health will occur at acceptable levels. Although the Alaska Department of Health and Social Services (ADHSS) utilized the ATSDR mercury minimal risk level in its mercury fish consumption advisory**, ADHSS noted that EPA's RfD should be utilized in the context of environmental regulation.**	The HHRA used RfDs to evaluate non-cancer hazards. The NOAEL is discussed regarding the ADHSS hair study, not the HHRA results.
Executive Summary Risk Results	ES-6	LK		We recommend that this section also discuss ADEC's view of acceptable quantitative risks.	ADEC guidance was incorporated into the discussion of risk results.
Executive Summary Risk Results	ES-6	LK		The use of Type I and Type II errors is associated with false acceptance or rejection of the null hypothesis in statistics. We recommend that it would be clearer for agency decision makers and the public to use plain English discussing whether the errors of over or underestimating actual risks and hazards are likely to occur.	The text has been revised to explain this terminology.
Executive Summary Risk Results	ES-6	LK		With regards to the arsenic slope factor, current information suggests that the current arsenic slope factor of 1.5 underestimates the true cancer risk. EPA is considering a revised slope factor of 25. In estimating arsenic's cancer potency, full consideration must be given to the range of cancers that may be induced by	The slope factor referenced in the HHRA reflects EPA's ***published*** slope factor. Uncertainties regarding the slope factor are further addressed in the uncertainty section.

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				arsenic exposure. Many other studies outside of the Taiwanese study document arsenic's carcinogenicity and in particular, arsenic's ability to induce lung and bladder cancer. We are unclear what is meant by "safety factors" in relation to the health protectiveness of the arsenic slope factor, and recommend that this discussion be clarified by the time of the release of the FEIS.	
Executive Summary Risk Results	ES-7	LK		As is the case for mercury, arsenic also has non-cancer toxic effects. We recommend that the incremental non-cancer arsenic hazard should be determined and considered in conjunction with background non-cancer arsenic hazards. For chemicals with a threshold mechanism of toxicity, the significance of project exposure is related to baseline exposure.	Section 7 of the HHRA addresses non-cancer arsenic hazards.
Executive Summary Risk Results	ES-7	LK		The executive summary notes that only one soil sample is available to characterize arsenic risks and hazards. This would appear to be an inadequate sample size for characterizing arsenic risks and hazards, and it imparts a considerable amount of uncertainty to the assessment of baseline and project-related risks and hazards. We recommend that additional analysis of the potential baseline and project-related arsenic exposures be included in the HHRA, and that may include the need to analyze additional soil samples in order to adequately characterize and discuss risks and hazards related to arsenic.	The HHRA p. E-7 does not state that only one soil arsenic sample is available. The text states "statistical comparisons of significance between baseline and future arsenic concentrations cannot be made because only a ***single future soil arsenic concentration was estimated***."
Executive Summary Risk Results	ES-7	LT		The discussion of arsenic on ES-7 does not mention that arsenopyrite is the dominant gold bearing mineral in a major portion of the area proposed to be mined, the Lewis Prospect. See Szumigala, Dodd, Arribas (1999), Geology and Gold Mineralization at the Donlin Creek Prospects, Southwest Alaska. For this reason, the HHRA may be underestimating the arsenic concentrations in all media at the site. For groundwater and possibly other exposure pathways, arsenic may be of more concern, and we recommend that additional analysis and discussion be included in the HHRA prior to the release of the FEIS.	Arsenic concentrations were evaluated based on total arsenic in soil, not individual forms. Groundwater exposure is an incomplete pathway.
Executive Summary Risks Due to Fish Consumption	ES-8	LK		We recommend some additional clarity here, as the State of Alaska's fish consumption advisory for mercury isn't based on EPA's reference dose (RfD), but rather an ATSDR MRL. Fish consumption advisory contaminant concentrations consider both adverse effects of the contaminant as well as the benefits of fish consumption. Environmental regulation is concerned with regulating release of toxic substances into the environment and does not include consideration of the benefits of fish consumption. They are two different things.	The HHRA does not make this statement. For clarity, P. E-8 states: "Estimates of future northern pike concentrations are also lower than State of Alaska (2016) fish consumption advisories for northern pike harvested from the Kuskokwim River in the vicinity of the Project." The HHRA does not use the northern pike advisory to estimate risks.
Executive Summary Risks Due to Fish Consumption	ES-8	LK		We recommend that the HHRA also include the review of all fish species harvested in the area potentially affected by the Donlin gold mine, with regards to the fish species' residence time and potential for mercury uptake, in order to more accurately characterize the human health risks due to fish consumption.	Section 2.2 discusses the fish species considered in developing the HHRA; also see Appendix B.
Executive Summary Summary Conclusion	ES-9	LK		We recommend that the summary conclusions also need to incorporate groundwater exposure and additional risks that have not been evaluated due to the assumption that containment or treatment will prevent risks from occurring. We also recommend that the Donlin project-related contaminant exposures to non-carcinogens should be summarized here along with the background-related exposures. Consideration of background exposures to non-carcinogens is important in determining whether or not site related exposures pose significant hazards. As noted previously, we recommend a number of changes in exposure parameter assumptions; most notably we suggest the use of ADFG-DS approved harvest rates that need to be utilized, and the potential for the need to re-compute risks discussed in the HHRA.	See above response to the first comment regarding groundwater exposure and response to comment six regarding the use of ADFG-DS harvest rates. We have not recalculated risks.

SECTION NUMBER	PAGE	ID	ORIGINAL LANGUAGE	PROPOSED LANGUAGE OR COMMENT	RESPONSE
1.0 Introduction	1-1	LK		We recommend that the overall approach to human health risk assessment for the Donlin Gold project be discussed at the beginning of the HHRA. This discussion would include an overview of the content and function of Chapter 3 of the FEIS, the focused risk assessment, and the human health risk assessment. This ensures that the FRA starts appropriately with a comprehensive list of all chemicals that have potential adverse effects on humans and that humans could be exposed to as a result of this project. However, we recommend that the Donlin Gold risk assessment process evaluate exposures to chemicals that could result from failure of treatment and containment (e.g. failure in the treatment facility, a seismically induced rupture of the pit containment, etc.). Specifically, the existence of control or containment should not preclude quantification of risk or hazard. There are many instances where controls have failed, leading to environmental contamination. Consideration of these additional exposures will likely create the need to consider additional receptor types (e.g. barge operators, individuals living in the vicinity of the mine). Additionally, we recommend that there should be some discussion of future land use and exposures to humans consistent with future land use. The salient reason for developing this risk assessment was the need for a quantitative analysis of the human health risks, not included in the Health Impact Assessment developed by the ADHSS. We recommend that the HIA be examined for key elements to should also be included in the HHRA.	Comment noted. The overall approach is discussed at the beginning of the HHRA, and reference to the DEIS included in paragraph 2 of the introduction. See above responses to comments to the Executive Summary for clarification on the scope of the HHRA and scenarios considered.
1.0 Introduction	1-1	LK		In the context of CERCLA, we recommend that the major objective of the HHRA is to characterize incremental, site related risks. We also recommend that the HHRA look at overall mercury exposure (as well as other chemicals such as arsenic and antimony) from both background and mine site-related sources. Mercury is regarded as a threshold toxicant, and the significance of the hazard posed by mine site-related exposures is dependent on understanding and sharing the existing exposures to mercury endemic in the Kuskokwim drainage prior to the addition of mine-related risk.	The reviewer should note the context within which this HHRA *was* developed. The rationale for considering incremental risk is stated above in the response to the third comment. The stated scope of the HHRA was to address incremental risks. Additive background + site related risks are shown in the resulting tables, which indicate no significant risk thresholds were exceeded as a result of additive exposure from project-related risk. However, Donlin is not responsible for hazards related to background risk.
2.0 Selection of Constituents of Potential Concern	2-1	LK		We recommend that the HHRA not preclude analysis of exposure and risk simply because treatment or containment technologies are in place. It is possible that these technologies could fail. We recommend that the HHRA evaluate the chemical exposures that might be associated with treatment and containment failures. This is particularly true given that potentially hazardous materials would be left on site in perpetuity. As we noted above, cyanide and other chemicals may be of concern on an incident specific basis. We recommend that the hazards of these exposures be assessed in conjunction with the probability of incidents that could result from these exposures.	See above responses regarding scenarios and scope of the HHRA.
3.1	3-1	TR	The HHRA calculated risks for the last year of the mine life (year 27), when the increase in COPC concentrations in the environment from the proposed Project would be expected to be highest. The planned 27-year-based exposure represents the temporal boundary for maximum estimated releases from the proposed Project.	See earlier recommendation to consider risks from exposure to contaminated groundwater even after year 27.	See above responses regarding groundwater exposure.
3.0 Conceptual Site Model	3-1	LK		As we noted previously, there are additional receptors, exposure media, and exposure routes (e.g. groundwater) that should be included in the Conceptual Site Model (CSM). These additions are affected by consideration of additional COPCs (e.g. cyanide). We recommend that all relevant receptors and exposure routes	The scope and purpose of the HHRA was articulated in the introduction section.

SECTION NUMBER	PAGE	ID	ORIGINAL LANGUAGE	PROPOSED LANGUAGE OR COMMENT	RESPONSE
				need to be included in the CSM and a sufficiently detailed rationale as to why an exposure pathway is incomplete or not quantitatively evaluated provided in the HHRA for decision makers and the public to understand. Again, the existence of a control for a particular type of exposure should not preclude evaluating that exposure. It is possible that control measures will fail, particularly given the duration over which they will be implemented. In addition, we recommend that the potential plausible future exposures be identified and considered in the CSM.	
3.1 Temporal Boundary	3-1	LK		The temporal boundary could change as a result of considering additional exposure scenarios outside of atmospheric mercury deposition and uptake by organisms. As we noted previously, we recommend consideration of future exposures and future incidents that could alter exposure (e.g. failure of water treatment at the pit or seismic activity that might cause release of contaminants) in the HHRA.	The HHRA does not assume that exposures to background constituents will cease at year 27. See previous responses regarding the scope of the HHRA.
3.2 Spatial Boundary	3-1	LK		The comment on temporal boundaries is also of relevance to spatial boundaries. We recommend that the HHRA consider both the temporal and spatial boundaries.	Temporal and spatial boundaries were described in the HHRA.
	3-2	LT	Exposure Pathway Diagram Figure 3.1-1	We note that there is a currently inactive non-transient, non-community water system (AK2271983) on site. Although it is listed by ADEC in EPA's SDWIS database (Safe Drinking Water Information System) as inactive, the Bedrock Aquifer has been used in the past for a source of drinking water and may be used again. We recommend contacting ADEC, if needed, for information on decommissioning the water system and properly capping the wellhead. Here is a link to ADEC's Best Management Practices for well decommissioning: http://dec.alaska.gov/eh/pdf/dw/dwp-alaska-bmps-for-decommissioning-water-wells-and-boreholes.pdf This document comes from ADEC's Drinking Water Protection page: http://dec.alaska.gov/eh/dw/dwp/dwp-main.html	Noted.
3.3	3-3	TR	Groundwater that could be impacted by the proposed Project is not a source of drinking water in the surrounding environment. As described in Section 3.7.3.2.3 of the DEIS (USACE 2015), groundwater impacts are anticipated to be limited to the American Creek drainage in the footprint of the Waste Rock Facility and extending to the pit, in the immediate vicinity of the pit, and groundwater in the Anaconda Creek drainage below the tailings storage facility that is captured in the seepage recovery system. As future development of groundwater wells is not reasonably anticipated in this area, consumption of groundwater is not a complete human health exposure pathway. Therefore, groundwater was not included as a source for the HHRA.	We continue to recommend that the HHRA evaluate groundwater as a major route for human health exposure to chemicals of potential concern. We note that discussion on the groundwater-surface water interaction is also important information to disclose when discussing the potential human health risks from the project.	Noted. See above responses regarding groundwater exposure.
3.3 Primary Sources and Transport Pathways	3-3	LK		We recommend that the HHRA consider additional sources and transport pathways. Again, the existence of control technologies should not preclude consideration of risks or hazards. As we know that groundwater has been used as a drinking water source in the past, we recommend that the HHRA also consider the exposure and risks from the **potential future use** of groundwater as a drinking	See above responses regarding scenarios and scope of the HHRA.

SECTION NUMBER	PAGE	ID	ORIGINAL LANGUAGE	PROPOSED LANGUAGE OR COMMENT	RESPONSE
				water source.	
3.3	3-3	CE	The primary sources of COPCs include fugitive and point source emissions generated by the proposed Project, and for mercury, existing deposition from global background sources. Other sources of COPCs that may be generated by the proposed Project are not expected to be transported or deposited outside the Core Operating Area. Surface water that comes in contact with mining infrastructure ("contact water") will be treated prior to discharge to levels at or below USEPA and ADEC surface water criteria.	While the mining contact water discharge levels will be at or below ADEC's surface water quality criteria, the increase in both Total Hg and sulfate need to be taken into consideration in section 5.1 when considering the future impacts of MeHg production. Tables 5.1-10 and 11 show that there will be no future changes in Total Hg water concentrations as a result of atmospheric deposition. However, because the contact water discharge concentrations were not taken into consideration in this calculation, we are not certain if the values presented in Tables 5.1-10 and 11 are representative of the actual future concentrations. Without a discussion of the potential impacts of sulfate and Hg inputs to the discharge from the WTP, calculations of MeHg levels in biota and resulting risks to humans may be significantly underestimated. We recommend that the HHRA also evaluate the potential impacts of sulfate and Hg inputs on risks to biota and human health in order to discuss more accurate concentrations that will help agency decision makers and the public better understand the values presented.	As a result of mine facilities intercepting flow from American Creek and Anaconda Creek, the predicted net changes to the mercury and sulfate load in Crooked Creek at Year 20 of mine operation are decreases of 5.3-percent and 4.5-percent, respectively. Since total flow in Crooked Creek is predicted to decrease by approximately 6.9% at this same point compared to undisturbed conditions, the mercury and sulfate concentrations are estimated to increase 3.0-percent and 2.6-percent (Rieser 2017). The overall effect would be to decrease the mass of MeHg relative to the calculations presented in the HHRA. For the purposes of the HHRA, this decrease was considered *deminimus* and no changes were made.
3.3	3-3	CE	The model showed that mercury would be emitted predominantly as gaseous, elemental mercury [Hg(0)], and the mercury that is deposited would consist of Hg(0), oxidized mercury [Hg(2+)], and particulate mercury [Hg(p)], with the majority in the particulate form.	There was a recently published paper by Daniel Obrist in the journal *Nature* that indicates that the majority of Hg deposition in northern latitudes is from Hg(0). "Here we present a comprehensive Hg-deposition mass-balance study, and show that most of the Hg (about 70%) in the interior Arctic tundra is derived from gaseous elemental Hg (Hg(0)) deposition, with only minor contributions from the deposition of Hg(ii) via precipitation or AMDEs. We find that deposition of Hg(0)—the form ubiquitously present in the global atmosphere— occurs throughout the year, and that it is enhanced in summer through the uptake of Hg(0) by vegetation. Tundra uptake of gaseous Hg(0) leads to high soil Hg concentrations, with Hg masses greatly exceeding the levels found in temperate soils." Our understanding of Hg pollution is complex and the science continues to evolve. In the short term, the above findings by Obrist et al, are not expected to be incorporated into atmospheric models or the calculated deposition as part of this project. However, because these results were published in a very influential scientific journal, they are worth noting. Furthermore, at the recent International Conference on Mercury as a Global Pollutant (Providence RI, July 2017), the results from this study figured prominently in both scientific and plenary talks. Because these results represent a different perspective than has been currently available in existing models, we recommend mentioning this study in the HHRA and providing an estimate of how the study might impact the results as they pertain to Hg deposition associated with the proposed project. Specifically, we recommend that this section of the HHRA mention the amount of increase in Hg(0) expected as a result of the project and how this Hg may be deposited to the landscape.	We assume this publication refers to the July 2017 issue of Nature, which was published after the HHRA was submitted to the USACE. The significance or validation of this publication on atmospheric modeling is unknown. However, given that this publication addresses the arctic tundra ecosystem and not the ecosystem of the Project, its potential applicability appears low and, though could be addressed in the uncertainty section, appears tangential to the body of literature reviewed and incorporated into the HHRA.
3.5 Exposure Media	3-5	LK		We recommend that ground and surface water need to be further considered in the HHRA, particularly in relation to incident based exposures.	See response to groundwater and surface water impacts above.
3.6 Exposure Populations	3-5	LK		We recommend that the HHRA needs to look at incident based exposures that may occur closer to the mine site (e.g. barge accidents involving cyanide, treatment plant failure, seismic breach of containment, etc.). Furthermore, we recommend that the HHRA include consideration to identifying populations that	See above responses regarding scenarios and scope of the HHRA.

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				could be affected by exposure to groundwater.	
3.6 Exposure Populations	3-6	LK		An additional point to be made is that infants and small children are also developing and hence may be impacted to a greater degree by COPC, particularly mercury. We recommend that the HHRA address potential exposure to sensitive populations, such as infants and small children.	Risks to infants and small children were addressed in the HHRA.
4.1 Data Sources and Usability	4-1	LK		We recommend that Appendix A include a discussion of the spatial representativeness of samples and why particular data sets will appropriately represent conditions at the Donlin mine site. We recommend that Appendix A also identify the reporting limits (RLs) used for various analytes/media and compare those RLs with risk-based levels of concern.	Maps and tables of sample locations have been added to the Final HHRA.
4.1 Data Sources and Usability	4-2	LK		We recommend that the ATSDR NOAEL mercury hair levels not be used to assess risks posed by mercury, but rather the hair concentration corresponding to EPA's mercury reference dose (one microgram per gram). Though ATSDR values have been used by ADHSS in a public health context, ADHSS supports the use of EPA's RfD in a regulatory context. We commented to this issue, as well as, in our comments on the PFEIS provided previously to the Corps.	NOAELs were not used to assess risk, but they were evaluated as weight of evidence in response to this comment from EPA.
5.1.1.	5-1	CE	Commonly, this rate is represented by the ratio of MeHg to THg (or %MeHg)	Methylation rates are typically expressed as an amount of MeHg generated per unit time, or normalized to the amount of inorganic Hg, which can be expressed on a per unit time basis. The %MeHg is a useful measure of methylation efficiency of an area (a proxy measure of net MeHg production), but it is not commonly represented as a "rate" as expressed in the HHRA. We recommend changing the text from the "methylation rate" to the "methylation potential" or "methylation efficiency"	Reference to %MeHg as methylation rate is commonly and frequently used in published literature, and referenced in the EIS. The definition of %MeHg is included in the HHRA which should be adequate for explaining this term.
5.1.1.	5-1	CE	Numerous studies have attempted to quantify driving factors, sometimes with conflicting results and rarely with quantifiable relationships	This is an important statement and we recommend that the HHRA would benefit from being more specific and with citations also provided. We are not certain which studies have quantified the driving factors of MeHg production and which findings are conflicting? And are these conflicts still ongoing, or have they been resolved in recent years? When considering the current paradigm regarding Hg methylation as expressed in recent review papers (Ullrich et al. 2001, Driscoll et al. 2013, Hsu-Kim et al. 2013, Lehnherr 2014), what are the conflicting results/disagreements? There seems to be some recent changes on the bioavailable forms of Hg (shift from thinking of passive diffusion of uncharged Hg-sulfide species, towards the role of Hg bound to organic matter) as well as an expansion of our understanding of which types of microbes are capable of methylation. We are not aware of current disagreements or conflicting understandings of the dynamics associated with Hg methylation, and we know that there are examples of methylation rates being quantified based on information on the driving variables. However, we concur that there is not a universally agreed upon equation (Harris et al. 2012). One thing to keep in mind during this discussion is that there is a lot of site-specific variability in terms of the major factors controlling MeHg production. We suggest that this variability does not necessarily mean that the results are conflicting.	Citations and discussions of specific citations are provided in the HHRA in the text immediately preceding this summary statement.
5.1.1.	5-1	CE	Finally, the rates of demethylation reactions (e.g., photo-demethylation) can be locally important, but are likely to be tertiary order controls	We recommend that the HHRA explain why photo-demethylation is a tertiary order control and why the rates of methylation and demethylation are considered to be equally important in determining the final concentrations of MeHg in a system. We have some questions regarding this statement that we would be happy to discuss further.	Recommendation noted. This level of detail does not appear warranted for an HHRA.

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5.1.1.	5-1	CE	The availability of Hg(2+) is a critical limiting factor for the production of MeHg; however, direct measurement and reporting of Hg(2+) concentrations are rare.	In several locations, the HHRA mentions that the form of Hg that is methylated is Hg2+. We note that almost all Hg in aquatic environments is Hg2+ bound to something, and that ionic Hg2+ would only occur in the complete absence of organic ligands. In the waters within and around the project area, there would not be expected to be any free Hg2+, as it would all be associated with sulfide or sulfur containing ligands (e.g. thiol groups on dissolved organic matter) or particles. The reason that direct measurement and reporting of Hg2+ do not occur in the literature is because Hg2+ is effectively the same as Total Hg. We recommend additional explanation of this in the HHRA.	Hg2+ is defined in the HHRA as oxidized/divalent mercury, not a free ion (see for reference the acronym section). Hg2+ is not the same as Total Hg and the form of Hg is a very important consideration for bioavailability, uptake and toxicity. No additional explanation has been provided.
5.1.1.	5-1	CE	Little research has focused on measuring methylation rate changes at very low or very high concentrations of THg, thus testing where the concentration of mercury would be a limiting factor in methylation.	There is a fair amount of research on how MeHg production can vary depending on concentrations of inorganic Hg and whether ambient inorganic Hg pools are limiting MeHg production or not (Mauro et al. 2002, Lehnherr et al. 2012). Whether inorganic Hg is a limiting factor of MeHg production will be dependent on site specific concentrations of other variables that influence the presence, abundance, and activity of methylating organisms, as well as factors that influence the bioavailability of the inorganic Hg. There seems to be general agreement within the scientific Hg community on this.	Noted. While we agree with the statement that MeHg production does vary as a function of total Hg in the system (this process is described in the HHRA, see section 5.1.1), the cited references refer to a mercury study in an Everglades nutrient removal lake system (Mauro et al), and a study on the contribution of particulate MeHg in snowpack in the oil sands region of Alberta to aquatic systems (Lehnherr et al.). Neither of these studies contradicts the other studies cited in the HHRA in support of our original statement.
5.1.1.2	5-3	CE	Primary Mechanism: Oxygen Content (Redox Controls)	A potentially important variable not considered in this section is how variations in surface and subsurface hydrology may impact redox conditions and how this might impact Hg methylation. During the process of mine pit dewatering, subsurface water will be brought to the surface. The fate of this water has the potential to create zones of saturation that could impact redox conditions and oxygen content of soils. Because this issue is not discussed in the HHRA, we are not clear whether there would potentially be an impact or not. We recommend that a discussion of hydrological impacts in the context of variations in redox conditions and Hg methylation be included in this section of the HHRA.	Dewatering impact on subsurface soil redox rates and subsequent transport to above ground components is a level of detail not warranted by either hydrological modeling conducted to date nor the agreed upon scope of the HHRA.
5.1.1.2	5-3	CE	Obrist (2012) found that in a forested system, THg decreased with soil depth (to 20 centimeters [cm]), but MeHg stayed approximately the same, resulting in a weak positive correlation (r2 of <0.3, slope of 0.0006) in MeHg to THg content with soil depth (Table 5.1-1).	We recommend taking another look at the data presented and discussed in the HHRA. In Table 5.1-1, we do not see the trends that are being described in this sentence. Soil THg goes from 43 to 33 ug/kg (23% decrease) and **MeHg goes from 0.07 to 0.04 ug/kg (43% decrease).** As such, this statement that THg decreases, but MeHg stays the same is not supported by the referenced Table. If we include leaf litter in this analysis, again the trend is not apparent for THg, which starts at 34 ug/kg at the surface and is pretty much the same at depth (33 ug/kg) and **MeHg shows a larger decrease from 0.29 ug/kg at the surface to 0.11 ug/kg at depth.**	It is correct that MeHg did increase from 0.04 to 0.07 ug/kg in the soil profile. In Obriest, the ratio of MeHg to THg was statistically compared and results indicated that ***there was not a statistical difference*** in the ratio of MeHg to THg between soil 0-20 cm and below 20cm. While text in the HHRA could be modified to remove the phrase "approximately the same", the conclusion statement is supported by Obriest and it is the ratio of MeHg to THg that is the point in the section's discussion.
5.1.1.2	5-3	CE	In general, in-river methylation is typically a negligible component of the MeHg budget for creeks (St. Louis et al. 1994, Berndt and Bavin 2012).	The degree to which in-river methylation drives the MeHg budget of a creek will be dependent on the catchment characteristics. In the two studies cited, the catchments contain wetlands which were determined to be more important zones of MeHg production than in-stream sediments. However, clearly in-stream sediments can be sources of MeHg (Marvin-DiPasquale et al. 2009). We do not believe that the relative importance of internal versus external MeHg production to the overall budget of a creek is universally applicable across systems, but is a feature of the characteristics of the catchment and the river/creek, and we recommend that the HHRA be revised to include this information.	We agree that in-river methylation can occur and that it depends on the environmental factors of the catchment system. The statement in the HHRA was not phrased to suggest that in-river methylation is never a driver. It is interesting to note that the conclusion of DiPasquale et al is "No significant relationship existed between overlying water MeHg concentrations and those in bed sediment or pore water", <u>suggesting upstream sources of MeHg production may be more important than local streambed production as a driver of water column MeHg concentration in drainage basins that receive Hg inputs primarily from atmospheric sources</u>. This conclusion also supports the statement made previous to the sentence in question in the HHRA: "In aquatic environments, methylation is less prevalent in environments with higher flow and low hydraulic retention (St. Louis et al. 1994)".

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5.1.1.2	5-3	CE	St. Louis et al. (1996) concludes that boreal forest catchments can be sinks for THg regardless of the proportion of wetlands in the catchment. Contradicting St. Louis et al. (1996), Brigham et al. (2009) studied streams in Oregon, Wisconsin, and Florida, and identified that there was a strong positive correlation between the proportion of wetlands in a basin and the filtered THg and MeHg concentrations in surface water.	We understand and recommend that the results of Brigham et al, 2009 do not actually contradict the results of St Louis et al, 1996. Forested catchments are large net sinks of atmospheric THg, but that doesn't mean that there can't be a positive correlation between the proportion of wetland cover and THg and MeHg concentrations. Catchments can be a net sink for THg and also show a positive correlation with % wetland cover. We recommend revising this statement in the HHRA.	Addressed by revised text in Section 5.1.1.2.
5.1.1.2	5-4	CE	Above this maximum, the concentration of MeHg decreased, perhaps due to formation of dimethylmercury (Craig and Moreton 1986)	We recommend that this sentence may not be necessary (speculative) and can be removed.	~~Noted.~~ The statement was taken from the referenced document. No change made to HHRA text.
5.1.1.2	5-4	CE	The reviewed research indicates that the factor increase in MeHg is 0.5 to 1.0 times the factor increase in sulfate, as described in the subsequent paragraphs.	We recommend that this statement includes an important calculation and therefore citations should be provided to indicate how this factor of 0.5 to 1.0 times was derived or what studies were used to come up with this value. Stating that "the reviewed research indicates…" needs to be cited in order to provide confidence in the calculation for agency decision makers and the public.	The HHRA discusses and provides citations to support the factors cited.
5.1.1.2	5-5	CE	Results from studies carried out in surface waters indicate that there is a negative relationship between pH and methylation rate; as pH decreases, the proportion of THg that is MeHg increases.	As mentioned above, we recommend providing citations in the HHRA that identify the studies/research that obtained these results.	The HHRA discusses and provides citations to support the factors cited.
5.1.1.2	5-6	CE	While there is a high degree of variability in the methylation rates reported for different wetlands studied, the average values in wetland porewater for THg, MeHg, and %MeHg are similar between geographically diverse studies in northern North America.	We recommend that a citation for this statement be included in the HHRA, particularly because this conclusion does not seem intuitive. It is expected that there is large spatial variability in THg, MeHg, and %MeHg levels in wetland pore water from geographically diverse studies. For example, in the following text, pore water % ranges from 2.7 to 15.9% in one study.	The HHRA discusses and provides citations to support the factors cited.
5.1.1.2	5-6	CE	MeHg concentrations are also low, ranging between 0.34 and 3.07 µg/kg	The 3.07 µg/kg does not seem like a low MeHg concentration. We recommend providing a reference concentration in the HHRA and explaining the thresholds for what is to be considered low and high concentrations.	This statement made in the context of a review of Canadian arctic wetlands, in which soils were characterized as having low THg concentrations, ranging between 10 and 250 micrograms per kilogram (µg/kg). Specific references are provided at the beginning of this section.
5.1.2 Baseline Methylation Rates – Soils	5-7	LK		We recommend that maps be provided in the HHRA identifying the sampling locations.	Maps and tables of sample locations have been added to the Final HHRA.
5.1.2 Baseline Methylation Rates – Soils	5-8	LK		We recommend that the description of background Hg concentrations for the Red Devil Mine site discuss the differential background concentration values for soils from mineralized vs. non-mineralized areas.	Data from the Red Devil mine was used for comparison purposes only; as such, further dissection of Red Devil as compared to Donlin or other areas of study is tangential to the purpose of the HHRA.
5.1.3 Baseline Methylation Rates –	5-8	LK		As mentioned above, we recommend that maps be provided in the HHRA identifying the sampling locations.	Maps and tables of sample locations have been added to the Final HHRA.

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Figure 5.1-1	5-13	CE	Figure 5.1-1	The units on this graph do not seem to be correct. These concentrations are below the reporting limit for these parameters. Also, because there is a big spread in the data points, with the regression being driven by a few large concentrations, we recommend improving the representativeness of the regression equation by plotting the data on a log-log scale.	The units on the graph have been corrected to µg/L. Conversion to a log-log scale would not alter the R^2.
5.1.4.	5-14	CE	The D-MCM is another lake-focused model that requires speciated mercury at greater spatial and temporal frequency than the proposed Project currently has in its baseline database. Additionally, the complexity of the D-MCM model is best utilized when extensive information is known about speciated mercury in the foodweb.	While we concur that D-MCM was developed for lakes, it has since been used successfully to model river systems. In order for D-MCM to run, we are interested to hear more about what specific data is missing from the project baseline dataset. For example, does the model have a requirement where X number of data points are needed from X area? If so, what are these requirements, and can data from surrounding projects (i.e. the work of John Gray, the data from the Red Devil Mine, etc.) be used to meet those requirements? Also, we understand that the model may require food web Hg data inputs, but we are unclear why it would need *speciated* Hg data in the food web as well. We recommend that the HHRA include more information for agency decision makers and the public as to why using this model will not work to model mercury in this system, and how that determination was made – as it is currently unclear.	We feel that the HHRA has done an adequate job of reviewing the most relevant literature, available data, and applicability of models, as applies to the scope of work.
5.1.5.1.	5-15	CE	This is an overestimate of the deposition rate in the study area for two reasons: (1) the model that was used to estimate deposition, CALPUFF, did not account for the pit retention of emissions; and (2) for approximately half the study area, deposition rates were estimated to be negligible (Environ 2015).	We recommend that the HHRA discuss the percentage of Hg deposited that is expected to be retained in the pit. We presume that this would be extremely small and may not provide much of an overestimation. We also recommend that examples of how the model may overestimate deposition be provided in the HHRA. Examples could include the recent work of Obrist et al, 2017, which suggests that Hg[0] deposition may be much more important than previously thought and that the model underestimates this form of deposition.	This is a level of detailed request that does not appear to impact the HHRA results, as pit retention was not incorporated into deposition estimates. Example(s) of how the model may overestimate deposition" were explained in the HHRA: for approximately half the study area, deposition rates were estimated to be negligible (Environ 2015).
5.1.5.1.	5-15	CE	Atmospheric mercury that would be deposited would consist of Hg(0), Hg(2+), and Hg(p), with the majority in the particulate form. A minor component (approximately 1 to 2%) would be deposited as oxidized mercury (Hg[2+]), a form that is more likely to be methylated.	We note that Hg(P) is Hg2+ bound to a particle. Mercury deposited as Hg2+ will quickly become associated with organic matter or particles in the environment. We are curious about, and recommend that the HHRA discuss, how much is known about the differing degrees of bioavailability of Hg deposited as Hg2+ versus HgP, especially over a time period of 27 years. If there is not much known on this topic, it would be conservative to assume that all forms of Hg deposited have the potential to be bioavailable for methylation (i.e. apply the %MeHg rate to the total amount of Hg deposited instead of just the 2% of deposited Hg that is gaseous oxidized Hg). The HHRA mentions over 40 times that the calculations provided are "conservative" and it mentions over 20 times that the impacts may be "overestimated". We recommend that in scientific studies such as this one, conservative assessments of risk are desired, and therefore assuming that all forms of newly deposited Hg are available for methylation would be the desired conservative approach to take. We note that assuming that Hg deposited as Hg(P) or Hg(0) is not bioavailable for methylation over the expected life of the mine (27-year time period) is not a conservative assumption, especially given that no literature/citations are provided to support the idea that Hg deposited as Hg(P) or Hg(0) is extremely recalcitrant and not available for methylation. We recommend consideration of this in the HHRA.	We feel that the HHRA has done an adequate job of reviewing the most relevant literature, available data, and applicability of models, as applies to the scope of work. Discussion of Hg(0) cycling is provided in the HHRA, as well as in ARCADIS (2014) and Environ (2015).
5.1.5.1	5-16	CE	Concentrations and deposition rates for Hg(2+) were not measured at the Alaska MDN stations. However, speciated mercury was	The majority of Hg in precipitation can be assumed to be Hg(2+). We recommend that this would be the conservative assumption and pose that it does not seem reasonable to apply the ratio of Hg(2+) to Hg(0) in air and assume that Hg2+ in	Background Hg(2+) deposition rates were revised to indicate wet and dry deposition rate estimates, based on follow up discussions with Environ. See last paragraph, section 5.1.5.1.

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			measured at 10 sites in northern Canada (Environment and Climate Change Canada 2016) and the ratio of Hg(2+) to Hg(0) was between 0.04 and 6.64% at these sites	precipitation has a similar proportion. This would then underestimate the amount of Hg2+ in precipitation, and we recommend correcting this in the HHRA.	
5.1.5.1	5-16	CE	Therefore, of the global background deposited mercury, less than 1% is Hg(2+).	Hg(0) is highly insoluble in water, whereas Hg(2+) is highly soluble. As mentioned above, we note that using the proportion of Hg(0) to Hg(2+) in the air and applying it to wet deposition as well would be inaccurate and that underestimates the proportion of Hg in precipitation that is oxidized Hg in the dissolved phase. We recommend taking another look at this in the HHRA.	Wet and dry deposition rates from the Project were considered. The wet + dry deposition was estimated at 0.58 µg/m2/yr, (this number stated in the text). The wet% versus dry% varies by watershed. The area-weighted average of Hg2+ is 0.0116 and so the Hg2+ fraction due to just Donlin sources is 0.0116/0.58 = 2%. The 2% value was stated in Section 5.1.5.1.
5.1.5.1	5-16	CE	Analysis of Sulfate Loading.	We recommend that the sulfate loading analysis needs to include sulfate inputs from the water treatment plant. Without this input included, the impacts on MeHg production on Hg in fish may be underestimated.	Sulfate loading to Crooked Creek is predicted to decrease as a consequence of interception of flow in American Creek and Anaconda Creek by mine facilities. For the purposes of the HHRA, this decrease was considered *deminimus* and no changes were made.
5.1.5.3	5-17	CE	The proposed Project is not expected to significantly impact the pH, DOC, temperature, oxygen content…	We recommend that the oxygen content should be mentioned/discussed in the context of the hydrological impacts from removing ground water for pit-dewatering and adding it to the surface water. We also recommend that the HHRA discuss whether this practice will create zones of surface saturation that did not previously exist. We think that it seems likely that after pit-dewatering ends and the ground water level rises, there may be a pulse of DOC into the areas waterways. This pulse of DOC has the potential to stimulate MeHg production, and we recommend that this be discussed in the HHRA.	See previous response to comments addressing the scope of the HHRA.
5.1.6	5-17	CE	Oxidized mercury (Hg[2+]) is more likely to be methylated upon deposition and is a minor component (approximately 1 to 2%) of the total deposited. The rate of methylation for the newly deposited Hg(2+) is not known for the study area	For clarification, we recommend that the HHRA discuss whether the deposition mentioned here refers to both wet and dry deposition combined or whether there would be separate deposition. The HHRA should also discuss the proportion of wet deposition versus dry deposition on an annual basis. While dry deposition may be dominated by Hg(P), wet deposition may have a larger proportion that is in the dissolved phase (i.e. Hg2+). We recommend that this information should be provided to agency decision makers and the public. In general, the assumption that 98 to 99% of all deposition (wet + dry) is either Hg(P) or Hg(0), does not seem accurate or representative of environmental measurements of Hg speciation, particularly in wet deposited Hg.	See revisions to sections 5.1.5.1 and 5.1.6.
5.1.6	5-17	CE	All deposited Hg(2+) was assumed to be converted to MeHg, and deposited non- Hg(2+) was assumed to undergo methylation at a rate of 1%"	Earlier in this paragraph the HHRA mentions that Hg(2+) is 1% to 2% of total deposition. As noted above, we believe that this may underestimate the contribution of Hg2+, particularly in wet deposition. We recommend that the HHRA should clearly note in the above assumption whether Hg(2+) is 1% or 2%. Adding this with the 1% of non Hg(2+) deposition results in either 2% or 3% of newly deposited Hg being methylated. Therefore, we recommend that the HHRA be clear about which methylation rate number is being used in the analysis.	See above comment.
5.1.6	5-18.	CE	The reviewed literature indicates that the factor increase in MeHg is 0.5 to 1.0 times the factor increase in sulfate, or in other words, the increase in %MeHg would be of a similar magnitude to the increase in sulfate concentration in systems where sulfate is initially at low concentrations	In a review of Wasik et al, 2012 and Jeremiason et al, 2006, we did not see how an X increase in sulfate equates to X increase in MeHg in the calculations presented. We therefore continue to recommend more details be included in the HHRA, including citations, on how the 0.5 to 1.0 times factor values were calculated, and/or from what studies the factor values originated. This calculation may be very important to the final estimates of fish MeHg concentrations. Therefore, we recommend that it is critical that its derivation be well documented in the HHRA.	We feel that the HHRA has done an adequate job of reviewing the most relevant literature, available data, and applicability of models, as applies to the scope of work. The HHRA has described both ranges of MeHg in environmental samples and presented the numbers used in the calculations.
5.1.6	5-18.	CE	This would result in a %MeHg of existing soil	We recommend that the HHRA clearly state where the 1% methylation rate value	See above response. Note that discussion regarding the fraction of

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			THg and newly deposited non-Hg(2+) pools increasing from the current estimated methylation rate of 1% to a future rate of 1.03%."	originates. Earlier in the document, the HHRA mentions 1% to 2% of Hg2+ and that an additional 1% of non-Hg2+ will be methylated. We conclude that this should equate to a 2% to 3%, not a 1%, methylation rate. Furthermore, the increase in sulfate loading impact on Hg methylation is based on the total amount of Hg in a system. Therefore, a 3% increase in sulfate with a one times factor increase in MeHg would equate to a methylation rate of 3%. If this is added to the existing 2% to 3%, it results in an overall methylation rate of 5% to 6%. This is very different than the 1.03% value presented in this statement. As mentioned above, this calculation only assumes sulfate from atmospheric loading and that the water treatment plant will release no sulfate. We recommend that sulfate (and Hg) loading from the water treatment plant also be taken into consideration in these calculations.	Hg(2+) in air (2% of Project related emissions) will be different than the fraction of Hg2+ in soil from the Project; additions of Hg2+ in soil from the Project were estimated at 0.0116 ug/m2/yr plus an estimated at 1.03% methylation rate of non-Hg2+ (0.58-0.0116) which, as stated in section 5.1.6. The 1.03% methylation rate reflects an estimated baseline future methylation rate of 1%, twice the median rate of all proposed Project baseline data, but reflecting the mean of paired soil samples collected in 2014 (ARCADIS 2014), plus contribution of sulfate to soil, which will affect methylation rate. Sulfate contribution to methylation rates would affect the pool of non-Hg2+ that has the potential to methylate to Hg2+ only. Table 5.1-9 has been revised to add more detail and correct for a typographical error.
Table 5.1-9	5-19	CE	estimated annual dustfall	We recommend that the HHRA discuss why only deposition from dust fall is being assessed instead of the total atmospheric deposition from wet and dry sources. We also note that not discussing total atmospheric deposition here could lead to a significant underestimation of the total atmospheric deposition associated with the project and the risk analysis.	Wet and dry deposition was considered from Project related emissions.
5.1.7	5-19	CE	*Projected Increase in Mercury in Aquatic Systems*	This section does not include direct releases into surface waters from the water treatment plant. This may have a much larger impact on Hg and sulfate concentrations than atmospheric deposition and may represent a significant underestimation of the impacts of the mine activities on MeHg production. We continue to recommend that this impact analysis be included in the HHRA, specifically in Tables 5.1-10 and 11.	See responses above to surface water loading.
Table 5.1-10	5-20	CE	Future THg is 35 ug/kg and MeHg is 0.059 ug/kg	If the atmospheric loading of sulfate increases by 3%, and this translates into a similar increase in MeHg, we believe that would result in 1.1 ug/kg of MeHg (i.e. 3% of 35 ug/kg) instead of 0.059 ug/kg. We also note the large difference between 1.1 and the currently reported 0.059 ug/kg of MeHg. We recommend that the calculation which resulted in 0.059 ug/kg needs to be better explained in the HHRA, and that the same issue applies to the MeHg calculations in Table 5.1-11.	See section 5.1.6., including table and footnotes provided in Table 5.1-9.
Table 5.1-11	P 5-20	CE	Table 5.1-11	We recommend that the HHRA clearly show how the water numbers were determined and state which water bodies are referred to in this table. It is currently unclear whether this is for Crooked Creek or another water body. We also recommend that the HHRA clearly show the relationship between Hg and sulfate deposited on the catchment and loading to the surface water and sediment. We further recommend that an export yield needs to be identified, in order to see how deposition to the catchment affects the water body. The text currently states that "The effect of current deposition on stream concentrations was then estimated as the increase in concentration from base flow conditions to average annual stream concentrations." In order for this calculation to make sense, we recommend that there needs to be a good balance of base flow and stormflow sampling to back it up, and that the HHRA discuss the different types of flow conditions being averaged into the annual average. We further recommend that this calculation could be better expressed as an export yield, so that agency decision makers and the public can compare these results with other values in the scientific literature on catchment Hg export yields and determine if the values presented in the HHRA seem reasonable. Currently, the calculation comparing base flow and annual average flow is hard to understand and not comparable to	The HHRA states that the data comes from Crooked Creek (p. 5-20). Further information on the data is provided in the figures. Further information on base flow and other flow conditions can be referenced in Tetra Tech (2013), the report referenced in the HHRA used to understand flow conditions. Runoff into the stream environment is already described in the HHRA.

SECTION NUMBER	PAGE	ID	ORIGINAL LANGUAGE	PROPOSED LANGUAGE OR COMMENT	RESPONSE
				other studies.	
5.1	5-20	CE	Applying the factor increase of 1.01 on the baseflow THg concentrations yielded a future surface water concentration resulting from deposition from global background and proposed Project-related sources of 2.7 ng/L THg.	When only looking at atmospheric contributions, the impact on surface water concentration is expected to be very minimal (~0.5% increase in surface water concentrations from 2.6 to 2.7 ng/L). However, as mentioned previously, the impacts from the water treatment output are not included and EPA has concerns about that. We recommend that the HHRA discuss whether WTP discharges may impact Crooked Creek concentrations and quantify those impacts, as they may be more than 1%.	See response above to surface water loading.
5.2	5-21	CE	For example, as noted above, ATSDR (2013) reports that MeHg comprises 90% or more of the THg in fish. However, not all studies indicate this is the case; Gray et al. (2000) reported that MeHg comprised less than 1% of the THg in aquatic biota collected at three mine sites in southwestern Alaska.	Gray et al, 2000 states "Muscle samples of fish collected downstream from mines contain as much as 620 ng/g Hg, of which 90-100% is methylmercury." We do not believe this statement from the study is consistent with the 1% value quoted in this statement, and recommend that the HHRA take another look at this before the release of the FEIS.	We acknowledge this statement is incorrectly cited to Gray et al. (2000). We have revised this statement.
5.2	5-21	CE	However, given the variability reported in the literature of the fraction of THg that is MeHg (less than 1% to over 90%) and the relative toxicity of MeHg to THg (ATSDR 1999), the assumption in this HHRA was that all THg in biota is MeHg. This assumption results in an overestimate of potential risk from consumption of subsistence foods due to exposures to mercury.	We note that while there is variability in the %MeHg in fish, the range is not nearly as large as being presented here -- for the vast majority of scientific studies, the percentage range of MeHg is typically 90-100%. Therefore, the "overestimate" of the potential risk is many times smaller than is currently implied in the HHRA by presenting the <1% to >90% range. On page 8-2, the HHRA mentions: "It was also conservatively assumed that mercury in biota was in the form of MeHg (rather than THg, which has a lower toxicity and bioavailability), even though there are varying proportions reported in the literature for various species of plants and wildlife." Therefore, we also note that while it is correct that this assumption is conservative, its degree of conservativeness is much lower than is implied when suggesting that the %MeHg in fish can range from <1% to >90%. The assumption of 100% MeHg in fish only makes the calculations a little more conservative. We recommend taking another look at this in the HHRA prior to the release of the FEIS.	We have revised this statement.
5.2	5-22	CE	Compared to other literature or regional information (Appendix B), the proposed Project-specific BAFs were high; suggesting BAFs for the study area may be overestimated. Reasons for the higher Project-specific BAFs are not known, but may in part be due to the nature of the sampling events during baseline collection, which sought to characterize the more mineralized areas of the study area. These more mineralized areas may not be representative of the study area as a whole. However, the bias represents a conservative assumption.	It is expected that the BAFs for this study area would be higher than for regional datasets if the regional data are based on contaminated sites (i.e. data from/near abandoned Hg mines). Because the BAFs are a ratio of fish to water (or sediment), if mineralized areas were sampled that were not representative this would bias the BAF low due to an increase in the denominator (water or sediment) and not the numerator. Mineralized areas may result in high sediment Hg with low bioavailability and/or be spatially discrete and not correlated with food web exposure. As a result, the bias may underestimate the potential risk and does not represent a conservative assumption. We recommend taking another look at this statement in the HHRA.	BAFs were not compared to contaminated site data (they were compared to background data sets in papers that were evaluating the difference between background and contaminated sites). We acknowledge that bioavailability of different forms of metals may be underestimated or overestimated and acknowledge uncertainty with respect to biota uptake in the uncertainty section.
5.3 Baseline Exposure Point Conc.	5-25	LK		We recommend that the HHRA include the upper bound estimates for modeled concentrations in the discussion here.	The HHRA discusses the rationale for use of average concentrations and why upper bound modeled concentrations cannot be derived.
Table 5.5-1	5-35	LK		We recommend further review as to whether or not exposure to contaminants ends when mine operations are discontinued. This is particularly true for potential exposures associated with contaminants in groundwater. Individuals	It is not Donlin's assertion that exposure to constituents will end when mine operations are discontinued, particularly since these constituents are present naturally; rather, exposure would be

SECTION NUMBER	PAGE	ID	ORIGINAL LANGUAGE	PROPOSED LANGUAGE OR COMMENT	RESPONSE
				may continue to reside in the area for long periods after mine operations cease, therefore we recommend using a lifetime exposure period for the risk assessment based on ingestion exposures.	highest to constituents during operations, and therefore the focus of the HHRA.
5.5.2.3 Exposure via Subsistence Food Ingestion	5-38	LK		We note that typical CERCLA risk assessment uses the upper percentile rather than central tendency statistics to represent media contact rates. We also recommend that the ADFG-DS harvest rates are expressed in terms of edible material, and do not overestimate harvest in that regard. The ADFG-DS has adopted a methodology to estimate upper percentile harvest rates that accounts for resource sharing, and we recommend taking a look at that for use in the HHRA.	The Project is not a CERCLA site. See above response regarding harvest and edible rates.
7.3 Risk Characterization Results and General Discussion	7-3	LK		We note that for this Donlin mine project risk assessment, the overall hazard index from exposure to background and project-related contaminants is important. For contaminants regarded to have threshold impacts, we continue to recommend that the significance of project-related exposures is determined in part by the amount of existing/background exposure to those chemicals of potential concern. In a situation with high background exposure, the addition of project-specific exposure would be more problematic. As noted elsewhere, the sole focus on atmospheric exposure may not be representative of human health risks from the project. We recommend further evaluation of groundwater, surface water, and soil/soil runoff exposures also be conducted and discussed in the HHRA. Additionally, given that the pit water treatment and tailings containment must be maintained in perpetuity, we continue to recommend that the HHRA include an analysis of the consequences of treatment failure or tailings dam breach.	See above responses regarding groundwater exposure. See above responses regarding scenarios and scope of the HHRA.
7.3	7-3	LK		As mentioned above, the use of Type I and Type II errors is associated with false acceptance or rejection of the null hypothesis in statistics. We recommend that it would be clearer to use plain English discussing whether the errors of over or underestimating actual risks and hazards are likely to occur.	See above response regarding this issue.
7.3	7-3	LK		As noted previously, we recommend that the hair concentrations of Alaskan women need to be interpreted in terms of the hair concentration equivalent to the **EPA mercury reference dose, one microgram per gram**, used in the environmental regulatory context. The use of the no observable adverse effect levels to determine public health hazards may be inappropriate in this case, and such comparisons don't consider variability in the susceptibility of members of the community.	See above response regarding this issue.
7.4 Risks due to Fish Consump.	7-5	LK		As mentioned earlier, we note that a comparison of the ADHSS Fish Consumption advisory for Pike mercury concentrations to the potential Donlin mine project-related fish tissue concentrations may be inappropriate for use in assessing risk in the HHRA. The fish consumption advisory balances the risks of mercury exposure with the benefits of fish consumption. The level of mercury associated with the allowable hazard in the absence of the benefits of fish consumption would be much lower. We recommend taking another look at this in the HHRA prior to the release of the FEIS.	See above response regarding this issue.
8.1.1 Uncertainties in Media Conc.	8-1	LK		We note that, despite the assurance provided that reporting limits are all below risk based concentrations of concern, we could not find a definitive analysis justifying this statement in the HHRA. Furthermore, there is currently no discussion of the spatial representativeness of the data in the risk assessment document. We recommend additional evaluation of this issue in the HHRA.	Maps and tables of sample locations have been added to the Final HHRA. As stated in section 4.1, the datasets collected for the proposed Project included method detection limits and sample quantitation limits below ADEC and/or USEPA criteria for their respective media, as applicable and included explanations for qualified data. For data reported by other sources, method and quantitation limits were not always reported. However, only

SECTION NUMBER	PAGE	ID	ORIGINAL LANGUAGE	PROPOSED LANGUAGE OR COMMENT	RESPONSE
					sources of information that were peer reviewed and/or that followed USEPA guidelines for HHRAs, which include a data adequacy evaluation, were used in this HHRA.
8.1.3 Uncertainties in Toxicity Values	8-4	LK		We note that, in contrast to the assertion in the HHRA that EPA uses high uncertainty factors (i.e. 100 to 1000 fold) for reference dose derivation, this is simply not the case for most of the major contaminants of concern for the Donlin project. The EPA RfD for methyl mercury is based on human epidemiologic data, and utilizes an uncertainty factor of 10. The arsenic RfD utilizes an uncertainty factor of three. We therefore recommend a more accurate discussion of this uncertainty in the HHRA.	We believe the discussion provided in the uncertainty section is reflective of the process of toxicity value derivation by EPA. The statement assumed to be in question could have qualified the magnitude of uncertainty factors as an example, but we feel this point does not warrant revision to the HHRA.
8.1.3.2 Uncertainties in Arsenic Cancer Toxicity Values	8-5	LK		We note that current scientific information suggests that the current EPA arsenic slope factor of 1.5 underestimates the true cancer risk posed by arsenic exposure. EPA is now considering a revised slope factor of 25. In estimating arsenic's cancer potency, full consideration must be given to the range of cancers that may be induced by arsenic exposure. As previously mentioned, we note that many other studies outside of the Taiwanese study document arsenic's carcinogenicity and in particular, arsenic's ability to induce lung and bladder cancer, and recommend additional discussion of this in the HHRA.	See above response regarding the arsenic slope factor.
9 SUMMARY CONCLUSION	9-1	LK		As mentioned previously, we recommend that a determination of exposure associated with only atmospheric deposition of contaminants may be too limited an analysis. We continue to recommend that exposure to contaminants of concern via groundwater and surface water runoff should also be included in the risk analysis. We also recommend that additional exposure scenarios that are currently deemed incomplete due to treatment and containment should be properly evaluated and disclosed in the HHRA, given that both treatment and containment must maintain efficacy in perpetuity. For non-carcinogens in particular, we continue to recommend that background exposures to contaminants be considered along with the additional project-related exposures. As mentioned, the degree of background exposure affects the significance of project related exposure. Again, we note that the use of public health related fish consumption advisories for methyl mercury to interpret the potential human health impacts of the Donlin Project may be inappropriate. As previously noted, the state fish consumption advisories balance the benefits of fish consumption with the hazards of methyl mercury exposure. In the context of a risk analysis, the allowable levels of methyl mercury in fish tissue that were solely based on hazard would surely be lower than those identified in the state's fish consumption advisories.	See above responses regarding scenarios and scope of the HHRA.
Appendix B		CE	However, given temporal variability often observed in water chemistry data, it is uncertain whether and to what degree concentrations in fish tissue are related to concentrations in surface water. Therefore, Project-specific sediment-to-fish BAFs were used (in preference to surface water-to-fish) to estimate constituent tissue concentrations.	In terms of MeHg uptake, we note that the pelagic pathways are often more important than benthic, and that though the values are more variable in water, the accumulation in fish may be more linked to water than to sediment. The following text discusses optimizing water sampling for Hg BAF calculations(Riva-Murray et al. 2013). We recommend taking another look at this in the HHRA.	We feel that the HHRA has done an adequate job of reviewing the most relevant literature, available data, and applicability of models, as applies to the scope of work.

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Appendix B		CE		Appendix B states that "Sediments are considered to be 'sinks' for metals in aquatic systems (USEPA 1992b) and it is reasonable to assume that sediment chemistry would be relatively stable over time (as compared to water chemistry)." And later it says "Sediments are a primary source of mercury to overlying water". This appears to be contradictory, so we recommend that the HHRA discuss whether sediment in the area is considered to be a source or a sink of Hg/MeHg. Or, if operating in both capacities, we recommend that this needs to be more clearly discussed and justified in the HHRA.	Sediments can be both sinks and sources, as we believe EPA notes in a different comment above, and for consistency the report could have rectified the two statements. However, the statements are neither contradictory nor merit a revision to the HHRA.

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Mercury Isotopes Reveal Atmospheric Gaseous Mercury Deposition Directly to the Arctic Coastal Snowpack

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The Cryosphere

Recent degradation of interior Alaska permafrost mapped with ground surveys, geophysics, deep drilling, and repeat airborne lidar

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Safety First

Guidelines for Responsible Mine Tailings Management

V2.0 MAY 2022

Safety First

Guidelines for Responsible Mine Tailings Management

V2.0 MAY 2022

Report available at earthworks.org/safety-first and miningwatch.ca/safety-first

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This report was written by Earthworks (Jan Morrill, Paulina Personius, and Payal Sampat), MiningWatch Canada (Ugo Lapointe, Jamie Kneen, and Rodrigue Turgeon), and London Mining Network (Richard Harkinson), with contributions from Dr. Ann Maest (Buka Environmental), Dr. David Chambers (Center for Science in Public Participation), Dr. Steven Emerman (Malach Consulting), and Dr. Bruno Milanez (Grupo Política, Economia, Mineração, Ambiente e Sociedade/Universidade Federal de Juiz de Fora). — *This report was written using publicly available data and interviews, and feedback from regional consultation workshops held by the authors with communities affected by tailings. The information contained herein is believed to be accurate but does not purport to be complete.*

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Quebec Meilleure Mine – *Canada*

Radio Emergency Communication Operations Network (RECON Phil. Inc.) – *Philippines*

Regroupement Vigilance Mines de l'Abitibi et du Témiscamingue (REVIMAT) – *Canada*

Richwood Advisory Council – *United States*

Rivers Without Borders – *United States*

Rock Creek Alliance – *United States*

Save Our Cabinets – *United States*

Save our Seas and Shores Coalition – *Canada*

Save Our St Vrain Valley, Inc. – *United States*

Save The Scenic Santa Ritas – *United States*

Sibuyanon Against Mining – *Philippines*

Sierra Club – *United States*

Silver Valley Community Resource Center – *United States*

Society for Threatened Peoples – *Switzerland*

SOS Grenville sur la rouge – *Canada*

Southeast Alaska Conservation Council – *United States*

Southeast Alaska Indigenous Transboundary Commission (SEITC) – *United States*

Southwest Research and Information Center – *United States*

St. Mary's River Association – *Canada*

Sulamesi Wildlife Foundation – *Papua New Guinea*

The Friends of the Stikine Society – *Canada*

The Mining Observatory (Observatório da Mineração) – *Brazil*

Transport & Environment – *Belgium*

Unidos em Defesa de Covas do Barroso – *United Kingdom*

Union of British Columbia Indian Chiefs – *Canada*

vetoNu – *Sweden*

Vida e Ria ou Minaria – *Spain*

Wilderness Committee – *Canada*

Wildsight – *Canada*

Wisconsin Resources Protection Council – *United States*

Yukon Conservation Society – *Canada*

Individuals

Andre Oliveira Sawakuchi – *Instituto de Geociências da Universidade de São Paulo*

Andrew Hopkins – *Australian National University*

Cathal Doyle – *Middlesex University*

Cristiana Losekann – *Universidade Federal do Espírito Santo*

Daniela Campolina Vieira – Grupo de Pesquisa Educação Mineração e Território - *Universidade Federal de Minas Gerais*

Dr. Robin Broad – *American University*

Felipe Fayer Mansoldo – *Universidade Federal de Juiz de Fora*

Gavin Mudd – *Independent Academic Expert*

Joám Evans Pim – *Abo Akademi University*

John Cavanagh – *Global Economy Project, Institute for Policy Studies*

Karine Gonçalves Carneiro – *Universidade Federal de Ouro Preto*

Manoela Carneiro Roland – *Universidade Federal de Juiz de Fora*

Marcos Antonio Pedlowski – *North Fluminense State University*

Martha Priscylla Monteiro Joca Martins – *Université de Montréal*

Mbalenhle Mpanza – *University of Johannesburg*

Tatiana Ribeiro de Souza – *Universidade de Ouro Preto*

Tchenna Fernandes Maso – *Universidade Federal de Juiz de Fora*

William Sacher – *Universidad Andina Simón Bolívar*

Indigenous Communities and Tribal Nations

Luutkudziiwus – *Gitsxan Nation*

Nuxalk Nation – *Nuxalkuimc*

To endorse *Safety First: Guidelines for Responsible Mine Tailings Management*, email us: info@earthworks.org

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Executive Summary

The 2019 mine tailings dam collapse near Brumadinho, Brazil, killed 272 people and decimated houses and buildings for kilometers before flowing into the Paraopeba River. The catastrophe stunned the world but should not have come as a surprise. Tailings facilities, which contain the processed waste materials generated from mining metals and other materials, are failing with increasing frequency and severity.

At present, industry standards and governmental regulations still do not go far enough to adequately protect communities and ecosystems from tailings failures. The design, construction, operation and closure of tailings facilities require significant changes to protect people and the environment.

Tailings facilities can fail in many ways and with varying degrees of severity. While this document outlines guidelines aimed at preventing catastrophic failures, the authors recognize that chronic contamination can sometimes be equally disastrous for communities and the environment.

The primary goals of tailings management must be to ensure that public and environmental safety are the determinative factors governing the operation of tailings disposal systems and to achieve zero tolerance for human harm or fatalities. It is important to recognize the interconnected relationship between people and the natural environment; protecting ecological resources is an extension of human safety. While operating companies must aim to minimize environmental harm everywhere, it must be the goal of every mining operation to at least limit environmental harm to within the mine site.

Operating companies must commit to making safety the primary consideration in tailings facilities and dam design, construction, operation, closure and post-closure, and the primacy of safety must be independently verified. If a regulatory agency, an operating company or another party charged with overseeing the safety of a tailings facility determine that loss of life could occur as a result of a

The Doce River, polluted from the Samarco tailings spill, runs through a hydro-electric power plant in July 2016. Minas Gerais, Brazil. Photo: Júlia Pontés.

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tailings dam failure, the dam must be designed to withstand the most extreme meteorological and seismic events theoretically possible at a given location.

Prior to permit approval and over the life of the mine, operating companies must demonstrate the meaningful engagement, participation and consent of potentially affected communities for any tailings facility, including the right of communities to say 'no' to facilities. The self-determination of all affected communities must be respected, particularly for Indigenous communities, and they must be allowed to determine what consultation mechanism is used and who is allowed to participate in the consultation process.

The use of upstream dams and all tailings facilities built on uncompacted tailings must be banned. Additionally, dams must not be built in close proximity to communities or upgradient from mining infrastructure, such as other dams or where workers are likely to be present. Tailings must never be discharged into bodies of water (rivers, streams, lakes, oceans, etc.), regardless of the challenges associated with other disposal methods.

The design, construction, operation and closure of a tailings facility must be subject to the best available technologies and practices. The Best Available Technology for tailings disposal is the use of filtered tailings, which reduces the probability and consequences of failure. Nevertheless, such technologies must also be subjected to strict social and environmental licensing processes. The disposal of filtered tailings improves the safety of closed facilities.

Operating companies must document the results of a detailed characterization of the dam foundation and the tailings material properties, with special attention to clay content, liquefaction potential, and the presence of brittle tailings. An Engineer of Record must submit an annual report verifying that dam operations and construction adhere to the approved dam design.

Tailings facilities must be monitored, inspected, maintained and reviewed in perpetuity, or until there are no credible (physically possible) failure modes. Without perpetual oversight, the failure of a tailings dam is inevitable. Given that operating companies will not exist long enough to accomplish perpetual monitoring, inspection, maintenance and review, the operating companies' ability to eventually eliminate all credible failure modes must be a key consideration during the permitting process. If a tailings facility is proposed in a location where the consequences of failure are too great, the facility must not be built.

Worst-case tailings failure scenarios must consider the loss of all tailings at full tailings facility buildout, and the results must be made public prior to permitting. Modeled failure scenarios must also be annually updated. Emergency and evacuation drills related to the catastrophic failure of tailings facilities must be held on an annual basis, and their planning and execution must include participation from affected communities, workers, local authorities and emergency management personnel. Communities must have access to independent technical experts of their choosing to assist them in evaluating the potential for and consequences of a catastrophic tailings failure at the time the facility is proposed and throughout the life of the facility.

A culture of safety and responsibility must be upheld at the highest level within a corporation. The board of directors must be held accountable for its actions (or lack thereof). The board of directors must bear the primary responsibility for the safety of tailings facilities, including the consequences of dam failures, and demonstrate that the company has the necessary financial assurance to cover the implementation of closure and post-closure plans, and adequate public liability insurance to cover the full costs of all failures, including catastrophic failures.

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The safest tailings facility is one that is not built. To avoid the long-term liability of mine waste facilities and their social and environmental impacts, we must reduce the volume of tailings produced and the overall demand for primary raw materials and new mining. A permanent above-ground tailings facility should be a last resort. Over the past 40 years, ore grades — the concentration of the metal or mineral of value — have declined on average by half for many commodities, effectively doubling the volume of mine waste generated for each unit of valuable material produced. Current trends suggest an additional 2- to 10-fold increase in the demand for many commodities, particularly those needed for energy transition technologies, by 2060. These trends are not sustainable. In order to transition away from fossil fuels in a way that is sustainable, just and equitable, we need to reduce the need for new mining and the amount of mine waste produced, while using the best standards and practices for any new mining activity.

SUMMARY OF GUIDELINES

- Make safety the guiding principle in design, construction, operation and closure of tailings facilities.
- Ban new tailings facilities in locations that would not allow for timely assisted evacuation of inhabited areas in the event of dam failure.
- Ban upstream dams at new mines and close existing upstream dams.
- Design dams to avoid any potential loss of life, which must be considered an extreme event.
- Mandate the use of best available technology for tailings facilities, including the use of filtered tailings, and implement rigorous controls for safety, including after mine closure.
- Demonstrate understanding of local conditions and tailings characteristics with robust monitoring systems.
- Develop appropriate emergency preparedness/response plans.
- Ensure the independence of reviewers to promote safety and transparency.
- Address financial risks, including proper financial assurance and insurance.
- Attempt to eliminate all credible failure modes to have safer facility closures.
- Establish grievance procedures, whistleblower protection, and community-based safety oversight for potentially affected communities.
- Obtain consent from potentially affected communities and guarantee the right to say 'no' to proposed or expanded tailings facilities.
- Make information regarding mine safety publicly available in relevant languages.
- Offer affected communities access to independent technical experts.
- Require corporate boards of directors assume full responsibility for the risks (including financial risks) and the consequences of tailings facility failures.

To understand how and why failures occur, we must understand the scope of the issue. A global inventory of the thousands of active and abandoned tailings disposal facilities does not exist, nor is there a complete registry of tailings dam failures. Compiling and sharing this information, publicly

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and transparently, is essential. An independent international agency, such as a United Nations-endorsed agency, in collaboration with civil society, States, and operating companies, must drive the process to collect information on tailings dams and tailings dam failures worldwide, and share it with the public to reduce the risks associated with these sites and promote the protection of human health and the environment.

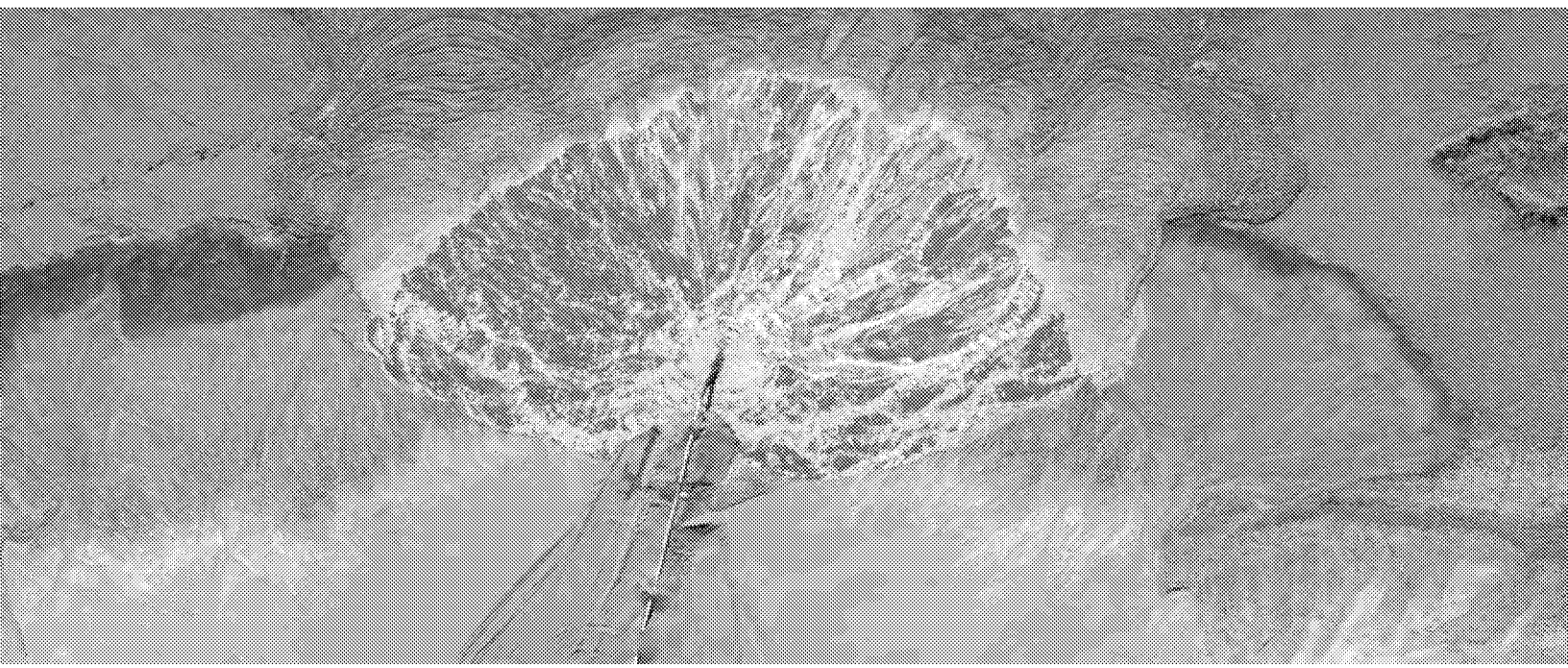
This international agency must be able to provide guidance and transparency on tailings management worldwide to protect the health and safety of people and the environment. It must be a well-resourced agency capable of efficiently analyzing global standards, investigating failures, collecting and disclosing site-level data, responding to grievances and making publicly available recommendations. The governance structure for this agency must be a multi-stakeholder body that includes affected communities, Indigenous Peoples, labor, and civil society organizations. It must ensure a co-equal decision making process that includes all stakeholders, without undue influence by the sector that is being monitored. It must provide secure access to a grievance mechanism for community or worker reports and whistleblower complaints.

Language

This document uses the word "must" to indicate an action or guideline that is required. The word "should" is used when the action or guideline is optional or unattainable at this time.

The authors chose to use tailings disposal instead of tailings storage throughout the document. The term storage implies that tailings are temporarily stored until another use is identified. The authors use disposal to indicate that tailings are a waste material without a guaranteed secondary use.

Aerial view of mine waste, Catalão, Goiás, Brazil. Photo: Júlia Pontés.



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Introduction

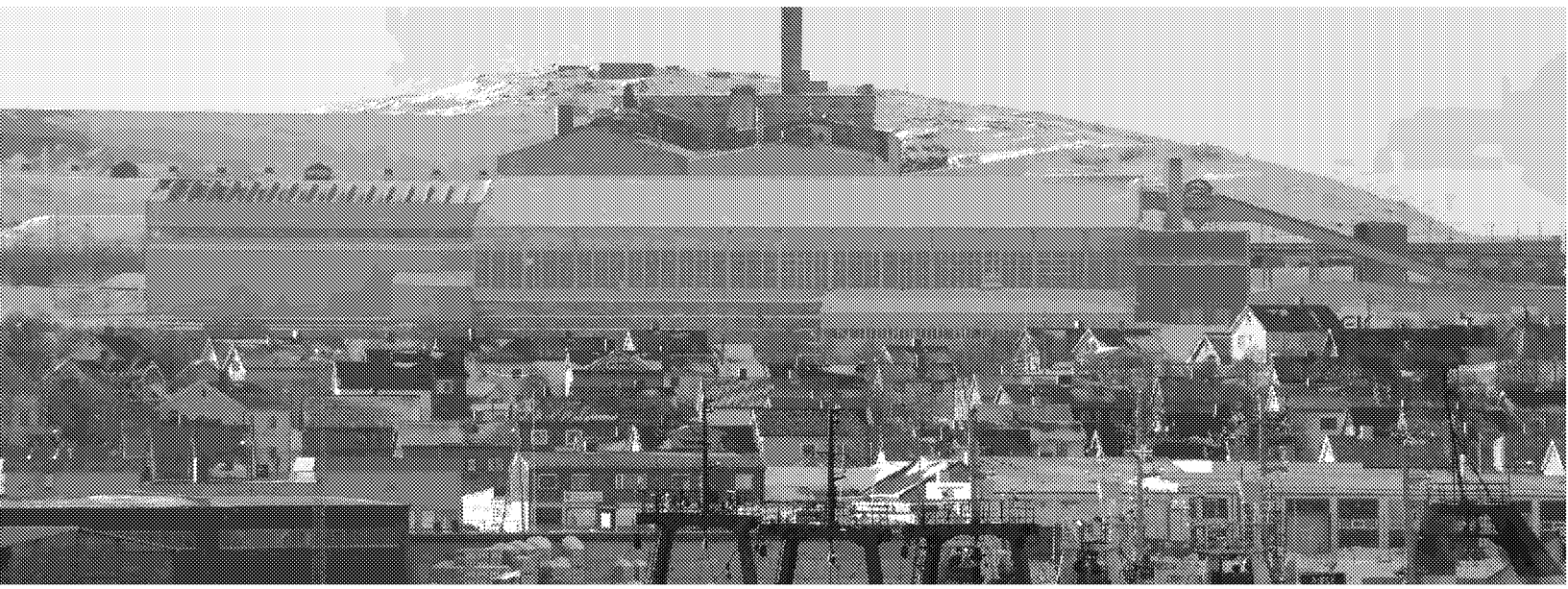
In January 2019, a dam at the Córrego do Feijão mine owned by Vale in Brumadinho, Brazil, collapsed, releasing about 9.7 million cubic meters of tailings. The mine waste traveled eight kilometers over land,[1] killed over 272 people,[2] destroyed houses and buildings, and eventually flowed into the Paraopeba River.

The Brumadinho catastrophe stunned the world, including the mining industry and investors, but should not have come as a surprise. It came on the heels of massive tailings dam collapses in 2014, at Imperial Metals' Mount Polley gold-copper mine in British Columbia, Canada, and in 2015 at the Samarco iron mine in Mariana, Brazil, a joint venture owned by Vale and BHP Billiton. The failure of the Samarco mine killed 19 people and sent tailings nearly 700 kilometers down the Rio Doce to the Atlantic Ocean. After the Mariana catastrophe, Vale's CEO vowed "never again." And yet, three years later, the dam at their Córrego do Feijão Mine collapsed.[3]

As tailings facilities fail with increasing frequency and severity,4 new regulations and standards have emerged in an effort to reign in dangerous practices and prevent future disasters. After the Brumadinho failure, investor intervention spearheaded by the Church of England, led to the swift rollout of the Global Tailings Review (GTR), co-convened by the International Council on Mining and Metals (ICMM), Principles for Responsible Investment (PRI) and the United Nations Environment Programme (UNEP). According to its website, the GTR sought "to establish an international standard for the safer management of tailings storage facilities."[5] The Global International Standard on Tailings Management (GISTM) was released in 2020.[6]

Current industry standards, including the GISTM, do not go far enough to adequately protect communities and ecosystems from the consequences of tailings failures. They often lack clear and

A fjord outside Kirkenes in Norway's northeastern corner, has filled up with tailings after decades of mining companies dumping waste in the harbor. Kirkenes Harbor, Finnmark, Norway. Photo: WikiCommons.



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mandatory technical guidelines to move away from technologies and practices that present the greatest risk, as is done in other high-risk industries, such as aviation and long-distance pipelines. Significant changes must be made to current practices in design, construction, operation, and closure of tailings facilities. As climate change exacerbates the risk and consequences of failures, this has only become more urgent. The following document outlines guidelines for safety, respect for affected communities, and corporate accountability that must be incorporated into any tailings standard or regulations.

Mine tailings are the waste that remains after the metals or minerals of economic value have been removed from ore using physical and/or chemical separation methods. Tailings consist of processed rock or soil, water, and possibly other mining products, including blasting chemicals (ammonia, nitrate), trace quantities of chemicals used in the separation process (e.g., petroleum byproducts, cyanide, caustic agents), and metals and other constituents leached from the rock or soil (e.g., copper, cadmium, lead, zinc, iron, arsenic, aluminum, manganese, sulfate). Tailings can be backfilled in underground mine workings or exhausted open pits, but in general, tailings are held in a permanent surface impoundment behind a dam that is constructed from other mine wastes. While this document mandates the use of filtered tailings in new tailings facilities, the authors recognize that there are existing tailings facilities that do not use filtered tailings and, for this reason, also provide guidance for tailings ponds.

Catastrophic tailings dam failures have most often occurred at iron and aluminum mines, but many failures have also occurred at gold, copper, uranium, and other types of mines – including both open pit and underground mines. In addition to catastrophic failures, slower releases of contaminants can occur by seepage from the impoundment, windblown tailings, and an overtopping of the dam that does not result in a catastrophic release of tailings and tailings water. Catastrophic and slower releases from tailings facilities have long-term adverse effects on groundwater, surface water, soils, vegetation, and communities.

This document recognizes that the safest tailings facility is the one that is never built. A permanent above ground tailings facility must be a last resort. We must instead find ways to reduce the amount of tailings produced and the overall demand for primary raw materials to avoid the long-term liability of mine waste sites and their social and environmental impacts. World production has already increased 2- to 10-fold for various commodities over the last 40 years.[7] During the same period, ore grades have declined on average by half for many of those commodities, effectively doubling the volume of mine waste generated for each unit of valuable material produced. According to the World Bank and Australia's Institute for Sustainable Futures, demand for metals, specifically for the energy transition, is set to explode between now and 2050, with anticipated increases of 300 to 8000 percent for certain metals, depending on the scenario.[8,9]

Clearly, these trends are not sustainable. If virgin extraction to source metals and other raw materials, including those needed to support energy transition technologies, is needed, best standards and practices must be enforced. As a society, and particularly for countries in the Global North, we also need to actively find ways to reduce the overall demand for raw materials by redesigning our cities and transportation systems to reduce dependence on single family vehicle ownership, and shifting away from some of the current raw material uses. Research shows that material recycling and demand reduction strategies can help us build a future that is less reliant on extraction and is more just and equitable for mining-affected communities and ecosystems.[10]

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To reduce the amount of tailings produced, and stored aboveground, it's important to:

1. Reduce the demand for metals and minerals by shifting away from disposable consumption and overconsumption.
2. Reduce the demand for new mines or expansion of existing mines by implementing circular economy solutions and minerals recycling, re-processing existing tailings, and deriving metals from other unconventional sources such as contaminated waters and other wastes.
3. Obtain commodities with the minimum production of tailings.
4. Maximize the conversion of tailings into useful and/or marketable products.
5. Maximize the use of tailings for the construction of mine infrastructure with proper safeguards in place to avoid contaminant leaching.
6. Maximize the backfilling of tailings into exhausted open pits or underground mine workings.[a]

This document is not intended to replace regulations or serve as a standalone comprehensive standard. However, any standard, regulation, or guidance document that is not protective of people, property and the environment, as outlined in this document, is insufficient. Additionally, there may be circumstances under which a tailings facility can meet all the guidelines in this document but must not be built or allowed to continue in operation.

Ultimately, protective tailings regulation must fall to the regulators charged with public safety. In many places, protective tailings regulations either do not exist or are not adequately enforced. Too frequently governmental agencies are unable, because of limited resources or technical expertise,

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[a] Currently California, U.S. and New Caledonia have requirements for backfilling open-pit mines. In Quebec, Canada it is mandatory to submit a cost-benefit analysis of backfilling open-pit mines, while guidance from British Columbia, Canada states that backfilling should be maximized in mine design and operations.

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or unwilling, because of political pressure, corruption or the undue influence of the mining industry, to enact and/or enforce regulations that prioritize safety. It is important to acknowledge the pervasive problem of "regulatory capture" in mining oversight, in which the mining industry directly or unduly influences decisions made by regulators.[11] This can take the form of lobbying, and/or political contributions and "revolving doors" between regulators and mining operators, as well as a lack of clarity between public interest and corporate interests in public policy.[12] In some jurisdictions, regulatory agencies charged with the oversight of safety in mining activities are funded wholly by the industry itself.

Furthermore, while voluntary standards and third-party certification schemes can be instrumental in advancing best practice and technology, they are not substitutes for governmental regulations, monitoring, and enforcement.

Governmental regulators must ensure their independence from the mining industry, uphold their commitment to public safety in tailings permitting and monitoring, and enforce financial or other types of sanctions and corrective actions for regulatory violations. Throughout this document, the authors often refer to the need for independent technical assistance, and independent or third-party reviews of mining operations. This is to create mechanisms for oversight beyond operating companies and their direct employees, and to address the distrust that many mining-affected communities feel toward operating companies. The authors hope the revised version of Safety First will empower civil society groups, frontline communities, Indigenous Peoples, labor unions, academic researchers, and NGOs to take a more active role in tailings management and the enforcement of safer tailings disposal practices. At the same time, Safety First highlights the need for transparent regulatory agencies that can operate without undue influence from the mining industry.

Safety First was originally released in 2020 to address the need for more protective tailings management. After its release, the authors received feedback on the guidelines from frontline community, Indigenous, NGO, academic, and technical experts. In light of this feedback, the authors held a series of regional workshops to hear from mining-affected communities, local NGOs, and Indigenous Peoples about their experiences with tailings and to receive their comments on the guidelines. The workshops were held in four languages and included over 200 participants from five continents. The authors also solicited and received written comments.

These comments helped inform the 2022 version of Safety First. The authors would like to thank all the community members, organizations, academics, and scientists who provided invaluable feedback on the original version of the guidelines and helped us create a stronger, more community-centered revised document. The Safety First guidelines are not final and will be regularly updated to reflect changes in tailings design, management, regulation, and best practices. The authors hope this document can be one step toward proactively protecting the interests of frontline communities in tailings management.

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The 2015 collapse of the tailings dam at the Samarco mine, owned by Vale and BHP, created a flash flood of tailings that covered houses in the town of Bento Rodrigues, Brazil. Minas Gerais, Brazil. Photo: Rogério Alves/TV Senado.

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Scope

Tailings facilities can fail in many ways and with varying degrees of severity. A tailings failure is an unintended or uncontrolled release of materials, including tailings, water or dust, from a tailings disposal facility. This document outlines guidelines aimed at preventing catastrophic failures, defined as failures that constitute a rapid shock, and that happen without warning (even if they could have been foreseen).[13,b] Sudden failures are not the only type of tailings failure, and failures that occur more slowly or over a longer period of time can also have disastrous impacts. While this report does not attempt to comprehensively address all tailings failures, such as chronic environmental contamination, the authors recognize that such impacts represent serious public and environmental health concerns for many communities living in the vicinity of tailings sites.

For each aspect of tailings management, the authors have based the guidelines on the most conservative criteria (most protective of people, property and the environment) from among the existing guidance documents and regulations. *Safety First* sometimes draws from guidance for water-retention dams, if they are more conservative than existing tailings dam guidance. Operating companies must identify, prevent and mitigate any environmental and public health impacts in addition to taking steps to prevent sudden catastrophic failures.

EXAMPLES OF LONG-TERM ENVIRONMENTAL IMPACTS

WATER CONTAMINATION: Ongoing and periodic water contamination caused by leaching, seeping, spills, pipeline leaks, or overtopping of tailings disposal facilities. At the San Finx mine in Galicia, Spain, an average of approximately 50,000 liters of water contaminated with mine waste are released per hour into a nearby river, leading to cadmium, copper and zinc concentrations that are above maximum allowable levels kilometers downstream.[14]

- Prevention measures: Tailings facilities must use multiple mechanisms, including liners, covers, and stormwater run-on and run-off controls, to minimize seepage from the facilities and infiltration to groundwater to the greatest extent possible. Treatment systems for water collected from tailings facilities must adequately reduce toxic metal contaminants without using off-site dilution.

DUST EMISSIONS: Fugitive dust emissions from tailings disposal facilities lead to air pollution, causing health issues, like respiratory problems, and environmental contamination of vegetation, soil, wildlife, and surface water. In South Africa gold mines in the Witwatersrand region have dust fallout that is high in silica and uranium concentrations. This dust has led to adverse respiratory health effects in local communities.[15,16]

- Prevention measures: Operating companies must undergo concurrent reclamation with covers to minimize dust production.

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[b] For example, the Mount Polley dam disaster could have been foreseen if the foundation had been properly characterized.

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AQUEOUS TAILINGS DISPOSAL: Every year, mining companies dump 220 million metric tons of mine waste directly into oceans, rivers and lakes.[17] This practice smothers river beds, seabed floors and coral reefs, decimates fish populations in freshwater and marine environments, and floods wetlands and forests. Since 2012, the Ramu nickel mine in Papua New Guinea has dumped millions of metric tons of tailings into the ocean. A study of the area found elevated levels of heavy metals "much above the allowed limits" in agricultural soils, beach sands, and water from the river and sea, including drinking water and food.[18]

- Prevention measure: Tailings must never be discharged into bodies of water (rivers, streams, lakes, oceans, etc.), regardless of the challenges associated with more protective disposal methods.

While environmental, health and safety effects warrant protective guidelines and effective long-term monitoring and mitigation measures, addressing the full range of remediation options for all types of tailings failures is beyond the scope of this document.

Operating companies are responsible for the perpetual care of a tailings facility until there are no credible failure modes. Operating companies may avoid using the word "dam" in an attempt to skirt tailings dam safety requirements. However, it is important to note that these guidelines apply to any engineered structure that contains mine tailings, regardless of the terminology used by the operating company to describe the engineered structure. In particular, the guidelines in *Safety First* apply to:

1. Conventional tailings impoundments;
2. Waste dumps that store a mixture of tailings, ore reject material,[c] and/or waste rock;
3. Filtered tailings facilities (with or without the admixture of ore reject and/or waste rock);
4. Tailings that are stored in exhausted open pits that employ dikes, berms or similar structures, and;
5. The structural zones (containment structures) of tailings disposal facilities, including the structural zones of filtered tailings facilities

RELEVANCE TO OTHER MINE FACILITIES

Mine facilities that do not contain tailings, such as waste rock, heap leach, and dump leach facilities, also have inherent risks. Heap and dump leach facilities are commonly used in gold and copper mining, respectively. The material in heap and dump leach facilities is initially considered ore but becomes waste after the application of cyanide or acid ceases – and the spent materials typically remain on the surface in perpetuity. Surface waste rock facilities are common at nearly all mines, although mixing waste rock into tailings impoundments has become more common recently. The potential for these facilities to leach contaminants during and after their active lives and to become physically unstable presents an ongoing risk to downstream and downgradient communities and the environment. A major landslide associated with the waste rock pile caused failure of the Bellavista Mine cyanide heap leach facility in 2007 and resulted in closure of the mine, groundwater

[c] Ore rejects are the gravel-sized materials that remain after a process that separates lower-grade from higher-grade ore fragments prior to mineral processing for extraction of the commodity of value. The purpose of ore reject technology is to avoid the creation of excessive tailings from low-grade ore fragments.

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contamination near the community of Miramar,[19] and is an example of the kind of adverse impacts that can occur at these types of facilities from slope instability.[20]

The 2015 collapse of the tailings dam at the Samarco mine, owned by Vale and BHP, created a flash flood of tailings that covered the town of Bento Rodrigues, Brazil. Minas Gerais, Brazil. Photo: Rogério Alves/TV Senado.

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Guidelines

1. Make safety the guiding principle in design, construction, operation, and closure

Given the hazardous nature of mine tailings, the fundamental goal of tailings management must be to "ensure that public safety, environmental safety, and economic safety are the determinative factors in governing what tailings disposal system will be implemented."[21] Specifically, tailings management must ensure zero harm to people and zero tolerance for human fatalities. It is important to recognize that mining is a fundamentally destructive industry, meaning that a goal of zero harm to the environment is impossible to achieve. Nevertheless, operating companies must do all that they can to minimize environmental harm everywhere. In particular, they must limit any environmental harm that inevitably occurs to within the mine site.[d]

Safety must be evaluated by independent third-parties, such as an Independent Tailings Review Board, to ensure that cost reduction is not prioritized at the expense of people and the environment. Operating companies must document that, at all points of design, operation, closure, and post-closure of tailings facilities, protecting human and environmental health and safety is the primary concern. Taking lessons from the 2014 Mount Polley mine disaster in Canada, and citing the Independent Expert Engineering Investigation and Review Panel,[22] the 2017 UNEP-GRID Arendal rapid response assessment on tailings disposal also made safety its first recommendation: "Safety attributes should be evaluated separately from economic considerations, and cost should not be the determining factor."[23] If a mining project is uneconomic due to the costs of a safe tailings disposal system, then it is uneconomic — costs and risks must not be transferred to the environment, communities or host governments.

2. Consent of affected communities[e]

Consent must be achieved through an ongoing dialogue over the life of the mine for both proposed and existing facilities. The First Nations Mining and Energy Council states that, "consent is simple — it is the right to say yes, the right to say no, or the right to say yes with conditions."[24] Consent can be given or withheld at distinct stages of a project, including exploration.[25] Operating companies must ensure the meaningful engagement, participation, and consent of all affected communities for any tailings facility.

All engagement must be conducted in local languages and align with the cultural norms and communication styles of any affected communities and stakeholders. Engagement must begin as early as possible, before any exploration has taken place and as part of the mine

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[d] A mine site is the area of surface disturbance necessary to conduct a mining operation. This includes extraction, processing, and waste disposal facilities, and roads. A mine site does not necessarily include the entire area as defined by the mine permit or claim.

[e] This guideline applies to both affected and potentially affected communities, including Indigenous, Afro-Descendant, Traditional, First Nation, Aboriginal, Adivasi, Janajati and non-Indigenous communities.

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permitting process. For existing mines, permits and licenses must be reviewed by relevant regulatory agencies and consent must be sought.[26]

Consent must be obtained through culturally appropriate processes, time frames and mechanisms that are determined by the Indigenous Peoples or affected communities. These may include customary decision-making processes, local democratic processes and local governance mechanisms, or other processes such as referenda.

For Indigenous Peoples, the United Nations recognizes that Free, Prior and Informed Consent (FPIC) must be in place in order for a mine to be developed, operated, and closed. The rights of Indigenous Peoples are human rights and are indivisible from their cultural, territorial and self-governance rights.[27] Indigenous People hold title on their lands by virtue of their occupation and stewardship of those lands prior to colonization and continuing to the present day. Indigenous laws have always existed and governed Indigenous lands.[28] Therefore, Indigenous Peoples have both self-governance rights as distinct, self-determining peoples with specific decision-making processes, laws, practices, and institutions, and collective territorial, self-governance, and cultural rights. Indigenous and Afro-Descendant Peoples are increasingly documenting their governance rules for consultations and Free, Prior and Informed Consent (FPIC) in the form of Autonomous FPIC Protocols for which they demand compliance by all external actors.[29] An FPIC process cannot be carried out where Indigenous or Tribal Peoples are living in voluntary isolation, such as uncontacted tribes in the Amazon.[30]

Indigenous Peoples and affected communities must be afforded the opportunity to establish land-use plans and "no-go zones."[31] This acknowledges that certain areas must never be considered for tailings disposal, no matter how the tailings facility is designed, monitored or operated. "No-go zones" may include potentially affected areas located in the zone of influence of tailings facilities (e.g. sacred sites) that would not allow for the construction of a facility. In some cases, Indigenous governmental bodies may have their own standards, requirements, and monitoring and inspection systems for mining operations. In these

After a rigorous Environmental, Social and Cultural Impact Assessment led by local Indigenous protocols, the Stk'emlupsemc Te Secwepemc Nation rejected in 2017 a large tailings facility proposed by the company KGHM near their sacred Pipsell site area. Pipsell, Secwepemc Territory, British Columbia, Canada.
Photo: Stk'emlupsemc Te Secwepemc Nation (SSN).

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instances, operating companies must comply with any directives made by relevant Indigenous governmental bodies.[32]

In accordance with the UN Declaration on the Rights of Indigenous Peoples, Indigenous People have the right to self-identify with an Indigenous community that accepts them as a member.[33] An operating company must respect any community that self-identifies as Indigenous and respect their right to establish no-go zones and autonomous FPIC protocols, regardless of whether or not they have obtained legally recognized status as Indigenous.[34]

Consent must be free of external manipulation, coercion or extortion. Indigenous Peoples and affected communities must be assured the right to say no to a tailings disposal facility without fear of potential backlash from local government, police or military forces, interested third-parties, and/or the operating company.[f] Given the power asymmetries that often exist between operating companies and communities, Indigenous Peoples and affected communities must be permitted to decide who is allowed to be present and participate in a consultation process.[35] This means that they may choose to hold consultation processes in which representatives from the operating company, national or local government, or police forces are not permitted to participate or be present.[36] The community can also choose how they will communicate the results of the consultation process to their government, relevant regulatory agencies, and the operating company. This helps ensure that consent is freely given.

Operating companies must provide a transparent risk analysis identifying and evaluating the geographic area and inhabited areas that could be affected by all proposed tailings facilities to all affected stakeholders.[37] The study must include, but not be limited to, both positive and negative impacts on affected communities and ecosystems, including chronic pollution, and labor and economic impacts.[38] It must also include an assessment of the outcomes where no mine or tailings facility is built. The study must be provided sufficiently in advance so as to give communities ample time to understand and analyze the proposed project. The time frame is dependent on the decision-making processes of the affected stakeholders, but consultation must be "sought sufficiently in advance of any authorization or commencement of activities, at the early stages of a development or investment plan, and not only when the need arises to obtain approval from the community."[39] The study must evaluate the impacts of all proposed facility designs and sites, and must be updated anytime a tailings facility's design is changed, expanded, or closed. Due to the ability of tailings to travel hundreds of kilometers and impact extensive areas in the event of a failure, the impact study must be based on the most comprehensive definition of affected people and area, with special consideration to any impacted watersheds.

Affected communities must have access to independent technical or other expert advice from the earliest stages of exploration, through monitoring and closure plans.[40] Affected communities must be able to select the experts in order to ensure they are trusted (See Guidelines 16).

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[f] The right to say no to a tailings facility and provide freely given consent was a commonly expressed concern by communities in the 2021 consultation process.

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If the representatives of affected communities or Indigenous Peoples clearly communicate, at any point during engagement with the operating company, that they do not wish to proceed with consent-related discussions, the company must recognize that it does not have consent, and must cease to pursue any proposed activities affecting the rights or interests of affected communities. The company may approach affected communities or Indigenous Peoples to renew discussions only if and when invited to do so by the communities' representatives.

Operating companies must document and report all steps taken towards community consent and/or FPIC. In some jurisdictions, there may be public agencies that mediate or supervise contact with Indigenous People. In these cases, operating companies must follow established protocols for contacting and obtaining consent from Indigenous People. Documentation on the consent process and FPIC must be made publicly available and filed with state agencies, however any public disclosures of FPIC or community consent must be approved by Indigenous Peoples and affected communities before their release. The operating company must document and make public how any feedback received was incorporated and addressed.

3. Ban new tailings facilities where inhabited areas are in the path of a tailings dam failure

The most effective way to minimize risk to people is to prevent the construction of new tailings facilities where there is a population living or working in close proximity, downstream, or down gradient from the facility. Operating companies must not build infrastructure in which workers are likely to be present—offices, cafeterias, warehouses—in the zone of influence. The zone of influence is the "area that would be significantly affected in case of a [tailings facility] failure and should be categorized as a risk zone."[41] New tailings facilities must not be constructed if the operating company cannot ensure the safe and timely assisted evacuation of any population that lives in the zone of influence.

The location and safety of a tailings facility must not only contemplate the impact to human lives in the case of a failure, but the environmental and economic impacts as well. Affected communities must be able to define no-go zones, or zones where a tailings facility is not permitted due to environmental, cultural or economic factors (See Guideline 2). Tailings facilities must not be constructed in a location where a failure would materially impact public water supplies or critical habitats, or near protected ecological resources. Additionally, tailings must never be deposited in bodies of water, such as rivers, streams, oceans, etc. Because tailings can flow for up to hundreds of kilometers during a failure, specific consideration of all downstream communities, ecosystems, cultural, sacred and touristic sites, and areas of economic production must be undertaken in the determination of potentially affected areas. It is important to recognize the interconnected relationship between people and the natural environment; protecting ecological resources is an extension of human safety.

The construction of new dams and the expansion of existing dams is banned in legislation in Ecuador and Minas Gerais, Brazil if there are settlements within 10 kilometers downstream along the course of the valley or if projections indicate that a flood from a tailings failure might reach nearby communities in less than 30 minutes. In Minas Gerais, the distance can

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be increased to 25 kilometers, depending upon the population density and the natural and cultural heritage of the area.[42] Although these geographic and temporal limits are better than no regulation, they do not necessarily ensure safe evacuation in every situation. Therefore, the minimum distance between communities and new dams must be defined on a case-by-case basis. This distance must be calculated based on the time it would take to evacuate the entire community with the support of a rescue team and the time it would take for a tailings flood to reach the community, with a safety buffer built into the calculation. The time it takes for a tailings flood to reach a community must be calculated based on a dam break study conducted for the specific tailings disposal facility.

When existing facilities are too close to communities to ensure safe evacuation, operating companies must negotiate with communities to close the tailings facility. While it is imperative that operating companies do all that they can to quickly close unsafe tailings facilities, in the case where a safe closure is not possible in a timely manner and no other solutions are available (see Guideline 11 for details on safe closure), the operating company must offer a package of voluntary resettlement. Involuntary resettlement must not be allowed under any circumstance. In many cases, however, resettlement that is called "voluntary" can be highly problematic and lead to forced relocation and inadequate compensation. Voluntary resettlement must be carried out in a manner that aligns with best practices and the highest international resettlement standards. Voluntary resettlement can only occur with the consent of affected communities (see Guideline 2), it must provide fair and appropriate compensation for loss of land and other assets, as well as security of tenure in the new location, and must result in improved livelihoods and standards of living for those who are resettled.[43,44,45]

Communities must have access to independent technical experts throughout the resettlement process (see Guideline 16). Any voluntary resettlement process must include collective and individual resettlement options.

4. Ban upstream dams at new mines and close existing upstream facilities

Because of the demonstrated risk associated with upstream dam construction,[46,47,48] upstream dams must not be built at any new facilities. Upstream construction is especially problematic in areas with moderate or high seismic risk, or in wet climate areas with net precipitation (more precipitation than evaporation), especially as weather events become increasingly severe with climate change. The structural zone of a filtered tailings stack must not be constructed on top of uncompacted or lightly-compacted filtered tailings. If it is, it would be an upstream dam and must be prohibited.

The construction of new upstream tailings dams has already been banned in Brazil,[49] Chile,[50] Peru,[51] and Ecuador.[52] It is theoretically possible to safely construct and operate an upstream tailings dam under the limited conditions of low seismicity, low precipitation and highly-trained personnel. Even under those limited conditions, a very influential tailings industry paper, with many antecedents, has argued that there are ten rules for upstream dams and not a single one can be violated without substantial risk of failure.[53] There is broad consensus within the engineering community, especially in high-risk industries such as aviation and pipelines, that engineered structures should be robust, with multiple back-ups

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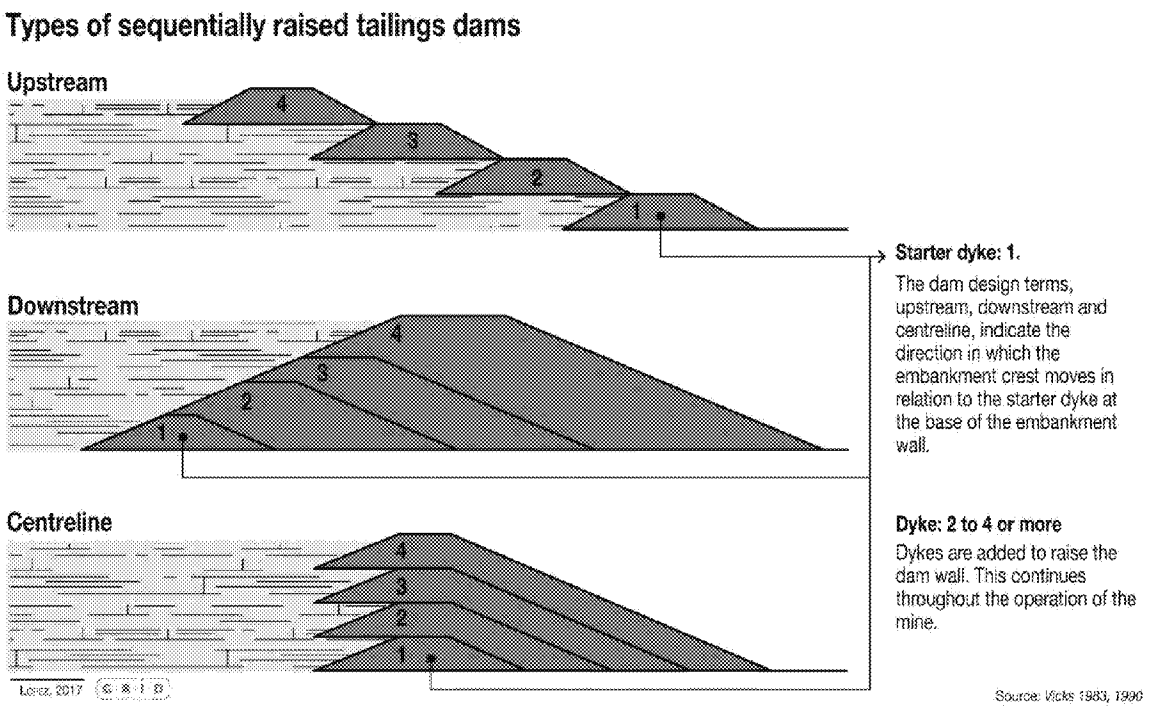
and defense mechanisms. The need to obey ten rules with no margin for error does not constitute a basis for safe design.

In comparison to upstream dams, centerline and downstream dams are much less vulnerable to all mechanisms of dam failure. A downstream or centerline raise constructed on top of an existing upstream dam or on top of uncompacted tailings still constitutes an upstream dam.[g] According to the International Commission on Large Dams (ICOLD) bulletin 181, variations on centerline dams include modified upstream or modified downstream dams.[54] In some jurisdictions where upstream dams have already been banned, operating companies have used the concept of "modified centerline" to avoid the prohibition. What these operating companies call a modified centerline design must be considered an upstream dam because it still includes construction of the dam on top of uncompacted tailings. Operating companies must correctly identify upstream construction to regulatory agencies.

Expansion of existing upstream tailings facilities must cease, and these facilities must be safely closed as soon as possible. This includes dams where companies have been approved for permits that have not begun or are just beginning construction. The deadline for safe closure must depend on engineering and the safety of affected communities, rather than economic considerations (see Guideline 11 for safe closure specifications).



Source: Grid

[g] The Riotinto Mine in Spain, operated by Atalaya Mining, can provide an example of this type of construction.

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5. Any potential loss of life is an extreme event and design must respond accordingly

If an operating company, regulatory agency, or independent third-party identifies any potential loss of life as a result of a tailings dam failure, the dam must be designed to withstand the Probable Maximum Flood (PMF), which is the largest flood that is theoretically possible at a given location, and the Maximum Credible Earthquake (MCE), which is the largest earthquake that is theoretically possible at a given location.[55] Where the failure of a tailings dam would have no potential for the loss of human life, the facility must be designed to withstand a 10,000-year flood and a 10,000-year earthquake.

In the United States, the U.S. Army Corps of Engineers and the U.S. Bureau of Reclamation have guidelines for water-retention dams that require dams are able to withstand the Probable Maximum Flood and Maximum Credible Earthquake when there is potential loss of life in the event of a dam failure. Considering that there are currently no federal guidelines in the U.S. for tailings dams, U.S. federal guidelines for water-retention dams must apply to tailings dams. The U.S. Federal Emergency Management Agency (FEMA) has three Hazard Potential Classifications, which are Low, Significant and High. High Hazard Potential means "probable loss of life due to dam failure or misoperation." These regulations clarify that "probable loss of life" means "one or more expected."[56] A dam in the High Hazard Potential category must be designed for the PMF. In addition, the U.S. Army Corps of Engineers (USACE) has four categories of dam safety standards. The strictest, "Standard 1 applies to the design of dams capable of placing human life at risk or causing a catastrophe, should they fail."[57] For Standard 1, "structural designs will be such that the dam will safely pass an IDF [Inflow Design Flood] computed from probable maximum precipitation (PMP) occurring over the watershed above the dam site."

Additionally, according to FEMA (2005), High Hazard Potential dams must be designed for the Maximum Credible Earthquake (MCE). Similarly, USACE guidelines from 2016 state, "for critical features, the MDE [Maximum Design Earthquake] is the same as the MCE."[58] All modeling and design for floods must take climate change into account — this applies for both closed and operating facilities.

Freeport McMoran's Gasberg mine in West Papua dumps tailings waste into the Otomin and Ajkwa rivers. Photo: Earthworks.

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6. Mandate the use of Best Available Technology for tailings, in particular filtered tailings

All new mines that create tailings must begin with an analysis of the best available technology (BAT) for tailings disposal. Best available technology[h] and practices in tailings management will continue to change, but tailings BAT was specified by the Mount Polley Independent Expert Engineering Investigation and Review Panel (the "Mount Polley Report") in the following way:

"While best practices [BAP] 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 first principles of soil mechanics:

1. Eliminate surface water from the impoundment.
2. Promote unsaturated conditions in the tailings with drainage provisions.
3. Achieve dilatant conditions[i] throughout the tailings deposit by compaction."[59]

The British Columbia Mining Code Guidance asserts, "Physical stability is of paramount importance, and options that require a compromise to physical stability should be discarded."[60] Reducing the water content in a tailings facility increases safety because it reduces both the probability and consequences of a tailings dam failure. When tailings are sufficiently filtered, they have a moisture content similar to that of a moist soil. Filtered tailings can be compacted in the tailings facility, which reduces the likelihood of liquefaction.

The initial disposal of filtered tailings facilitates an eventual safe closure. Tailings placed by conventional methods, i.e. slurry, thickened, and paste tailings, can be drained after placement, but this approach does not reduce the water content as low as filtering the tailings (See Guideline 11 for more discussion of safe closure). Nevertheless, filtered tailings do not eliminate all risks. Because they still require a structural zone (which is a type of dam) for containment,[61] they must be treated as an engineered tailings facility (i.e. tailings dam) from a regulatory standpoint. The structural zone of a tailings facility must not be placed on top of a non-structural zone, such as uncompacted or lightly compacted tailings (See Guideline 4).

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[h] When Best Available Technology is capitalized in the document it refers to BAT as it was specified in the Mount Polley Report. When best available technology is not capitalized it refers to best available technology and practices more generally, without explicit reference to the Mount Polley Report.

[i] Tailings in a dilatant state are less likely to liquefy because they will tend to expand, rather than contract, in response to disturbance.

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The Mount Polley Report recommends that:

- "For existing tailings impoundments. Constructing filtered tailings facilities on existing conventional impoundments poses several technical hurdles....[j] Attempting to retrofit existing conventional tailings impoundments is therefore not recommended ... reliance instead (should be) 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."[62]

The Mount Polley Report goes on to say, "Filtered tailings technology embodies all three BAT components" and "[t]here are no overriding technical impediments to more widespread adoption of filtered tailings technology." All three BAT components must be incorporated into tailings disposal. While filtered tailings are considered Best Available Technology, filtered tailings can still fail and their use is not an excuse to ignore other aspects of tailings safety.

Additionally, best available technology includes reducing the amount of tailings stored above ground as much as possible. The BC Mining Code Guidance recommends minimizing the surficial footprint of tailings facilities and maximizing in-pit or underground backfill.[63]

The use of subaqueous tailings disposal to prevent acid mine drainage can no longer be regarded as a best practice. The Mount Polley Report emphasized, "It can be quickly recognized that water covers run counter to the BAT principles ... The Mount Polley failure shows why physical stability must remain foremost and cannot be compromised."[64]

Although subaqueous disposal of potentially acid generating tailings has been shown to effectively decrease acid-generation potential (AGP) in some cases, leaching can continue even after submergence, especially if oxidation and acid generation have already begun.[65,66] Filtered tailings reduces the amount of entrained water, but any leachate produced must be collected and often requires long-term treatment.[67] The design of filtered tailings facilities must include an effective drainage system, as well as the water management infrastructure for preventing the rewetting of the tailings by precipitation or surface runoff. If there are existing tailings facilities that use drainage ponds, they must be located a safe distance from the tailings facilities to prevent the failure of one structure from impacting the stability of the other structure. If long-term water treatment is required, a cover or other design that will eliminate or minimize infiltration must be utilized.[68]

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[j] While there are examples of successful filtered tailings facilities constructed on top of conventional tailings impoundment, there are also examples where this has led to failure. For this reason, the authors agree with the Mount Polley Report and do not recommend it.

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7. Implement rigorous controls for safety

The design, construction, operation, and closure of any tailings facility must be subject to best available technologies and practices. An annual report must verify that dam operations and construction adhere to the approved final dam design. If a feature of the design was approved by a regulatory agency, all requested changes to that design must be submitted to the same regulatory agency for approval. Any deviation from the original design must be justified, documented, and evaluated by an Independent Tailings Review Board (ITRB).

As a guidance for safe operation and closure, a conservative Factors of Safety (FoS), meaning the FoS that is the most protective of people, property and the environment, must be established and enforced for all tailings dams. When calculating FoS, single input values must be avoided and a range of values, methods, and/or models must be applied to assess the various possible FoS values (static and pseudo-static). For operation and closure of a tailings dam, a static FoS of 1.5 (in non-earthquake conditions), and pseudo-static FoS of 1.1 (in response to the design earthquake, which establishes that even during the strongest seismic acceleration theoretically possible, the dam will still have 10% more shear resistance than is necessary to avoid failure), is presently viewed as conservative.

The ICMM Tailings Management: Good Practice Guide notes that, "FoS is not a measurable value; it is an outcome based on inputs which are derived by the designer based on site data, laboratory testing, and modeling."[69] For this reason, the guide describes many limitations to the use of FoS and cautions against overreliance on FoS leading to complacency in tailings facility design and monitoring.

Although the FoS is still included in many regulations and guidelines, it is a poor predictor of the annual probability of failure.[70] In order to more accurately identify risk, dam designs

The Mount Polley (Imperial Metals) 2014 tailings spill in British Columbia created a 100 m wide flow path for over 10 km downstream before dumping 24 billion litres of mine tailings and other debris into Quesnel Lake, in the Fraser River watershed, home to one of the largest salmon runs in North-America. Secwepemc Territory, British Columbia, Canada. Photo: Chris Blake, Quesnel River Watershed Alliance.

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and evaluations must consider the annual probability of failure, in addition to the FoS. Annual probabilities of failure have been relied upon in many industries, such as aviation and aerospace, since the Second World War. For tailings dams where failure would not result in the potential loss of human life, an acceptable annual probability of failure would be 0.01% (equivalent to design for a 10,000-year earthquake or 10,000-year flood). For tailings dams where failure would result in the potential loss of human life, an acceptable annual probability of failure must be no greater than 0.001%.[k]

The annual probability of failure must be periodically calculated by the operating company. The annual probability of failure and the methodology used to reach it must be published both as a technical document, and as a document that affected communities can access and understand. Risk analysis used to calculate the annual probability of failure must consider more than just the maximum credible precipitation or seismic events.

The slope of the outer embankment of the tailings dam must be low enough to keep the annual probability of failure due to piping (also called internal erosion) below an acceptable level. New outer embankments must be constructed with slopes 1V:5H or less, and additional fill must be added to existing outer embankments with a slope steeper than 1V:5H in order to reduce the slope to 1V:5H, as per guidance from the USACE.[71] A proposal to construct or maintain an outer embankment steeper than 1V:5H must be justified in writing to both regulators and the public. The justification cannot be based solely on economic considerations, but must demonstrate that, for a particular design, failure by internal erosion is still sufficiently unlikely even with a steeper slope. In all instances, a dam slope must not be steeper than 1V:2H. Regardless of the outer embankment slope, any new upstream dams must be banned and existing upstream dams must be safely closed in a timely manner.

The water management infrastructure prevents overtopping of the supernatant tailings pond. For tailings dams where failure could result in loss of life, the water management infrastructure, including, for example the beach, the required freeboard, spillways, internal drains, and diversion canals, must be sufficiently conservatively designed so that the tailings pond will not reach the dam crest even during the PMF. Otherwise, the water management infrastructure must ensure that the tailings pond will not reach the dam crest even during a 10,000-year flood. Maximum credible event calculations, such as the PMF, cannot rely solely on historical data and must consider changes produced by climate change. The operating company must provide documentation in Dam Safety Reviews (DSRs), overseen by a qualified engineer, that show that the entire system of water management of the tailings facility is capable of resisting either the PMF or the 10,000-year flood, depending on its consequence classification.

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[k] This annual probability of failure derives from the statement from the USACE Hydrologic Engineering Center's 2003 Application of paleohydrology to Corps flood frequency analysis: RD 47 on page 34 that says "the PMF [Probable Maximum Flood] does not incorporate a specific exceedance probability, but is generally thought to be well beyond the 10,000 year recurrence interval." In other words, the PMF has an annual probability of exceedance significantly less than 0.01%. It also derives from the statement by FEMA's 2005 Federal guidelines for dam safety—Earthquake analyses and design of dams: FEMA-65 on page 75 that says "for high-hazard potential dams, movement of faults within the range of 35,000 to 100,000 years BP is considered recent enough to warrant an 'active' or 'capable' classification." In other words, the MCE (Maximum Credible Earthquake) could be as rare as a 100,000-year earthquake (annual probability of exceedance of 0.001%).

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8. Ensure a detailed evaluation of the dam foundation and of the tailings properties

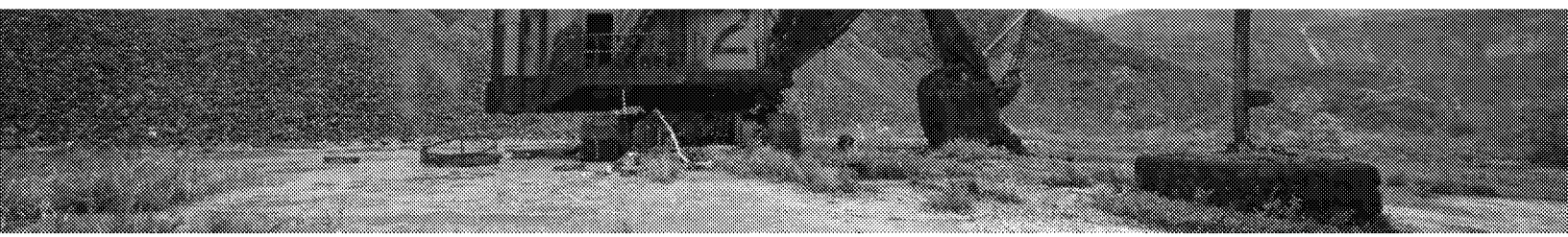
Prior to permitting approval, operating companies must provide relevant regulatory agencies a detailed engineering evaluation of the dam foundation, and a physical and chemical characterization of the tailings, with special attention to tailings clay content, brittleness and susceptibility to liquefaction. The characterization of the underlying geology must be conducted before the dam and the impoundment are constructed. The failure of the Mount Polley dam was related in part to the presence of an unstable glaciolacustrine layer underlying the dam.

The 2019 Brazilian Brumadinho Dam I failure was caused in part because the dam stored brittle tailings,[72] so all tailings must be evaluated for contractive or brittle behavior. The structural zone of a tailings dam must not include contractive or brittle tailings due to their increased risk of failure by liquefaction.

Tailings and tailings supernatant and pore water must be characterized and the results used to estimate the likelihood and consequence of a potential dam failure. The geochemical characteristics of the supernatant and pore water of a tailings facility, as well as the tailings themselves can affect the consequences of a dam failure and control the extent and recoverability of ecosystems. As acid generation and contaminant leaching potential increase, the consequences associated with dam failure increase. Tailings and tailings water must be sampled and the results reviewed, considering potential environmental risk, at least every three years, or when there is a substantial change in the ore deposit being processed or the processing methods.

Because tailings with high acid generation or a contaminant leaching potential increase the severity of consequences in the event of a failure, tailings with those geochemical characteristics must be designed to withstand the PMF and the MCE. Tailings facilities must be designed to withstand the 10,000-year flood or the 10,000-year earthquake only when the tailings are non-potentially acid generating with low contaminant leaching potential and there is no potential for loss of human life. The GARD Guide provides state-of-the-art recommendations for tailings geochemical characterization methods and interpretation of the results (for design criteria related to potential loss of life refer to Guideline 5).[73] Scanning Electron Microscope (SEM) and other mineralogic and geochemical techniques must be used for tailings characterization during mining and after mining ceases, especially at iron ore mines, or where iron-ore tailings are used for dam construction. As more is learned from past failures, best practice characterization methods must be regularly updated to ensure that the most relevant and comprehensive approaches are incorporated in tailings management and assessment guidance.

The abandoned Panguna mine, Bougainville, Papua New Guinea. Photo: Damian Baker.



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9. Appropriate monitoring systems must be in place to identify and mitigate risk

Tailings facilities must have appropriate monitoring systems in place to identify and mitigate risk. Tailings facilities must also have a clearly defined Adaptive Management Plan (AMP) linked to tailings monitoring results that encompasses a complete set of predictions and pre-planned actions.[74] The AMP is a way to rigorously implement the Observational Method, and the two terms are often used interchangeably. The Observational Method must be applied only under the oversight and concurrence of an Independent Tailings Review Board and there must be a system in place to respond to the observations.[I]

The AMP must include:

- Numeric and measurable expected performance criteria based on predictions of engineering behavior.
- Numeric trigger levels related to monitoring results that will identify risks before they occur, such as piezometer readings, supernatant pool characteristics, tailings and tailings water chemistry, and other characteristics.
- Mitigation measures designed for each performance criterion or trigger aimed at avoiding a catastrophic or other type of facility failure.
- An evaluation of the effectiveness of the measures taken.
- Reporting responsibilities for the operating company and responses by the regulatory agency and to relevant stakeholders.
- An annual AMP report for the tailings facility that reviews any triggers met or exceeded, mitigation actions taken, the effectiveness of the actions, and any AMP modifications needed. The report and its raw data must be made public, and a meeting must be held to explain the results to any affected communities and other interested stakeholders.

[I] The Observational Method must not be used for the prevention of liquefaction because liquefaction tends to occur without warning, i.e. with no time to make relevant observations (see Jefferies, M and K. Been. 2016. "Soil Liquefaction: A Critical State Approach"(2nd ed.). CRC Press. 690 p.). For the avoidance of liquefaction, all appropriate preventive actions must be carried out from the outset of the project.

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10. Ensure the independence of reviewers to promote safety

There must be an independent evaluation of all aspects of the design, construction, operation, and maintenance—including during closure and rehabilitation—of tailings and other mine waste facilities, regardless of the projected consequences of failure of the mine waste facility, by a group of competent, objective, third-party reviewers (e.g., an Independent Tailings Review Board).[75] The competence of reviewers must include demonstrated experience and skill engaging with communities, including rural and Indigenous communities, in a meaningful way. An ITRB provides ongoing advice on tailings operations that complement periodic DSRs. The ITRB must not be used exclusively as a means for obtaining regulatory approval.[76]

The independence of those performing reviews is essential for safety. The operating company must not be able to influence decisions made by the ITRB, and its members must not be dismissed or terminated during a review in an attempt to influence the outcomes or as an intimidation tactic. Any fees paid to the ITRB must be independent of the conclusions reached during the review.

In order to ensure objective reviews, the ITRB should be contracted through public procurement by local regulatory agencies and compensated by the operating company through those agencies. ITRBs must have a mandate to protect communities and the environment.[77] ITRBs must be obligated to engage with all stakeholders, and must have an accessible way to receive third-party information from whistleblowers and civil society.

Every jurisdiction should have a regulatory agency with the expertise and capacity to appoint independent reviewers to ITRBs. However, this has not been prioritized in many jurisdictions. When operating companies appoint their own reviewers, ITRB members, as individuals or as representatives of organizations, must not have a financial conflict with the mine being reviewed. Financial conflicts include but are not limited to direct financial interest (employment, contracts, stock, etc.),[78] and personal or family connections to the mine or operating company that could incur any kind of benefits. Reviewers must sign a disclosure declaration about past and present personal and economic relationships between the operating company/commissioning party and the reviewer, as well as a personal declaration by the specific reviewer that no incompatible parallel contracts or negotiations exist with the

The 2015 collapse of the tailings dam at the Samarco mine, owned by Vale and BHP, created a flash flood of tailings that covered the town of Bento Rodrigues, Brazil. Minas Gerais, Brazil. Photo: Bruno Milanez.

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operating companies whose facilities are under review. These declarations must include a fine for misrepresentation. Operating companies must not hire the same independent reviewers for multiple projects simultaneously or for subsequent reviews for three years prior to and after a review is completed.[79] Reviewers must not be dependent on a single operating company for the majority of their income.

The report and recommendations of the ITRB, the response of the operating company, and the subsequent response of the ITRB must be provided to the local regulatory agency and any communities affected by the tailings facility. The operating company must also publicly disclose the recommendations, as well as its rationale for any non-acceptance or inaction.

Additionally, operating companies must conduct an independent DSR yearly. An Environmental Social Impact Assessment (ESIA) must be carried out for every mining operation that includes a tailings disposal facility. The ESIA must be scientifically credible, respectful of local and Indigenous knowledge, have a transparent methodology, and be made publicly available. The authors of the ESIA must be subject to the same requirements for independence as the ITRB.

11. Towards safer closure with no credible failure modes

It is imperative that the reclamation and closure of tailings facilities be a factor in their initial design and siting. The failure of a tailings facility is inevitable, because no engineered structure can survive indefinitely without ongoing monitoring, inspection, and maintenance. This leaves the "reduction of failure consequences as the only effective strategy for risk reduction during closure."[80] A tailings facility is safely closed when deposition of tailings has ceased and all closure activities have been completed so that the facility requires only routine monitoring, inspection and maintenance in perpetuity or until there are no credible failure modes.

If the consequences of failure at some future time are unacceptable, the tailings facility must not be built in that location. Currently, there is no technology to ensure that an active tailings facility can be closed in such a way so as to withstand the PMF or MCE indefinitely without perpetual monitoring, inspection, and maintenance.

Operating companies must not be allowed to declare bankruptcy or sell to junior companies to avoid closure monitoring and liability (for additional details on closure costs see Guideline 12).

Given that operating companies will not exist long enough to accomplish perpetual monitoring, inspection, maintenance, and review, the operating company's ability to eventually eliminate all credible failure modes must be a key consideration during the permitting process. If a regulatory agency does not believe an operating company can carry out perpetual care and financial responsibility, or eliminate all credible failure modes, they must not approve the facility. Operating companies must prove they have successfully eliminated all credible failure modes to the relevant regulatory agencies.

Operating companies must provide transparent documentation of the estimated cost of the cleanup of a mine site, including closure and reclamation, and all monitoring and maintenance. Cleanup must be self-funded from financial resources, which must be demonstrably large enough to ensure sufficient funding in perpetuity (See Guideline 12).

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12. Addressing financial risks, including securities for site closure and proper insurances for accidental spills

Operating companies must have the necessary financial assurance to cover the full cost of closure and post-closure plans. The purpose of financial assurance is to ensure that there is a source of funds available to local regulators if the operating company fails to perform adequate reclamation activities, including necessary closure and postclosure maintenance. All existing facilities must have financial assurance in place. For new facilities, financial assurance must be secured during the permitting process and before construction begins. Any sale or transfer of ownership of the tailings facility must be conditional on the new operating company retaining such financial assurance. Because of the relatively low rate-of-return on investments that are typically utilized by the public agencies that assure long-term financial stability, post-closure financial assurance value calculations must be run for a minimum of 300 years.

Financial assurance must be independently guaranteed, reliable, and readily liquid to ensure that funds will be available in the event of bankruptcy by the operating company.[81] This means that all required funding must be immediately available upon request of the regulatory agency, and there must be no limitations on the use of funds for mine-related cleanup activities. Financial assurance must undergo review by third-party analysts, using accepted accounting methods, at least every three years or whenever there is a material change either to the tailings facility or to the social, environmental, and local economic context.[82] Unless the financial assurance is updated annually, the cost for inflation until the next financial review must also be included in the financial assurance calculation.

Destruction from the 2019 Minas Gerais tailings dam collapse near Brumadinho, Brazil. Photo: IBAMA Brazil.

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Additionally, operating companies must have public liability insurance to cover economic, social and environmental damages from sudden, accidental, or gradual pollutant releases including waste dump and tailings dam failures. The amount must be sufficient to financially compensate for harm to people, property, and natural resources that may occur, on or off the mine, including after closure of the tailings facility. Insurance or pooled assurance for unintentional hazardous spills is already required for many industries in certain jurisdictions, including for tankers, offshore drilling, nuclear energy production and pipelines.[83] The State of Maine requires "proof of comprehensive general liability insurance for the site for sudden and accidental occurrences" and "[n]on-sudden occurrence insurance may be required by the Department on a case by case basis and, and shall be required whenever there are land disposal units, land storage units, or mine waste units."[84] As per Guideline 11, tailings facilities must be monitored, inspected, and maintained in perpetuity or until there are no credible failure modes. Therefore, operating companies must have public liability insurance in perpetuity.

An analysis of public liability resulting from the tailings facility failure must be updated on a yearly basis and made publicly available. It must be based on the worst-case outcomes derived from dam break studies, which must account for a complete loss of tailings at full tailings facility buildout during a failure. Assessments of previous catastrophic tailings dam failures indicate that financial responsibilities can exceed U.S. $32 billion.[85,86]

Operating companies must not be allowed to self-bond or use parent or corporate guarantees[m] for mine closure, financial assurance or public liability insurance.[87,88]

Safety risks are not separate from financial risks. It is of paramount importance that operating companies be able to pay for the safest technologies and practices. In addition to financial assurance and insurance mechanisms, financially risky operations must be identified and fully considered as part of tailings safety prior to permitting and throughout the mining lifecycle.

As stated by in the Mount Polley Report: "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% ... [including] a detailed evaluation of all potential failure modes and a management scheme for all residual risk [and a] 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."[89,90]

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[m] According to the U.S. EPA, a corporate guarantee is when an operating company ensures another company will provide coverage for closure and post-closure costs (https://www.epa.gov/hwpermitting/financial-assurance-requirements-hazardous-waste-treatment-storage-and-disposal).

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13. Grievance procedures and whistleblowers

Independent grievance procedures must be established and made available in a culturally appropriate manner to all employees, contractors, suppliers, regulators, and affected community members. The system for reporting and filing grievances must be available in multiple formats, such as online, by mail, in person, etc. All pertinent information and documentation related to the grievance procedure must be provided in relevant languages.[91] All grievance mechanisms must adhere to the effectiveness criteria outlined in Principle 31 of the United Nations Guiding Principles on Business and Human Rights, which stipulates that they be: (a) legitimate, (b) accessible, (c) predictable, (d) equitable, (e) transparent, (f) rights-compatible, (g) a source of continuous learning, and (h) based on engagement and dialogue.[92] Rights holders must have decision-making power in the design and operation of grievance mechanisms. Operating companies must not use non-disclosure agreements to prevent individuals from openly filing and/or pursuing a complaint. Remedy for complaints must be adequate, effective, and prompt, and may include one or more of the following: an apology, guarantees of non-repetition, restitution, rehabilitation, financial or non-financial compensation, and punitive sanctions.[93]

Grievance mechanisms must be functionally independent from the project's operating company, for example, it may be run by a third-party trusted by the rights holders for whom it is intended. Grievance mechanisms must allow the complainants confidentiality and anonymity, if requested. Complainants must be provided the funds necessary to access independent forms of support (e.g. legal, technical or medical) in all phases of engagement with the procedure, including during the initial filing of the complaint (see Guideline 16). Additionally, a settlement through the operational level grievance procedures must not require the complainant(s) to sign legal waivers prohibiting them from civil legal action at a future date. There must be a clear, established time frame within which grievance mechanisms are resolved. There must be regular, timely and clear communication with the complainant in their relevant language throughout all steps of the grievance process. The operating company must publish the number of grievances received annually, the nature of the grievances, as well as any official decisions or resolutions.[94]

Whistleblower protection best practices must apply to all workers as well as vendors, contractors and auditors.[95] Mine workers have the right to refuse unsafe work, and must be allowed to stop their tasks at any time if they identify imminent risk to health and safety without suffering any punishment, as is already stipulated in Brazilian regulation.[96]

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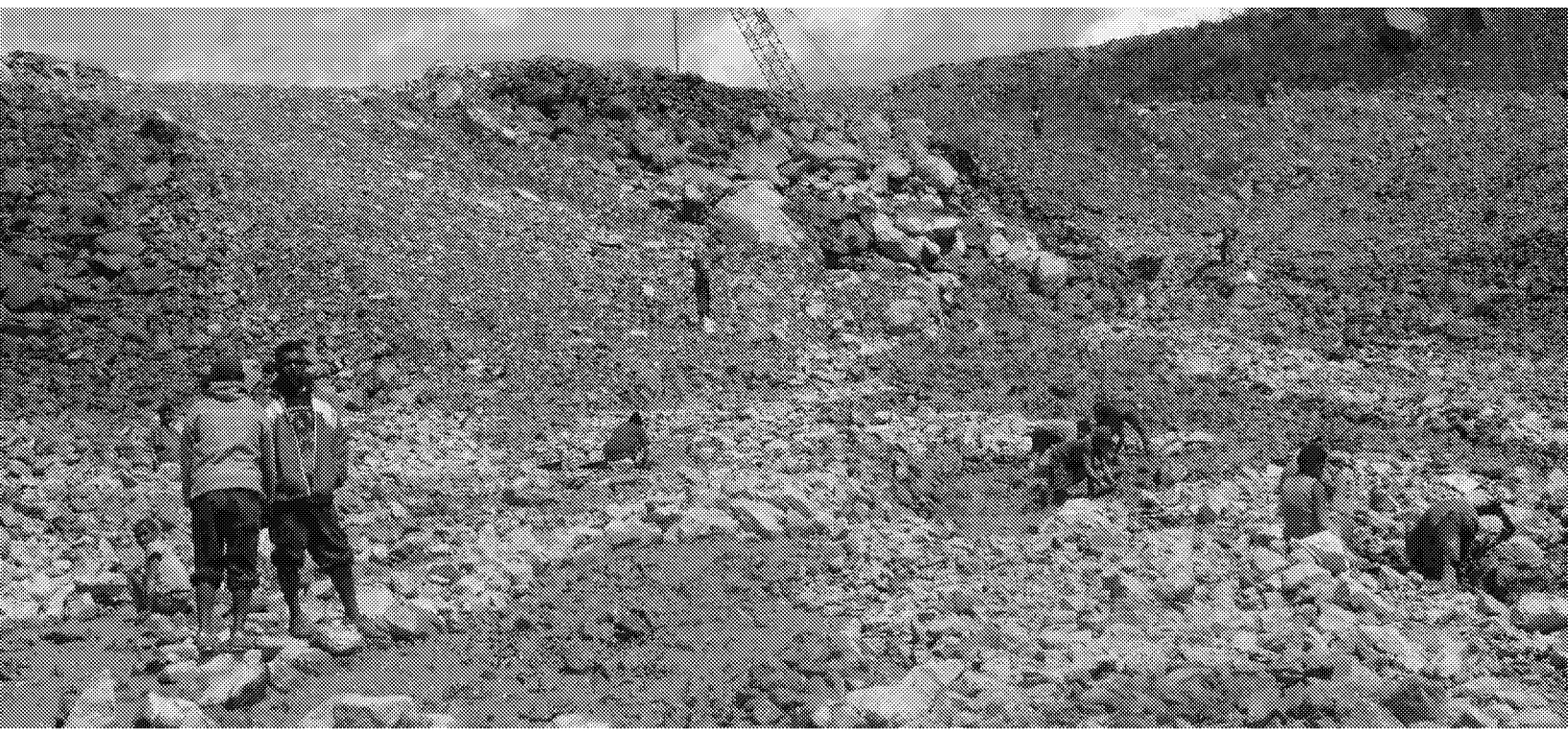
14. Emergency preparedness and response

Emergency preparedness and response plans, or emergency action plans, related to catastrophic failures of tailings facilities must be discussed and prepared together with all potentially affected communities, mine workers, agricultural producers and businesses downstream of the flow of a potential failure, and in collaboration with first responders and relevant government agencies.[97,98]

In the case of a sudden failure, the operating company is responsible for taking all steps necessary to save lives and provide appropriate humanitarian aid. The operating company must provide all needed resources and support to local and national governments and first responders during and after a failure. The operating company must assume the entirety of the costs of indemnification, remediation, and reclamation for a failure, including any additional damages incurred during remediation and reclamation efforts.

The full scope of indemnification, remediation, and reclamation criteria must be determined through a participatory process subject to the approval of affected communities, agricultural producers, and businesses, and made publicly available. Discussions with affected communities to establish identification criteria must begin before construction of a tailings disposal facility, undergo periodic updates, and continue in the event of a failure. Affected communities must have access to independent technical assistance at every stage of this process (see Guideline 16).

Community members standing on a mine waste pile at the Porgera mine in Papua New Guinea. Photo: Porgera Alliance.



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Worst-case tailings failure scenarios must consider the loss of all tailings at full tailings facility buildout, and the results must be made public prior to permitting. Failure model scenarios must also be annually updated to account for changes in the material consequences of a dam break due to social, economic or environmental changes in areas surrounding or downstream of the facility. Worst-case scenarios must model the complete loss of stored tailings and water, as occurred, for example, in the failure of the tailings dams at the Xiangjiang Wanji mine in China, the Church Rock uranium mill and the Buffalo Creek coal plant in the United States, and the El Soldado mine in Chile.

Emergency and evacuation drills related to catastrophic failure of tailings facilities must be held on an annual basis, and their planning and execution must include participation from affected communities, workers, local authorities, and emergency management. Emergency and evacuation drills can be traumatizing for communities. Special care must be given during planning so that communities are able to access the information they need for their safety, while ensuring they are not negatively impacted by the process.[99]

Tailings facilities must not be constructed where there are facilities that present considerable evacuation challenges in the zone of influence, including, but not limited to, jails or prisons, hospitals, and assisted-living or elder care facilities (See Guideline 3). Even if operating companies carry out training and emergency drills, certain social groups (the elderly, small children, people with disabilities, etc.) require special assistance. Based on the goal of zero harm to people, companies must ensure that trained professional support will be provided during an emergency and will reach all affected populations in a timely manner.

Contamination of the Paraopeba River after the 2019 tailings dam collapse near Brumadinho, Brazil. Photo: Maria Otávia Rezende.

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15. Information regarding mine safety must be made publicly available

Operating companies must make all information relevant to the safety and stability of tailings facilities publicly available, including the name, exact location, ownership, date of initial operation, footprint, and height. Information related to tailings disposal facilities must be made publicly available during the design stage and must be updated on a regular basis over the life of the mine.

Operating companies must immediately publicly disclose the date, location, amount of tailings released, and impacts on surrounding areas following any tailings failure.

Safety practices must be considered non-competitive. Industry association guidelines related to tailings safety must be freely available. While some operating companies assert that revealing information about tailings facilities presents a national security risk, there is no evidence for these claims and the authors reject this argument.

Relevant information that must be publicly available includes, but is not limited to:

- Dam Safety Reviews (DSRs)
- Consequence or hazard classification and decisions made by the board of directors or corporate management to approve the classification
- Environmental Impact Assessments (EIAs) or Environmental Social Impact Assessments (ESIAs)
- Design, maintenance, and monitoring documents (Design Basis Report, Construction Record Report, Construction vs. Design Intent Verification Report, (Annual Tailings Facility Performance Report, Deviance Accountability Report, etc.)
- Documentation of stability of the facility, including a record of past stability issues
- Closure and reclamation plans
- Dam break studies and assessments of social, economic, and environmental impacts
- Environmental monitoring and Social Management System summaries and reports
- Independent Tailings Review Board reports
- Adaptive Management Plan reports
- Impact and mitigation plans for affected communities, including compensation and indemnification criteria
- Documentation of FPIC and any community consent processes (the information divulged must be approved by the affected communities)
- Complaints and grievance procedures
- Emergency Preparedness and Response Plans
- Documentation of financial assurance and public liability insurance (including insurance estimates)
- Reports that are required by and filed with governmental agencies.

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Governments and regulators must also make all information relevant to the safety and stability of tailings facilities publicly available, including but not limited to environmental baseline studies on ground stability, geology, watersheds, fault lines, etc; all documents related to permitting and monitoring; and all information related to emergency preparedness and response.

This information must be made available by operating companies and regulators at no charge, as soon as possible, in one or more languages as necessary, in an accessible format, and in plain language whenever possible to afford adequate access for all interested stakeholders. This must also include all raw data obtained, input parameters used, and any updates to the models and simulations carried out as part of continued environmental monitoring. Proprietary software should be avoided in favor of commercial or freely available software.

Operating companies and regulators must respond to all stakeholder requests for information regarding the tailings facility to the fullest extent possible in formats and languages that are understandable to all stakeholders. If requests are not met in full, or in a timely manner, the company must provide written justification to those filing the requests.

16. Ensure access to independent technical assistance

Resources are unequally distributed between operating companies and affected communities; affected communities often do not have the same level of financial, technical, and logistical support that is available to operating companies. Many regulatory bodies are also out-resourced by operating companies. Too often, affected communities are forced to depend on operating companies to provide information about the scope, impacts, and potential consequences of tailings disposal facilities. Operating companies can withhold, misinterpret, or falsify information, and affected communities may not have the internal capacity to analyze documents to identify errors and/or omissions. Therefore, in order for affected communities and Indigenous Peoples to exercise their rights to access information, participate, and consent, they often require independent technical assistance at various stages of the life of a tailings facility.

Operating companies must fund access to independent technical assistance for affected communities and Indigenous Peoples. Experts must be trusted and chosen by the affected communities, Indigenous Peoples or individuals. The scope of services provided must encompass the full range of assistance needs, including, but not limited to, technical, legal, medical, social, and economic support. Operating companies must fully fund these services.[100] Communities must have the ability to change independent experts or choose new experts at any time over the life of the mine, if the experts do not demonstrate the necessary competencies for working with affected communities.

Affected communities and Indigenous Peoples must be offered access to independent technical assistance during the earliest stages of the lifecycle of the mine, starting with exploration, through monitoring and closure, and specifically during any consultation or FPIC processes (Guideline 2). Additionally, communities may request technical assistance to analyze and interpret publicly available information (Guideline 15). If a rights holder decides to use the grievance mechanism to file a complaint, they must have access to independent forms of support (e.g. legal, technical or medical) in all phases of engagement with the

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procedures (Guideline 13). If an operating company proposes a voluntary resettlement agreement, communities must have access to independent technical assistance throughout the agreement process (Guideline 3).

In the event of a tailings dam failure, operating companies must pay for independent technical assistance for affected communities to address collective and individual remediation, reconstruction, and compensation needs. Technical assistance is a critical tool for communities to understand the scope and impacts of a tailings facility failure, as well as to advocate for their collective rights. The technical experts hired must be able to clearly articulate the impacts and importance of the failure for affected and/or Indigenous communities.

Access to technical experts chosen by affected communities and funded by the operating company after dam failures is mandated in mining legislation in Minas Gerais, Brazil.[101] For example, after the 2015 Fundão tailings dam failure, the community of Barra Longa selected 13 independent technical experts in agriculture, law, architecture, urban planning, psychology, engineering, and social services to help determine the scope and extent of reparations and indemnification criteria. While accountable to the community and individuals affected by the failure, the experts were paid by the mining company through a foundation established for remediation and indemnification.[102]

17. Accountability for risk, minimizing the consequences of failure, preventing failure, and the consequences of failure must primarily rest with the board of directors

The corporate board of directors, as the body that is ultimately responsible for the well-being of the operating company, must bear the primary responsibility for the safety of tailings facilities, including the consequences of dam failures.[103] A push for profit maximization creates a tendency for operating companies to prioritize production over all other considerations, including safety considerations.[104] Liability for tailings dam failures must extend to the corporate board of directors.

The board of directors must have the capacity and tools to guarantee that safety considerations are not sacrificed at the expense of production. The board must proactively ensure that safety extends throughout the entire operating company by approving policies and budgets that identify and mitigate the risks posed by tailings disposal facilities and that prioritize safety, including in staff performance evaluations. The board of directors must take an active role in identifying and signing off on safety risks related to tailings disposal facilities where human lives could be at stake or severe environmental damage could occur.

The Control of Major Accident Hazards (COMAH) Competent Authority in the United Kingdom, the intragovernmental regulatory body that inspects major hazard enterprises, suggests that at least one board member have an appropriate competence level on major hazard risk to advise the board and senior leadership team on relevant issues.[105] Operating companies must ensure that the board of directors includes at least one member with expertise in tailings disposal facility failure risks.

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Additionally, the board of directors must be responsible for approving and overseeing the implementation of company procedures to ensure that no employee or contractor is participating in, promoting or facilitating bribery. For example, facilitation payments to government officials to fast-track tailings facility permits must be prohibited, and there must be zero tolerance for any bribery by mine employees or contractors of auditors, consultants, and government officials.

Destruction from the 2019 tailings dam collapse near Brumadinho, Brazil. Photo: Maria Otávia Rezende.

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Next Steps

The safest tailings facility is the one that is never built. It is imperative that we find ways to reduce overall demand for primary raw materials; our current consumption levels, especially in the Global North, are unsustainable. Implementing strong standards and best practices for tailings disposal is a necessary stopgap for frontline communities already dealing with the impacts or threat of unsafe tailings facilities, however research shows that we can build a future that is less reliant on extraction and generates less mine waste.[106] This document aims to provide a tool that helps frontline and Indigenous communities, civil society, States, regulators, and operating companies prevent catastrophic tailings failures, nevertheless the guidelines contained here must be implemented alongside transformative changes that move us away from an extractive economy.

Worldwide, there are many thousands of tailings disposal facilities and dams, some under the responsibility of private corporations, others under the responsibility of States. Because there is currently no global inventory of tailings disposal facilities, including the thousands of abandoned facilities, there is an urgent need for a transparent assessment, in which the results are made publicly available in a global tailings database. Ecosystems, livelihoods, and human lives are at stake.

This inventory must include all relevant information regarding the safety of tailings disposal facilities (See Guideline 15). In 2020, GRID-Arendal launched The Global Tailings Portal in collaboration with the Investor Mining and Tailings Safety Initiative to catalog voluntary disclosures and publicly available data on tailings disposal facilities.[107] While it is an important step towards the creation of a comprehensive registry, the portal must continue to expand in scope of facilities and depth of information collected. There are also a number of national registries, including ones in Brazil,[108] the United States,[109] Chile,[110] Mexico,[111] Spain.[112]

Mount Polley Mine tailings dam failure, 2014. Photo: Courtesy of IRMA.

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The database must also include a registry of dam failures. It is essential to better understand how and why each failure occurred in order to prevent them in the future. The work being compiled by the Center for Public Participation database can serve as a model for this type of documentation and analysis.[113]

An independent international agency, such as a United Nations-endorsed agency, in collaboration with responsible States, operating companies, and civil society, must drive this process, collect information on tailings dams and tailings dam failures worldwide, and share it with affected communities in order to de-risk tailings facilities and support the creation of proper emergency action plans.

It is crucial that United Nations agencies and international partners, including States, industry, labor representatives, civil society organizations, and independent experts, establish or endorse a credible, transparent, and independent international agency capable of certifying safe tailings disposal worldwide. This must be a well-resourced agency capable of efficiently updating global standards, investigating failures, and making publicly-available recommendations. This agency must not rely solely on industry experts, must include broad State or civil society engagement, and must be accountable to the public and affected communities. The governance structure for this agency must be a multi-stakeholder body that includes affected communities, Indigenous Peoples, labor, and civil society organizations. It must ensure a co-equal decision making process that includes all stakeholders.

The polluted Doce River after the 2015 Samarco mine tailings dam failure. Minas Gerais, Brazil. Photo: Júlia Pontés.

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Glossary

Adaptive Management

A structured, iterative process of robust decision-making in the face of uncertainty, with an aim to reduce uncertainty over time via system monitoring. It includes the development of management practices based on clearly identified outcomes, and monitoring to determine if management actions are meeting desired outcomes. If outcomes are not being met, the process requires development and implementation of management changes to ensure that outcomes are met or re-evaluated. Adaptive Management is similar to the Observational Method (see definition below), and sometimes the terms are used interchangeably.

Source: Initiative for Responsible Mining Assurance, 2018. IRMA Standard for Responsible Mining IRMA-STD-001, Glossary of Terms.

Affected Community

A community that is subject to actual or potential impacts from a project. Impacts include, but are not limited to, socioeconomic, environmental, and public health or safety impacts, impacts to cultural, touristic or sacred sites, and risk of intimidation, violence or coercion.

Source: Initiative for Responsible Mining Assurance, 2018. IRMA Standard for Responsible Mining IRMA-STD-001, Glossary of Terms. IRMA Standard Adapted from IFC. IFC Policy & Performance Standards and Guidance Notes. Glossary of Terms.

Brittle Tailings

Tailings that exhibit substantial (> 40%) strength loss or strain-softening in response to an exceedance of the peak or yield strength.

Source: Adapted from Bishop, A.W., 1967. Progressive failure with special reference to the mechanism causing it. Proceeding of the geotechnical conference, Oslo, Sweden.

Board of Directors

The ultimate governing body of the Operator typically elected by the shareholders of the Operator. The Board of Directors is the entity with the final decision-making authority for the Operator and holds the authority to, among other things, set the Operator's policies, objectives, and overall direction and oversee the firm's executives. As the term is used here, it encompasses any individual or entity with control over the Operator, including, for example, the owner or owners. Where the State serves as the Operator, the Board of Directors shall be understood to mean the government official with ultimate responsibility for the final decisions of the Operator.

Source: Adapted from the Global Tailings Review, 2020. Global Industry Standard on Tailings Management. 25 p.

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Catastrophic Tailings Failure

A tailings facility failure that results in material disruption to social, environmental and local economic systems. Such failures are a function of the interaction between hazard exposure, vulnerability, and the capacity of people and systems to respond. Catastrophic events typically involve numerous adverse impacts, at different scales and over different timeframes, including loss of life, damage to physical infrastructure or natural assets, and disruption to lives, livelihoods, and social order.

Source: Global Tailings Review, 2020. Global Industry Standard on Tailings Management. 26 p.

Centerline Construction

The centerline raising method is a compromise between the upstream and downstream methods in many respects. As a result, it shares to a degree the respective advantages of the two methods, while mitigating their disadvantages. ... Initially, a starter dike is constructed, and tailings are peripherally spigotted from the dike crest to form a beach. Subsequent raises are constructed by placing fill onto the beach and onto the downstream slope of the previous raise. The centerlines of the raises are coincident as the embankment progresses upward, giving rise to the method's name.

Source: Source: Vick, S. G., 1990. Planning, Design, and Analysis of Tailings Dams. 77 p.

Contaminant Leaching Potential

The potential for tailings samples to release contaminants based on short- and long-term leach tests. The potential for adverse water quality effects from a tailings dam breach can also be determined from the quality of supernatant and pore fluids in the impoundment. If leach test results or tailings do not exceed water quality standards (e.g., aquatic life criteria), the contaminant leaching potential would be considered low; if concentrations exceed standards by 1 to 10 times, the potential would be intermediate; and if concentrations exceed standards by more than 10 times the potential would be high.

Source: The International Network for Acid Prevention (INAP), 2009. Global Acid Rock Drainage Guide (GARD Guide).

Credible Failure Mode

A physically possible sequence of events that could potentially end in tailings dam failure. According to the GISTM, "the term 'credible failure mode' is not associated with a probability of this event occurring."

Source: Global Tailings Review, 2020. Global Industry Standard on Tailings Management. 27 p.

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Dam Break Study

Also called an inundation study or dam-breach or failure-consequence analysis, a dam break study assumes a failure of the tailings facility and estimates its impact. The analysis must be based on credible failure modes. The results should determine the physical area impacted by a potential failure, flow arrival times, depth and velocities, duration of flooding, and depth of material deposition. The Breach Analysis is based on scenarios which are not connected to probability of occurrence. It is primarily used to inform emergency preparedness and response planning and the consequence of failure classification. The classification is then used to inform the external loading component of the design criteria.

Source: Global Tailings Review, 2020. Global Industry Standard on Tailings Management. 26 p.

Dam Safety Review

A periodic and systematic process carried out by an independent qualified review engineer to assess and evaluate the safety of a dam or system of dams (or in this case a tailings facility) against failure modes, in order to make a statement on the safety of the facility. A safe tailings facility is one that performs its intended function under both normal and unusual conditions; does not impose an unacceptable risk to people, property or environment; and meets applicable safety criteria.

Source: Global Tailings Review, 2020. Global Industry Standard on Tailings Management.

Downstream Construction

A method of dam construction in which the centerline of the dam is shifted downstream with subsequent raises, resulting in a core inclined in the downstream direction. This method requires that the structural fill be placed in the downstream shell during raising to support the inclined core.

Source: Klohn Crippen Berger, 2017. Study of tailings management technologies: Report to Mining Association of Canada and Mine Environment Neutral Drainage (MEND) Program, MEND Report 2.50.1, 164 p.

Facilitation Payments

Facilitation payments are sums of money paid to get preferential treatment for something the receiver is otherwise still required to do — for example, paying an official to speed up, or "facilitate," an authorisation process.

Source: Responsible Jewelry Council, 2019. Code of Practices Guidance. 105 p.

Factor of Safety (FoS)

The lowest ratio of available shear resistance along a potential plane of failure to the activating shear forces along the same plane, as considered over all possible failure surfaces.

Source: Canadian Dam Association, 2013. Dam safety guidelines 2007 (2013 edition).

Filtered Tailings

Tailings dewatered such that they behave like a moist soil; achieved by thickening followed by vacuum or pressure filtration.

Source: Klohn Crippen Berger, 2017. Study of tailings management technologies: Report to Mining Association of Canada and Mine Environment Neutral Drainage (MEND) Program, MEND Report 2.50.1, 164 p.

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Free, Prior and Informed Consent (FPIC)

Consent based on: engagement that is free from external manipulation, coercion and intimidation; notification, sufficiently in advance of commencement of any activities, that consent will be sought; full disclosure of information regarding all aspects of a proposed project or activity in a manner that is accessible and understandable to the people whose consent is being sought; acknowledgment that the people whose consent is being sought can approve or reject a project or activity, and that the entities seeking consent will abide by the decision.

Source: Initiative for Responsible Mining Assurance, 2018. IRMA Standard for Responsible Mining IRMA-STD-001, Glossary of Terms.

Grievance

A perceived injustice evoking an individual's or a group's sense of entitlement, which may be based on law, contract, explicit or implicit promises, customary practice, or general notions of fairness of aggrieved communities.

Source: Ruggie, J., 2011. Guiding Principles on Business and Human Rights.

Grievance Mechanism

Any routinized, State-based or non-State-based, judicial or non-judicial process through which mining-project related complaints or grievances, including business-related human rights abuses, stakeholder complaints, and/or labor grievances, can be raised and remedy can be obtained.

Source: Ruggie, J., 2011. Guiding Principles on Business and Human Rights.

Independent

In order for an individual, institution, mechanism or agency to be considered independent it must be objective, impartial, consistent, transparent and accountable to all stakeholders. It also requires that payment for services, funding of work, long-term financial stability and the potential for future contracts do not depend on outcomes or conclusions that are favorable to an operating company or the mining industry.

Source: Adapted from The Organisation for Economic Co-operation and Development, Creating a Culture of Independence: Practical Guidance against Undue Influence.

Independent Review

The Mining Association of Canada defines independent review as "independent evaluation of all aspects of the design, construction, operation, maintenance of a tailings or other mine waste facility by competent, objective, third-party review on behalf of the operating company/mine owner." In addition to the MAC's definition, independent review must demonstrate financial independence from the operating company/mine owner (see above definition of independence).

Source: Adapted from Mining Association of Canada, 2017. A Guide to the Management of Tailings Facilities.

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Indigenous Peoples

An official definition of "[I]ndigenous" has not been adopted by the United Nations system due to the diversity of the world's [I]ndigenous [P]eoples. Instead, a modern and inclusive understanding of "[I]ndigenous" includes peoples who: identify themselves and are recognized and accepted by their community as [I]ndigenous; demonstrate historical continuity with pre-colonial and/or pre-settler societies; have strong links to territories and surrounding natural resources; have distinct social, economic or political systems; maintain distinct languages, cultures and beliefs; may form non-dominant groups of society; and resolve to maintain and reproduce their ancestral environments and systems as distinctive peoples and communities. In some regions, there may be a preference to use other terms such as: [T]ribes, [F]irst [P]eoples/[N]ations, [A]boriginal, ethnic groups, Adivasi and Janajati. All such terms fall within this modern understanding of "[I]ndigenous."

Source: Adapted from Initiative for Responsible Mining Assurance, 2018. IRMA Standard for Responsible Mining IRMA-STD-001, Glossary of Terms.

Internal Erosion (see Piping)

Inundation Study (see Dam Break Study)

Maximum Credible Earthquake (MCE)

The largest earthquake magnitude that could occur along a recognized fault or within a particular seismotectonic province or source area under the current tectonic framework.

Source: FEMA ((U.S.) Federal Emergency Management Agency), 2005. Federal guidelines for dam safety—Earthquake analyses and design of dams: FEMA-65, 75 p.

Meaningful Engagement

Described by the United Nations (UN), The World Bank, the International Finance Corporation (IFC), the Organization for Economic Cooperation and Development (OCED), the Inter-American Bank, amongst other international and multilateral organizations and agencies, as a process whereby project proponents not only have an obligation to consult and listen to stakeholder perspectives, but also have an obligation to take their perspectives into account. Meaningful engagement involves understanding and addressing structural and practical barriers to the active participation of diverse groups of people, for example: women, ethnic minorities, people who live in remote areas, and/or different language groups. Access to relevant information that can be reasonably understood by the external party and transparent communication is a precondition of meaningful engagement. Affected communities must have a say in what meaningful engagement looks like for them.

Source: Global Tailings Review, 2020. Global Industry Standard on Tailings Management.

Mine Site

A mine site is the area of surface disturbance necessary to conduct a mining operation. This includes extraction, processing, and waste disposal facilities, and roads. A mine site does not necessarily include the entire area as defined by the mine permit or claim.

Source: Modified definition created by the authors.

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Modified Centerline Construction

Modified centerline construction is similar to conventional centerline construction, but with the contact between the compacted fill and the tailings sloping slightly upstream. Since modified centerline construction still involves constructing a portion of the dam on top of the uncompacted tailings, it must be considered a variant of upstream construction, similarly subject to the cautions and restrictions associated with upstream-type dams presented in this document.

Source: Adapted from J.P. Haile & K.J. Brouwer, Knight Piesold Ltd, Modified Centreline Construction of Tailings Embankments, 3rd International Conference on Environmental Issues and Waste Management in Energy and Mineral Production, August, 1994. Perth, Australia; and Independent Expert Engineering Investigation and Review Panel, 2015. Report on Mount Polley Tailings Storage Facility Breach, Province of British Columbia.

Observational Method

A project management method in which observed performance from instrumentation data is used for implementing preplanned design features or actions in response. According to the Mount Polley Report, the Observational Method is useless without a way to respond to the observations. The Observational Method is similar to Adaptive Management (see definition above), and sometimes the terms are used interchangeably.

Source: Independent Expert Engineering Investigation and Review Panel, 2015. Report on Mount Polley Tailings Storage Facility Breach.

Operating Company

Any person, corporation, partnership, owner, affiliate, subsidiary, joint venture, or other entity, including any State agency, that operates or controls a tailings facility.

Source: Global Tailings Review, 2020. Global Industry Standard on Tailings Management. 30 p.

Piping (also called Internal Erosion)

A phenomenon where seeping water progressively erodes or washes away soil particles, leaving large voids (pipes) in the soil. These voids simply continue to erode and work their way backward under the structure, or they may collapse. Either way, if piping is not stopped promptly, failure is imminent. The critical place for piping is usually right at the corner of the toe of a dam.

Source: R.D. Holtz, Kovacs, W.D., and Sheahan, T.C., 2011. An Introduction to Geotechnical Engineering, 2nd ed., Pearson, 863 p.

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Potentially Acid Generating (PAG)

An indication, based on laboratory testing, that the mine sample could produce acid drainage under field conditions. Samples are considered PAG if the neutralizing-potential (NP) to acid production potential (AP) ratio (NP:AP) is <1 and non-PAG if NP:AP is >2. Samples with NP:AP between 1 and 2 have an uncertain potential to generate acid (GARD Guide, Section 5.4.16; INAP, 2009). Site-specific and mineralogic evaluations and longer-term testing are needed to set appropriate ratios. Safety factors may be needed to address limitations in sampling, material handling, or prediction (INAP, 2009). Conservative non-PAG ratios ranging from 1.3 to 5 have been recommended by some practitioners (Maest et al., 2005).

Source: Adapted from The International Network for Acid Prevention (INAP), 2009. Global Acid Rock Drainage Guide (GARD Guide), and Maest, A.S. and J.R. Kuipers (primary), C.L. Travers, and D.A. Atkins (contributing). 2005. Predicting Water Quality at Hardrock Mines: Methods and Models, Uncertainties, and State-of-the-Art. Earthworks, Washington, DC.

Probable Maximum Flood

The flood that may be expected from the most severe combination of critical meteorologic and hydrologic conditions that is reasonably possible in the drainage basin under study.

Source: FEMA ((U.S.) Federal Emergency Management Agency), 2013. Selecting and accommodating inflow design floods for dams: FEMA-94, 38 p.

Stakeholders

Persons or groups who are directly or indirectly affected by a project, such as rights holders, as well as those who may have interests in a project and/or the ability to influence its outcome, either positively or negatively.

Source: Initiative for Responsible Mining Assurance, 2018. IRMA Standard for Responsible Mining IRMA-STD-001, Glossary of Terms Adapted from IFC, 2007. Stakeholder Engagement: A Good Practice Handbook for Companies Doing Business in Emerging Markets.

Structural Zone

The containment structure of a tailings disposal facility. In a filtered tailings facility, "typically, the filtered tailings form the containment structure ('structural zones') and uncompacted tailings, which can have a lower solids content, can be placed in the interior" (ICOLD, 2021). The structural zone of a filtered tailings facility serves the same function as a dam.

Source: ICOLD (International Commission on Large Dams), 2021. Tailings dam design—Technology update: ICOLD Bulletin 181, 97 p. Klohn Crippen Berger, 2017. Study of tailings management technologies: Report to Mining Association of Canada and Mine Environment Neutral Drainage (MEND) Program, MEND Report 2.50.1, 164 p.

Tailings

Tailings are the materials left after the extraction of metals or minerals of interest from ore.

Source: Dougherty and Schissler, 2020. SME Mining Reference Handbook, 2nd Edition, p. 513

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Tailings Dam

A structure or embankment that is built to retain tailings and/or to manage water associated with the disposal of tailings, and includes the content of the structure.

Source: Adapted from Guidelines on Tailings Dams, Planning, Design, Construction, Operation and Closure, Australian National Committee on Large Dams, ISBN: 978-0-9808192-4-3, May 2012; and Klohn Crippen Berger, 2017. Study of tailings management technologies: Report to Mining Association of Canada and Mine Environment Neutral Drainage (MEND) Program, MEND Report 2.50.1, 164 p.

Tailings Dam Failure

A tailings dam failure can generally be defined as the inability of the dam to meet its design intent, whether in terms of management, operational, structural or environmental function, resulting in potential loss of life, loss to the stakeholders, or adverse environmental effects.

Source: Canadian Dam Association Tailings Dam Breach Analysis (2022).

Upstream Construction

A method of dam construction in which the centerline is translated upstream, over the tailings beach, with subsequent raises. This method requires that material placed in the upstream direction is well-drained and compacted or that it settles naturally to an adequate density.

Source: Klohn Crippen Berger, 2017. Study of tailings management technologies: Report to Mining Association of Canada and Mine Environment Neutral Drainage (MEND) Program, MEND Report 2.50.1, 164 p.

Voluntary Resettlement

Voluntary land transactions (i.e., market transactions in which the seller is not obliged to sell and the buyer cannot resort to expropriation or other compulsory procedures sanctioned by the legal system of the host country if negotiations fail) that lead to the relocation of willing sellers.

Source: Initiative for Responsible Mining Assurance, 2018. IRMA Standard for Responsible Mining IRMA-STD-001, Glossary of TermsGlossary of Terms.

Worker

All non-management personnel including outsourced workers and contractors.

Source: Adapted from Initiative for Responsible Mining Assurance, 2018. IRMA Standard for Responsible Mining IRMA-STD-001, Glossary of Terms.

Zone of Influence

The zone of influence is the area that would be significantly affected in case of a TSF failure and should be categorized as a risk zone.

Source: Atif, I., et al., 2020. "Modelling and analysis of the Brumadinho tailings disaster using advanced geospatial analytics." In the *Journal of Southern African Institute of Mining and Metallurgy*. 405 p.

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Residents of the Y-K Delta should expect more tundra fires as the climate continues to warm

KYUK | By Olivia Ebertz

Published August 18, 2022 at 12:22 PM AKDT

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Olivia Ebertz

Olivia Ebertz is a News Reporter for KYUK. She also works as a documentary filmmaker. She enjoys learning languages, making carbs, and watching movies.

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Historically massive tundra fire burning 3.5 miles from St. Mary's on lower Yukon River. Another fire is 10 miles from Sleetmute on upper Kuskokwim River.

Anna Rose MacArthur, June 12, 2022

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Science and Environment

Evacuees from St. Mary's arrive in Bethel, as tundra fire gets closer to town

Olivia Ebertz, June 10, 2022

Regional airline Yute Commuter Service canceled most of its flights on June 9, and instead sent its fleet to St. Mary's to shuttle 80 evacuees to Bethel.

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Half of Pilot Station is without running water as tundra fire nears

Olivia Ebertz, June 13, 2022

As a historically large tundra fire burns to its north, about half of the community of Pilot Station is currently without running water. The fire is about 12 miles from the village, and the Pilot Station mayor said that he may soon have to turn off running water to the entire community.

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Public Safety

Several tundra fires are threatening Southwest Alaska communities. A climate specialist says a warming climate has made them spread faster and farther

Olivia Ebertz, June 9, 2022

The largest tundra fire in the history of the Lower Yukon valley is burning eight miles from the city of St. Mary's. On the coast, another fire is burning within five miles of the communities of Tununak and Toksook Bay.

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Public Safety

People who fled the lower Yukon River tundra fires are asking when they can return home

Anna Rose MacArthur, June 14, 2022

"It's going to be a personal decision and a family decision on whether it makes sense to have those folks come back," Alaska Incident Management Team Operations Section Chief Karen Scholl said.

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Public Safety

Superintendent Dee Dee Ivanoff is helping St. Mary's stay safe as the surrounding tundra burns

Olivia Ebertz, June 15, 2022

St. Mary's village officials who stayed in their village during a massive tundra fire are working tirelessly to keep their community safe. Meet St. Mary's School District Superintendent Dee Dee Ivanoff.

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Science and Environment

A large tundra fire is burning 12 miles away from St. Mary's

Olivia Ebertz, June 8, 2022

The fire has been burning since the tundra was struck by lightning on May 31, and it is now within 12 miles of the community.

LISTEN • 2:16

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Public Safety

The East Fork Fire is no longer threatening lower Yukon River communities, according to fire officials

Anna Rose MacArthur, June 28, 2022

In an online update, fire officials say that several Native allotments along the Andreafsky River remain at potential risk from the fire, but the nearest cabin sits 5 miles away.

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Science and Environment

Alaska never saw large tundra fires like the East Fork Fire until climate change provided more fuel

Casey Grove, Alaska Public Media - Anchorage, June 16, 2022

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Human Health Risk Assessment for the Donlin Gold Project, Alaska

June 2017

ERM Project # 0401326

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EXECUTIVE SUMMARY

This HHRA evaluated the potential addition of metal constituents to the environment in areas where subsistence populations live and harvest wild foods near the proposed Core Operating Area of the Donlin Gold project (Project). The approach of the HHRA was to evaluate incremental risk; that is, what is the added human health exposure and associated incremental risk due to predicted future concentrations of certain metals in soil, sediment, surface water, wildlife and fish that may be harvested and eaten near the Project as well as from inhalation associated with air emissions. Incremental risk from antimony, arsenic, and mercury (constituents of potential concern, or COPCs) were quantified in the HHRA. A health-protective approach was taken to quantify incremental exposure to these constituents, in that conservative exposure assumptions were used to calculate potential incremental risk to subsistence populations that may be hunting, gathering, or living in the area around the proposed Core Operating Area.

A deterministic-based computation of non-cancer and cancer risks was completed following Alaska Department of Environmental Conservation (ADEC) and United States Environmental Protection Agency (USEPA) guidelines for HHRAs. The HHRA integrated the results of the environmental media baseline studies, human receptor characteristics, subsistence information, and agency-recommended toxicity values to estimate non-cancer and cancer risks.

CONCEPTUAL MODEL

A conceptual site model (CSM) was developed to describe the sources, transport mechanisms, exposure pathways, and media that may result in human exposure to COPCs. Both background sources and Project-related emissions contribute to total environmental exposure. The primary sources of Project-related constituents would be fugitive and point source air emissions. Surface water that comes in contact with mining infrastructure ("contact water") will be treated prior to discharge to levels at or below ADEC surface water quality criteria, which are protective of human health. Groundwater around the Core Operating Area is not a source of drinking water.

The HHRA considered exposures within a 20 mile radius outside the Core Operating Area, which represents the spatial extent of the mercury air deposition model (Environ 2015). This spatial boundary is referred to as the "study area". The HHRA calculated risks at the end of mine life (year 27), because the increase in constituent concentrations in the environment due to emissions from the proposed Project is expected to be highest at that time. After operations cease, Project emissions will diminish, and accordingly, evaluating potential exposure as of the end of operations represents a reasonable temporal boundary for maximum potential risk related to releases from the proposed Project.

Exposure pathways evaluated in the HHRA included inhalation of airborne constituents, incidental ingestion of constituents bound to soil, and ingestion of constituents associated with biota (fish, plants, and wildlife) that may be harvested in the study area. Because consideration of all individual species or wildlife trophic components of an ecological system is not practical or necessary in order to quantify incremental risk, representative species were evaluated in the

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HHRA. Based on a review of the subsistence food items reported to be harvested by the Upper Kuskokwim group, and considering physiological factors of different species, the HHRA evaluated the incremental risk from consumption of northern pike (representing resident fish consumption), beaver (representing small mammal consumption), mallard ducks (representing wild bird consumption), and blueberries and cranberries (representing wild berry consumption).

The HHRA evaluated receptor populations that would have the highest exposure potential in the study area, which would be people who live in or near the Project and engage in subsistence activities such as harvesting, hunting, and fishing in the study area. Crooked Creek, located south-southeast of the proposed Project, and Georgetown, located east-southeast of the proposed Project, are the only villages in the study area. Based on Brown et al. (2012) and other studies cited in the Draft Environmental Impact Statement (DEIS; [USACE 2015]), the information on subsistence harvest patterns establishes that people living closest to the Project do not limit or concentrate their subsistence activities to the study area. Regional subsistence harvesting patterns shown in Brown et al. (2012) indicate that harvesting occurs predominantly outside of the study area. In order to be health-protective, a generalized subsistence population was conceptualized to evaluate exposures in the HHRA. This generalized population was assumed to live in the village of Crooked Creek (thus exposed to air and soil concentrations year around) and to hunt, fish, and gather only within the study area for beaver, mallard ducks, berries, and northern pike.

Quantities harvested and consumed were based on data presented for the Upper Kuskokwim subregion group (Brown et al. 2012), as this group lives nearest and most frequently harvests nearest to the proposed Project. Both the generalized subsistence population and assumptions about levels of consumption resulted in an overestimate of the exposure frequency and duration in the study area. This is a conservative analytical approach that ensures that potential effects on human health due to exposures via inhalation, as well as consumption of wild food collected within the study area, are not underestimated.

EXPOSURE ASSESSMENT

The calculation of chemical intake, or dose, requires estimation of exposure point concentrations (EPCs), and estimation of intake rates. Future (and some baseline) EPCs were estimated based on models rather than empirical data. To estimate future EPCs, the potential for future mercury methylation was evaluated, and bioaccumulation factors (BAFs) developed to understand potential future mercury bioavailability and constituent uptake into biota.

Methylation Rates

Atmospheric emissions from the Project have the potential to increase mercury loadings to the environment. Transformation of deposited mercury into methylmercury (MeHg) is of particular concern because: (a) it is the most toxic form of mercury and (b) it bioaccumulates in food chains to a greater extent than other, inorganic forms of mercury. The rate of conversion of total mercury (THg) to MeHg is the methylation rate, or %MeHg. The %MeHg is dependent on complex environmental factors. Numerous studies (e.g., USEPA 1997, Environment and

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Climate Change Canada 2016, Frohne et al. 2012, Houben et al. 2016, Scudder et al. 2009, Ullrich et al. 2001) have attempted to quantify these factors, sometimes with conflicting results and rarely with quantifiable relationships. The primary and secondary mechanisms that affect %MeHg are identified as the availability of mercury, followed by oxygen, sulfate, organic carbon, pH and temperature. Other tertiary mechanisms such as photomethylation reactions may occur on a localized basis. Of the factors that have been identified as potentially affecting %MeHg, the Project is expected to change the THg and sulfate content through aerial deposition. These factors were incorporated into future estimates of MeHg in soil and the aquatic environment.

Future %MeHg was estimated using simple models based on empirical data. The Project is estimated to increase mercury deposition over baseline in the nearest watersheds, decreasing with distance from the Project. Atmospheric mercury that would be deposited would consist of gaseous mercury (Hg(0)), oxidized mercury (Hg2+), and particulate mercury (Hg(p)), with the majority in the particulate form. A minor component (approximately 1 to 2 percent) would be deposited as oxidized mercury, a form that is more likely to be methylated. Environ (2015) estimates that the deposition rate of Hg2+ from the Project sources will be approximately 2% of total Project deposition. Though Hg2+ can easily be methylated, the rate of methylation for the newly deposited Hg2+ is not known for the study area. As different forms of Hg may have different methylation rates, and "new" deposited Hg may be methylated more rapidly, instantaneous methylation of the newly deposited Hg2+ was assumed for purposes of the HHRA. Of the deposited mercury, 2% was assumed to be Hg2+, and 98% was assumed to be Hg(p). The USEPA (2005a) equation to calculate soil concentration based on deposition rate was used to calculate the future soil Hg2+ and non-Hg2+ concentrations from Project-related atmospheric deposition. All deposited Hg2+ was assumed to be converted to MeHg, and deposited non-Hg2+ is assumed to undergo methylation at a rate of 1%, twice the median of Project baseline data, but reflecting the mean of paired soil samples collected in 2014.

Increases in sulfate concentrations in natural systems with low concentrations of sulfate (as within the study area) will increase concentrations of MeHg. The reviewed literature indicates that the factor increase in MeHg is 0.5 to 1.0 times the factor increase in sulfate, or in other words, the increase in %MeHg would be of a similar magnitude to the increase in sulfate concentrations in systems where sulfate is initially at low concentrations. The estimated sulfur dioxide (SO_2) emissions (including fugitive emissions) from the proposed Project are predicted to increase atmospheric sulfate concentrations by 0.04 $\mu g/m^3$ at the Core Operating Area boundary, which equates to a 3% increase in atmospheric SO_2. A highly conservative assumption would be that the SO_2 concentration throughout the study area increased by this same amount, and that all the SO_2 produced was deposited locally as aqueous sulfate, increasing local annual load by 3%. Applying this conservative assumption in calculating %MeHg of existing soil THg, and newly deposited non-Hg2+, increases the initial estimated methylation rate of 1% to a rate of 1.03%.

Compounding these factors would result in soil THg concentrations increasing by a factor of 1.01, and MeHg increasing by a factor of 1.05. Mercury concentrations and %MeHg values are similar between soil and sediment datasets, implying similar processes and rates for both

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systems. Thus, to estimate future concentrations in aquatic systems, the same factor increase computed for soil systems is used to derive THg and MeHg in sediments. Changes in sediment mercury content are then proportionally reflected in surface water THg and MeHg concentrations. Using this conservative analysis, future surface water THg concentrations are predicted to be below the EPA-approved Alaska state water quality criterion of 12 ng/L.

Bioaccumulation Factors

Because future concentrations of the constituents in subsistence food items cannot be measured, they were estimated by developing BAFs. Project-specific baseline data, other regional studies, and the general literature were reviewed to determine appropriate BAFs for the HHRA. Unlike arsenic or antimony, mercury can bioconcentrate in biota, and the bioconcentration factor is much higher for organic forms of mercury compared to inorganic forms. Therefore, differences in the bioavailability between inorganic and organic mercury forms were considered in deriving BAFs. BAFs were developed this way to account for potential changes in bioavailable mercury in the soil. MeHg is readily bioavailable and taken up by biota whereas the bioavailability of THg is more variable. Therefore, deriving MeHg to THg BAFs allows for some accountability of increasing future concentrations of MeHg in soil.

Compared to other literature or regional information, the Project-specific BAFs are high, suggesting BAFs may be overestimated. Reasons for the higher Project-specific BAFs are not known, but may in part be due to the nature of the sampling events during baseline collection, which sought to characterize the more mineralized areas of the study area. These more mineralized areas are not representative of the study area as a whole. However, the bias represents a conservative assumption.

Exposure Point Concentrations

An EPC is the concentration of a constituent in an exposure medium at the location where a receptor may contact that medium, and is representative of the time period over which exposure may occur.

For media baseline EPCs with empirical data, USEPA guidance and the associated software program proUCL v5.1 was used to calculate EPCs. Media that did not have empirical data included small mammals, waterfowl, and arsenic and antimony concentrations in berries; EPCs were estimated for these media using BAFs. Air concentrations were based on baseline analyses completed by Environ (2015). Summary statistics generated for baseline EPCs included both upper-bound and mean estimates. However, future EPCs are based on modeling estimates, which generate mean estimates. Therefore, mean baseline EPCs were used in computations of baseline risk.

Future air EPCs were estimated from modelling completed by Environ (2015) and Air Sciences (2017). Future soil EPCs were estimated following USEPA methods for calculating constituent concentrations in soil due to atmospheric dust deposition (USEPA 2005a), with subsequent increases in the proportions of THg and MeHg as described above. Constituent dustfall onto aquatic systems is assumed to be initially bound into stream sediments, then to become available for uptake into fish through the sediment. Therefore, dust deposition into sediments

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was also estimated using USEPA (2005a). As described above, changes in surface water mercury would then be proportional to future soil and sediment concentrations, as surface water concentrations would reflect inputs by sediment dissolution into surface water and/or soil runoff.

The potential solubility of arsenic and antimony into surface water from sediments or soil runoff was assumed to be negligible, particularly after factoring the contribution of treated water from the water treatment plant, which will be at concentrations less than 0.005 mg/L (below water quality criteria). Therefore, future concentrations of arsenic and antimony in surface water were assumed to be unchanged from baseline concentrations.

Exposure Factors

Exposure factors define the magnitude, frequency, and duration of exposure for the populations and pathways selected for quantitative evaluation. Exposure factors are combined with EPCs to calculate dose. For purposes of this HHRA, exposure factors were selected based on a "reasonable maximum exposure" scenario that combines upper-bound and average values that reflect exposures somewhere between the 90th and 98th percentile of the range of possible exposures that reasonably can be expected to occur for a given population (USEPA 1989).

Exposure equations from the *Risk Assessment Guidance for Superfund, Human Health Evaluation Manual, Part A* (USEPA 1989) were followed in the HHRA. Consumption (i.e., ingestion) rates of food items were based on Brown et al. (2012), a subsistence study that reported harvesting data for the Upper Kuskokwim River subsistence population. As stated previously, the HHRA evaluated a generalized subsistence population conceptualized to evaluate exposures in the HHRA. This generalized population was assumed to live in the village of Crooked Creek (thus exposed to air and soil concentrations year around) and to hunt, fish, and gather only within the study area for beaver, mallard ducks, berries, and northern pike. Consumption rates of subsistence foods were based on per capita harvest rates (kg/year) for the Upper Kuskokwim Group reported by Brown et al. (2012). Because no information is available to estimate the proportion of harvested food that was subsequently consumed, it is assumed, for the purposes of the HHRA, that all harvested food items are consumed. The use of harvest rates to estimate consumption rates is an overestimate; the study indicates that people do not consume all of each animal harvested (e.g., often just the fish fillet is consumed, not the entire fish), and further, people may not necessarily consume the total amount of subsistence food harvested (e.g., primary subsistence providers frequently share with others who may reside in the area or in other distant communities). However, by utilizing the harvested amount to estimate intake, this HHRA provides a "health-protective" estimate of potential exposures from this pathway: if no incremental risk is indicated by this approach, then groups ingesting only a portion of harvested foods are unlikely to be at risk.

For other intake rates and other exposure factors (e.g., body weights and averaging times), ADEC (2015) exposure factors for subsistence receptors, or, where not available, USEPA (2014) exposure factors for residential receptors were used to develop exposure rates.

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TOXICITY ASSESSMENT

Exposure to constituents can result in cancer and/or non-cancer effects, which are characterized separately. The toxicity hierarchy to select toxicity values for the HHRA reflects guidance from USEPA (2003) and ADEC (2015). This system prioritizes toxicity values as the following:

- Tier 1: USEPA's Integrated Risk Information System (IRIS).
- Tier 2: USEPA's Provisional Peer Reviewed Toxicity Values (PPRTVs).
- Tier 3: Other resources as needed, such as the Agency for Toxic Substances and Disease Registry's Minimal Risk Levels (MRLs), or USEPA's Health Effects Assessment Summary Tables (HEAST) values.

USEPA's IRIS system is the source for the toxicity values of all constituents evaluated in the HHRA.

RISK RESULTS

Non-cancer risks were estimated by calculating hazard quotients (HQs), which were then summed across all exposure pathways and constituents to estimate a hazard index (HI) for each receptor. Additionally, the potential for carcinogenic effects of arsenic was evaluated by estimating the probability of developing cancer over a lifetime. The interpretation of HQs or HIs is typically that exposures at or below the reference level (i.e., HQ=1) are unlikely to be associated with adverse health effects, while exposures above the reference level increase the potential for adverse effects.

Conservative assumptions were incorporated into this HHRA to prevent Type II errors, which are the elimination of a constituent, area, or activity from further consideration when, in fact, there should be a concern (i.e., false-negative conclusion). In the risk assessment process, uncertainties are handled conservatively (i.e., health-protective choices are preferentially made). This strategy is more likely to produce false-positive errors than false-negative errors. Particularly for this HHRA, a number of conservative estimates were made to assure that risk predictions erred on the side of Type I errors (i.e., false-positive conclusion) rather than Type II.

Non-cancer risk estimates were all at or less than 1 for both baseline and future risks. Even with the conservative assumptions of the HHRA, HQs and HIs indicate that non-cancer effects are highly unlikely. Baseline risk estimates are consistent with a mercury hair study completed by the Alaska Department of Health and Social Services (ADHSS). ADHSS conducted MeHg testing of hair samples from pregnant women in selected communities including the Upper Kuskokwim River region communities. Every study participant had a hair mercury level that was below the Agency for Toxic Substances and Disease Registry (ATSDR) No Observed Adverse Effect Level (15.3 ppm), as well as the Environmental Public Health Program cut-off for follow-up (5 ppm) (ADHSS 2013, as cited in the DEIS), also indicating exposure to mercury in the region is not at unacceptable levels.

In the case of cancer risk estimates for arsenic (the only carcinogenic COPC), both baseline and future risk estimates are $5x10^{-5}$, which is within the USEPA risk management range of $1x10^{-4}$ to

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$1x10^{-6}$. Future estimates of cancer risks changed from baseline results by less than $1x10^{-6}$, indicating essentially no unacceptable change in risk.

Arsenic is a naturally occurring metal often found at concentrations above "background", as referred to in regulatory cleanup levels in 18 AAC 75.341. Baseline concentrations of arsenic in the study area are naturally occurring and consistent with regional, state and nationally published studies of naturally occurring arsenic in soil (Gough et al. 1988). Due to the prevalence of naturally occurring arsenic in Alaskan soil, ADEC recommends that cumulative risk calculations do not include risk contributions from naturally occurring arsenic sources (ADEC 2009). Statistical comparisons of significance between baseline and future arsenic concentrations cannot be made because only a single future soil arsenic concentration was estimated. However, if baseline cancer risk estimates were subtracted from future cancer risk estimates, the resulting cancer risk for adults would be $5x10^{-7}$, well below acceptable risk thresholds.

Further, cancer slope factors were used to estimate an upper-bound probability of an individual developing cancer as a result of a lifetime of exposure to arsenic. Upper-bound estimates conservatively exaggerate the risk to ensure that the risk is not underestimated if the underlying model is incorrect. The arsenic ingestion slope factor is based on one affected population in Taiwan concerning non-fatal skin cancer incidence, age, and level of exposure to arsenic via drinking water rather than food (USEPA 2017). The predominant form of arsenic in the drinking water was in an inorganic form (arsenic trioxide), which is a highly toxic form of arsenic and not the predominant form of arsenic that occurs in the study area. The confidence in the oral slope factor is considered to be low overall. Studies that show the strongest link between ingestion of arsenic and cancer involve ingestion of inorganic arsenic at elevated levels in drinking water (Naujokas et al. 2013). Arsenic in soil is less bioavailable, and an adjustment is made to the soil exposure concentration accordingly. There are additional uncertainties estimating cancer risk from arsenic because the mechanism of action in causing human cancers is not known, and studies on arsenic mutagenicity are inconclusive (USEPA 2017). However, safety factors included in the slope factor provide a conservative estimate of risk.

The low confidence in the arsenic slope factor, and the safety factors applied to the slope factor overall, may lead to an overestimate of potential cancer risk due to arsenic in the current environment, in addition to exposure assumptions that overestimate the amount of arsenic ingested by receptors. Further, the incremental changes in cancer risk due to future estimated arsenic exposures are very small. Given that the overestimated potential current and future risks are within the risk management range and are related to naturally occurring levels of arsenic, an unacceptable increase in cancer risk due to site-related arsenic exposure is unlikely.

Risks Due to Fish Consumption

This HHRA evaluated risks due to northern pike fish consumption. Resident fish were incorporated into the HHRA because of their relatively greater exposure period compared to

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migratory fish. Northern pike, a large, relatively long-lived top predator that is found in the Crooked Creek watershed, was used to estimate fish EPCs and assess risk associated with subsistence fishing. Top predators, such as northern pike, also bioaccumulate mercury to a greater degree than lower-trophic level species. Tissue burdens for northern pike were estimated by applying trophic transfer factors to sculpin data collected for the Project. Estimates for northern pike indicate that both baseline and future HQs are at or less than 1, indicating that noncancer effects are unlikely from northern pike consumption. As noted in the previous section, the estimated incremental cancer risk increase is less than $1x10^{-6}$.

Estimates of future northern pike concentrations are also lower than State of Alaska (2016) fish consumption advisories for northern pike harvested from the Kuskokwim River in the vicinity of the Project. Therefore, subsistence populations currently consume northern pike at rates well below the northern pike consumption advisory level for the State of Alaska, and consumption would be expected to remain below the advisory level in the future.

As reflected in the DEIS comments, there is public concern regarding constituents in salmon species, which are a primary subsistence food in the region. Salmon species are present within the study area, including coho salmon. However, within the study area, only juvenile coho (and other species of) salmon reside within the Crooked Creek drainage system for extended periods. Adults, rather than juvenile species, are harvested for consumption. Juveniles migrate out of the freshwater system at an early age, spending the majority of their lifetimes in marine environments. These migratory fish gain the bulk of their body mass over a much larger exposure area (marine waters) that is entirely outside the study area. Because the exposure conditions of salmon are largely unrelated to the study area, the HHRA did not quantify risk due to salmon ingestion.

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SUMMARY CONCLUSION

This HHRA demonstrates that the small increases in constituent concentrations estimated to occur outside of the Core Operating Area due to Project-related activities will not result in unacceptable risks to human populations who would have the highest exposure. Based on the exposures to the conservatively defined receptors analyzed in this health-protective HHRA, other human populations, such as residents in the region, would not be expected to be exposed to unacceptable risk due to exposure to Project-related concentrations of mercury, arsenic, or antimony.

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ACRONYMS AND ABBREVIATIONS

µg .....Microgram
%.....Percent
ADD.....Average daily dose
ADEC .....Alaska Department of Environmental Conservation
ADHSS .....Alaska Department of Health and Social Services
ATSDR.....Agency for Toxic Substances and Disease Registry
As .....Arsenic
BAF .....Bioaccumulation Factor
BLM .....Bureau of Land Management
BW .....Body weight
cm.....Centimeter
COPC.....Constituent of potential concern
CR .....Cancer risk
CSM .....Conceptual site model
D-MCM .....Dynamic Mercury Cycling Model
DEIS.....Draft Environmental Impact Statement
DL .....Detection limit
DOC.....Dissolved organic carbon
DOM.....Dissolved organic matter
Donlin.....Donlin Gold, LLC
dw .....Dry weight
EC.....Exposure concentration
EFSA .....European Food Safety Authority
EPC .....Exposure point concentration
FCM .....Food chain multiplier
g.....Gram
Hg .....Mercury
Hg(0).....Elemental mercury
Hg(2+) .....Oxidized/divalent mercury
Hg(p) .....Particulate mercury
Hg-S.....Mercury-sulfur complexes
HHRA.....Human Health Risk Assessment
HI .....Hazard index
HQ .....Hazard quotient
IR.....Ingestion rate
IRIS .....Integrated Risk Information System
kg .....Kilogram
L .....Liter
LADD .....Lifetime average daily dose
m .....Meter
m^2.....Square meter

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m^3 ..... Cubic meter
MDN ..... Mercury Deposition Network
MeHg ..... Methylmercury
mg ..... Milligram
n ..... Sample size
ng ..... Nanogram
NOAEL ..... No-observed-adverse-effect-level
$PM_{2.5}$ ..... Particulate matter less than 2.5 microns
ppm ..... Parts per million
Project ..... the Donlin Gold Project
PSD ..... Prevention of Significant Deterioration
RBA ..... Relative bioavailability
redox ..... Oxidation-reduction
RfC ..... Reference concentration
RfD ..... Reference dose
RI ..... Remedial Investigation
Sb ..... Antimony
SERAFM ..... Spreadsheet-based Ecological Risk Assessment for the Fate of Mercury
SF ..... Slope factor
S2- ..... Free sulfide
SO_2 ..... Sulfur dioxide
SRB ..... Sulfate reducing bacteria
THg ..... Total mercury
URF ..... Unit risk factor
USACE ..... United States Army Corps of Engineers
USEPA ..... United States Environmental Protection Agency
USGS ..... United States Geological Survey
ww ..... Wet weight

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1. INTRODUCTION

This Human Health Risk Assessment (HHRA) evaluated the likelihood of adverse effects to subsistence populations that could be exposed to constituents released into the environment by the operation of the proposed Donlin Gold, LLC (Donlin) project in remote western Alaska (Project). The proposed Project would build mining and milling facilities at the mine site and other associated transportation and fuel facilities.

The purpose of this HHRA was to address a concern expressed in comments on the *Donlin Gold Project: Draft Environmental Impact Statement* (DEIS; United States Army Corps of Engineers [USACE] 2015), which is to evaluate potential addition of metal constituents from the proposed Project to the environment in areas where subsistence populations live and harvest wild foods near the proposed Core Operating Area of the Project (Figure 1.1-1). A health-protective approach was taken to address this concern, in that conservative exposure assumptions were used to calculate potential incremental risk to subsistence populations that may be hunting, gathering, or living in the area around the Core Operating Area. A deterministic-based computation of non-cancer and cancer risks was completed following Alaska Department of Environmental Conservation (ADEC) and United States Environmental Protection Agency (USEPA) guidelines for HHRAs.

Risk assessments are not intended to predict the actual risk for an individual person. Rather, they provide conservative estimates of risk with an adequate margin of safety, according to USEPA guidelines for the protection of the majority of people that may potentially come into contact with constituents. General USEPA guidelines include 1989, 2000, and 2009a; other specific guidance incorporated is referenced within the HHRA.

Incremental risk from the proposed Project was raised as a concern in the DEIS comments. Both background (i.e., baseline) sources and Project-related air emissions would contribute to future environmental exposure. Therefore, the HHRA includes both a baseline estimate of potential risk and an incremental risk estimate from future Project-related sources.

This HHRA follows the format outlined in the ADEC Risk Assessment Procedures Manual (ADEC 2015), which describes five components of an HHRA: data evaluation, exposure assessment, toxicity assessment, risk characterization, and uncertainty assessment.

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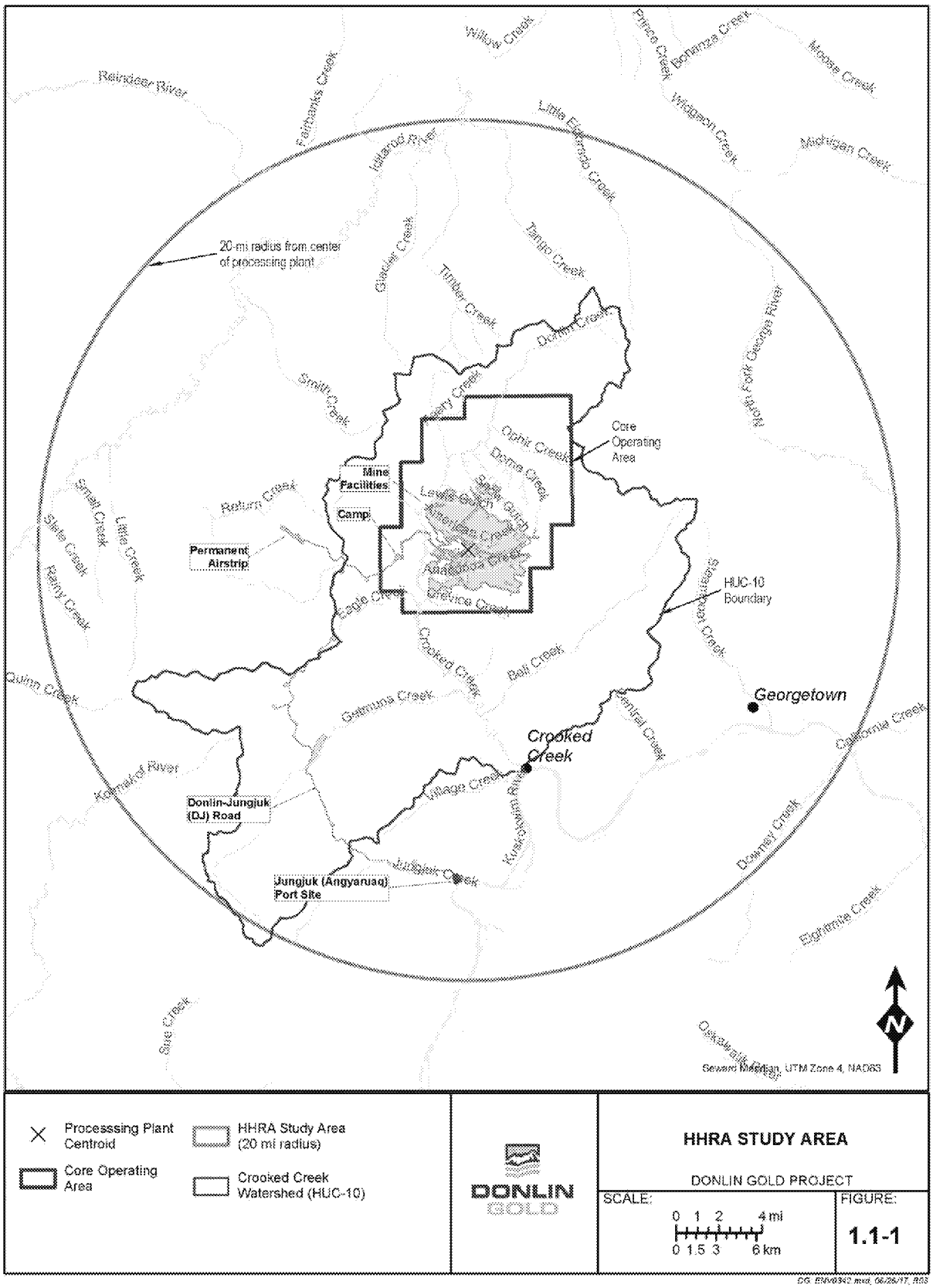
Reindeer River
Fairbanks Creek
Willow Creek
Prince Creek
Bonanza Creek
Moose Creek
Little Eldorado Creek
Widgeon Creek
Michigan Creek
Idaho River
Glacier Creek
Tanlo Creek
Timber Creek
20-mi radius from center of processing plant
Dome Creek
North Fork George River
Smith Creek
Ophir Creek
Core Operating Area
Mine Facilities
Camp
Dome Creek
Lewis Gulch
Slate Creek
Small Creek
Little Creek
Return Creek
Permanent Airstrip
Rainy Creek
Eagle Creek
Crooked Creek
HUC-10 Boundary
Bell Creek
Quinn Creek
Gemuns Creek
Georgetown
Crooked Creek
California Creek
Kemrokovik River
Donlin-Jungjuk (DJ) Road
Village Creek
Kuskokwim River
Jungjuk Creek
Jungjuk (Angyaruaq) Port Site
Downey Creek
Eighmile Creek
Sue Creek
Oskawalik River
Seward Meridian, UTM Zone 4, NAD83
Processsing Plant Centroid
Core Operating Area
HHRA Study Area (20 mi radius)
Crooked Creek Watershed (HUC-10)
DONLIN GOLD
HHRA STUDY AREA
DONLIN GOLD PROJECT
SCALE:
0 1 2 4 mi
0 1.5 3 6 km
FIGURE:
1.1-1
DG_ENV0342.mxd, 06/26/17, BSS

2. SELECTION OF CONSTITUENTS OF POTENTIAL CONCERN

Potential exposure to mercury (associated with mining activities) is a health concern expressed by stakeholders. Natural and anthropogenic sources of mercury currently exist in the environment in and around the proposed Core Operating Area. Proposed mining and processing activities could increase mercury levels in upland and aquatic habitats surrounding the Core Operating Area through point source (e.g., stack) and fugitive dust emissions. These concerns were raised in comments on the DEIS. A focused "Mercury Workshop" was held in December 2016 to address concerns and comments on Project-related mercury impacts. As a result of the December 2016 Mercury Workshop, Donlin Gold proposed to complete a focused, health-protective HHRA to address comments regarding this constituent.

The geochemistry of baseline soils and potential dust sources was evaluated in the DEIS (see Section 3.2.3.2.4 of USACE 2015). The analysis estimated potential dust deposition from the mine site on future soil levels. This analysis suggested that other metals of potential concern for soil quality include antimony and arsenic (Section 3.2.3.2.4 of USACE 2015). Therefore, antimony and arsenic were identified as constituents of potential concern (COPCs) and were evaluated in this HHRA.

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3. CONCEPTUAL SITE MODEL

As part of the HHRA, a conceptual site model (CSM) was developed to describe the relationship between the sources of COPCs and potential exposure to human populations. The CSM is a representation of the relationship between COPC sources and exposed populations. It characterizes the distribution of COPCs across the study area and identifies all potential exposure pathways and migration routes. Figure 3.1-1 illustrates the sources, pathways, exposure routes, and exposed populations that the HHRA evaluated quantitatively. Each of these components is discussed in detail below. In addition, a description of the spatial and temporal boundaries of the HHRA is included, as these aspects also define the scope of the HHRA.

Complete and incomplete pathways of exposure were also identified in the CSM. Complete and potentially significant exposure pathways were identified and were evaluated quantitatively in the HHRA, while incomplete and/or non-significant pathways were eliminated from further consideration.

3.1. Temporal Boundary

The temporal boundary selected for the HHRA was determined by the periods during which planned Project activities would occur and have potential to affect the health of human receptors. The HHRA calculated risks for the last year of the mine life (year 27), when the increase in COPC concentrations in the environment from the proposed Project would be expected to be highest. The planned 27-year-based exposure represents the temporal boundary for maximum estimated releases from the proposed Project.

The potential exists that receptors may continue to be exposed to constituents after Project-related releases cease. This is due to the timeframe in which COPCs might move through the food web after the end of mine life and the longevity of fish and other species that people may consume. However, post-closure exposure is expected to be lower than during the operational mine life when proposed Project-related emissions will be highest, thus maximum potential exposure to proposed Project-related sources of COPCs were captured in the HHRA.

3.2. Spatial Boundary

The spatial boundary selected for the HHRA was determined by the proposed Project's potential impact on the health of human receptors. The HHRA considers exposures within a 20-mile radius outside the Core Operating Area, which represents the spatial extent of the mercury air deposition model (Environ 2015). This spatial area encompasses the watersheds in the vicinity of the proposed Project where the majority of deposition is estimated to occur from the proposed Project.

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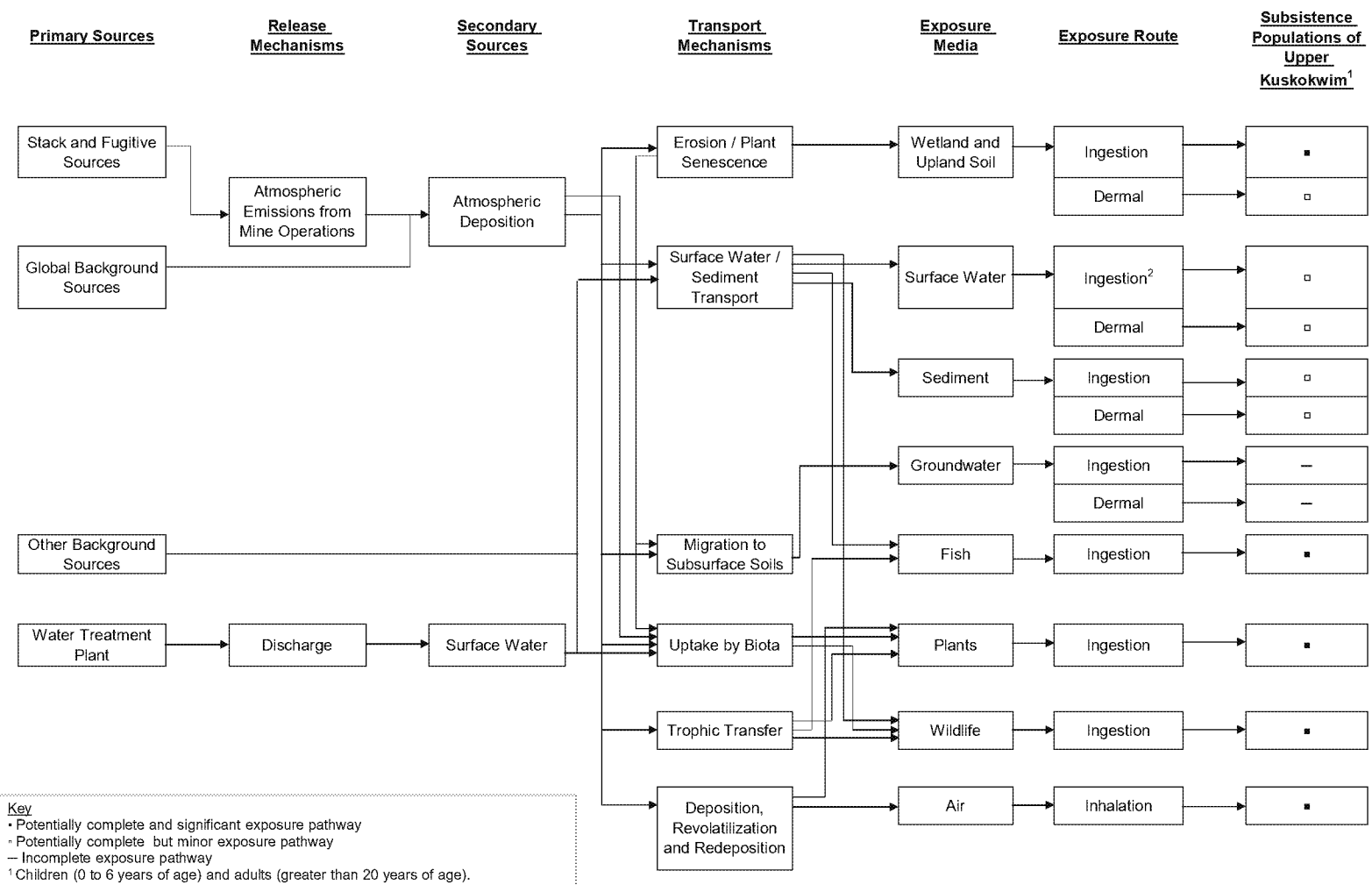

ERM

Human Health Conceptual Site Model

Donlin Gold Project

FIGURE **3.1-1**

This spatial boundary, referred to henceforth as the "study area," represents the highest exposure area for subsistence populations that could harvest wild foods in this area. It is within this boundary that risks associated with the individual exposure activities (e.g., hunting and gathering) were quantified in the HHRA. Even though subsistence gathering and hunting activities also occur outside this boundary (Brown et al. 2012), exposure to food items was conservatively assumed to occur entirely within this spatial boundary to estimate the maximum incremental exposure due to emissions from the proposed Project.

3.3. Primary Sources and Transport Pathways

The primary sources of COPCs include fugitive and point source emissions generated by the proposed Project, and for mercury, existing deposition from global background sources. Other sources of COPCs that may be generated by the proposed Project are not expected to be transported or deposited outside the Core Operating Area. Surface water that comes in contact with mining infrastructure ("contact water") will be treated prior to discharge to levels at or below USEPA and ADEC surface water criteria. Groundwater that could be impacted by the proposed Project is not a source of drinking water in the surrounding environment. As described in Section 3.7.3.2.3 of the DEIS (USACE 2015), groundwater impacts are anticipated to be limited to the American Creek drainage in the footprint of the Waste Rock Facility and extending to the pit, in the immediate vicinity of the pit, and groundwater in the Anaconda Creek drainage below the tailings storage facility that is captured in the seepage recovery system. As future development of groundwater wells is not reasonably anticipated in this area, consumption of groundwater is not a complete human health exposure pathway. Therefore, groundwater was not included as a source for the HHRA.

Atmospheric emissions from the proposed Project have the potential to enter the atmosphere, travel some distance, and be inhaled by receptors or settle as dustfall where they can reside in different media such as soil, vegetation, and subsistence foods. Modeled mercury deposition from the processing plant point and fugitive sources was estimated for watersheds surrounding the Project (Environ 2015). The model showed that mercury would be emitted predominantly as gaseous, elemental mercury [Hg(0)], and the mercury that is deposited would consist of Hg(0), oxidized mercury [Hg(2+)], and particulate mercury [Hg(p)], with the majority in the particulate form. Oxidized mercury (Hg(2+) is more likely to be methylated upon deposition and is a minor component (approximately 1 to 2 percent) of the total deposited.

Antimony and arsenic will also be emitted into the atmosphere from proposed Project point and fugitive sources. Transport and deposition mechanisms of these constituents are expected to be comparable to elemental mercury transport, as summarized in Table 3-9 from Environ (2015).

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The particulate-bound mercury emissions estimate used by Environ (2015) was derived from the fugitive dust inventory. Arsenic and antimony emissions were also calculated in the fugitive dust emissions inventory, as presented in Air Sciences (2016), and scaling factors were derived from the relative mass emissions to estimate arsenic and antimony deposition. The mass loading values for arsenic and antimony compared to mercury produce scaling factors of 10.1 for antimony and 320 for arsenic. Background concentrations of arsenic and antimony bound to particulate matter less than 2.5 microns ($PM_{2.5}$) are assumed to be negligible.

3.4. Exposure Pathways

Human exposure pathways are the routes by which people are exposed to COPCs. COPCs must be absorbed into the body of humans, animals, or plants to cause a toxic response. Absorption can occur through oral ingestion, dermal absorption, or inhalation. The exposure pathways that may exist between COPCs and human receptors depend on many factors which may be direct, indirect, or both.

An exposure pathway must include a source (e.g., proposed Project-related atmospheric emissions), a mechanism of release and transport pathway to an affected medium (e.g., atmospheric deposition onto soil), a receptor (e.g., subsistence harvester), and an exposure route (e.g., incidental soil ingestion during harvesting). An exposure pathway is deemed complete when all components are present. If one or more components are missing, then the pathway is incomplete. Complete pathways may be deemed insignificant as the level of exposure may be too low to be quantifiable or a health concern.

Exposure pathways selected for quantitative evaluation in the HHRA include:

- Inhalation of COPCs present in air;
- Incidental ingestion of COPCs bound to soil; and
- Ingestion of COPCs associated with biota (fish, plants, and wildlife) that may be harvested in the study area.

Dermal absorption of COPCs was considered a potentially complete but negligible pathway and was not quantified in the HHRA. Absorption of antimony, arsenic, and some forms of mercury (e.g., Hg[0]) following dermal exposure is negligible in humans and animals. Robust exposure data to quantify dermal absorption of these COPCs are lacking. The predominant form of COPCs present on the surfaces of biota or associated with primary media (soil, sediment) would be inorganic forms (e.g., Hg(0)). Further, the predominant exposure pathway of organic forms (e.g., MeHg) is through oral ingestion in the diet (USEPA 2009a).

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3.5. Exposure Media

Exposure media include air, soil, and biota that could be collected and ingested by subsistence populations. Because not all individual species or wildlife trophic components of an ecological system are practical or potentially necessary to quantify incremental risk, representative species were chosen. From a technical risk perspective, the criteria used to select representative subsistence food exposures included consideration of:

- Potential presence and abundance in the study area (i.e., plant species abundant in the study area, and fish/wildlife that have limited migration patterns and small home ranges were preferred over species that are migratory or that move in and out of the study area);
- Physiological characteristics of wildlife species that would result in relatively higher rates of exposure or bioaccumulation of COPCs (e.g., dietary sources that would occur within the study area, and/or higher trophic levels that would accumulate mercury to a higher degree than other species); and
- Subsistence consumption patterns (species that are harvested/consumed more frequently were preferred over species with low consumption rates).

Based on review of the subsistence food items harvested by the Upper Kuskokwim group (see Section 3.21 in the DEIS), and accounting for physiological considerations and residency in the study area, the HHRA quantified the incremental risk of subsistence population consumption of northern pike (representing residential fish species consumption), beaver (representing small mammal consumption), mallard ducks (representing wild bird consumption), and blueberries and cranberries (representing wild berry consumption).

3.6. Exposure Populations

The HHRA focused on receptor populations that would have the highest potential to be exposed. The receptor population with the highest potential to be exposed in the study area included subsistence receptors. Subsistence receptors are individuals who consume locally caught and harvested food items (e.g., locally caught fish) as major sources of food. Thus, their intake rates of these food items are typically higher than the general population (USEPA 2011). These populations are also exposed via direct contact with abiotic media (e.g., incidental ingestion of soil and inhalation of particulate material).

Subsistence groups live in and around the study area, and harvest, hunt, and fish throughout the region. Subsistence harvest patterns described in the DEIS focus on community profiles from nine subregions. Four of those subregions harvest food near and within the study area: Upper, Central, Lower-Middle, and Lower Kuskokwim groups. Only the Crooked Creek village and Georgetown subsistence populations live in the study area. The Crooked Creek village is located south-southeast of the proposed Project, and Georgetown is to the east-southeast of the proposed Project. The

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predominant wind direction in the study area, when blowing to the south, is to the south-southeast.

The subregions share a common ecology and some common harvest patterns. Harvesting, hunting, and fishing ranges of subregion groups are large and only include a portion of the study area. Exact harvests from one area compared to the next were not reported, and areas of harvest also vary seasonally and annually. For the purposes of the HHRA, a generalized subsistence group was developed to quantify risks. This generalized subsistence group was assumed to live in the study area (therefore evaluating year-round inhalation and soil ingestion risks), and to hunt, fish, and gather only within the study area for beaver, mallard ducks, berries, and northern pike. Inhalation risk was specifically quantified for air concentrations predicted for the Crooked Creek watershed, which includes the Crooked Creek village area. Quantities of wild foods harvested and consumed were based on data presented for the Upper Kuskokwim subregion group, as this group lives nearest and most frequently harvests nearest to the proposed Project. Because these groups also hunt, fish, and gather outside the study area to varying extents, these assumptions overestimate the exposure frequency and duration in the study area. This is a conservative analytical (i.e., health protective) approach that ensures that potential effects on human health due to exposures via inhalation, as well as consumption of wild food collected within the study area, are not underestimated.

The HHRA evaluated children and adults in the subsistence population: children between 0 and 6 years old, and adults greater than 20 years of age. Children are often most susceptible to constituents due to their small body size relative to their ingestion rates compared to other human life stages.

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4. DATA EVALUATION

4.1. Data Sources and Usability

Selection of data for this HHRA followed as closely as possible the ADEC guidelines for data usability. Both Project-specific studies, collected for the purposes of baseline environmental characterization, and other regional datasets, were used to develop baseline exposure point concentrations (EPCs) for various media, as well as used to develop bioaccumulation factors (BAFs) and predict future methylation rates.

Sources of data used in this HHRA are summarized in Appendix A. Only data that gave accurate chemical-specific concentrations were used. The datasets collected for the proposed Project included method detection limits and sample quantitation limits below ADEC and/or USEPA criteria for their respective media, as applicable and included explanations for qualified data. For data reported by other sources, method and quantitation limits were not always reported. However, only sources of information that were peer reviewed and/or that followed USEPA guidelines for HHRAs, which include a data adequacy evaluation, were used in this HHRA.

In addition to Project-specific sources of information, data collected regionally, near to the study area, were considered. Regional datasets included:

1) Bureau of Land Management (BLM) study on mercury, arsenic, and antimony in aquatic biota from the Middle Kuskokwim River Region, Alaska (Matz 2012).
2) United States Geological Survey (USGS) studies of metals in sediment, stream water, and fish collected within and surrounding the Middle Kuskokwim River in southwestern Alaska (Wang 1999; Bailey and Gray 1997; Bailey et al. 2002; and Gray et al. 1996, 1997, 2000).
3) BLM's Final Remedial Investigation Report (RI Report), authored by Ecology and Environment, Inc. (E&E 2014). This was specifically prepared for the Red Devil Mine site.

Of the regional reports available, only the RI Report disclosed raw dataset(s), though reporting limits and method detection limits were not reported. The RI Report was subsequently used for comparisons of BAFs. Donlin requested that the BLM provide mercury, arsenic, and antimony analytical data and sample collection details (raw data) for sample locations referenced in a report prepared for the BLM by the US Fish and Wildlife Service titled "*Mercury, Arsenic, and Antimony in Aquatic Biota from the Middle Kuskokwim River Region, Alaska, 2010-2011, Interim Report*" (Matz 2012). The BLM responded that they anticipate the raw data collected for the study will be available to the public in the future but only after the BLM has decided on a final remedial action for the Red Devil Mine. The BLM consequently did not anticipate the data being available until sometime after 2017, and the data were not available for use in the HHRA.

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The Alaska Department of Health and Social Services (ADHSS) conducted MeHg testing of hair samples from pregnant women in selected communities, including the Upper Kuskokwim River region communities, between May and September 2012. A total of 186 hair samples were obtained from eight Upper Kuskokwim River communities. As reported in the DEIS (Section 3.22.2), the median hair mercury level for the study population was 0.510 parts per million (ppm), with a range of 0.030-3.707 ppm. Every study participant had a hair mercury level that was below the ATSDR No-observed-adverse-effect-level (NOAEL) (15.3 ppm), as well as the Environmental Public Health Program cut-off for follow-up (5 ppm) (ADHSS 2013, as cited in the DEIS). Overall, increasing median hair mercury levels were weakly associated with increasing age (r^2=0.28, $p<0.05$). Mercury hair levels did not differ significantly between communities.

Hair sampling as a method of biomonitoring offers a less invasive method to monitor for possible exposure to mercury and other bioaccumulative substances. However, as noted by ATSDR (2003), sampling and analysis of hair samples has many limitations, notably, standard procedures have not been published for collecting, washing, and analyzing hair samples. There is no developed method to relate dose (as is quantified in HHRAs) to concentrations in hair, in part because hair analytical results cannot pinpoint the sources of constituents (e.g., ingested versus dust that falls onto hair) that were detected. Other assumptions in the HHRA, such as exposure frequency and duration (selected to generally overestimate potential exposure), may not match actual frequency and duration of the populations measured for mercury in hair. For these reasons, hair data collected by Newfields (2015) was not used to quantify baseline risks in the HHRA. However, overall outcomes of the hair sampling study are compared to risk results (Section 7) to provide additional context in evaluation of baseline exposure and risk.

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5. EXPOSURE ASSESSMENT

Exposure assessment is the process of determining magnitude, frequency, duration, and route of exposure to COPCs. The results of the exposure assessment include estimates of chemical intake that, combined with chemical-specific toxicity information, characterize potential risks. The calculation of chemical intake, or dose, requires estimation of EPCs, and estimation of intake rates. Because future (and some baseline) EPCs need to be estimated, future potential for mercury methylation was evaluated (Section 5.1), and BAFs were developed (Section 5.2), to understand potential future mercury, antimony, and arsenic bioavailability and uptake into biota.

5.1. Current and Future Methylation

Mercury is a naturally occurring, reactive metal that exists in various chemical forms under different environmental conditions. Mercury is capable of existing in three oxidation states: 0, +1, and +2. In the atmosphere, mercury exists predominantly in the elemental (Hg[0]) form, while most mercury in water, soil, sediments and biota is in the form of inorganic and organic mercury complexes. Inorganic mercury is regionally enriched as evidenced by cinnabar ore deposits of sufficient grade to support development of the nearby Red Devil Mine.

Anthropogenic emissions, particularly atmospheric emissions, have the potential to increase mercury loadings to the environment. Following atmospheric deposition, various complex and interrelated environmental factors in terrestrial and aquatic ecosystems determine mercury fate and transport, including the potential for mercury methylation. MeHg is of particular concern because: (1) it is the most toxic form of mercury and (2) it bioaccumulates in food chains to a greater extent than inorganic forms of mercury. Formation of MeHg is mediated by certain naturally occurring bacteria, and rates of methylation are dependent on a variety of factors affecting the metabolism of these organisms. Current concentrations of total mercury (THg) and MeHg were measured in the study area (ARCADIS 2014). The ratio of THg to MeHg, referred to as the baseline methylation rate, was computed. Future methylation potential must be estimated to understand future THg and MeHg concentrations and bioaccumulation potential into biota. This section discusses the following key topics:

- Review of factors affecting methylation rates;
- Review of baseline methylation potential;
- Literature review/discussion of approaches to estimate future methylation, including consideration of mercury speciation models suggested by USEPA (Spreadsheet-based Ecological Risk Assessment for the Fate of Mercury [SERAFM] and Dynamic Mercury Cycling Model [D-MCM]);

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- Analysis of sulfate loading, different sources and geochemical forms of mercury, and other environmental factors as they may affect future methylation rates;
- Basis and rationale for the approach to predict future mercury methylation potential; and
- Estimates of future THg and MeHg concentrations in soil and surface water based on the analyses described.

5.1.1. Environmental Factors Affecting Methylation Rates

The rate of conversion of THg to MeHg is the methylation rate. Commonly, this rate is represented by the ratio of MeHg to THg (or %MeHg). The methylation rate (%MeHg) is dependent on complex environmental factors (USEPA 1997b, Environment and Climate Change Canada 2016, Frohne et al. 2012, Houben et al. 2016, Scudder et al. 2009, Ullrich et al. 2001). Numerous studies have attempted to quantify driving factors, sometimes with conflicting results and rarely with quantifiable relationships. Subsequent sections draw from comprehensive reviews of mercury science in the cited literature.

In the aquatic and terrestrial environments, sulfate reduction by sulfate reducing bacteria (SRB) is the primary mechanism for generating MeHg from divalent mercury (Hg[2+]). Consequently, inhibiting or promoting the activity of the SRB will have a strong effect on methylation rates. Metabolism by SRB is the primary mechanism for the conversion of mercury into MeHg; therefore, the primary controls on methylation are the presence/absence of an appropriate mercury pool and the presence/absence of an oxygenated environment. Once these two conditions are met, the secondary controls are the availability of nutrients and metabolic materials, including sulfate and organic carbon. Additional controls are related to factors controlling the rate of microbial metabolism, such as temperature and pH. Finally, the rates of demethylation reactions (e.g., photodemethylation) can be locally important, but are likely to be tertiary order controls.

5.1.1.1. Primary Mechanism: Mercury Content

The availability of Hg(2+) is a critical limiting factor for the production of MeHg; however, direct measurement and reporting of Hg(2+) concentrations are rare. Concentrations of MeHg and THg are typically positively correlated, but the relationship is not universal, as shown by Watras et al. (1995) and Gray et al. (2002). Little research has focused on measuring methylation rate changes at very low or very high concentrations of THg, thus testing where the concentration of mercury would be a limiting factor in methylation. Consequently it is not known if there is a lower or upper bound on mercury concentration that inhibits methylation.

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5.1.1.2. Primary Mechanism: Oxygen Content (Redox Controls)

Sulfate- and iron-reducing microbes are most efficient in anoxic environments, but can respire in sub-oxic environments (Environment and Climate Change Canada 2016, Baumgartner et al. 2006). Aquatic environments with oxidation-reduction (redox) values of -0.05 to -0.22 Eh (V) are typically required for biotic methylation suggesting that saturated wetlands, lake sediments, and hypolimnetic lakes are prime locations for methylation (Environment and Climate Change Canada 2016, Eckley and Hintelmann 2006). Obrist (2012) found that in a forested system, THg decreased with soil depth (to 20 centimeters [cm]), but MeHg stayed approximately the same, resulting in a weak positive correlation (r2 of <0.3, slope of 0.0006) in MeHg to THg content with soil depth (Table 5.1-1), possibly reflecting declining oxygen content. In aquatic environments, methylation is less prevalent in environments with higher flow and low hydraulic retention (St. Louis et al. 1994). In general, in-river methylation is typically a negligible component of the MeHg budget for creeks (St. Louis et al. 1994, Berndt and Bavin 2012).

Upland soils tend to be more oxygenated than lowland/wetland soils and consequently, upland soils have a lower MeHg generation potential. In general, wetlands are considered to be net sources of MeHg, and uplands are sinks for MeHg. St. Louis et al. (1996) concludes that boreal forest catchments can be sinks for THg regardless of the proportion of wetlands in the catchment. Contradicting St. Louis et al. (1996), Brigham et al. (2009) studied streams in Oregon, Wisconsin, and Florida, and identified that there was a strong positive correlation between the proportion of wetlands in a basin and the filtered THg and MeHg concentrations in surface water. The contrasting studies illustrate the complex and site-specific nature of mercury fate and transport and the lack of consistent, predictable mechanisms to predict mercury flux.

TABLE 5.1-1: OBRIST (2012) SUMMARY: THG, MEHG, AND MEHG/THG RATIOS IN SOIL

Mercury Species	Litter Oi	Litter Oe	Litter Oa	Soil 1-20 cm	Soil >20 cm
THg (µg/kg)	34	81	190	43	33
MeHg (µg/kg)	0.12	0.25	0.23	0.07	0.04
MeHg/THg (%)	0.29	0.33	0.12	0.16	0.11

Source: Obrist (2012).

5.1.1.3. Secondary Mechanism: Sulfate

Sulfate concentrations and methylation rates can be both positively and negatively correlated. Low concentrations of sulfate can limit reduction reactions by SRB, while high concentrations of sulfate can slow down or inhibit the reactions due to the production of sulfide metabolic waste products, mercury-sulfur (Hg-S) complexes, which compete for available Hg(2+) (Environment and Climate Change Canada 2016).

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While a lower limit of sulfate concentration has not been explicitly identified in research, it has been noted that the optimal sulfate concentration for Hg(2+) methylation to occur ranges from 1 to 29 milligrams per liter (mg/L) (Environment and Climate Change Canada 2016, Drott et al. 2008, Benoit et al. 1999, Benoit et al. 2001). Up to about 50 mg/L sulfate can stimulate SRB (Houben et al. 2016), indicating that until that concentration is reached; sulfate is a rate-limiting factor. One study noted that the concentration of MeHg increased in proportion to the concentration of free sulfide (S2-) ions, reaching a maximum at 1.8 milligrams S2- per gram of sediment. Above this maximum, the concentration of MeHg decreased, perhaps due to formation of dimethylmercury (Craig and Moreton 1986). An additional complication is that circum-neutral pH Hg-S complexes are highly bioavailable to mercury-methylating microbes.

Generally, sulfate concentrations below 50 mg/L will limit the metabolic rate of SRB. At higher sulfate concentrations, the formation of sulfide phases may also limit the metabolic rate of SRB. Increases to sulfate concentration in natural systems with low concentrations of sulfate will result in increases in the concentration of MeHg. The reviewed research indicates that the factor increase in MeHg is 0.5 to 1.0 times the factor increase in sulfate, as described in the subsequent paragraphs.

Studies involving enhancing sulfate concentrations in a wetland/peatland (Jeremiason et al. 2006 and references contained therein) demonstrated that the MeHg response to enhanced sulfate concentrations was approximately proportional; i.e., a 10-fold increase in porewater sulfate concentration was accompanied by a 5- to 7-fold increase in porewater MeHg concentrations. In these studies, the background sulfate concentrations were initially low (at or below 0.05 mg/L) until the initial spike. Subsequent spikes in the summer did not increase the sulfate or MeHg concentrations in porewater due to warmer temperatures enhancing sulfate reduction rates.

Building on previous work performed at the Marcell Experimental Forest in northern Minnesota, a study by Coleman Wasik et al. (2012) investigated the effect that enhanced sulfate concentrations had on MeHg concentrations in peat/wetland porewater. Artificially increasing the sulfate concentration from approximately 2 to 2.9 mg/L in 2006 and from less than 0.25 to 3.8 mg/L in 2008 resulted in an increase of MeHg concentrations from approximately 2 nanograms per liter (ng/L) to 4.3 ng/L in 2006 and to 3.6 ng/L in 2008. The proportion of THg attributed to MeHg also increased after sulfate addition. One of the study's conclusions was that increasing the sulfate concentration in porewater by four times led to an MeHg increase of a similar magnitude in both the peat porewater and the peat solid.

Data presented in Mitchell et al. (2007) indicate that this consistent positive relationship between sulfate concentration and MeHg concentration is not observed at higher sulfate concentrations. In their study, high %MeHg results occurred at sulfate concentrations below 5 mg/L, while above 7 mg/L, the %MeHg decreased to near zero

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at 47 mg/L sulfate, supporting the assertion that high concentrations of sulfate can slow down or inhibit the reactions due to the production of sulfide metabolic waste products, Hg-S complexes, which compete for available Hg(2+) (Environment and Climate Change Canada 2016).

Overall, the literature review indicates that increases in sulfate concentrations are commonly accompanied by increases in MeHg concentrations. Although variable, literature suggests that in systems where sulfate is initially at low concentrations, methylation rates may increase up to a similar magnitude as the increase in sulfate concentrations.

5.1.1.4. Secondary Mechanism: Organic Carbon Availability

Organic carbon concentrations and methylation rates have displayed both positive and negative correlations. Organic carbon is a nutrient for SRB microbes; therefore, higher concentrations are often accompanied by increased methylation rates. However, dissolved organic matter (DOM) forms complexes with Hg(2+). Smaller organic ligands can easily pass through microbe cell walls and are used as electron donors enhancing reaction rates, while higher molecular weight DOM cannot pass through the cell wall inhibiting the reaction rate (Environment and Climate Change Canada 2016, Golding et al. 2002, Barkey et al. 1997). At moderate to high DOM concentrations (9-30 mg/L; Miskimmin et al. 1992), the influence of other parameters such as pH may be more important, making correlations difficult to determine.

Generally, at lower concentrations of DOM, an increase in DOM is accompanied by an increase in the rate of methylation. However, high concentrations of DOM can decrease methylation rates (Ullrich et al. 2001).

5.1.1.5. Other Secondary Mechanisms: pH, Temperature

Temperature affects microbial and abiotic reactions. The metabolism of most microbes is positively correlated up to about 35 degrees Celsius (Winfrey and Rudd 1990). Consequently, the methylation rates in aquatic ecosystems are positively correlated with the temperature of the aquatic environment, with the highest methylation rates occurring in mid- to late summer (Ullrich et al. 2001, Environment and Climate Change Canada 2016, Bodaly et al. 1993). Methylation can occur year-round if the sediment does not freeze, resulting in a winter contribution to many frozen lakes. However, streams in the study area freeze, beginning in about early-October.

Results from studies carried out in surface waters indicate that there is a negative relationship between pH and methylation rate; as pH decreases, the proportion of THg that is MeHg increases. Most natural ecosystems do not have pH values low enough to severely inhibit SRB metabolism. A commonly postulated reason for increased methylation rates at lower pH is decreased binding of Hg(2+) by dissolved organic carbon (DOC) resulting in greater concentrations of Hg(2+) being available for

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methylation reactions (Environment and Climate Change Canada 2016, Kelly et al. 2003). However, Ullrich et al. (2001) noted that the relationship is complicated as pH can affect multiple biogeochemical systems.

Multiple studies have attempted to quantify the relationship between pH and mercury. While some studies found that pH was the dominant factor affecting the methylation rate (Miskimmin et al. 1992), others found only a weak correlation (Frohne et al. 2012).

As pH drops from 7 to 5, the methylation rate typically increases (Miskimmin et al. 1992, Ullrich et al. 2001). It is not clear if this increase is a function of increasing methylation rates or decreasing demethylation rates, or some combination of the two. pH values below 5 were commonly associated with decreasing %MeHg (Mitchell et al. 2007). As baseline pH values reflected in proposed Project baseline data for terrestrial ecosystems are below pH 5, the methylation rate may be limited slightly.

5.1.1.6. Tertiary Mechanism: Photodemethylation Reactions

Photodemethylation is an abiotic process prevalent in the surface waters of lakes. Demethylation can also occur when mercury-resistant microbes reduce the MeHg to Hg(0). Oxidative demethylation can also occur and is thought to be mediated by anaerobic microbes. The largest of these three methods is photodemethylation (Environment and Climate Change Canada 2016, Amyot et al. 2001, Garcia et al. 2005).

Visible and ultra-violet wavelengths can produce both Hg(0) and Hg(2+) from MeHg. Hg(0) can easily escape the aquatic environment to become atmospheric Hg(0) while Hg(2+) has a longer residence time and has the potential to be re-methylated (Environment and Climate Change Canada 2016). However, in most instances the rate of demethylation is lower than the rate of methylation in lakes.

5.1.2. *Baseline Methylation Rates – Soils*

While there is a high degree of variability in the methylation rates reported for different wetlands studied, the average values in wetland porewater for THg, MeHg, and %MeHg are similar between geographically diverse studies in northern North America. In Canadian Arctic wetlands, soils typically have low THg concentrations, ranging between 10 and 250 micrograms per kilogram (µg/kg). MeHg concentrations are also low, ranging between 0.34 and 3.07 µg/kg, with %MeHg less than 1% (AANDC 2012). Other studies have identified porewater MeHg concentrations between <0.6 and 0.63 ng/L and %MeHg between <7 and 13.3% as baseline conditions for peatlands and wetlands (Coleman Wasik et al. 2012, St. Louis et al. 1994). In a more intensive sampling program to identify peatland hotspots of high %MeHg in the interior, Mitchell et al. (2007) sampled four wetlands and reported the following median porewater ranges: THg 5.5 - 13.3 ng/L, MeHg 0.35 - 0.62 ng/L, and %MeHg 2.7 - 15.9%.

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Summary statistics for upland and wetland (or lowland) soil samples collected in the HHRA study area are presented in Tables 5.1-2 and 5.1-3. In general, the wetland sites had somewhat higher MeHg and %MeHg than the upland samples. However, median values for upland and wetland datasets were similar and varied by less than one standard deviation. A similar observation was made by ARCADIS (2014) in evaluating paired upland and wetland samples collected in the study area.

TABLE 5.1-2. SUMMARY STATISTICS FOR UPLAND SOILS COLLECTED IN THE HHRA STUDY AREA

	Min	Median	Max	Count >DL	SD	DL
THg (µg/kg)	26.5	94.9	1740.0	45	270.4	0.2
MeHg (µg/kg)	0.10	0.29	3.95	10	1.21	0.01
MeHg/THg (%)	0.15	0.47	2.59	10	0.77	NA
TOC (%)	4.6	18.0	70.0	10	20.2	NA
pH	4.00	4.55	6.70	10	0.75	NA
C:N ratio calculated	14.9	40.7	77	10	21.3	NA
Sulfate (mg/kg)	10.0	11.0	12.0	2	NA	10
Sulfide (mg/kg)	NA	5.32	NA	1	NA	5
%MeHg/ SO_4	0.00015	0.00047	0.00259	10	0.00073	NA
THg/ SO_4	0.00265	0.00797	0.17400	10	0.0497	NA
MeHg/ SO_4	0.000010	0.000029	0.000395	10	0.00012	NA

TABLE 5.1-3. SUMMARY STATISTICS FOR WETLAND SOILS COLLECTED IN THE HHRA STUDY AREA

Parameter	Min	Median	Max	Count >DL	SD	DL
THg (µg/kg)	49.5	106.5	1850.0	10	528.5	0.2
MeHg (µg/kg)	0.17	0.60	3.98	10	1.09	0.01
MeHg/THg (%)	0.09	0.54	1.83	10	0.47	--
TOC (%)	6.6	28.0	55.0	10	15.6	--
pH	4.30	4.50	4.80	10	0.17	--
C:N ratio calculated	18.5	33.6	57.6	10	10	--
Sulfate (mg/kg)	12.0	14.5	17.0	2	NA	10
Sulfide (mg/kg)	NA	NA	NA	0	NA	5
%MeHg/ SO_4	0.00009	0.00047	0.00183	10	0.00047	--
THg/ SO_4	0.00438	0.01065	0.185	10	0.0524	--
MeHg/ SO_4	0.000017	0.000060	0.000234	10	0.000068	--

NA = *not applicable because the value cannot be calculated.*

-- Detected in all samples.

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Study area data were compared to other data collected in the region and to a study (Obrist 2012) that evaluated mercury ratios across 14 US forests, described below.

Median THg was lower and %MeHg was higher in study area soils compared to background samples at the Red Devil Mine (Bailey et al. 2002) and in material from the Sleetmute Quadrangle, Alaska (Miller et al. 1998). Rock data from the Sleetmute Quadrangle represent primarily upland outcrops, while the stream sediment data represent lowland sediments (Miller et al. 1998). The rock samples had a mean THg content of 191 ppm (191,000 µg/kg), while stream sediments from the same region had a mean THg content of 0.14 ppm (141 µg/kg). The slightly higher values in the Sleetmute Quadrangle (relative to the study area) may reflect naturally elevated mercury concentrations in a localized area around the Red Devil Mine mercury deposit. The mean concentrations of THg and MeHg in background soil samples near the Red Devil Mine were 400 and 0.8 µg/kg, respectively (Bailey et al. 2002), and MeHg/THg ratios were between approximately <0.01 and 1.0% (median ratio approximately 0.2%).

Median THg and %MeHg values for study area upland and wetland soils were higher than MeHg data presented from 12 forest sites by Obrist (2012). One conclusion of this study was that MeHg concentrations varied through the leaf litter and into the soil profile. Typically, the more decomposed leaf litter (Oa layer) had the highest MeHg concentrations, the highest MeHg/carbon ratios, and the highest MeHg/THg ratios (Table 5.1-1). The study compared the 12 upland forest sites to other upland studies and found that MeHg in leaf litter was comparable, but MeHg in soils was on the low end compared to other studies. The relationship between THg and MeHg had a weak positive correlation (r^2 of <0.3) with a slope of approximately 0.0006 (MeHg/THg).

In summary, the Project baseline methylation rate of soils is slighter higher than results in other studies in the region, but the values are within the range of other background sites in North America. The median baseline methylation rate is estimated at 0.47% (Tables 5.1-2 and 5.1-3). ProUCL-generated means of THg and MeHg in soils (see Section 5.3.3) also suggest an overall, mean %MeHg of about 0.5%. However, a paired sample collection program (ARCADIS 2014) determined a mean %MeHg of closer to 1%.

5.1.3. Baseline Methylation Rates – Aquatic Ecosystems

Mercury can be dissolved or remain in a particulate state in aquatic systems. Aqueous inorganic mercury can consist of both free ions and inorganic mercury complexes. Aqueous organic mercury occurs either as covalently bonded organomercurials such as MeHg, or mercuric complexes with organic matter, such as humic substances.

The baseline water quality is very similar to unimpacted regional and continental values (Enos 2013, Weglinski 2016). Summary statistics are presented for surface water and sediment in Tables 5.1-4 through 5.1-7. Surface water and sediment data were divided into two datasets as described in the DEIS (USACE 2015): (1) Category I

(upgradient of mineralized areas) and (2) Categories II and III (within or downstream of mineralized areas) for purposes of discussion. Percent MeHg was similar between categories for both surface water and sediment datasets, as were minimum and median THg and MeHg. However, maximum THg and MeHg were higher in the Category II/III dataset. Also noted, sediment summary statistics were very similar to the soil data statistics (see Tables 5.1-2 and 5.1-3).

Methylation rates based on unfiltered baseline THg and MeHg surface water data were within regional ranges indicating no particular process that enriches or depletes mercury within the study area. The median %MeHg values are close to 2%; however, the ranges of %MeHg values were similar between soil and surface water datasets, implying similar processes and rates for both media. A linear relationship provides the best fit for baseline stream water samples (Figure 5.1-1), and the equation of the line is approximately:

$$MeHg = 0.0024*THg + 0.00000005;\ r^2 = 0.81,\ n = 28$$

The slope of the above equation implies that the overall %MeHg is approximately 0.24%. This does not agree with the average %MeHg for the water quality sample set (2.0%), because the majority of the data are clustered at low THg values and subsequently exhibit a much higher %MeHg. However, it does agree with %MeHg results from baseline soil samples, as well as sediment samples. Summary statistics for baseline sediment samples show median %MeHg, THg, and MeHg results very similar to the upland and wetland soil dataset, with a median %MeHg of 0.28.

The surface water sulfate values are also similar to the sulfate concentrations in soil samples, while sediment sulfate values were below the method detection limit.

Although a relationship has been observed between increased THg concentrations and MeHg concentrations in aquatic ecosystems, the relationship is not necessarily linear. For example, increasing the concentration of THg in laboratory mesocosms representing lakes resulted in increased MeHg concentrations (Orihel et al. 2007). Mesocosms were spiked with THg loads, resulting in concentrations between two and 12 times higher than background; however, while the measured response in sediment and water mercury concentrations mirrored the addition of mercury, the relationship was not directly linear.

Stream sediments are intermediate between uplands and wetlands, and encompass energetic, oxygenated environments and slower, organic-rich environments. Stream sediments represent the upstream inputs and outputs and can therefore vary along individual reaches.

Scudder et al. (2009) summarized THg and MeHg sediment results for hundreds of US streams in mined and unmined basins. Concentrations of THg in sediment ranged from 0.84 to 4,520 µg/kg. About 75% of THg results were less than 80 µg/kg. Concentrations

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of MeHg ranged between 0.01 to 15.6 µg/kg. The %MeHg ratios varied between 0.02 to 41.0%, with unmined basins having higher %MeHg ratios than mined basins.

Stream water data summarized by Scudder et al. (2009) showed THg concentrations between 0.27 and 446 ng/L and MeHg concentrations of <0.010 to 4.11 ng/L. Some data were collected from mined basins, and hence the data represent a very broad set of unimpacted and impacted conditions. The %MeHg ratios varied between 0.02 and 81.5% with unmined basins having higher %MeHg ratios than mined basins.

Stream sediment samples collected from upstream and downstream of the Red Devil, Cinnabar Creek, and Red Top mercury mines in Alaska were found to have Hg(2+):THg ratios generally less than 5% and %MeHg less than 1% (Gray et al. 2000). The Red Devil Mine results showed that THg varied between approximately 200 and 3,000,000 µg/kg, while MeHg concentrations varied between approximately 300 and 4,000 µg/kg, indicating that the %MeHg decreased with increasing THg. In the unfiltered stream water samples, the MeHg concentrations were less than 1.5 ng/L and constituted less than 3% of the THg.

Regional stream sediment data from the Kuskokwim River, Holitna River, Red Devil Creek, and Crooked Creek were summarized by Wang (1999). THg concentrations were low in the Kuskokwim River and Holitna River samples with nine of the 10 sample sites having mean bulk THg values lower than 100 µg/kg and a mean MeHg concentration of 0.18 µg/kg. Red Devil Creek had bulk THg values from 500 to 150,000 µg/kg, and bulk MeHg concentrations of 1.75 µg/kg; the results were lower than those presented in Gray et al. (2000). Crooked Creek had a bulk THg value of 280 µg/kg and a bulk MeHg concentration of 3.12 µg/kg.

Water samples from the Kuskokwim River and Holitna River sites had mean THg and MeHg concentrations of 4.3 and <0.06 ng/L. The Red Devil Creek and Crooked Creek sites had THg concentrations of 236.5 and 10.5 ng/L and MeHg concentrations of 0.32 and 0.49 ng/L, five times lower than data presented in Gray et al. (2000).

Table 5.1-8 summarizes sediment and water mercury concentrations from three different scales of studies—continental, large river basin, and small river basin. In general, the broader continental data had lower mercury concentrations than the large river basin data, which had lower concentrations than the small river basin data. The sediment mercury results varied by a factor of 9 compared to the water mercury results which varied by a factor of about 5. However, the %MeHg for sediments and water was fairly consistent between the three scales of studies, varying by a factor of 6 or less. In comparison, the heavily influenced Red Devil Creek had THg values two orders of magnitude higher than the continental dataset and MeHg values less than an order of magnitude higher than the continental dataset and lower than the Crooked Creek data. This result indicates that a significant point source, such as a mercury mine, can

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increase MeHg concentrations much more slowly than THg even when sulfate concentrations are higher near the mine (e.g., Table 4 in Wang 1999).

In summary, the Project baseline %MeHg of sediments and surface water is similar; if not slightly lower, than the soil %MeHg within the study area. Sediment %MeHg is also similar to other studies in the region. ProUCL-generated mean concentrations of THg and MeHg in sediments (see Section 5.3.4) also suggest an overall, low mean %MeHg of about 0.3%.

TABLE 5.1-4. SUMMARY STATISTICS FOR SURFACE WATER AT CATEGORY I SAMPLE LOCATIONS

	Min	Median	Max	Count >DL	SD	DL
THg (ng/L)	0.50	2.05	12.50	31	3.551	0.5
MeHg (ng/L)	0.027	0.062	0.093	14	0.0191	0.02
MeHg/THg (%)	0.6%	1.7%	3.9%	14	0.011	NA
pH	6.80	7.20	7.70	30	0.25	NA
Sulfate (mg/L)	1.80	10.80	53.20	30	12	0.031
%MeHg/Sulfate	0.00025	0.00225	0.00439	31	0.00119	NA
THg/Sulfate	$2*10^{-08}$	$2.2*10^{-07}$	$6.94*10^{-06}$	30	$1.3*10^{-06}$	NA
MeHg/Sulfate	$1*10^{-09}$	$6*10^{-09}$	$3.8*10^{-08}$	14	$9*10^{-09}$	NA

NA = *not applicable because the value cannot be calculated.*

Based on surface water data collected between 2013 and 2015.

TABLE 5.1-5. SUMMARY STATISTICS FOR SURFACE WATER AT CATEGORY II AND III SAMPLE LOCATIONS

	Min	Median	Max	Count >DL	SD	DL
THg (ng/L)	1.14	2.79	96.90	42	16.969	0.5
MeHg (ng/L)	0.024	0.074	0.550	29	0.1009	0.02
MeHg/THg (%)	0.2%	2.0%	3.7%	29	0.011	NA
pH	6.50	7.15	7.90	42	0.34	NA
Sulfate (mg/L)	1.51	7.56	33.20	42	5.86	0.031
%MeHg/Sulfate	0.00036	0.00202	0.00889	42	0.00181	NA
THg/Sulfate	$6*10^{-08}$	$3.5*10^{-07}$	$2.91*10^{-05}$	42	$6.6*10^{-06}$	NA
MeHg/Sulfate	$1*10^{-09}$	$8*10^{-09}$	$1.08*10^{-07}$	29	$2.7*10^{-08}$	NA

NA = *not applicable because the value cannot be calculated.*

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TABLE 5.1-6. SUMMARY STATISTICS FOR SEDIMENT AT CATEGORY I SAMPLE LOCATIONS

Parameter	Min	Median	Max	Count >DL	SD	DL
THg (µg/kg)	43.4	191.0	303.0	10	73.5	0.2
MeHg (µg/kg)	0.20	0.42	0.81	10	0.2	0.01
MeHg/THg (%)	0.09	0.28	1.16	10	0.29	NA
TOC (%)	6.6	28.0	55.0	3	15.6	NA
pH	4.3	4.5	4.8	3	0.17	NA
C:N ratio calculated	15.6	19.8	80.0	3	29.4	NA
Sulfate (mg/kg)	NA	NA	NA	0	NA	10

NA= *not applicable because the value cannot be calculated.*

TABLE 5.1-7. SUMMARY STATISTICS FOR SEDIMENT AT CATEGORY II AND III SAMPLE LOCATIONS

Parameter	Min	Median	Max	Count >DL	SD	DL
THg (µg/kg)	38.0	170.0	231.0	4	80.9	0.2
MeHg (µg/kg)	0.13	0.39	1.02	4	0.34	0.01
MeHg/THg (%)	0.22	0.29	0.44	4	0.09	NA
TOC (%)	6.6	28	55	1	15.6	NA
pH	4.3	4.5	4.8	1	0.17	NA
C:N ratio calculated	NA	21.9	NA	1	NA	NA
Sulfate (mg/kg)	NA	NA	NA	0	NA	10

NA = not applicable because the value cannot be calculated.

TABLE 5.1-8. MEDIAN MERCURY CONCENTRATIONS FOR STREAM SEDIMENTS AND WATERS FROM DIFFERENT STUDIES

Mercury	Continental [1]	Large River Basin [2]	Small River Basin [3]
Sediment THg (µg/kg)	31.8	55.0	280
Sediment MeHg (µg/kg)	0.51	0.24	3.12
Sediment MeHg/THg (%)	1.72%	0.30%	1.11%
Water THg (ng/L)	1.90	3.80	10.5
Water MeHg (ng/L)	0.11	0.06	0.49
Water MeHg/THg (%)	5.35%	1.58%	4.67%

[1] *Median values from Scudder et al. (2009)*
[2] *Median value from Kuskokwim River and Holitna River samples from Wang (1999)*
[3] *Values from Crooked Creek from Wang (1999)*

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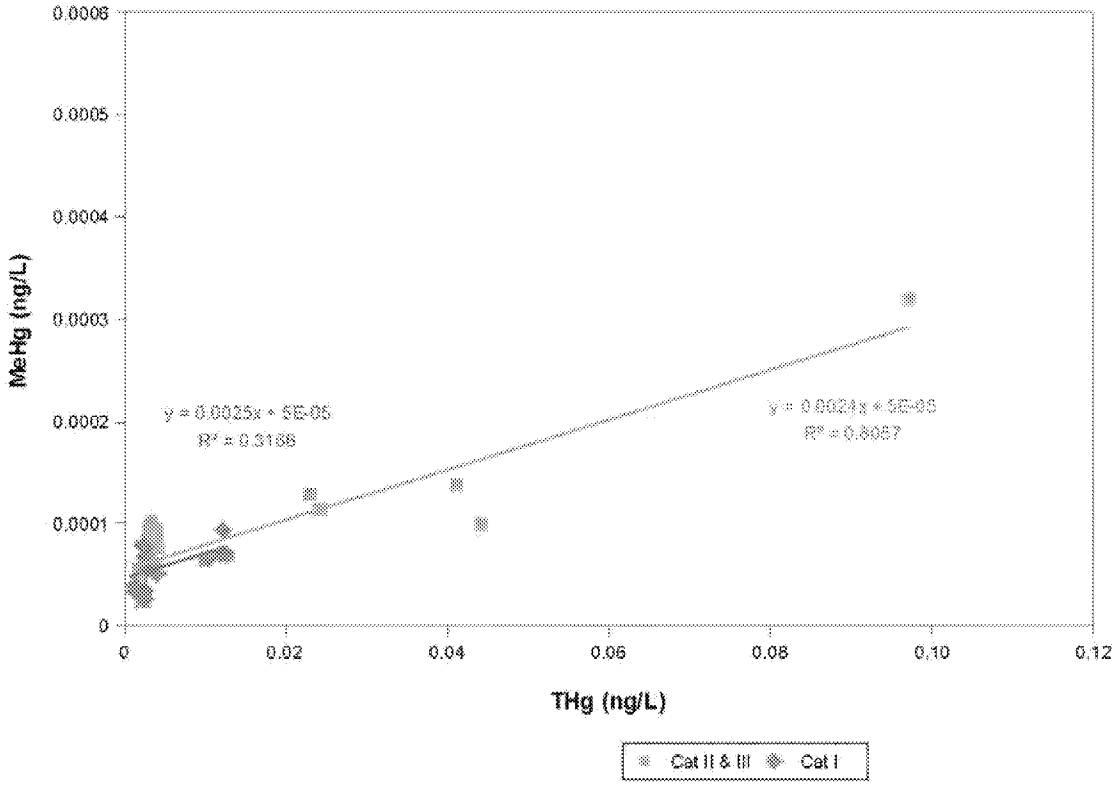
Figure 5.1-1
THg and MeHg Results for Stream Water Quality Samples



DONLIN Proj # 0386481 | Graphics # MPF-0001-091a

5.1.4. *Review of Current Models*

As part of this assessment, existing mercury models were assessed for potential use in evaluating proposed Project effects.

In USEPA's report to Congress (1997a), USEPA noted there is a general lack of conclusive data characterizing many aspects of mercury methylation rates, and that the rate of movement of mercury from watershed soils to water bodies is prohibitive to modeling. This lack of information has caused poor predictability in modeling to date.

USEPA's report also stated that its analysis relied heavily on computer modeling to describe the environmental fate of emitted mercury because no monitoring data have been identified that conclusively demonstrate or refute a relationship between any of the individual anthropogenic sources in the emissions inventory and increased mercury concentrations in environmental media or biota. For example, USEPA (1997a) used IEM-2M to predict environmental media concentrations and the exposures that result from atmospheric mercury concentrations and deposition. The IEM-2M model is mainly soil-based and represents a watershed with untilled, upland soils (not intended for wetlands); it is also not designed to model transformations among mercury species. A significant input to the IEM-2M model was the estimate of existing mercury concentrations in the environment (including all sources of mercury). The IEM-2M has not been validated with site-specific data. The uncertainty inherent in the modeled estimates arises from many individual assumptions present within the three models. Because of these uncertainties, USEPA interpreted the model results qualitatively rather than quantitatively.

The SERAFM model was designed to simulate lakes in a watershed. The model is not designed to predict future impacts to a watershed. Rather, the model was designed to be used at contaminated sites. It is developed for application in lake systems, not wetlands, uplands, or streams. Essential data to run the model include data collected at three points within the summer with replicates, and must include:

- Filtered and unfiltered THg and MeHg from lake water column;
- THg and MeHg from lake sediments; and
- Mercury from fish tissue.

Future predictions of concentrations in media would not have the necessary data to satisfy the spatial and temporal requirements to run the SERAFM model. More importantly, the data used to develop the SERAFM model are not applicable to the wetland system being addressed in this assessment.

The D-MCM is another lake-focused model that requires speciated mercury at greater spatial and temporal frequency than the proposed Project currently has in its baseline database. Additionally, the complexity of the D-MCM model is best utilized when extensive information is known about speciated mercury in the foodweb.

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Because none of the available models are applicable to the proposed Project, a calculation approach was used, as described in the following sections.

5.1.5. Future Methylation Rate Estimates

Estimates of future methylation rates considered all the environmental factors that affect methylation rates as discussed in Section 5.1.1.

5.1.5.1. Mercury Availability

Less than 10% of THg samples from baseline soil and sediment samples collected in the study area were below the detection limit, indicating that THg is not a rate-limiting parameter.

Deposition due to Donlin point and fugitive sources varies by watershed. The proposed Project is estimated to increase mercury deposition over baseline values in the nearest watersheds, decreasing with distance from the proposed Project. The average deposition rate of the affected watersheds is estimated at 0.58 micrograms per square meter per year (µg/m^2/yr) (area-weighted average of the six Crooked Creek watersheds in the study area using values from Table 4-4 in Environ (2015). This is an overestimate of the deposition rate in the study area for two reasons: (1) the model that was used to estimate deposition, CALPUFF, did not account for the pit retention of emissions; and (2) for approximately half the study area, deposition rates were estimated to be negligible (Environ 2015). Environ (2015) estimated that the deposition rate of oxidized mercury (Hg[2+]) from the proposed Project sources will be approximately 0.0116 µg/m^2/yr, or 2% of the Project deposition.

Atmospheric mercury that would be deposited would consist of Hg(0), Hg(2+), and Hg(p), with the majority in the particulate form. A minor component (approximately 1 to 2%) would be deposited as oxidized mercury (Hg[2+]), a form that is more likely to be methylated. Though Hg(2+) can easily be methylated, the rate of methylation for the newly deposited Hg(2+) is not known for the study area. As different forms of mercury may have different methylation rates, and "new" deposited mercury may be methylated more rapidly, it was assumed that newly deposited Hg(2+) (0.0116 µg/m^2/yr) would be rapidly methylated.

The global background, dominant mercury species in the atmospheric environment is gaseous elemental mercury (Hg[0]), constituting greater than 90% of total atmospheric mercury (Lyman et al. 2007). Atmospheric transport and deposition of mercury are complex, as there are chemical, diurnal, and seasonal trends that affect the redox state of mercury. Atmospheric deposition flux has been estimated globally and regionally and can vary by two or more orders of magnitude. Annual THg deposition rates from the six Mercury Deposition Network (MDN) stations located in Alaska vary between 1.2 and 5.7 µg/m^2/yr with annual THg precipitation weighted mean concentrations due to total

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deposition varying between 1.5 and 10.0 ng/L. Estimated global background deposition near the proposed Project site is 8.4 µg/m^2/yr (Environ 2013).

Concentrations and deposition rates for Hg(2+) were not measured at the Alaska MDN stations. However, speciated mercury was measured at 10 sites in northern Canada (Environment and Climate Change Canada 2016) and the ratio of Hg(2+) to Hg(0) was between 0.04 and 6.64% at these sites. The two highest values (1.73% and 6.64%) were from Churchill, Manitoba and Alert, Nunavut, which are small communities located along the Arctic coastline; these sites border sea ice and are subject to atmospheric mercury deposition events (AMDEs) in spring that result in spikes of RGM and TPM not seen at the other sites. The other measurement sites and the proposed Project location are not subject to AMDEs, and, therefore, the data from Churchill and Alert were not included in this evaluation of deposition rates. The mean ratio of Hg(2+) to Hg(0) among the eight sites was 0.45%. Therefore, of the global background deposited mercury, less than 1% is Hg(2+).

5.1.5.2. Analysis of Sulfate Loading

As discussed in the above sections, the increase in methylation rate is of a similar magnitude to the increase in sulfate concentration in systems where sulfate is initially at low concentrations. The estimated sulfur dioxide (SO_2) emissions (including fugitive emissions) from the proposed Project are approximately 25.7 ton/yr. The average annual background atmospheric SO_2 concentration is approximately 1.3 µg/m^3 and annual emission will result in an additional 0.04 µg/m^3 at the Core Operating Area boundary (Rieser 2017a), which equates to a 3% increase in atmospheric SO_2. A highly conservative assumption would be that the SO_2 concentration throughout the study area increased by this same amount, and that all the SO_2 produced was deposited locally as aqueous sulfate, increasing local annual load by 3%. This would raise the average sulfate concentration in local soils and streams by approximately 3%.

Sulfate concentrations in proposed Project soil, sediment, and surface water samples were low (maximum 17.0 mg/kg in soil; see Tables 5.1-2 through 5.1-7). As many sulfate minerals are soluble and there are no Project-specific soil porewater data, the assumption was made that sulfate concentrations in the solid phase are equivalent to porewater concentrations. Compared to values reported in the literature (reviewed in Section 5.1.1.3), the proposed Project soils and sediments have sulfate concentrations that are in the methylation rate-limiting range of values. Increases to sulfate concentrations may result in increases to the methylation rate.

The reviewed research indicates that increases in sulfate concentrations are commonly accompanied by increases in MeHg concentrations of the same factor. In other words, if the proposed Project added twice the baseline sulfate load to the local receiving environment, the methylation rate would expect to approximately double. Additional increases in sulfate would not be expected to result in continued increases in

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methylation rates; literature suggests that concentrations greater than 50 mg/L in aquatic systems would have diminishing returns or result in a net decrease in the methylation rate.

5.1.5.3. Other Parameters

The proposed Project is not expected to significantly impact the pH, DOC, temperature, oxygen content, or redox potential of the receiving environment. Therefore, no additional adjustments to methylation rates for items such as carbon loading were incorporated.

5.1.6. Projected Increase in Soil Mercury

Due to the absence of applicable models for evaluating potential Project effects on mercury methylation in the receiving environment, a calculation-based approach was employed. The steps of the calculation are as follows:

1. Using an average THg deposition rate of 0.582 µg/m²/yr (Environ 2015), atmospheric mercury that would be deposited would consist of Hg(0), Hg(2+), and Hg(p), with the majority in the particulate form. Oxidized mercury (Hg[2+]) is more likely to be methylated upon deposition and is a minor component (approximately 1 to 2%) of the total deposited.The rate of methylation for the newly deposited Hg(2+) is not known for the study area. As different forms of mercury may have different methylation rates, and "new" deposited mercury may be methylated more rapidly, it was assumed that all Hg(2+) was converted to MeHg. The USEPA (2005a) equation to calculate soil concentration based on deposition rate was used to calculate the future soil Hg(2+) and non-Hg(2+) concentrations from proposed Project-related atmospheric deposition. All deposited Hg(2+) was assumed to be converted to MeHg, and deposited non-Hg(2+) was assumed to undergo methylation at a rate of 1%, twice the median of all proposed Project baseline data, but reflecting the mean of paired soil samples collected in 2014 (ARCADIS 2014).

$$C_S = 100 \times \left(\frac{D}{Zs \times BD}\right) \times t_D$$

Where:

C_s = future soil concentration (mg/kg soil)
100 = unit conversion factor (from mg-m² to kg-cm²)
D = yearly dry deposition rate of constituent (g/m²-year)
t_D = time period over which deposition occurs (years), 27 years of the Project
Z_s = soil mixing zone depth (cm); assume 2 cm
BD = soil bulk density (g/cm³); assume 1.5 g/cm³

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The total increase in soil Hg(2+) and non-Hg(2+) from proposed Project-related atmospheric deposition is shown in Table 5.1-9.

2. Increases to sulfate concentration in natural systems with low concentrations of sulfate (as is the case within the study area) will result in increases in the concentration of MeHg. The reviewed literature indicates that the factor increase in MeHg is 0.5 to 1.0 times the factor increase in sulfate, or in other words, the increase in %MeHg would be of a similar magnitude to the increase in sulfate concentration in systems where sulfate is initially at low concentrations. The estimated SO_2 emissions (including fugitive emissions) from the proposed Project will result in an additional 0.04 µg/m^3, which equates to a 3% increase in atmospheric SO_2. A highly conservative assumption would be that all SO_2 produced was deposited locally as aqueous sulfate increasing local annual load by 3%. This would result in a %MeHg of existing soil THg and newly deposited non-Hg(2+) pools increasing from the current estimated methylation rate of 1% to a future rate of 1.03%.

Compounding these factors would result in MeHg soil concentrations as shown in Table 5.1-9. THg concentrations would increase by a factor of 1.01, and MeHg would increase by a factor of 1.05.

Project effects are expected to increase the THg load to the receiving environment, primarily due to deposition of Hg(p) from fugitive dust and point source emissions. Proposed Project-related emissions are also expected to increase the sulfate load to the receiving environment by approximately 3%. Increases in sulfate concentrations are commonly accompanied by increases in MeHg concentrations of the same factor. Other environmental factors commonly cited as influencing the methylation rate are not expected to be affected by the proposed Project. Consequently, the overall MeHg concentration in the study area receiving environment is expected to increase, resulting in increased future THg and MeHg soil concentrations due to both Project-related and global background deposition.

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TABLE 5.1-9. CALCULATION OF FUTURE SOIL MERCURY CONCENTRATIONS

Parameter	Units	Atmospheric Deposition from Project:		Totals
		Hg(2+)	Non-Hg(2+)	
Estimated Annual Dustfall	µg/m²/yr	0.017	0.85	
Concentration in Soil (C_s)	mg/kg	0.000016	0.00077	
Future methylation rate (% of baseline)	%	---	1.03	
MeHg increase in soil due to Hg(2+) direct deposition*	mg/kg	0.0000016	---	
Mean baseline concentration, THg in soil	mg/kg			0.217
Baseline MeHg in soil at 1% methylation rate**	mg/kg			0.0022
Total Future THg in soil	mg/kg			0.218
MeHg addition to soil due to future increased methylation of future THg	mg/kg			0.0022
Total Future MeHg in soil	mg/kg			0.00226
Factor Increase, THg				1.01
Factor Increase, MeHg				1.05

**Hg will be deposited as Hg(2+) but is assumed, for purposes of this study, to rapidly convert to MeHg.*
*** An upper-bound baseline methylation rate of 1% was assumed, based on paired comparisons by ARCADIS (2014); however, ProUCL-calculated MeHg to THg means indicate an overall soil methylation rate closer to 0.5%, and sediment methylation rate <0.5%.*

5.1.7. Projected Increase in Mercury in Aquatic Systems

Mercury concentrations and %MeHg values were similar between soil and sediment datasets (sediment %MeHg was actually slightly lower than soil %MeHg), implying similar processes and rates for both systems. These comparisons indicate that methylation mechanisms are similar between soil and aquatic systems. To estimate future concentrations in aquatic systems, the same factor increase computed for soil systems was used to derive THg and MeHg in sediments. Changes in sediment mercury content should then be proportionally reflected in surface water THg and MeHg concentrations. Future sediment and surface water THg are shown in Tables 5.1-10 and 5.1-11.

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TABLE 5.1-10. CURRENT BASELINE AND ESTIMATED FUTURE SEDIMENT MERCURY CONCENTRATIONS

	Minimum	Mean	95th UCLM	Maximum
Baseline THg (µg/kg)	35	179	201	303
Baseline MeHg (µg/kg)	0.057	0.503	0.627	1.6
Future THg (µg/kg)	35	179	201	303
Future MeHg (µg/kg)	0.059	0.52	0.65	1.66

TABLE 5.1-11. CURRENT BASELINE AND ESTIMATED FUTURE SURFACE WATER MERCURY CONCENTRATIONS

	Minimum	Mean	95th UCLM	Maximum
Baseline THg (ng/L)	0.55	2.76	5.66	24.30
Baseline MeHg (ng/L)	0.02	0.07	0.08	0.55
Future THg (ng/L)	0.55	2.76	5.66	24.30
Future MeHg (ng/L)	0.02	0.07	0.08	0.57

The concentration of mercury in Crooked Creek under baseflow conditions was assumed to represent mercury loading without contribution from material originating from atmospheric deposition being washed into the creek by stormwater runoff. The effect of current deposition on stream concentrations was then estimated as the increase in concentration from baseflow conditions to average annual stream concentrations.

The baseflow conditions were identified by baseflow separation analysis at four select stations where flow is continuously monitored. Concentrations for all monitoring stations during baseflow conditions were then calculated for these same time periods (TetraTech 2013). The average of the calculated baseflow THg concentrations for the stations in the Crooked Creek drainage (TetraTech 2013) was 2.6 ng/L.

Applying the factor increase of 1.01 on the baseflow THg concentrations yielded a future surface water concentration resulting from deposition from global background and proposed Project-related sources of 2.7 ng/L THg. As discussed in Section 3.4, exposure to COPCs in surface water is negligible. As described in Section 5.2.2, BAFs based on surface water concentrations are less robust than those based on sediment concentrations. Future estimated surface water concentrations are provided to show that the proposed Project will not adversely impact surface water quality.

5.2. Bioaccumulation Factors

This HHRA evaluated potential, incremental future exposures and risks related to the consumption of subsistence food items that may uptake mine-related metals. Because future concentrations of subsistence food items cannot be measured, they were estimated by developing BAFs. BAFs relate a chemical's concentration in the

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environment (soil, sediment, water) to its concentration in biota and are commonly used in risk assessments to estimate exposures via plant, fish, or wildlife ingestion.

Mercury, arsenic, and antimony can bioaccumulate in biota. Mercury is known to biomagnify through the food chain, while arsenic and antimony do not; consequently, mercury concentrations tend to be higher in higher trophic level organisms. Studies have shown for example that predatory fish tend to have higher mercury levels than omnivorous or herbivorous species (De Lacerda 1994, Eisler 1987).

Because mercury can biomagnify, the form of mercury is important to understand uptake and bioaccumulation potential. While inorganic mercury does not biomagnify, MeHg is of particular concern because it can build up in certain edible fish and mammals to levels that are many times greater than levels in the surrounding environment (ATSDR 1999).

Mercury must be absorbed into the body of humans or animals, or taken up by plants to cause a toxic response. Absorption can occur through oral ingestion, dermal absorption, or inhalation. Inorganic mercury absorption following dermal, oral, or inhalation exposure is low; absorption following oral ingestion is estimated for example between 10 to 30% depending on the medium in which the mercury is ingested (e.g., gavage, water, milk, or food). Estimated absorption rates of organic mercury forms are much higher than inorganic forms, as much as 95% in humans when consumed in drinking water (Aberg et al. 1969 as cited in ATSDR 1999). Studies suggest that MeHg comprises 90% or more of the THg in fish (ATSDR 2013).

Given the differences in bioavailability between inorganic and organic mercury, as well as limitations of mercury data in biota (i.e., THg was often measured but MeHg was seldom measured), proposed Project-specific uptake factors for mercury were derived using:

- THg data for primary media and THg data for biota; and
- MeHg data for primary media and THg data for biota.

These two types of BAFs were developed to allow for comparisons to other regional data and the general literature, and to account for potential future changes in bioavailable forms of mercury in the environment. MeHg is readily bioavailable and taken up by biota, whereas the bioavailability of THg is more variable. Therefore, deriving MeHg to THg BAFs allows for some accountability of increasing proportions of MeHg in future soils.

Existing literature suggests that MeHg is likely to comprise a relatively large proportion of the THg that is measured in biota (ATSDR 1999, 2013). For example, as noted above, ATSDR (2013) reports that MeHg comprises 90% or more of the THg in fish. However, not all studies indicate this is the case; Gray et al. (2000) reported that MeHg comprised less than 1% of the THg in aquatic biota collected at three mine sites in southwestern Alaska. However, given the variability reported in the literature of the fraction of THg that is MeHg (less than 1% to over 90%) and the relative toxicity of MeHg to THg

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(ATSDR 1999), the assumption in this HHRA was that all THg in biota is MeHg. This assumption results in an overestimate of potential risk from consumption of subsistence foods due to exposures to mercury.

Baseline biota values were estimated using BAFs developed from Project-specific data or BAFs from the literature, if Project-specific data are lacking. Appendix B describes in detail how BAFs were developed or selected for mercury, arsenic, and antimony for representative subsistence foods, which included berries (blueberry and cranberry), northern pike, mallard ducks, and beaver.

Deriving bioaccumulation models using empirical datasets is preferred to using literature-based (generic) models when estimating concentrations in food items (Sample et al. 1998, Bechtel 1998). Additionally, due to the heterogeneity of bioaccumulation patterns in environmental media, proposed Project-specific empirical data are preferred over other, regional data (or models). Use of regional data or models is less likely to be representative of site conditions and is likely to result in an unspecified level of uncertainty when estimating exposure.

Though proposed Project-specific empirical data could be used to develop BAFs, there were limited Project data to develop regression model-based BAFs. Therefore, in most cases, median concentrations of primary media and biota tissue were used to derive BAFs. Compared to other literature or regional information (Appendix B), the proposed Project-specific BAFs were high; suggesting BAFs for the study area may be overestimated. Reasons for the higher Project-specific BAFs are not known, but may in part be due to the nature of the sampling events during baseline collection, which sought to characterize the more mineralized areas of the study area. These more mineralized areas may not be representative of the study area as a whole. However, the bias represents a conservative assumption. The derivation of the BAFs for use in the HHRA is described in detail in Appendix B. Table 5.2-1 provides the BAFs that were used in the HHRA.

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TABLE 5.2-1. BIOACCUMULATION FACTORS USED IN THE HUMAN HEALTH RISK ASSESSMENT

Food	Media	Mercury[1]	Arsenic	Antimony
Plants – berries	Soil	2.9	0.0375	$\ln(C_{plant}) = 0.938 \times \ln(C_{soil}) - 3.233$
Fish – northern pike[2]	Sediment	55	0.016	0.018
Bird – mallard	Soil	0.054	$\ln(C_{bird}) = 0.8188 \times \ln(C_{soil}) - 4.8471$	0.05
Mammal – beaver	Soil	0.054	$\ln(C_{mammal}) = 0.8188 \times \ln(C_{soil}) - 4.8471$	0.05

The soil-to-plant uptake factor for mercury is in units of $kg_{soil,dw}/kg_{tiss,ww}$.

The soil-to-plant uptake factors for arsenic and antimony are in units of $kg_{soil,dw}/kg_{tiss,dw}$.

All sediment-to-fish uptake factors are in units of $kg_{sed,dw}/kg_{tiss,ww}$.

All soil-to-mammal uptake factors are in units of $kg_{soil,dw}/kg_{tiss,dw}$.

[1] *Uptake factors (median) are based on Project-specific MeHg data for soils and THg data for biota.*

[2] *Uptake factor modeled using sculpin data. Food chain multiplier of 3 is applied to this value to derive northern pike concentrations.*

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5.2.1. *Bioaccumulation in Berries*

Project-specific, baseline soil and berry tissue data were used to develop soil-to-plant uptake factors to use for future estimates of uptake of THg into blueberries and cranberries ("berries"). The datasets included site-specific baseline sampling for the proposed Project, which included a total of 137 berry samples (71 blueberry samples and 66 cranberry samples) collected from 43 locations in 2006 and 2007. The specific parts of the plants that were collected were not reported; however, the stated objective of the sampling program was to collect data relevant to subsistence harvesting (ARCADIS 2007a), and it was therefore assumed that the data represent berry data that would be consumed by humans. Project-specific data for antimony and arsenic were not available. Literature-based BAFs were used for antimony and arsenic.

5.2.2. *Bioaccumulation in Fish*

Northern pike is a resident, large, and relatively long-lived top predator. For these reasons, it provides a conservative estimate of potential fish uptake of metals, particularly mercury. However, northern pike has only recently been observed in Crooked Creek (OtterTail 2009). In addition, the Project-specific tissue burden dataset for northern pike consists of only two samples, only one of which was measured in an adult individual, and only THg was analyzed for tissue burden. Given the limited dataset, other fish species were considered for the HHRA.

A fairly large, Project-specific sculpin dataset was available for the study area. Although sculpin are not large, top predators and are not widely harvested for subsistence consumption, other regional studies have used sculpin data to estimate mercury concentrations in higher trophic level game fish such as northern pike (E&E 2014). As discussed in Appendix B, sculpin BAFs were developed using surface water and sediment data. The sediment-based BAFs are considered more robust (see Appendix B) and recommended for use in estimating fish concentrations for the HHRA. Due to the greater bioavailability of MeHg in sediment, the MeHg to THg BAF was used. Sculpin are one trophic level lower than northern pike, and to account for greater potential bioaccumulation of MeHg in northern pike, a food chain multiplier (FCM) of 3 was applied to sculpin MeHg concentrations derived using the sediment to fish BAF (McGeer et al. 2004; E&E 2014). An FCM of 1 was applied to arsenic and antimony, which do not biomagnify through the food chain.

5.2.3. *Bioaccumulation in Beaver*

There is no Project-specific or regionally available empirical data that relate metal concentrations in the environment to tissue burdens of wild mammal game. However, there are models available that characterize the bioaccumulation of metals into mammals. Thus, given the lack of Project-specific data, literature-based soil-to-mammal uptake factors from USEPA (2005b) for arsenic, USEPA (2005c) for antimony, and Sample et al. (1998) for mercury were used to estimate tissue burdens in beaver.

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5.2.4. *Bioaccumulation in Mallard Ducks*

There are no Project-specific empirical data that relate metals concentrations in the environment to tissue burdens of birds. Similarly, few data exist in the peer-reviewed literature or regulatory guidance that relate metals concentrations in the environment to tissue burdens of birds. While there is a large amount of literature documenting the accumulation of metals in birds, the majority of these studies often do not include both co-located environmental and bird tissue concentrations and, hence, cannot be used to develop quantitative uptake models. Therefore, available uptake factors for small mammals were adopted for birds.

5.3. Baseline Exposure Point Concentrations

To calculate health risks, an estimate must be made of the constituent concentration to which an individual may be exposed. An EPC is the concentration of a COPC in an exposure medium at the location where a receptor may contact that medium, and that is representative of the time period over which exposure may occur.

For all media except air, the USEPA guidance document to calculate EPCs (USEPA 2002), and recommendations in the associated software program ProUCL, were the primary references used to calculate EPCs. USEPA's *ProUCL v5.1* software (USEPA 2016a) was used. Empirical data were not available for all COPCs in small mammals and waterfowl, and for arsenic and antimony in berries; EPCs were estimated for these media using BAFs. Baseline mercury air concentrations were based on analyses completed by Environ (2015). Baseline antimony and arsenic air concentrations were assumed to be negligible, and for calculation purposes were assumed to be zero.

USEPA (1992a, 2002) guidance recommends using an upper-bound estimate of the average concentration to which an individual would be exposed over a significant part of a lifetime, due to the uncertainty associated with estimating the true average concentration at a site. Upper-bound and mean estimates of baseline EPCs were computed; however, future EPCs are based on modeling estimates, which generate mean estimates. Therefore, mean baseline EPCs were used to estimate baseline risks to evaluate incremental risk.

The data distributions encountered while computing the EPCs fell into one of three categories: normal (having a symmetric, bell-shaped distribution about the mean), lognormal with a small coefficient of variation (where the distribution of values around the mean is somewhat skewed towards larger values), and neither normal nor lognormal. The Shapiro-Wilk W-test is a statistical hypothesis test used to determine whether the data are normally or lognormally distributed, or consistent with neither distribution. A significance level of 0.05 was employed in the Shapiro-Wilk W-test.

Table 5.3-1 presents the baseline EPCs.

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TABLE 5.3-1. BASELINE EXPOSURE POINT CONCENTRATIONS OF CONSTITUENTS OF POTENTIAL CONCERN IN ENVIRONMENTAL MEDIA

COPC	Baseline Exposure Point Concentration						
	Air (µg/m³)	Soil (mg/kg dw)	Sediment (mg/kg)	Berries (mg/kg ww)	Northern Pike (mg/kg ww)	Beaver (mg/kg ww)	Mallard Duck (mg/kg ww)
Antimony	NA	4.93	0.3	0.0539	0.00610	0.0789	0.0813
Arsenic	NA	15.1	24.4	0.173	0.390	0.0232	0.0239
Mercury	0.0000084	0.217	0.179	NA	NA	NA	NA
MeHg	NA	0.00087	NA	0.00254	0.0829	0.00375	0.00387

COPC = constituent of potential concern

dw = dry weight

ww = wet weight

NA = Not applicable (mercury in biota is assumed to be 100% MeHg; antimony and arsenic are negligible in baseline air)

The baseline exposure point concentrations are mean values.

Arsenic concentrations in biota were converted to inorganic arsenic in dose calculations.

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5.3.1. *Air*

Baseline air quality is described in the DEIS, Chapter 3, Section 3.4. Details of the baseline sampling program can be found in Environ (2013).

Because of the lack of Project-specific or regional data for antimony and arsenic concentrations in air, the estimated incremental increase in concentrations was evaluated with the assumption that baseline air concentrations of these COPCs were zero. This is a conservative assumption, as these COPCs are present in soil in the region and particulates in air under baseline conditions would be expected to contain minor amounts of these COPCs.

To determine inhalation EPCs for mercury, it is necessary to calculate the baseline COPC concentrations bound to fine particulate matter, as it is the fine size fraction of particles that can be inhaled deep into the alveoli. Furthermore, mercury bound to particulate matter is primarily present in the fine fraction of particulate matter ($PM_{2.5}$), although some particulate-bound mercury may also be present in coarse particulate matter (Bullock and Brehme 2002).

A baseline annual average mercury concentration bound to $PM_{2.5}$ (0.0000084 $\mu g/m^3$) was obtained from Environ (2013). This concentration was based on monitoring data collected in the study area. Baseline mercury air concentrations are not expected to vary widely in the area in general due to the large global background of atmospheric mercury (Environ 2015). Therefore, the spatial representativeness was determined to be acceptable for the HHRA. Because methylation does not occur in the atmosphere, it was assumed that all atmospheric mercury is inorganic for risk evaluation.

5.3.2. *Soil*

Soil datasets considered for baseline EPCs, and also used in BAF calculations, included site-specific baseline sampling for the proposed Project (ARCADIS 2007a, 2014; Fernandez 2014), which included 122 soil samples from 45 locations, collected between 2006 and 2013. The samples were collected within the Crooked Creek Hydrologic Unit Code (HUC) 10 drainage. Soil arsenic within the Core Operating Area is locally enriched relative to the samples collected outside this area (Fernandez 2014); because exposures will occur outside the Core Operating Area, soil arsenic data was excluded from the data used to determine baseline soil EPCs. All soil arsenic data, however, was used to determine potential BAFs and air concentrations. Samples were analyzed for THg (n = 52; all samples were above the detection limit [DL]) and MeHg (n = 20; eight samples were below the DL); total arsenic (n = 35; all samples were above the DL); and total antimony (n = 35; all samples were above the DL). It was assumed that 100% of the total arsenic in soil was inorganic.

The baseline distributions of antimony and arsenic concentrations in soil were not normal (at a 5% significance level) and did not follow a discernable distribution. The

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baseline distribution of mercury concentrations in soil was lognormal (at a 5% significance level) and the baseline distribution of MeHg concentrations in soil was normal (at a 5% significance level).

5.3.3. *Berries*

Blueberry and cranberry ("berry") Project-specific datasets (ARCADIS 2007a) were used to generate BAFs (Section 5.2.1).

Baseline concentrations of antimony, arsenic, and mercury were estimated using BAFs for comparability to future concentrations.

5.3.4. *Small Mammals (Beaver)*

Baseline beaver tissue metals concentrations were derived from small mammal BAFs. The arsenic concentration in beaver was adjusted to account for the amount of inorganic arsenic that is likely to be present in tissues. Inorganic arsenic is the most toxic form of arsenic; also the oral reference dose (RfD) for arsenic is based on inorganic arsenic (USEPA 2017). For beaver, it was assumed that 70% of the total arsenic was inorganic (European Food Safety Authority [EFSA] 2009, 2014).

5.3.5. *Waterfowl (Mallard Duck)*

Baseline mallard duck tissue metal concentrations were derived from mallard duck BAFs (small mammal BAFs were used due to lack of BAFs for avian species). For mallard duck, it was assumed that 50% of the total arsenic was inorganic (EFSA 2009, 2014).

5.3.6. *Fish*

In the HHRA scope of work (ERM 2017), northern pike were identified to be a representative resident species that would be used to estimate incremental risks to humans from fish consumption. However, as discussed in Section 5.2.2, data were only available for two northern pike tissue samples, one from an adult individual, and one from a juvenile individual. Both samples were analyzed for THg (in wet weight [ww]). The adult northern pike tissue THg concentration was 0.421 mg/kg ww and the juvenile northern pike tissue THg concentration was 0.0852 mg/kg ww.

Both the small sample size and the age and trophic level disparity in the two samples (juvenile northern pike consume plants, while adult northern pike consume fish and are more commonly consumed) created relatively large uncertainties with the use of this dataset. To fulfill the HHRA scope, risks were estimated using northern pike concentrations modeled from sculpin BAFs and a FCM of 3 to account for the higher trophic level of northern pike.

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For fish tissue, mercury is assumed to be present as 100% MeHg (ATSDR 1999). Based on studies in various fish species (Phillips 1990, Slejovec et al. 2004, Rosemond et al. 2008, and Rahman et al. 2002), it is assumed that 10% of the arsenic is inorganic. Organic forms of arsenic have a low to negligible toxicity to humans.

5.4. Future Media Concentrations

Future EPCs were estimated by modeling. While there are always inherent uncertainties with estimating future concentrations, in general, simple models with conservative assumptions are favored over complex models that bring additional uncertainties to future EPC estimation. However, sensitivity runs with a few key parameters were made and are presented in the Uncertainty Analysis (Section 8) to examine HHRA outcomes with respect to incremental risks. The subsections below describe how future EPCs were computed. Table 5.4-1 presents a summary of all the future EPCs.

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TABLE 5.4-1. FUTURE EXPOSURE POINT CONCENTRATIONS OF COPCs IN ENVIRONMENTAL MEDIA

COPC	Future Exposure Point Concentration						
	Air (µg/m³)	Soil (mg/kg dw)	Sediment (mg/kg)	Berries (mg/kg ww)	Northern Pike (mg/kg ww)	Beaver (mg/kg ww)	Mallard Duck (mg/kg ww)
Antimony	5.71E-07	4.94	0.3	0.0539	0.00611	0.0790	0.0814
Arsenic	1.80E-05	15.3	24.4	0.175	0.391	0.0234	0.0241
Mercury	8.46E-6	0.219	0.181	NA	NA	NA	NA
MeHg	NA	0.00092	0.000528	0.00266	0.0871	0.00379	0.00391

COPC = constituent of potential concern

dw = dry weight

ww = wet weight

NA = Not applicable due to assumption that mercury in biota is MeHg and MeHg is not present in air.

Arsenic concentrations in biota were converted to inorganic arsenic in dose calculations.

5.4.1. *Air*

The air quality model developed to support the Prevention of Significant Deterioration (PSD) permit application (Air Sciences 2016, Donlin 2016) was used to simulate the incremental annual average $PM_{2.5}$ concentration at the village of Crooked Creek that would occur as a result of activity at the mine. The air quality model simulated impacts from the mine during the projected peak emission year, which is mine year 16. Several receptor locations were selected around the village, and the model was run using five years of meteorological data collected at the site. The location with the highest average $PM_{2.5}$ concentration was used to characterize the $PM_{2.5}$ material originating from the proposed Project. The antimony, arsenic, and mercury concentrations in the $PM_{2.5}$ material were then calculated using the relative concentrations of these metals in dust particulate material from the site emissions inventory prepared for the PSD permit application (Donlin 2016, Air Sciences 2017).

As reported by Air Sciences (2017), the predicted annual average mercury concentration was a maximum of 0.00148 $\mu g/m^3$ within the Crooked Creek village watershed. This concentration was used to calculate risk to residents via inhalation. The concentration was multiplied by the weighted percentage of particulate to THg emissions (2.8%; Environ 2015) to obtain the predicted annual average particle-bound mercury concentration (0.0000414 $\mu g/m^3$). The predicted annual average particle-bound antimony and arsenic concentrations were calculated in the same manner.

5.4.2. *Soil*

Soil concentrations of COPCs are estimated to increase over the life of the mine due to atmospheric deposition of COPCs emitted from mine operations. The USEPA method for calculating constituent concentrations in soil due to atmospheric dust deposition was used to estimate future soil concentrations (USEPA 2005a). Future dustfall levels were based on air quality estimates. As reported by Environ (2015), the simulated maximum average deposition flux of Hg(p) due to proposed Project-related sources in local watersheds ranged from 0.1 to 3.7 micrograms per square meter per year ($\mu g/m^2/yr$). An area-weighted average value (0.582 $\mu g/m^2/yr$) was adopted as the annual dustfall deposition for mercury, to be used for predicting future soil mercury concentrations.

Arsenic and antimony deposition rates were estimated by using the concentration of particulate arsenic and antimony relative to mercury as calculated for the PSD application (Donlin 2016), and multiplying the mercury deposition attributable to fugitive particulates (Environ 2015) by these ratios.

For soil quality modeling, in addition to assumptions made in the air dispersion model (Environ 2015), it was conservatively assumed that all dust deposited onto soil remains in place and would not be entrained in run-off during rain events. Further, it was

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assumed that the predicted concentrations of COPCs in dustfall apply to the entire study area.

The incremental increase in soil COPC concentrations due to dustfall deposition was calculated for each COPC using Equation 1, as suggested by the USEPA (2005a):

$$C_S = 100 \times \left(\frac{D}{Zs \times BD}\right) \times t_D \qquad \text{[Equation 1]}$$

where:

C_s	= average soil concentration over exposure duration (mg COPC/kg soil)
100	= unit conversion factor (from mg-m^2 to kg-cm^2)
D	= yearly dry deposition rate of constituent (g COPC/m^2-year)
t_D	= time period over which deposition occurs (years)
Z_s	= soil mixing zone depth (cm)
BD	= soil bulk density (g/cm^3)

The time period (t_D) over which dust deposition may occur was assumed to be 27 years of proposed Project operations. The COPCs deposited with fugitive dust were assumed to mix with the top 2 cm of soil (Z_s), as recommended by the USEPA (2005a) for untilled soils. The bulk density (BD) for soil was set at the default value of 1.5 g soil/cm^3 soil, as recommended by the USEPA (2005a). Weathering and degradation are considered to only be significant for organic constituents and not metals (USEPA 2005a); thus, a soil loss constant was not necessary (i.e., it was assumed that none of the metals were lost to weathering or degradation).

The incremental increase in soil COPC concentrations was summed with baseline COPC concentrations to estimate total future soil COPC concentrations in the study area.

5.4.3. Sediment

Future dustfall containing arsenic and antimony was assumed to be deposited in stream sediments. Sediment antimony and arsenic concentrations were therefore modeled to increase proportional to dustfall. Sediment mercury concentrations were based on analyses presented in Section 5.1.7.

5.4.4. Berries

Predicted berry concentrations were calculated by multiplying the predicted future soil concentration by the MeHg (soil) to THg BAF for berries. It was assumed that 100% of THg in berries is in the form of MeHg. Although dustfall onto berries is also a factor in the total berry concentration, for the purposes of the HHRA, the soil to berry uptake route was assumed to be the primary exposure route to berries. Uncertainties with regard to additional exposure via dustfall onto berries are addressed in the Uncertainty Analysis (Section 8).

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5.4.5. *Small Mammals (Beaver)*

Future beaver tissue metals concentrations were calculated from predicted soil concentrations and the MeHg (soil) to THg BAF (see Section 5.2.4). Note that future mercury concentrations in beaver were predicted using the MeHg content in soil to obtain the THg concentration in beaver tissue. The same fractions of total arsenic to inorganic arsenic, and THg to MeHg, in beaver were assumed for future EPCs as for baseline EPCs.

5.4.6. *Waterfowl (Mallard Duck)*

Future mallard tissue metal concentrations were calculated from predicted soil concentrations and BAFs (see Section 5.2.3). Note that future mercury concentrations in beaver were predicted using the MeHg content in soil to obtain the THg concentration in mallard duck tissue. The same fractions of total arsenic to inorganic arsenic, and THg to MeHg, in mallard ducks, were assumed for future EPCs as for baseline EPCs.

5.4.7. *Fish*

Predicted northern pike tissue concentrations were calculated by multiplying the predicted future sediment concentrations by the BAF (based on MeHg in sediment) for sculpin. Details are presented in Section 5.2.2 and Appendix B. It is assumed that 100% of the mercury in fish is MeHg. Ten percent of the estimated arsenic concentrations were assumed to be inorganic arsenic, as was assumed for baseline EPCs.

5.5. **Intake Rates**

Exposure factors define the magnitude, frequency, and duration of exposure for the populations and pathways selected for quantitative evaluation. Exposure factors are combined with EPCs to calculate dose. Exposure factors were selected based on a "reasonable maximum exposure" scenario that combines upper-bound and average values that reflect exposures somewhere between the 90th and 98th percentile of the range of possible exposures that reasonably can be expected to occur for a given population (USEPA 1989).

The basic structure of the exposure equations used in this HHRA is from *Risk Assessment Guidance for Superfund, Human Health Evaluation Manual, Part A* (USEPA 1989). The general intake equation that serves as the basis for the pathway-specific equations is:

$$Intake = \frac{C_i \times CR \times EF \times ED}{BW \times AT} \qquad \text{[Equation 2]}$$

where:

Intake = rate of COPC available for uptake at an exchange boundary (mg /kg body weight/day)

C_i = concentration of constituent *i* at exposure point (e.g., mg/kg sediment)

CR = contact rate with the environmental medium (e.g., mg sediment/day)

EF = exposure frequency (days/year)

ED = exposure duration (year)

BW = body weight (kg)

AT = averaging time for toxicological effects (days)

Intake is specified as the rate at which a constituent becomes available for uptake at an exchange boundary, such as the walls of the gastrointestinal tract or the skin. Hence, it is not equivalent to an absorbed dose, which is the amount of a constituent actually entering the bloodstream across an exchange boundary.

5.5.1. *Human Receptor Characteristics*

The human receptors selected were children (0 to 6 years old) and adults (greater than 20 years of age). Children are often most susceptible to constituents with a threshold response due to their ratio of body size to ingestion rates (IRs) compared to other human life stages.

Health effects are generally divided into two categories: threshold (non-carcinogenic) and non-threshold (carcinogenic) responses. Constituents may elicit one or both types of response. Because these two categories of constituents are evaluated differently, separate intake calculations are performed. For non-carcinogenic effects, the averaging time over which effects are assessed is equal to the exposure duration (USEPA 1989), and the resulting potential for effects is the ratio of the estimated dose to a reference dose. Cancer risk, on the other hand, is assessed as exposure averaged over a lifetime, and is expressed as a probability of incremental lifetime cancer risk (additional cancer incidences in the population to the background cancer risk).

Consumption (i.e., ingestion) rates of food items were based on a local subsistence study that reported data for the Upper Kuskokwim River subsistence population, as described in Sections 3.6 and 5.5.2.3. For other intake rates, ADEC (2015) or USEPA (2014) exposure factors for residential receptors were selected.

The receptor characteristics for adults and children used to calculate the dose of COPCs from the different exposure pathways are summarized in Table 5.5-1. Pathway-specific intake equations are described in the following subsections.

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TABLE 5.5-1. EXPOSURE FACTORS FOR ADULT AND CHILD SUBSISTENCE POPULATIONS

			Adult		Child [2]	
Exposure Parameter [1]	Symbol	Units	Value	Reference	Value	Reference
Body Weight	BW	kg	80	10	15	10
Exposure Duration	ED	years	21	4	6	4
Exposure Frequency - Soil [11]	EFsoil	days/year	270	10	270	10
Exposure Frequency - Subsistence Foods	EFfoods	days/year	365	10	365	10
Averaging Time (non-carcinogens)	ATnon-carcinogens	days	7,665	4	2,190	4
Averaging Time (carcinogens)	ATcarcinogens	days	25,550	10	25,550	10
Relative Bioavailability (general)	RBA	unitless	1	8	1	8
Relative Bioavailability (arsenic)	RBAAs	unitless	0.6	9	0.6	9
Ingestion Rates						
Soil - Incidental Ingestion	IRs	kg/day	0.0001	5	0.0002	5, 10
Subsistence Foods - Beaver	IRbeaver	kg/day	0.0129	6	0.00841	7
Subsistence Foods - Mallard Duck	IRduck	kg/day	0.00113	6	0.000740	7
Subsistence Foods – Pike	IRpike	kg/day	0.00909	6	0.00593	7
Subsistence Foods - Berries	IRberry	kg/day	0.0148	6	0.00968	7
Inhalation Factors						
Exposure Time	ET	hours/day	24	4	24	4
Exposure Frequency	EF	days/year	365	4	365	4
Exposure Duration [12]	ED	years	21	10	6	10
Averaging Time (non-carcinogens)	ATnon-carcinogens	hours (ED [years] x 365 days/year x 24 hours/day)	183,960	3	52,560	3
Averaging Time (carcinogens)	ATcarcinogens	hours (Lifetime [years] x 365 days/year x 24 hours/day)	613,200	10	613,200	10

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Notes:

[1] *The exposure assumptions presented are used to assess non-cancer and cancer risk. Default exposure parameters were selected preferentially from ADEC (2015) and then USEPA (2014). Parameters not available in these sources were selected from other agency guidance or peer-reviewed literature. Reference for each value is identified in the table and defined below.*

[2] *Assumed children were in the age group of 0 to 6 years old (USEPA 2011).*

[3] *USEPA (2011).*

[4] *Site-specific characteristics.*

[5] *USEPA (2014).*

[6] *Brown et al. (2012).*

[7] *Consumption rates for children are assumed to be 65% of adult consumption rates.*

[8] *USEPA (2007b).*

[9] *USEPA (2012).*

[10] *ADEC (2015).*

[11] *The soil exposure frequency is based on the climate zone of the proposed Project. Subsistence population soil exposure frequency is 270 days/year for the under 40-inch zone, in which the proposed Project is located.*

[12] *ADEC (2015) recommends an exposure duration for adults of 20 years and for children 6 years. However, because the Project Operations phase lasts 27 years, the exposure duration for adults was assumed to be 21 years, for a total of 27 years when adult and child exposure durations are summed.*

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5.5.2. *Non-Carcinogenic Exposure*

5.5.2.1. Exposure via Air Inhalation

Following USEPA (2009a) guidance, risk due to air exposure requires a calculation of the exposure concentration.

The equation for the exposure concentration at the point of exposure (µg/m^3) from inhalation of COPCs bound to $PM_{2.5}$ is (USEPA 2009a):

$$EC = \frac{CA \times ET \times EF \times ED}{AT} \quad \text{[Equation 3]}$$

where:

EC	= exposure concentration of COPC in air (µg/m^3)
C_{Air}	= concentration of COPC in air (µg/m^3)
ET	= exposure time (hours/day)
EF	= exposure frequency (days/year)
ED	= exposure duration (years)
AT	= averaging time (ED in years x 365 days/year x 24 hours/day)

5.5.2.2. Exposure via Soil Ingestion

The equation used to calculate the average daily dose (ADD) of COPCs (mg/kg BW/day) from ingestion of soil is (USEPA 1992b):

$$ADD = \frac{C_S \times IR_S \times EF \times ED}{BW \times AT} \quad \text{[Equation 4]}$$

where:

C_S	= concentration of COPC in soil (mg/kg)
IR_S	= soil ingestion rate (kg/day)
EF	= exposure frequency (days/year)
ED	= exposure duration (days)
BW	= body weight (kg)
AT	= averaging time (days)

The assumptions used in the calculation of the ADD of COPCs via soil ingestion are as follows:

- Baseline soil quality at the sampling sites is representative of baseline soil quality within the study area;
- Adults and children are exposed 270 days per year, the value recommended by ADEC (2015) for exposure in the under 40-inch zone;
- Children have a soil IR of 0.0002 kg/day and a body weight (BW) of 15 kg (ADEC 2015); and

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- Adults have a soil IR of 0.0001 kg/day and a BW of 80 kg (ADEC 2015).

5.5.2.3. Exposure via Subsistence Food Ingestion

The consumption rates of subsistence foods were based on per capita harvest rates (kg/year) of subsistence foods (i.e., northern pike, beaver, mallard duck, and berries) for eight communities in the Upper Kuskokwim group (Brown et al. 2012). These communities include Aniak, Chuathbaluk, Crooked Creek, Lower Kalskag, Red Devil, Sleetmute, Stony River, and Upper Kalskag. Because no information was provided to estimate the proportion of harvested food that was subsequently consumed, it was assumed, for the purposes of the HHRA, that all harvested food items were consumed. The use of harvest rates to estimate consumption rates is an overestimate; the study indicated that people do not consume all harvested food, and further, people may not necessarily consume the total amount of harvested food components (e.g., often just the fish fillet is consumed, not the entire fish). However, by utilizing the harvested amount to estimate intake, this HHRA overestimates potential exposures from this pathway: if no incremental risk is indicated by this approach, then groups ingesting only a portion of harvested foods are unlikely to be at risk.

Equation 4 was also used to calculate the ADD for COPCs except arsenic (mg/kg BW/day) from the ingestion of subsistence foods, by using the tissue concentration in place of the soil concentration and the ingestion rate for the specific food in place of the soil ingestion rate. To calculate the ADD for arsenic (mg/kg BW/day) from the ingestion of subsistence foods, the following equation was used:

$$ADD = \frac{(C_F \times IAF) \times IR_F \times EF \times ED}{BW \times AT} \qquad \text{[Equation 5]}$$

Where:

C_F = concentration of COPC in subsistence food (mg/kg)
IAF = Inorganic arsenic fraction in subsistence food (%)
IR_F = ingestion rate of subsistence foods (kg/day)
EF = exposure frequency (days/year)
ED = exposure duration (days)
BW = body weight (kg)
AT = averaging time (days)

The subsistence food consumption rates for children (0 to 6 years of age) were assumed to be 65% of an adult's rate, based on comparison of the overall food IR of adults to overall food IR of children. The total mean consumption rate from the mean per capita food intakes and body weights presented in the USEPA Exposure Factors Handbook (USEPA 2011) for adults was compared to those for children. For an adult, average total food consumption is 2,320 g/day (29 g/kg/day for an 80 kg adult). For children 1 to <3 years old, the average daily total food consumption is 1,559 g/day (113 g/kg-day and

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body weight 13.8 kg). For children 3 to <6 years old, the total food consumption is 1,469 g/day (79 g/kg-day and body weight 18.6 kg). The average of the two child IRs is 1,514 g/day. Dividing the mean total consumption rate for the two child categories (1 to <3 years old and 3 to <6 years old) by the total mean consumption rate for the adult indicates that children consume at a rate that is 65% of the adult rate. This factor is applied to the adult consumption rate for individual subsistence foods to obtain the corresponding child consumption rate.

5.5.3. Carcinogen Exposure

5.5.3.1. Inhalation

Arsenic is considered to be a carcinogen via the inhalation exposure route; however, baseline concentrations of arsenic bound to $PM_{2.5}$ were assumed to be zero (Section 5.3.1), thus there is no exposure to arsenic via inhalation under baseline conditions and no carcinogenic risk.

Under future conditions, the predicted annual average arsenic concentration bound to $PM_{2.5}$ (which is equivalent to the concentration in air) is 0.000018 µg/m³. Equation 3 was modified for carcinogens to use lifetime for the averaging time, in hours.

5.5.3.2. Ingestion

The exposure to carcinogens via ingestion was calculated with the lifetime average daily dose (LADD), using the following equation (USEPA 1992a):

$$LADD = \frac{C \times IR \times EF \times ED}{BW \times AT} \qquad \text{[Equation 6]}$$

Where:

C	= concentration of the COPC (mg/kg)
IR	= ingestion rate (kg/day)
EF	= exposure frequency (days/year)
ED	= exposure duration (days)
BW	= body weight (kg)
AT	= averaging time (for carcinogens, AT is lifetime) (days)

The exposure duration for the site was assumed to be 21 years for an adult and 6 years for a child (7,665 and 2,190 days, respectively). Receptor lifetime is assumed to be 70 years (ADEC 2015), which is equivalent to 25,550 days.

The concentrations of arsenic in the subsistence food items were adjusted to account for the amount of inorganic arsenic (see Section 5.3), which was used in the calculation of the LADD for subsistence foods.

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5.6. Dose and Concentration Estimates

The baseline inhalation exposure concentrations and ingestion doses from all pathways for adult and child human receptors are shown in Tables 5.6-1 and 5.6-2. Tables 5.6-3 and 5.6-4 show the future inhalation exposure concentrations and ingestion doses from all pathways for adult and child human receptors.

TABLE 5.6-1: BASELINE DOSE OF CONSTITUENTS OF POTENTIAL CONCERN FOR ADULT SUBSISTENCE

COPC	Oral – Soil ADD	Oral - Beaver ADD	Oral - Mallard Duck ADD	Oral - Pike ADD	Oral - Berries ADD	Inhalation EC
Antimony	4.56E-06	1.27E-05	1.15E-06	6.93E-07	1.00E-05	NA
Arsenic	1.40E-05	2.61E-06	1.70E-07	4.43E-06	3.21E-05	NA
Mercury	2.01E-07	NA	NA	NA	NA	8.40E-06
MeHg	8.09E-10	6.04E-07	5.48E-08	9.42E-06	4.70E-07	NA
COPC	**Oral – Soil LADD**	**Oral - Beaver LADD**	**Oral - Mallard Duck LADD**	**Oral - Pike LADD**	**Oral - Berries LADD**	**Inhalation EC**
Arsenic	4.19E-06	7.84E-07	5.09E-08	1.33E-06	9.64E-06	NA

COPC = constituent of potential concern
ADD = average daily dose (mg/kg BW/day)
EC = effect concentration (µg/m³)
LADD = lifetime average daily dose (mg/kg BW/day)
NA = Not applicable (mercury in biota assumed to be 100% MeHg; antimony and arsenic are negligible in baseline air; MeHg is not present in air)

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TABLE 5.6-2: BASELINE DOSE OF CONSTITUENTS OF POTENTIAL CONCERN FOR CHILD SUBSISTENCE

COPC	Oral - Soil ADD	Oral - Beaver ADD	Oral - Mallard Duck ADD	Oral - Pike ADD	Oral - Berries ADD	Inhalation EC
Antimony	4.86E-05	4.42E-05	4.01E-06	2.41E-06	3.48E-05	NA
Arsenic	1.49E-04	9.10E-06	5.90E-07	1.54E-05	1.12E-04	NA
Mercury	2.14E-06	NA	NA	NA	NA	8.40E-06
MeHg	8.63E-09	2.10E-06	1.91E-07	3.28E-05	1.64E-06	NA
COPC	**Oral - Soil LADD**	**Oral - Beaver LADD**	**Oral - Mallard Duck LADD**	**Oral - Pike LADD**	**Oral - Berries LADD**	**Inhalation EC**
Arsenic	1.28E-05	7.80E-07	5.06E-08	1.32E-06	9.59E-06	NA

COPC = constituent of potential concern
ADD = average daily dose (mg/kg BW/day)
EC = effect concentration (µg/m³)
NA = Not applicable (mercury in biota assumed to be 100% MeHg; antimony and arsenic are negligible in baseline air; MeHg is not present in air)

TABLE 5.6-3: FUTURE DOSE OF CONSTITUENTS OF POTENTIAL CONCERN FOR ADULT SUBSISTENCE

COPC	Oral - Soil ADD	Oral - Beaver ADD	Oral - Mallard Duck ADD	Oral - Pike ADD	Oral - Berries ADD	Inhalation EC
Antimony	4.56E-06	1.27E-05	1.15E-06	6.94E-07	1.00E-05	5.71E-07
Arsenic	1.41E-05	2.64E-06	1.71E-07	4.44E-06	3.25E-05	1.80E-05
Mercury	2.03E-07	NA	NA	NA	NA	8.46E-06
MeHg	8.49E-10	6.10E-07	5.54E-08	9.89E-06	4.94E-07	NA
COPC	**Oral - Soil LADD**	**Oral - Beaver LADD**	**Oral - Mallard Duck LADD**	**Oral - Pike LADD**	**Oral - Berries LADD**	**Inhalation EC**
Arsenic	4.24E-06	7.91E-07	5.13E-08	1.33E-06	9.75E-06	5.39E-06

COPC = constituent of potential concern
ADD = average daily dose (mg/kg BW/day)
EC = effect concentration (µg/m³)
LADD = lifetime average daily dose (mg/kg BW/day)
NA = Not applicable (mercury in biota assumed to be 100% MeHg; MeHg not present in air)

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TABLE 5.6-4: FUTURE DOSE OF CONSTITUENTS OF POTENTIAL CONCERN FOR CHILD SUBSISTENCE

COPC	Oral - Soil ADD	Oral - Beaver ADD	Oral - Mallard Duck ADD	Oral - Pike ADD	Oral - Berries ADD	Inhalation EC
Antimony	4.87E-05	4.43E-05	4.02E-06	2.42E-06	3.48E-05	5.71E-07
Arsenic	1.51E-04	9.18E-06	5.96E-07	1.55E-05	1.13E-04	1.80E-05
Mercury	2.16E-06	NA	NA	NA	NA	8.46E-06
MeHg	9.06E-09	2.12E-06	1.93E-07	3.44E-05	1.72E-06	NA
COPC	**Oral - Soil LADD**	**Oral - Beaver LADD**	**Oral - Mallard Duck LADD**	**Oral - Pike LADD**	**Oral - Berries LADD**	**Inhalation EC**
Arsenic	1.29E-05	7.87E-07	5.11E-08	1.33E-06	9.70E-06	1.54E-06

COPC = constituent of potential concern
ADD = average daily dose (mg/kg BW/day)
EC = effect concentration (µg/m³)
NA = Not applicable (mercury in biota assumed to be 100% MeHg; MeHg not present in air)

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6. TOXICITY ASSESSMENT

The toxicity assessment weighs the available and relevant evidence regarding the potential for constituents to cause adverse health effects in exposed individuals and provides a quantitative estimate of the relationship between the magnitude of exposure and the likelihood of adverse effects (USEPA 1989). A fundamental principle of toxicology is that the dose determines the severity of the effect. Accordingly, the toxicity criteria describe the quantitative relationship between the dose of a constituent and the type and incidence of the toxic effect. This relationship is referred to as the dose-response. Exposure to constituents can result in cancer or non-cancer effects, which are characterized separately. Essential dose-response criteria are the slope factor (SF) and unit risk factor (URF) used for assessing cancer risks, and the reference dose (RfD) and reference concentration (RfC) used for evaluating non-cancer effects.

The RfD is defined as the amount of COPC per unit body weight that can be taken into the body each day (e.g., mg/kg BW/day) without risk of adverse health effects. The RfC is defined as the amount of COPC (in milligrams per cubic meter) that can be taken into the body each day without risk of adverse health effects. A SF is the upper-bound estimate of the probability of a response-per-unit intake of material of concern over an average human lifetime. It is used to estimate an upper-bound probability of an individual developing cancer as a result of a lifetime exposure to a particular level of arsenic. Upper-bound estimates conservatively exaggerate the risk to ensure that the risk is not underestimated if the underlying model is incorrect.

The OSWER hierarchy (USEPA 2003) was used to select toxicity values for the HHRA, which prioritizes toxicity values from the USEPA (2017) Integrated Risk Information System (IRIS) database.

Toxicity information is typically derived from laboratory studies, where dose-response information is extrapolated from animal test subjects to humans by applying uncertainty or safety factors. In most cases, uncertainty factors of 100 to 1,000 are applied to the laboratory-derived NOAELs. A NOAEL is the highest concentration used in a toxicity test that results in no observed or measured chronic health effects. These uncertainty factors account for interspecies extrapolation and the protection of the most susceptible individuals in the population (i.e., children and the elderly). Therefore, toxicity values based on animal studies generally have large margins of safety to ensure that the toxicity or risk of a substance to people is not underestimated.

The toxicity values used in the HHRA are presented in Table 6.1-1.

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TABLE 6.1-1: TOXICITY VALUES FOR CONSTITUENTS OF POTENTIAL CONCERN

COPC	Oral RfD (mg/kg BW/day)	Inhalation RfC (µg/m³)	Cancer Slope Factor (mg/kg BW/day)⁻¹	Inhalation Unit Risk Factor (µg/m³)⁻¹	Reference
Antimony	0.0004	0.2	NA	NA	USEPA (2017) (oral); ATSDR (1992) (inhalation) [a]
Arsenic	0.0003	0.015	1.5	0.0043	USEPA (2017)
Mercury	0.0003	0.3	NA	NA	USEPA (2017)
MeHg	0.0001	-	NA	NA	USEPA (2017)

COPC = constituent of potential concern

RfD = reference dose

RfC = reference concentration

BW = body weight

NA = not applicable; not classified as a human carcinogen by USEPA.

(-) = not available

[a] *The USEPA has not derived an inhalation RfC for antimony.*

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7. RISK CHARACTERIZATION

Risk characterization integrates the exposure assessment and the toxicity information. Non-cancer and cancer health risks were calculated for each COPC and for each media and potentially complete and significant exposure pathway. Non-cancer hazard quotients (HQs) represent the ratio of the estimated dose from exposure to a constituent in a particular medium to the dose that is not expected to result in adverse health effects, other than cancer. Cancer risk estimates represent the potential for cancer effects by estimating the probability of developing cancer over a lifetime due to site exposures (e.g., a risk of 1×10^{-6} indicates a one in 1 million chance of developing cancer due to exposures at the site). Equations for developing non-cancer and cancer risk estimates are described below, followed by a results and discussion section.

7.1. Non-carcinogenic Hazard Equations

The potential for adverse health effects other than carcinogenic effects (i.e., non-carcinogenic effects) is characterized by dividing estimated constituent doses (ADDs) or exposure concentrations (ECs) in air, by constituent-specific RfDs (for ADDs) or RfCs (for ECs). The resulting ratio is the HQ, which is derived as follows (USEPA 1992a):

$$HQ = \frac{ADD\ or\ EC}{RfD\ or\ RfC} \qquad \text{[Equation 7]}$$

where:

ADD = average daily dose (mg/kg BW/day)
EC = exposure concentration (µg/m^3)
RfD = reference dose (mg/kg BW/day)$^{-1}$
RfC = reference concentration (µg/m^3)$^{-1}$

A toxic effect can only occur if the metal is absorbed into the bloodstream. Not all constituents that are ingested or inhaled are subsequently absorbed. The fraction of constituents that are absorbed into the bloodstream by a receptor is termed the "bioavailable" fraction. USEPA (2007b, 2012) provided guidance on incorporating bioavailability estimates of metals in soil that might be ingested and subsequently absorbed via the gastrointestinal tract. The equation is:

$$HQ = \frac{ADD \times RBA}{RfD} \qquad \text{[Equation 8]}$$

where:

ADD = average daily dose (mg/kg BW/day)
RBA = relative bioavailability from the gastrointestinal tract (unitless)
RfD = reference dose (mg/kg BW/day)$^{-1}$

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Bioavailability was not specifically measured for samples in and around the proposed Project area. However, based on extensive literature review, USEPA (2012) has developed a recommended soil arsenic relative bioavailability factor of 0.6, a conservative, upper-end mean of measured relative bioavailability factors for different arsenic sources in soil. For antimony, mercury, and MeHg, bioavailability was assumed to be 100% (or a factor of 1.0), as no guidance is available for these constituents.

For a risk assessment that considers all potential exposure sources, doses and risk, USEPA's (1989) risk assessment guidelines consider the additive effects associated with simultaneous exposure to all constituents by summing HQs across exposure pathways and constituents to estimate the total hazard index (HI). This summation conservatively assumes that the toxic effects of all constituents would be additive or, in other words, that all constituents cause the same toxic effect and act by the same mechanism. For non-carcinogens, summing HQ values across different chemicals is properly applied only to compounds that induce the same effect by the same mechanism of action. Consequently, summation of HQ values for compounds that are not expected to include the same type of effects or that do not act by the same mechanisms could overestimate the potential for effects. Thus, all of the total HI values in this report, which sum HQ values across multiple metals, are likely to overestimate the true level of human health non-cancer risk.

7.2. Carcinogenic Risk Equations

The potential for carcinogenic effects is evaluated by estimating the probability of developing cancer over a lifetime based on exposure assumptions and constituent-specific toxicity criteria. The increased likelihood of developing cancer from exposure to a particular constituent is defined as the excess cancer risk (CR). Excess CR is the risk in excess of a background CR for subsistence residents.

Of the COPCs evaluated in this HHRA, arsenic (in the inorganic form) was recognized as a potential human carcinogen. CR estimates for ingestion exposures are the product of exposure assumptions (i.e., intake) and the constituent-specific SF, while CR estimates for inhalation exposures are the product of ECs and URFs. Excess lifetime CRs were estimated by multiplying the ingestion LADD or the inhalation EC by the cancer SF or URF, as follows:

$$\text{CR} = \text{LADD or EC} \times \text{SF or URF} \qquad \text{[Equation 9]}$$

where:

LADD = lifetime average daily dose (mg/kg BW/day)
EC = exposure concentration (µg/m^3)
SF = cancer slope factor (mg/kg BW/day)$^{-1}$
URF = cancer unit risk factor (µg/m^3)$^{-1}$

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7.3. Risk Characterization Results and General Discussion

USEPA (1991) provides guidance on the role of the HHRA in supporting risk management decisions, and in particular, evaluating whether a response action is necessary. Though this guidance was originally developed for Superfund remedial investigations, it provides the frame of reference used by regulatory agencies to evaluate potential health effects of environmental impacts. An HQ or HI less than 1 indicates a noncancer effect is highly unlikely. For cancer risk, the "target range" is defined as "an excess upper-bound lifetime cancer risk to an individual of between 10^{-4} and 10^{-6}," or 1 in 10,000 to 1 in 1,000,000.

Additionally, the focus and purpose of this HHRA was to evaluate the potential incremental risk resulting from the proposed Project; therefore, the most relevant comparison was the incremental change in HQ, HI, and cancer probability estimates. For purposes of the HHRA, incremental changes in risk were considered substantial if:

- Non-cancer risks (i.e., HQs or HIs) changed from less than 1 to greater than 1 (based on USEPA (1989) guidance, HQs less than 1 indicate a an effect is very unlikely); or
- Cancer estimates increased in the risk assessment by 10-fold or more (for example, if baseline cancer risks are $1x10^{-6}$ and future cancer risks are $1x10^{-5}$ or greater).

Non-cancer and cancer risk estimates are shown in Tables 7.3-1 through 7.3-5.

As shown, even when incorporating the conservative assumptions of the HHRA, HQs and HIs were equal to or less than 1, indicating that noncancer effects are highly unlikely. The conservative assumptions were incorporated into this HHRA to prevent Type II errors, which are the elimination of a constituent, area, or activity from further consideration when, in fact, there should be a concern (i.e., false-negative conclusion). In the risk assessment process, uncertainties are handled conservatively (i.e., health-protective) estimates of exposure. This strategy is more likely to produce false-positive errors than false-negative errors. Particularly for this HHRA, a number of conservative estimates were made to assure that risk predictions erred on the side of Type I errors (i.e., false-positive conclusion) rather than Type II.

Non-cancer risks related to both THg and MeHg were low, with all HQs and HIs less than 1. Baseline risk estimates are consistent with a mercury hair study completed by the ADHSS. The ADHSS conducted MeHg testing of hair samples from pregnant women in selected communities including the Upper Kuskokwim River region communities, between May and September 2012. A total of 186 hair samples were obtained from eight Upper Kuskokwim River communities. Every study participant had a hair mercury level that was below the ATSDR NOAEL (15.3 ppm), as well as the Environmental Public Health Program cut-off for follow-up (5 ppm) (ADHSS 2013, as cited in the DEIS).

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In the case of cancer risk estimates for arsenic, both baseline and future risk estimates ranged between $2x10^{-5}$ and $5x10^{-5}$, which is within the USEPA risk management range of $1x10^{-4}$ to $1x10^{-6}$. Future estimates of cancer risk are estimated to increase from baseline results by less than $1x10^{-6}$, which is below the USEPA risk management range, and is considered a negligible incremental increase. Cancer SFs were used to estimate an upper-bound probability of an individual developing cancer as a result of a lifetime of exposure to arsenic. Upper-bound estimates conservatively exaggerate the risk to ensure that the risk is not underestimated if the underlying model is incorrect.

Arsenic is a naturally occurring metal often found at elevated concentrations throughout Alaska, as described in Title 18 of the Alaska Administrative Code, Chapter 75.341(c). Baseline concentrations of arsenic are consistent with regional, state and nationally published studies of naturally occurring arsenic in soil (Gough et al. 1988). Due to the prevalence of naturally occurring arsenic in Alaskan soil, ADEC recommends that cumulative risk calculations do not include risk contributions from naturally occurring arsenic sources (ADEC 2009). Statistical comparisons of significance between baseline and future arsenic concentrations cannot be made because only a single future soil arsenic concentration was estimated. However, if baseline cancer risk estimates are subtracted from future cancer risk estimates, the resulting excess cancer risk for adults due to Project-related exposure would be $5x10^{-7}$, well below acceptable risk targets.

Other uncertainties related to the arsenic ingestion SF, as discussed in Section 8, likely result in an overprediction of potential cancer risk. Given that the overestimated potential current and future risks are within the risk management range and are related to naturally occurring levels of arsenic, unacceptable cancer risk due to arsenic exposure is unlikely.

7.4. Risks due to Fish Consumption

This HHRA evaluated risks due to northern pike fish consumption. EPCs were developed based on this resident fish species to estimate the incremental impact of proposed Project-specific COPCs. Resident fish were incorporated into the HHRA because of their relatively greater exposure period compared to migratory fish. While migratory fish may be exposed to proposed Project-related constituents while present in the study area, the exposure duration would be much less than for resident fish. As a result, migratory fish originating from the study area that are then harvested as returning adults pose a lower exposure of COPCs from the study area to consumers than harvesting resident fish. Further discussion on potential risks of salmon species are discussed in the next section.

Northern pike, a large, relatively long-lived top predator that is found in the Crooked Creek watershed, was used to estimate fish EPCs and assess risks associated with subsistence fishing. Top predators, such as northern pike, also bioaccumulate mercury to a greater degree than lower-trophic level species. Tissue burdens for northern pike were

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estimated by applying trophic transfer factors to sculpin data collected for the proposed Project. Risk estimates for northern pike indicated that both baseline and future HQs are at or less than 1, indicating that non-cancer effects are unlikely from northern pike consumption.

Estimates of future northern pike concentrations were also compared to the State of Alaska (2016) fish consumption advisory for northern pike that would be harvested from the Kuskokwim River in the vicinity of the proposed Project. The mean northern pike tissue mercury concentrations from different water bodies identified in the advisory range from 0.11 to 0.61 mg/kg ww. The mercury concentration in the one adult northern pike tissue sample collected within the study area falls within this range (0.421 mg/kg ww). When mean mercury concentrations in northern pike range from >0.34 to 0.46 mg/kg ww, the State of Alaska (2016) recommends limiting fish consumption to 0.068 kg/day. This consumption rate is higher than the estimated adult consumption rate for northern pike that was used in the HHRA (0.0091 kg/day), which is the average consumption rate of northern pike for eight communities in the Central Kuskokwim River Drainage (Brown et al. 2012). Therefore, subsistence populations currently consume northern pike at rates well below the northern pike consumption advisory level for the State of Alaska, and consumption would be expected to remain below the advisory level in the future.

As reflected in the DEIS comments, there is public concern regarding constituents in salmon species, which are a primary subsistence food in the region. Salmon species are present within the study area, including coho salmon. However, within the study area, only juvenile coho (and other species of) salmon reside within the Crooked Creek drainage system for extended periods. Adults, rather than juvenile species, are harvested for consumption. Juveniles migrate out of the freshwater system at an early age, spending the majority of their lifetimes in marine environments. These migratory fish gain the bulk of their body mass over a much larger exposure area (marine waters) that is entirely outside the study area. Because the exposure conditions of salmon are largely unrelated to the study area, the HHRA did not quantify risk due to salmon ingestion.

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TABLE 7.3-1. BASELINE NON-CANCER RISK CHARACTERIZATION FOR ADULTS IN SUBSISTENCE POPULATIONS

COPC	Oral - Soil HQ	Oral - Beaver HQ	Oral - Mallard Duck HQ	Oral - Pike HQ	Oral – Berries HQ	Inhalation HQ	Total HI
Antimony	0.01	0.03	0.003	0.002	0.02	NA	0.07
Arsenic	0.03	0.01	0.001	0.01	0.1	NA	0.2
Mercury	0.0007	NA	NA	NA	NA	0.00003	0.0007
MeHg	0.000008	0.006	0.0005	0.09	0.005	NA	0.1
Final HI							**0.3**

COPC = constituent of potential concern

HQ = hazard quotient

HI = hazard index

NA = Not applicable (mercury in biota assumed to be 100% MeHg; antimony and arsenic are negligible in baseline air; MeHg is not present in air)

TABLE 7.3-2. BASELINE NON-CANCER RISK CHARACTERIZATION FOR CHILDREN IN SUBSISTENCE POPULATIONS

COPC	Oral - Soil HQ	Oral - Beaver HQ	Oral - Mallard Duck HQ	Oral - Pike HQ	Oral – Berries HQ	Inhalation HQ	Total HI
Antimony	0.1	0.1	0.01	0.006	0.09	NA	0.3
Arsenic	0.3	0.03	0.002	0.05	0.4	NA	0.8
Mercury	0.007	NA	NA	NA	NA	0.00003	0.007
MeHg	0.00009	0.02	0.002	0.3	0.02	NA	0.4
Final HI							**1**

COPC = constituent of potential concern

HQ = hazard quotient

HI = hazard index

NA = Not applicable (mercury in biota assumed to be 100% MeHg; antimony and arsenic are negligible in baseline air; MeHg is not present in air)

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TABLE 7.3-3. FUTURE NON-CANCER RISK CHARACTERIZATION FOR ADULTS IN SUBSISTENCE POPULATIONS

COPC	Oral - Soil HQ	Oral - Beaver HQ	Oral - Mallard Duck HQ	Oral - Pike HQ	Oral - Berries HQ	Inhalation HQ	Total HI
Antimony	0.01	0.03	0.003	0.002	0.03	0.000003	0.07
Arsenic	0.03	0.01	0.001	0.01	0.1	0.001	0.2
Mercury	0.0007	NA	NA	NA	NA	0.000032	0.0007
MeHg	0.000008	0.006	0.0006	0.1	0.005	NA	0.1
Final HI							**0.3**

COPC = constituent of potential concern

HQ = hazard quotient

HI = hazard index

NA = Not applicable (mercury in biota assumed to be 100% MeHg; MeHg is not present in air)

TABLE 7.3-4. FUTURE NON-CANCER RISK CHARACTERIZATION FOR CHILDREN IN SUBSISTENCE POPULATIONS

COPC	Oral - Soil HQ	Oral - Beaver HQ	Oral - Mallard Duck HQ	Oral - Pike HQ	Oral - Berries HQ	Inhalation HQ	Total HI
Antimony	0.1	0.1	0.01	0.006	0.09	0.000003	0.3
Arsenic	0.3	0.03	0.002	0.05	0.4	0.001	0.8
Mercury	0.007	NA	NA	NA	NA	0.000032	0.007
MeHg	0.00009	0.02	0.002	0.3	0.02	NA	0.4
Final HI							**1**

COPC = constituent of potential concern

HQ = hazard quotient

HI = hazard index

NA = Not applicable (mercury in biota assumed to be 100% MeHg; MeHg is not present in air)

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TABLE 7.3-5. BASELINE AND FUTURE CANCER RISK CHARACTERIZATION

COPC	Oral - Soil CR	Oral - Beaver CR	Oral - Mallard Duck CR	Oral - Pike CR	Oral - Berries CR	Inhalation CR	Total CR
Baseline Arsenic - Adults	3.8E-06	1.2E-06	7.6E-08	2.0E-06	1.4E-05	NA	**2.E-05**
Baseline Arsenic - Children	1.1E-05	1.2E-06	7.6E-08	2.0E-06	1.4E-05	NA	**3.E-05**
Total Baseline Cancer Risk	1.5E-05	2.3E-06	1.5E-07	4.0E-06	2.9E-05	NA	**5.E-05**
Future Arsenic - Adults	3.8E-06	1.2E-06	7.7E-08	2.0E-06	1.5E-05	2.3E-08	**2.E-05**
Future Arsenic - Children	1.2E-05	1.2E-06	7.7E-08	2.0E-06	1.5E-05	6.6E-09	**3.E-05**
Total Future Cancer Risk	1.5E-05	2.4E-06	1.5E-07	4.0E-06	2.9E-05	3.0E-08	**5.E-05**

NA = Not applicable (arsenic concentrations negligible in air)

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8. UNCERTAINTY ANALYSIS

8.1. General Discussion

Estimating and evaluating health risks from exposure to environmental constituents is a complex process with inherent uncertainties. Uncertainty reflects limitations in knowledge, and simplifying assumptions must be made to quantify health risks. The uncertainty analysis provides decision makers with a broader understanding of the basis of the risk assessment, and how changes in key assumptions can change risk assessment results. Many uncertainties in selection of HHRA input parameters are identified throughout this report. This section summarizes several key areas of uncertainty in the analysis.

The process of evaluating human health risks from exposure to environmental media involves multiple steps, each containing inherent uncertainties that ultimately affect the final risk estimates. These uncertainties may be related to the collection of samples, laboratory analysis, estimation of potential exposures, and derivation of toxicity values, resulting in either an over- or under-estimation of risk. However, for the present assessment, where uncertainties existed, assumptions made lead to overestimating potential risks.

Uncertainty in the risk assessment produces the potential for two kinds of errors. A Type I error is the identification of a specific constituent, area, or activity as a health concern when, in fact, it is not a concern (i.e., false-positive conclusion). A Type II error is the elimination of a constituent, area, or activity from further consideration when, in fact, there should be a concern (i.e., false-negative conclusion). In the risk assessment process, uncertainties are handled conservatively (i.e., health-protective choices are preferentially made). This strategy is more likely to produce false-positive errors than false-negative errors and was applied in this HHRA.

8.1.1. Uncertainties in Media Concentrations

Primary media data collected in the study area were used to estimate baseline EPCs in soil and air, and in the development of BAFs for biota. Future EPCs rely on models to estimate future concentrations using certain assumptions that have some uncertainty.

In baseline estimates of EPCs, samples are assumed to be representative of concentrations found in the environment that receptors may be exposed to. Uncertainties are always present in the representativeness of samples. Sample sizes for soil, surface water, and sediment were considered to be adequate to represent conditions in the study area. This HHRA used only data that gave accurate chemical concentrations and had associated laboratory reports with which to verify sample qualifiers and reported detection limits. The datasets collected for the proposed Project included

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method detection limits and sample quantitation limits below ADEC and/or USEPA criteria for their media, and included explanations for qualified data.

Where possible, site-specific baseline data were compared to other regional data, and as noted throughout this report, baseline concentrations were generally consistent with other regional studies.

Uncertainties exist in estimating future EPCs. As noted throughout this report, uncertainties are associated with mechanisms of future fate and transport, including deposition onto surfaces, uptake into biota, and transformations in soil and aquatic systems. Simple, conservative models were preferred over complex models, both due to the volume of data that would be required in the latter (thus generating new uncertainties in data representativeness and robustness), as well as the lack of better predictive power demonstrated by the more complex models. In the case of mercury, key conservative approaches taken to estimate future EPCs in soil and biota included: estimating future soil/sediment EPCs based on an upper bound methylation rate of 1% (lower rates were calculated by ProUCL, 0.3 to 0.5%); estimating biota EPCs based on predicted methylmercury content in primary media; and use of the same factor for increases associated with sulfate deposition and the methylation rate.

Uncertainties are related to BAFs used to model biota concentrations, including the use of median concentrations to develop BAFs. It was also conservatively assumed that mercury in biota was in the form of MeHg (rather than THg, which has a lower toxicity and bioavailability), even though there are varying proportions reported in the literature for various species of plants and wildlife.

In estimating fish EPCs, using data for resident fish was preferred, because of their greater exposure period compared to migratory fish. For this reason, northern pike was preferred to estimate fish EPCs, because it is a resident, large, relatively long-lived top predator. However, the limited dataset for northern pike resulted in uncertainties in estimating baseline and future tissue concentrations. Because of this, available data for other residential fish species was used. As noted in Section 5.2.2, the sculpin dataset was appropriately large to develop BAFs. Using a method consistent with other regional studies (Ecology and Environment 2014), sculpin BAFs were derived using the project-specific dataset. Northern pike concentrations were then estimated using the sculpin-based BAF and applying a food chain multiplier (FCM) of 3. Although there is some uncertainty in this method, use of this FCM is accepted to account for biomagnification between sculpin and northern pike, as northern pike is one trophic level higher than sculpin (McGeer 2004).

In estimating future air exposures, several assumptions were made that likely overestimate the $PM_{2.5}$ concentrations of COPCs: The air quality model simulated impacts from the mine during the projected peak emission year (mine year 16); the receptor location in Crooked Creek with the highest average $PM_{2.5}$ concentration was

used to estimate COPCs in the $PM_{2.5}$ material originating from the proposed Project; it was assumed that all exposure throughout the mine life was at these concentrations.

8.1.2. Uncertainties with Subsistence Population Assumptions

The HHRA evaluated subsistence populations because this receptor group is thought to have the highest exposure potential to COPCs. Subsistence population intake rates of locally caught food items are typically higher than the general population (USEPA 2011). These populations are also exposed via direct contact with abiotic media (e.g., incidental ingestion of soil).

For the purposes of the HHRA, a generalized subsistence group was developed to quantify risks. This generalized subsistence group is assumed to live in the study area (therefore evaluated for year-round inhalation and soil ingestion risks), and to hunt, fish, and gather only within the study area. Because not all individual species or wildlife trophic components of an ecological system are practical or potentially necessary in order to quantify incremental risk, representative species were chosen, which includes a level of uncertainty with respect to whether all substantial risks were identified and quantified.

Based on review of the subsistence food items harvested by the Upper Kuskokwim group (see Section 3.21 in the DEIS), and accounting for physiological considerations and residency in the study area, the HHRA quantifies the incremental risk of subsistence population consumption of items thought to best represent types of foods that could be frequently harvested within the study area.

The comprehensive study by Brown et al. (2012) was used to develop area-specific subsistence intake estimates, based on Upper Kuskokwim harvest patterns and rates. However, the study reported only harvest rates, rather than consumption rates, and it was conservatively assumed that all harvested food was consumed. Additionally, individual harvest patterns and annual variability were not considered for the HHRA; instead, a very conservative assumption was incorporated that all harvested items quantified in the HHRA would be harvested within the study area at the same annual rate. Because these groups also hunt, fish, and gather outside the study area to varying extents, these assumptions overestimate the exposure frequency and duration in the study area. However, by utilizing the harvested amount to estimate intake, this HHRA provides a "health-protective" estimate of potential exposures from this pathway: if no incremental risk is indicated by this approach, then groups ingesting only a portion of harvested foods are unlikely to be at risk.

Only two subsistence populations live within the study area: the village of Crooked Creek, and Georgetown. Inhalation risk was specifically quantified for air concentrations predicted for the Crooked Creek watershed, which includes the Crooked Creek village

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area. This village is within the watershed predicted to have the highest incremental increases in COPC concentrations related to the proposed Project. This assumption will over-predict exposures by other subsistence groups, but addresses populations with the highest potential exposure.

Other exposure rates, body weights, and the proportion of subsistence foods consumed by children as a function of adult intake, were based on USEPA and ADEC guidance. These parameters are based on national studies that may not be representative of subsistence populations specifically for the Upper Kuskokwim region.

8.1.3. Uncertainties in Toxicity Values

There is uncertainty associated with estimating toxicity values by extrapolating potential effects on humans from animal studies in the laboratory. In developing toxicity values, it is standard practice to assume that people are more sensitive to the toxic effects of a substance than laboratory animals. Therefore, the toxicity benchmarks for human health are set at much lower levels than the animal benchmarks (by applying a safety factor of 100 to 1,000 or more). This large margin ensures that doses less than the toxicity value are safe and that minor exceedances of these benchmarks are unlikely to cause adverse health effects.

8.1.3.1. Uncertainties in Evaluating Effects of Multiple Constituents

Toxicity values are derived for individual constituents. However, it is recognized that multiple constituents may be present within a food item and interactions between compounds may result in additivity (overall effect is the sum of the individual effects), antagonism (overall effect less than the sum of the individual effects), synergism (overall effect is greater than the sum of the individual effects), or potentiation (presence of one constituent results in toxicity of another constituent that otherwise would have been safe). Many of these interactions are poorly understood or remain unknown by modern science. Furthermore, in natural systems numerous physical variables (e.g., media temperature, pH, salinity, hardness) can accelerate or impede these constituent interactions. In most cases, available toxicity data are not sufficient to define what type of interaction is expected, so USEPA generally assumes effects are additive for non-carcinogens that act on the same target tissue and for carcinogens (all target tissues). Because documented cases of synergistic interactions between chemicals are relatively uncommon, this approach is likely to be conservative for most chemicals.

8.1.3.2. Uncertainties in Arsenic Cancer Toxicity Values

Cancer SFs were used to estimate an upper-bound probability of an individual developing cancer as a result of a lifetime of exposure to arsenic through inhalation and ingestion. Upper-bound estimates conservatively overestimate the risk to ensure that the risk is not underestimated if the underlying model is incorrect. The arsenic ingestion slope factor is based on one affected population in Taiwan concerning non-fatal skin

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cancer incidence, age, and level of exposure to arsenic via drinking water rather than food or soil ingestion (USEPA 2017). The predominant form of arsenic in the drinking water was in inorganic form (arsenic trioxide), which is a highly toxic form of arsenic and not the predominant form of arsenic that occurs in the study area. The confidence in the oral slope factor is considered to be low overall. Studies that show the strongest link between ingestion of arsenic and cancer involve ingestion of inorganic arsenic at elevated levels in drinking water (Naujokas et al. 2013). Arsenic in soil is less bioavailable, and an adjustment is made to the soil exposure concentration accordingly. There are additional uncertainties estimating cancer risk from arsenic because the mechanism of action in causing human cancers is not known, and studies on arsenic mutagenicity are inconclusive (USEPA 2017). However, safety factors included in the slope factor provide a conservative estimate of risk.

8.1.4. Uncertainties in Risk Estimates

A number of uncertainties are present in the risk characterization approach for non-cancer and cancer health effects.

First, because risk estimates for a chemical are derived by combining uncertain estimates of exposure and toxicity (see above), the risk estimates for each chemical are more uncertain than either the exposure estimate or the toxicity estimate alone. However, even if the risk estimates for individual chemicals were quite certain, there is considerable uncertainty in how to combine risk estimates across different chemicals. As noted above, the effects caused by one chemical may or may not influence the effects caused by other chemicals. In some cases, the effects of one chemical may interact with effects of other chemicals, causing responses that are approximately additive, greater than additive (synergistic), or less than additive (antagonistic).

For non-carcinogens, summing HQ values across different chemicals is properly applied only to compounds that induce the same effect by the same mechanism of action. Consequently, summation of HQ values for compounds that are not expected to include the same type of effects or that do not act by the same mechanisms could overestimate the potential for effects. Thus, all the HI values in this report, which sum HQ values across multiple metals, are likely to overestimate the true level of human health non-cancer risk.

8.2. Sensitivity Analysis

To investigate the sensitivity of the risk calculations to input parameters, the following sensitivity analyses were conducted:

1. Modification of ingestion rates: the soil and subsistence food ingestion rates were decreased by 25% and 50% from those listed in Table 5.5-1 for both baseline and future scenarios.
2. Modification of EPCs: the soil, sediment, and air EPCs were increased by 25% and decreased by 25% from those listed in Tables 5.3-1 and 5.4-1. Changes in soil

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and sediment EPCs are reflected in biota EPCs modeled using these concentrations and BAFs.

8.2.1. *Modification of Ingestion Rates*

To develop biota ingestion rates, it was conservatively assumed that the entire harvest amounts reported in Brown et al. (2012) were consumed, and that the food items were harvested only within the study area; however, it is likely that both assumptions and, therefore, the consumption rates are overestimates. The consumption rate was amortized over an entire year to determine the daily ingestion rate. For the purposes of the analysis, only the HQs for were compared. Risk results for the child subsistence user (the more sensitive receptor) under baseline and future scenarios using these lower ingestion rates are shown in Tables 8.2-1 and 8.2-2.

The effect of reducing all food and soil ingestion rates by 25% (meaning 25% of ingestion occurs outside the study area) generally resulted in only a slight decrease in child subsistence HQ values and a similar overall HI. If it is assumed that 50% of ingestion occurs is associated with outside the study area, the overall HQ drops below 1.0. The effect on individual exposure pathway HQs depends on the constituent being evaluated and is shown in the tables.

TABLE 8.2-1. BASELINE RISK CHARACTERIZATION, CHILD SUBSISTENCE, DECREASED INGESTION RATES

COPC	Oral - Soil HQ	Oral - Beaver HQ	Oral - Mallard Duck HQ	Oral - Pike HQ	Oral - Berries HQ	Inhalation HQ	Total HI
Antimony	0.12	0.1	0.01	0.006	0.09	NA	0.3
Arsenic	0.3	0.03	0.002	0.05	0.4	NA	0.8
Mercury	0.007	NA	NA	NA	NA	0.00003	0.007
MeHg	0.00009	0.02	0.002	0.3	0.02	NA	0.4
Final HI							**1**
							IR 25% lower
Antimony	0.09	0.10	0.009	0.005	0.07	NA	0.3
Arsenic	0.2	0.03	0.002	0.04	0.3	NA	0.6
Mercury	0.005	NA	NA	NA	NA	0.00003	0.005
MeHg	0.00006	0.02	0.002	0.3	0.014	NA	0.3
Final HI							**1**
							IR 50% lower
Antimony	0.08	0.07	0.006	0.004	0.06	NA	0.2
Arsenic	0.2	0.02	0.001	0.03	0.2	NA	0.5
Mercury	0.005	NA	NA	NA	NA	0.00003	0.005
MeHg	0.00006	0.01	0.001	0.2	0.011	NA	0.2
Final HI							**0.9**

COPC = constituent of potential concern
HQ = hazard quotient; HI = hazard index
IR = ingestion rate
NA = Not applicable

TABLE 8.2-2. FUTURE RISK CHARACTERIZATION, CHILD SUBSISTENCE, DECREASED INGESTION RATES

COPC	Oral - Soil HQ	Oral - Beaver HQ	Oral - Mallard Duck HQ	Oral - Pike HQ	Oral - Berries HQ	Inhalation HQ	Total HI
Antimony	0.1	0.1	0.01	0.006	0.09	0.000003	0.3
Arsenic	0.3	0.03	0.002	0.05	0.4	0.001	0.8
Mercury	0.007	NA	NA	NA	NA	0.0000282	0.007
MeHg	0.00009	0.02	0.002	0.3	0.02	NA	0.4
Final HI							**1**
							IR 25% lower
Antimony	0.1	0.1	0.01	0.005	0.07	0.000003	0.3
Arsenic	0.2	0.02	0.001	0.04	0.3	0.001	0.6
Mercury	0.005	NA	NA	NA	NA	0.0000282	0.005
MeHg	0.00007	0.02	0.001	0.3	0.01	NA	0.3
Final HI							**1**
							IR 50% lower
Antimony	0.1	0.1	0.01	0.003	0.04	0.000003	0.2
Arsenic	0.2	0.02	0.001	0.03	0.2	0.001	0.4
Mercury	0.004	NA	NA	NA	NA	0.0000282	0.004
MeHg	0.00005	0.01	0.001	0.2	0.01	NA	0.2
Final HI							**0.7**

COPC = constituent of potential concern
HQ = hazard quotient; HI = hazard index
IR = ingestion rate
NA = Not applicable

8.2.2. Modification of Exposure Point Concentrations

Determining EPCs, particularly for a future condition that does not yet exist, inherently contains uncertainties because it relies on models rather than empirical data. A number of conservative assumptions were included in this HHRA to estimate future concentrations. A sensitivity analysis was run where future concentrations of soil and sediment EPCs were increased and decreased by 25% to assess the effect on future risk calculations. Increasing or decreasing those primary media EPCs also affects estimated biota concentrations, which are derived from soil and sediment EPCs and BAFs. Table 8.2-3 compares the estimated baseline HQs for children when the baseline EPCs in Table 5.4-1 are increased and decreased by 25%, and Table 8.2-4 provides the same comparison for the future scenario. As shown, risk calculations are not very sensitive to changes in EPCs, and this indicates that if the models used to predict future EPCs are inaccurate by a large margin, the results do not change significantly.

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TABLE 8.2-3. BASELINE RISK CHARACTERIZATION, CHILD SUBSISTENCE, CHANGED EPCS

COPC	Oral - Soil HQ	Oral - Beaver HQ	Oral - Mallard Duck HQ	Oral - Pike HQ	Oral - Berries HQ	Inhalation HQ	Total HI
Antimony	0.12	0.1	0.01	0.006	0.09	NA	0.3
Arsenic	0.3	0.03	0.002	0.05	0.4	NA	0.8
Mercury	0.007	NA	NA	NA	NA	0.00003	0.007
MeHg	0.00009	0.02	0.002	0.3	0.02	NA	0.4
Final HI							**1**
							EPC 25% lower
Antimony	0.09	0.10	0.009	0.005	0.07	NA	0.3
Arsenic	0.2	0.03	0.002	0.04	0.3	NA	0.6
Mercury	0.005	NA	NA	NA	NA	0.00003	0.005
MeHg	0.00006	0.02	0.002	0.3	0.014	NA	0.3
Final HI							**1**
							EPC 25% higher
Antimony	0.15	0.14	0.012	0.008	0.11	NA	0.4
Arsenic	0.4	0.04	0.002	0.06	0.5	NA	0.9
Mercury	0.009	NA	NA	NA	NA	0.00004	0.009
MeHg	0.00011	0.03	0.002	0.4	0.020	NA	0.5
Final HI							**2**

COPC = constituent of potential concern
EPC = exposure point concentration
HQ = hazard quotient; HI = hazard index
NA = Not applicable

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TABLE 8.2-4. FUTURE RISK CHARACTERIZATION, CHILD SUBSISTENCE, CHANGED EPCS

COPC	Oral - Soil HQ	Oral - Beaver HQ	Oral - Mallard Duck HQ	Oral - Pike HQ	Oral - Berries HQ	Inhalation HQ	Total HI
Antimony	0.12	0.1	0.01	0.006	0.09	0.000003	0.3
Arsenic	0.3	0.03	0.002	0.05	0.4	0.001	0.8
Mercury	0.007	NA	NA	NA	NA	0.0000282	0.007
MeHg	0.00009	0.02	0.002	0.3	0.02	NA	0.4
Final HI							**1**
							EPC 25% lower
Antimony	0.09	0.08	0.008	0.004	0.07	0.000002	0.3
Arsenic	0.2	0.02	0.002	0.04	0.3	0.0009	0.6
Mercury	0.005	NA	NA	NA	NA	0.0000281	0.005
MeHg	0.00007	0.02	0.001	0.3	0.01	NA	0.3
Final HI							**1**
							EPC 25% higher
Antimony	0.15	0.14	0.013	0.004	0.11	0.000004	0.4
Arsenic	0.4	0.04	0.002	0.04	0.5	0.0015	0.9
Mercury	0.009	NA	NA	NA	NA	0.0000282	0.009
MeHg	0.00011	0.03	0.002	0.4	0.02	NA	0.5
Final HI							**2**

COPC = constituent of potential concern
EPC = exposure point concentration
HQ = hazard quotient; HI = hazard index
NA = Not applicable

9. SUMMARY CONCLUSION

This HHRA evaluated the likelihood of adverse effects to subsistence populations that could be exposed to constituents released into the environment by the operation of the proposed Donlin Gold Project. Risks from antimony, arsenic, and mercury were quantified in the HHRA. A health-protective approach was taken to quantify exposure to these constituents. Highly conservative exposure assumptions were used to calculate potential incremental risk to subsistence populations that may be hunting, gathering, or living in the area around the proposed Project.

This HHRA demonstrates that the small increases in constituent concentrations estimated to occur outside of the Core Operating Area due to Project-related activities will not result in unacceptable risks to human populations who would have the highest exposure. Based on the exposures to the conservatively defined receptors analyzed in this health-protective HHRA, other human populations, such as residents in the region, would not be expected to be exposed to unacceptable risk due to exposure to Project-related concentrations of mercury, arsenic, or antimony.

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APPENDIX A. SOURCES OF DATA IN THE HHRA

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Appendix A. Summary of Project-specific data sources used in the HHRA

Reference	Summary of data collected	Year Data Collected	Air	sediment	soil	surface water	berry plant	fish	intake rates
Air Sciences. 2016. Air Quality Analysis Report, Donlin Gold Project, Alaska. Prepared by Air Sciences, Inc., Golden, Colorado, for Donlin Gold LLC. February	air As, Sb	Future	x						
Air Sciences. 2017. Air Quality predictions contained in spreadsheet "Crooked Creek PM2.5 Annual Results (2017-05-17).xlsx" provided via e-mail to Mike Rieser, Donlin Gold, by Ejaz Memon, Air Sciences, Inc., May 17.	air As, Sb	Future	x						
ARCADIS. 2007a. Baseline Mercury in Vegetation, Soil, and Stream Sediment, Donlin Creek Project, Alaska. Ref. CO001194.0001.00001, March 2007.	soil, sediment, plant (Hg only)	2006		x	x		x		
ARCADIS. 2007b. DRAFT - Donlin Creek Project Stream Sediment Analysis Report. Prepared for Barrick Gold Corporation. November 2007.	sediment (As, Sb only)	2007		x					
ARCADIS. 2008. DRAFT - Mercury/Metals Sediment 2008 Report, Donlin Creek Project, Alaska. Prepared for Barrick Gold Corporation, Donlin Creek Joint Venture. September 2008.	sediment (Hg only)	2008		x					
ARCADIS. 2014. Assessment of Mercury Fate in the Environment from Changes in Atmospheric Deposition. Prepared by ARCADIS for Donlin Gold, LLC. June. 196 pp.	soil, sediment (Hg only)	2013		x	x				
Brown, C., J.S. Magdanz, D.S. Koster and N.M. Braem. 2012. Subsistence Harvests in 8 Communities in the Central Kuskokwim River Drainage, 2009. Alaska Department of Fish & Game, Division of Subsistence. Technical paper No. 365.	subsistence harvest data	2009							x

Appendix A. Summary of Project-specific data sources used in the HHRA

Reference	Summary of data collected	Year Data Collected	Air	sediment	soil	surface water	berry plant	fish	intake rates
Enos, Robert (Nick). 2013. Personal communication. Environmental & Permitting Manager. Donlin Gold. Remaining data/document needs for Donlin geochem (#15, 16, 27, 28); and file Data Request 79.zip. September 11, 2013. Nancy Darigo. URS	surface water data	2013				x			
Environ. 2013. Monitoring of Baseline Air Concentration and Deposition of Mercury for the Donlin Gold Project. Prepared for the Donlin Gold Project, Alaska. December 2013.	Air (Hg baseline)	2011 - 2013	x	x					
Environ. 2015. Modeling of Local Impacts of Mercury Air Emissions from Stacks and Fugitive Sources, Advanced Water Treatment Scenario: Donlin Gold Mine, Alaska, Final Report. September 10.	Air (Hg emission estimates)	Future	x						
Fernandez, E. 2014. Personal communication. Senior Environmental Coordinator. Donlin Gold. Donlin Soil Samples 20140825.xlsx. August 25, 2014. Dave Every. URS.	soil As, Sb	1988 - 2010			x				
Ottertail. 2009. 2008 Aquatic Biomonitoring Report For the Donlin Creek Project (2004, 2005, 2006, 2007, and 2008 data compilation). May 2009	fish (As, Sb, Hg)	2004 - 2008						x	
OtterTail. 2012a. Access Database: OtterTail_Fish_Tissue_Data_04-12_130829	fish (As, Sb, Hg)	2005 - 2012						x	
Rieser, M. 2016.Personal communication, Senior Environmental Engineer. Subject: SO2 and sulfate emissions. Attachments: Port Emissions - Extract from 28-02-2014 EIS.xlsx, and Donlin_EI_FSU2_2016-11-08-ReportADECr0-summary.xlsx. Email to Penny Hunter, ERM. December 29, 2016.	SO2 emission estimates	Future	x						

Appendix A. Summary of Project-specific data sources used in the HHRA

Reference	Summary of data collected	Year Data Collected	Air	sediment	soil	surface water	berry plant	fish	intake rates
Rieser, M. 2017a. Personal communication, Senior Environmental Engineer. Subject: Sulfate discharge at average discharge rate, with attachment: 2015-06-09 Most Recent Results Summary – SO2.pdf. Email to Penny Hunter, ERM. January 11, 2017.	WTP discharge estimates	Future				x			
Rieser, M. 2017b. Personal Communication, Senior Environmental Engineer. Subject: Question about the arsenic/antimony air data. Attachments: Arsenic and Antimony LOM Year 16-2015 Air Impacts Emissions.xlsx, Environ 2013.pdf	As & Sb emission estimates	Future	x						
Weglinski. 2016. Personal communication, Senior Permitting Coordinator. Subject: Mercury info for Donlin. Attachments: AK-Hg4-Rusak-revised.xlsx; Existing MeHg Data-SW+Sed_083016.docx; Table 3.7-6 revised_Baseline MeHg Crooked Creek SW_083016.docx; WQ_Analytical_Results_SW_Update_3Q2013-3Q2015.xlsx	surface water baseline (and references for soil/sediment data)	2013 - 2015				x			

APPENDIX B. DEVELOPMENT OF BIOACCUMULATION FACTORS FOR THE HHRA

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Appendix B

Development of Bioaccumulation Factors for the HHRA

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1. TYPES AND APPLICATION OF BIOACCUMULATION (UPTAKE) MODELS

In risk assessments, concentrations of a constituent in biota are commonly estimated using an uptake model that takes one of the following forms (U.S. Environmental Protection Agency [USEPA] 2005a):

Form 1:	$C_{tissue} = UF \bullet C_{environ}$	...Equation 1	(constant)
Form 2:	$C_{tissue} = a \bullet C_{environ} + b$	...Equation 2	(linear regression)
Form 3:	$\ln(C_{tissue}) = a \bullet \ln(C_{environ}) + b$	...Equation 3	(log-linear regression)

Where:

C_{tissue} = concentration in tissue of subsistence food (biota)

$C_{environ}$ = concentration in environmental medium (e.g., soil, water, sediment)

UF = uptake factor

a = slope

b = y-intercept

An uptake factor (UF) is a simple ratio of the concentration in the tissue divided by the concentration in a particular environmental medium (e.g., soil, sediment, water). Regression models (Forms 2 and 3) are developed by fitting a relationship to paired concentrations, i.e., co-located concentrations in environmental medium and concentrations in the tissue. Consistent with methods used to develop USEPA ecological soil screening levels (2005a), a regression model is considered to be acceptable when both a statistically significant and a reliably predictive model exist. Regression models are developed in a manner consistent with standard practice, regulatory guidance (USEPA 2010), and basic concepts/techniques described in USEPA (2012) Benchmark Dose Software.

Consistent with USEPA (2005a) guidance, a constituent-specific regression model can be developed if both of the following performance criteria are not met:

1. The model equation is significant — i.e., the slope differs significantly from zero ($p < 0.1$); and
2. The model reliably predicts concentrations — i.e., the coefficient of determination (r^2) is greater than 0.2.

Consistent with the general rule for regression analyses (USEPA 2010), at least eight detect pairs (detect-detect pairs of concentrations in both environmental media and

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subsistence food) are needed. If eight detect pairs were not available, then the median bioaccumulation factor (BAF) was used to estimate bioaccumulation.

2. DEVELOPMENT OF HHRA BAFS

In developing uptake factors (also referred to as BAFs) for the Human Health Risk Assessment (HHRA), Project-specific baseline tissue data that was temporally and spatially co-located with primary environmental media (soil, sediment or water) was preferred. In reviewing available data, most of the Project-specific data did not meet these criteria. However, in many cases, biota samples were collected in the vicinity of primary media and within the same season or sampling timeframe.

Given the need to evaluate potential changes in future methylation rates and differences in bioaccumulation[1] between total mercury (THg) and methylmercury (MeHg), BAFs for mercury were derived in two ways:

- THg data for primary media and THg[2] data for biota; and
- MeHg data for primary media and THg data for biota.

The first type of BAF was developed to allow for comparisons to other regional data and the general literature. The second type of BAF was derived to account for potential future changes in bioavailable forms of mercury in the environment.

Derivation of each BAF is described below.

2.1. Plant (Berry)

In the case of berry data, biota samples were matched with soil samples collected for mercury analysis on an area-by-area basis. Although samples may not have been collected co-temporally, it was assumed that soil concentrations were relatively stable during the 2006-2007 timeframe and that soil samples collected in 2006 can be related to biota samples collected in 2007 to develop soil-to-berry BAFs. Project-specific soil data include measurements of both THg and MeHg. However, Project-specific plant tissue burden data (blueberry and cranberry samples) were reported for THg only. Project-specific median BAFs for THg for both blueberry and cranberry samples are reported and were found to be similar.

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[1] Biomagnification is the process by which a constituent increases its concentration in the tissues of organisms at successively higher levels in a food chain. MeHg can biomagnify to levels that are many times greater than levels in the surrounding environment; whereas, inorganic mercury does not biomagnify up the food chain.

[2] Only (THg concentrations in tissues are reported for Project-specific data.

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Project-specific biota and soil empirical data for THg were plotted and regression analyses conducted (Attachment A). Although sufficient detect pairs were available, the resulting regression model did not meet performance criteria; specifically, the model slope was not significant and did not meet the criterion for reliably predicting concentrations in biota (see model *p* and r^2 in Figure 1). Therefore, the median soil-to-berry BAF for Hg was selected to estimate tissue burdens in berries (Table 1).

TABLE 1: PROJECT-SPECIFIC BAFS FOR BERRY PLANTS

	THg to THg[1] ($kg_{soil,dw}/kg_{tiss,ww}$)	**MeHg to THg[2]** ($kg_{soil,dw}/kg_{tiss,ww}$)	**Arsenic** ($kg_{soil,dw}/kg_{tiss,dw}$)	**Antimony** ($kg_{soil,dw}/kg_{tiss,dw}$)
Cranberry	0.020	2.9	No data	No data
Blueberry	0.015	2.0		

1. *BAFs (median) based on Project-specific empirical data (blueberry n = 29, cranberry n = 25) – plant part not specified.*
2. *BAFs (median) are based on Project-specific methylmercury data for soils and THg data for plants (blueberry n = 3, cranberry n = 3) – plant part not specified.*

$kg_{soil,dw}$ = *kilograms soil as dry weight*
$kg_{tiss,ww}$ = *kilograms tissue as wet weight*

Project-specific empirical data were available for MeHg in soil and THg in biota, but detected paired data were limited (n = 3) and did not meet the minimum dataset requirement to confidently use a regression model. Hence, a regression analysis was not conducted for MeHg. No Project-specific data for arsenic (As) and antimony (Sb) concentrations in blueberry or cranberry plants were available. Therefore, literature-based models were used to estimate As and Sb concentrations in subsistence plants (see Section 3).

2.1.1. Comparison to Other Datasets

Regional studies and regulatory sources were reviewed to provide perspective on the BAFs derived using Project-specific data (Table 2). For the Red Devil Mine[3] (Ecology and Environment, Inc. [E&E] 2014), blueberry tissue concentrations in unimpacted areas were measured separately for leaf and stem (leaf-stem) samples and for fruit samples. Non-detect concentrations in berry leaf-stem and soil samples were assigned the surrogate value of one-half the method detection limit (½ DL). For consistent comparisons to Donlin project-specific BAFs, only detect pairs were considered and

[3] The Red Devil Mine is an abandoned cinnabar mine and mercury production facility in the same region as the Project. The mine operated from 1933 to 1971, before more rigorous current-day environmental regulations and standards, and is now the subject of a number of environmental restoration projects.

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berry leaf-stem data were adjusted for moisture content.[4] Eight blueberry (fruit) samples were analyzed — one collected in 2011 and seven collected in 2012. Although the sample number of blueberry fruit is appropriate, the E&E (2014) report notes that statistical analysis for background levels in blueberry fruit was not performed due to the high rate of non-detections. Given the limited data for fruit, the authors decided to use soil-to-plant (above ground produce) BAFs from Baes et al. (1984) (Table 2).

TABLE 2: REGIONAL STUDY, USEPA, AND USDOE SOIL-TO-PLANT BAFS[1]

Constituent	Red Devil Mine[3,4]		USEPA		Baes et al. (1984)[5]
	#Detect Pairs	*BAF*[2]	(2005b,c)[3]	(2005d)[4]	
THg[6]	8	0.034	-	0.015	0.20
Arsenic	5	0.0014	0.0375	0.0063	0.006
Antimony	—	No data	$\ln(C_{plant}) = 0.938 \bullet \ln(C_{soil}) - 3.233$	0.032	0.03

1. *Soil-to-plant BAFs in units of* $kg_{soil,dw}/kg_{tiss,dw}$.
2. *Geometric mean background soil-to-blueberry (stem/leaf composite) BAFs – from Table 6-78 of the E&E (2014) report.*
3. *Generic (not species-specific) soil-to-plant uptake.*
4. *Soil-to-plant BAF for mercuric chloride* ($HgCl_2$) *from USEPA (2005d) Hazardous Waste Companion Database – no value for THg.*
5. *Baes et al. (1984) BAFs also used in Red Devil Mine (Table 6-24b of E&E 2014).*
6. *THg to THg.*

ln = lognormally transformed
(C_{plant}) *= plant tissue concentration*
(C_{soil}) *= soil concentration*

Combining the Red Devil Mine study data and the Donlin Project baseline data was considered in order to increase sample size and improve the robustness of the soil-to-blueberry uptake model. When examining these two datasets (adjusted for moisture content and only using detect pairs), the datasets appeared markedly different (Figure 2). Although the combined dataset resulted in a significant slope ($p < 0.1$), the slope is 'driven' by an extreme data point (upper right point) (Figure 2). When datasets are examined separately, there is no significant slope ($p > 0.1$) and there is poor predictability ($r^2 < 0.2$). When removing the outlier (upper right point), the slope is significant, but the predictability is poor ($r^2 < 0.2$). Given the apparent differences in the two datasets and the above findings, the two datasets were not combined. The sample sizes ($n > 25$) of the Donlin project dataset were considered to provide a robust estimate of the median BAF. In addition, other factors (e.g., method of collection, sample

[4] E&E (2014) reported tissue concentrations in dry weight. To facilitate comparisons with Project-specific BAFs, Red Devil plant concentrations were adjusted assuming a moisture content of 69.8 percent (median moisture content of Donlin blueberries).

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processing, and analytical methods) increase the uncertainties associated with pooling these two datasets. No other regional datasets (e.g., Matz 2012) were available to compare berry BAFs.

USEPA's soil-to-plant (above ground produce) BAFs reported in USEPA's *Human Health Risk Assessment Protocol for Hazardous Waste Combustion Facility* (USEPA 2005d) are derived from uptake slope factors provided in USEPA (1992a) or from Baes et al. (1984). This guidance document's BAF for Hg is comparable to the Project-specific soil-to-berry BAF (Table 2).

Differences in soil-to-plant BAFs among studies are not remarkable due to the following possible sources of differences (including, but not limited to):

- Portions of plants that were analyzed (e.g., fruit vs. leaf-stem);
- Degree of co-spatial / co-temporal correspondence[5] between soil and berry samples in the study ;
- Soil attributes affecting bioavailability (e.g., pH, grain size, total organic carbon); and
- Methods of collection, sample processing, and analytical methods and limits.

Nonetheless, regional and other sources of soil-to-plant BAFs appear to suggest that Project-specific BAFs are relatively consistent with existing regional information.

2.1.2. *Berry BAF Uncertainty Discussion*

Stems and leaves of the blueberry/cranberry plants were measured for Project-specific Hg concentrations. However, humans typically consume the fruit (berry) of blueberry or cranberry plants. In reviewing the Red Devil Mine remedial investigation (RI) findings, the fruits of the plants typically contained lower concentrations of constituents than the stems and leaves of the plants. Therefore, it is likely that THg concentrations estimated for berries are overestimated.

In addition, Project-specific concentrations measured in soil and in berries are neither precisely co-temporal nor co-located. All soil and berry plant samples were not collected in the exact same location. Therefore in these cases, concentrations measured in plants may be less related to concentrations in soils in which the plants were growing. In addition, soil samples were collected in 2006, while berry tissue burdens were collected in 2006-2007. Hence, this evaluation presumes that 2006 soil concentrations are representative of those related to plant samples collected in 2007. Soil concentrations are

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[5] The lack of co-temporal correspondence in Project-specific soil-plant data may be mitigated in part because soils tend to be more temporally stable (lower variability) and hence likely to be more representative of soil concentrations at the time plant samples were collected.

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considered to be relatively stable over time as compared to other environmental media (e.g., water). The lack of co-location (spatial and temporal) introduces uncertainty in characterizations of soil-to-berry bioaccumulation.

2.2. Fish

Regulatory agencies consider the consumption of fish an important exposure pathway for human exposure to mercury (Agency for Toxic Substances and Disease Registry [ATSDR] 2013). The following resident fish have been observed in Crooked Creek (Ottertail Environmental, Inc. [Ottertail] 2009):

- Slimy sculpin[6]
- Northern pike
- Arctic grayling
- Dolly Varden
- Burbot
- Ninespine stickleback
- Longnose sucker
- Alaskan brook lamprey
- Round whitefish

The Project-specific data for these species were limited; specifically, the dataset primarily contains tissue burdens for juveniles or fish of 'unspecified' age.

In the HHRA, northern pike were initially selected to evaluate fish consumption exposure. Northern pike is a large (relatively long-lived) top predator and is the preferred fish for characterizing uptake of metals (particularly Hg) given the existence of an Alaskan fish advisory (tissue target level). However, the northern pike has only recently been observed[7] in Crooked Creek (Ottertail 2009). Moreover, the Project-specific tissue burden dataset for adult northern pike consists of only one sample.[8]

Given the limited dataset for adult northern pike, other fish species were considered. Although sculpin are not large, top predators, and they are not widely harvested for subsistence consumption, Project-specific tissue data are abundant, and sculpin data have been used in the Red Devil RI to estimate Hg concentrations in subsistence fish (E&E 2014). Therefore, estimates of subsistence fish tissue burdens using sculpin data (with a food chain multiplier [FCM]) were developed. Consistent with USEPA guidance,

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[6] Among the most abundant species observed, but not a popular game fish.

[7] Four individuals were caught at the Crooked Creek weir and although not previously observed, their presence is not unexpected (Ottertail 2009).

[8] Other mercury data for the northern pike in the Project's database were apparently for matrix spike/matrix spike duplicate (MS/MSD) that are used for laboratory quality assurance purposes.

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an FCM was applied to account for food chain biomagnification of MeHg into subsistence fish (McGeer et al. 2004, E&E 2014).

First, scuplin BAFs were derived. To derive these BAFs, both sediment-to-fish and surface water-to-fish BAFs were considered. Project-specific fish tissue burden data were reported for THg only, while sediment and surface water data included both THg and MeHg data. Project-specific sculpin samples were co-located by reach (specifically for Donlin and Crooked Creek reaches), but were not collected from the exact location or within the same timeframe as surface water or sediment samples. Fish samples were matched with sediment and surface water samples on a reach-by-reach basis. Surface water data are available spanning from 2005 and 2015, and indicate daily, seasonal, and annual variability (Tetra Tech 2013). Sediment data, on the other hand, appear relatively similar from one year to the next, though like surface water, concentrations vary spatially by reach.

Sediments are considered to be 'sinks' for metals in aquatic systems (USEPA 1992b) and it is reasonable to assume that sediment chemistry would be relatively stable over time (as compared to water chemistry). With this in mind, sediment samples collected during 2007-2008 were related to sculpin samples collected during 2004-2006 to develop Project-specific sediment-to-fish BAFs. Surface water-to-fish and sediment-to-fish BAFs derived from Project-specific data (Ottertail 2009) are shown in Tables 3 and 4, respectively.

TABLE 3: PROJECT-SPECIFIC SURFACE WATER-TO-FISH BAFS [1]

Constituent	# Samples	BAF ($L_{surface\ water}/kg_{tiss,ww}$)	Age Class
Northern Pike			
THg[2]	1	271,613	Adult
Sculpin			
THg[2]	44	21,032	Juvenile (1+ yrs and juvenile)
THg[2]	27	24,323	Unspecified
Arsenic	44	136	Juvenile (1+ yrs and juvenile)
Arsenic	27	138	Unspecified
Antimony	44	8.7	Juvenile (1+ yrs and juvenile)
Antimony	27	8.7	Unspecified

1. *Given temporal variability and lack of temporal co-location, surface water-to-tissue BAFs were not derived.*
2. *BAFs were based on Project-specific THg data for surface water and THg data for fish.*

* *Surface water data had a non-detect rate of 54% and fish tissue data had a non-detect rate of 100%; therefore, no BAFs were derived.*

L = liter

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TABLE 4: PROJECT-SPECIFIC SEDIMENT-TO-FISH BAFS[1]

Constituent of Interest	# Samples	BAF ($kg_{sediment,dw}/kg_{tiss,ww}$)	Age Class
Northern Pike			
THg[2]	1	1.7	Adult
Sculpin			
THg[2]	44	0.23	Juvenile (1+ yrs and juvenile)
THg[2]	27	0.26	Unspecified
THg[2,4]	105	0.22 – 0.68	Unspecified
MeHg (to THg)[3]	44	55	Juvenile (1+ yrs and juvenile)
MeHg (to THg)[3]	27	49	Unspecified
Arsenic	44	0.016	Juvenile (1+ yrs and juvenile)
Arsenic	27	0.011	Unspecified
Antimony	44	0.018	Juvenile (1+ yrs and juvenile)
Antimony	27	0.016	Unspecified

1. *Given regressions did not achieve the model reliability performance criterion of $r^2 > 0.2$, median BAFs were used to estimate fish tissue burdens.*
2. *BAFs were based on Project-specific THg data for sediments and THg data for fish.*
3. *BAFs were based on Project-specific MeHg data for sediments and THg data for fish.*
4. *ARCADIS (2014) data included for comparison. All other data from Ottertail 2009.*

* *There were no detect pairs (0 of 11 pairs) for antimony data, so no BAF was calculated.*

$kg_{sediment,dw}$ = *kilograms sediment as dry weight*

A regression model-based uptake model was considered for mercury BAFs (see Attachment B). However, although there were a number of fish samples, they were related to only two to three reaches (for which surface water or sediment sample results have been averaged). Hence, Project-specific regression models were composed of 'repeated' measures for two to three surface water or sediment concentrations (Figure 3, Attachment B). Hence, the resulting regression models (with 'repeated measures') had limited data to detect a trend and did not meet the criterion for reliably predicting concentrations in fish tissue (e.g., the regression model r^2 were less than 0.2). Therefore, median sediment-to-fish BAFs were selected to estimate tissue burdens in subsistence fishes (Table 4).

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2.2.1. *Comparison to Other Datasets*

Despite numerous regional studies that have measured fish concentrations, few studies have developed BAFs. A brief discussion of each study comparison is included below. Tables 5 and 6 summarize the BAFs derived from regional studies or other guidance.

THg measured in fish for Project-specific studies were consistent with U.S. Geological Survey samples of fish collected from the region (Gray and Sanzolone 1996, Gray et al. 1997, Gray et al. 2000, as discussed in ARCADIS 2014), and was consistent overall with Bureau of Land Management (BLM) samples collected from the Kuskokwim River and tributaries within the middle Kuskokwim Region (Matz 2012). The BLM data indicated slightly higher average THg concentrations in whole body fish tissue samples (average 240 micrograms per kilogram [µg/kg] wet weight) compared to Project data. However, the fish data presented in the BLM study did not separate upstream and downstream reaches. Samples collected from some reaches where there was historical mining impact from the Red Devil Mine showed, at times, higher Hg content in fish than in other reaches (Matz 2012). BLM is working with USEPA and the Alaska Department of Environmental Conservation to investigate the extent of contamination and develop and implement remediation methods for the Red Devil Mine.

TABLE 5: SURFACE WATER-TO-FISH BAFS FROM REGIONAL STUDIES AND USEPA

Constituent	Red Devil Mine (E&E 2014)			USEPA (2005d)
	Sample Size	BAF[1,2]	Fish / Age Class	BAF[3]
THg[4]	45	5,715	Sculpin (adult)	NA
MeHg (to MeHg)[5]	7	1,656,000	Sculpin (adult)	NA
Arsenic	45	97	Sculpin (adult)	114
Antimony	21	126	Sculpin (adult)	40

1. *BAFs in units of $L/kg_{tiss,ww}$.*
2. *BAFs (= $tissue_{95UCL}$ / $surface\ water_{95UCL}$) in units of $L/kg_{tiss,ww}$ – data from Table O-3 and O-5 of E&E (2014) report.*
3. *Hazardous Waste Companion Database (USEPA 2005e).*
4. *BAFs were based on THg data for surface water and THg data for fish.*
5. *BAFs were based on MeHg data for surface water and MeHg data for fish.*

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TABLE 6: SEDIMENT-TO-FISH BAFS FROM REGIONAL STUDIES

Constituent	Red Devil Mine (E&E 2014)		
	Sample Size	BAF[1]	Fish / Age Class
THg[2]	45	0.028	Sculpin (adult)
MeHg (to MeHg)[3]	7	0.051*	Sculpin (adult)
Arsenic	45	0.015	Sculpin (adult)
Antimony	21	0.013	Sculpin (adult)

1. BAFs were (= $tissue_{95UCL}$ / $sediment_{95UCL}$) in units of $kg_{sed,dw}/kg_{tiss,ww}$ – data from Table O-2 and O-5 of E&E (2014) report.

2. BAFs were based on THg data for sediments and THg data for fish.

3. BAFs were based on MeHg data for sediments and MeHg data for fish.

** Derived from the 95% Upper Confidence Limit (95UCL) for seven fish samples for MeHg and 95UCL for 36 sediment samples for MeHg.*

2.2.1.1. Red Devil Mine RI Report (E&E 2014)

In general, the Red Devil surface water-to-fish and sediment-to-fish BAFs for As are similar to Project-specific BAFs for As. However, surface water-to-fish and sediment-to-fish BAFs for Hg reported in the Red Devil Mine RI report are lower than Project-specific BAFs for Hg. Modeled concentrations of As and Hg in the Red Devil Mine study are also lower than measured concentrations in subsistence fish (Table 6-24a of E&E 2014).

In the Red Devil Mine RI report, concentrations of metals in fish are estimated using slimy sculpin whole-fish tissue concentration data from Red Devil Creek, multiplied by an FCM.[9] Using sculpin data to estimate subsistence fish was considered by the authors to be health-protective because slimy sculpin are a resident fish. For MeHg, an FCM of 3 is assumed to account for biomagnification[10]; for other metals, an FCM of 1 is assumed.[11]

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[9] Game fish concentration is set equal to three times the concentration in sculpin (= 3 • EPC_{fish}). If modeled, this would be equivalent to the following general model: $C_{fish} = 3 \cdot C_{water} \cdot BAF$.

[10] This approach is supported by the fact that the biomagnification of MeHg typically is three-fold with each trophic transfer (McGeer et al. 2004).

[11] This approach is defensible because biomagnification of metals (other than MeHg) in aquatic organisms is rare.

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2.2.1.2. *Kuskokwim River Region (Matz 2012)*

During 2010-2011, fish[12] were collected in the Kuskokwim River and its tributaries, and analyzed for Hg, As, and Sb. As and Sb concentrations were higher in fish collected from Red Devil Creek compared to all other tributaries.

Northern pike, burbot, and arctic grayling had variable Hg concentrations across the study area. Significant, positive correlation between age and size of fish to Hg burdens were observed in northern pike, but not in burbot, arctic grayling, or sheefish. MeHg to THg ratios were near 1.0, suggesting chronic, long-term exposure to Hg via ingestion of prey (Guilherme et al. 2010).[13] This study's findings were used to issue fish consumption advisories based on Hg by the State of Alaska.

Note that this study reported only concentrations in fish; no corresponding surface water and sediment concentrations were reported. Given the lack of co-located water or sediment concentrations, data could not be used to derive surface water-to-fish or sediment-to-fish BAFs.

2.2.1.3. *HHRA Protocols for Hazardous Waste Combustion Facilities (USEPA 2005d)*

No surface water-to-fish BAFs for THg, mercuric chloride ($HgCl_2$), or MeHg are provided in this guidance document. Surface water-to-fish factors for As and Sb are provided and shown in Table 5. Literature for surface water-to-fish BAFs is often unclear whether the water concentrations are dissolved or total concentrations[14]; nonetheless, USEPA (2005d) recommends multiplying concentration (total or dissolved) in water and the surface water-to-fish BAFs.

No surface water-to-fish or sediment-to-fish BAFs for THg, $HgCl_2$, MeHg, As, or Sb are provided in USEPA 2005d.

2.2.2. ***Fish BAF Uncertainty Discussion***

Co-location and co-temporal collection of concentration data are preferred when deriving relationships between surface water and fish burden. Neither the sediment-to-fish nor the surface-water-to-fish datasets were exactly co-temporal or spatially co-located.

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[12] Adult salmon were not sampled because they spend most of their lives at sea (Matz 2012).

[13] MeHg-to-THg ratios much less than 1.0 indicate acute, short-term exposure to mercury in water (Guilherme et al. 2010).

[14] Most of the literature reviewed indicate that laboratory experiments were conducted using filtered or distilled water (USEPA 2005d).

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However, given temporal variability often observed in water chemistry data, it is uncertain whether and to what degree concentrations in fish tissue are related to concentrations in surface water. Therefore, Project-specific sediment-to-fish BAFs were used (in preference to surface water-to-fish) to estimate constituent tissue concentrations.

BAFs reflect the interactions of numerous biotic and abiotic factors, and are site-specific, reflecting both abiotic media geochemistry and area populations. Constituent content in sediment may not be the predominant exposure medium for the fish species (exposure via food pathways in uncontaminated sites typically dominates fish exposure), but sediment metal contents are often used to estimate bioaccumulation in prey items (plants, sediment-dwelling invertebrates), and sediments are a primary source of mercury to overlying water. Therefore given available data, Project-specific sediment-to-fish BAFs provide a defensible approximate measure of bioaccumulation rates to fish in aquatic systems of interest.

2.3. Waterfowl (Mallard Duck)

No Project-specific empirical data exist that relate metals concentrations in the environment to tissue burdens of birds. Similarly, few data exist in the peer-reviewed literature or regulatory guidance that relate metals concentrations in the environment to tissue burdens of subsistence birds.

A general query was conducted to search several peer-reviewed literature databases including, but not limited to:

- PubMed
- Google Scholar
- Science Direct

Additionally, regional studies were reviewed for relevant information. While there is literature documenting the accumulation of metals in birds, many studies examined uptake as function of concentration in food, not in environmental media (e.g., soil). Further, the remaining studies found to-date did not include both co-located environmental and bird tissue concentrations. Accordingly, no appropriate literature-based studies were found that could be used to develop quantitative uptake models.

Similarly, no relevant data or soil-to-bird BAFs are presented in USEPA (2005d). However, USEPA (2005d) provides a method to develop a biotransfer factor to estimate Hg burdens in subsistence birds for Hg. Biotransfer factors for birds are expressed as the ratio of the constituent concentration in the fresh weight tissue to the constituent intake from food. Biotransfer factors for birds are derived by dividing the uptake slopes (from

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USEPA 1992a) by a daily consumption rate,[15] and then converted to fresh weight by using a moisture content.[16] If using a biotransfer factor, tissue burdens in wild game birds may be estimated using the following two-step calculation (USEPA 2005d):

Step 1: Estimate concentrations in food using plant BAFs.

Step 2: Estimate concentrations in the subsistence game bird (e.g., mallard) tissues using biotransfer factors and the subsistence game bird's ingestion rate.

There are a number of uncertainties involved in deriving a biotransfer factor using this method. First, tissue concentrations of plants consumed by mallard ducks were not measured in the study area, and so would have to be estimated by developing additional BAFs. Additional uncertainties would be 'compounded' because of estimates needed for intake rates by mallard ducks, the types of plants consumed, and the proportion of plants consumed by mallards in the study area versus outside the study area.

Given the lack of both Project-specific empirical data and available widely recognized literature-based models/factors, no soil-to-bird BAFs were derived. The absence of numerical soil-to-bird BAFs is the state-of-the-practice and is not unique to this Project.

2.3.1. *Comparison to Other Datasets*

No other regional or relevant datasets for the mallard were found to conduct appropriate comparisons.

2.3.2. *Waterfowl BAF Uncertainty Discussion*

Currently, there are insufficient Project-specific empirical data to reliably characterize the bioaccumulation of metals (including Hg) into game bird tissue. Further, there is a lack of widely accepted bioaccumulation models to estimate tissue burdens in representative game birds (e.g., the mallard).

2.4. Small Mammals (Beaver)

No Project-specific empirical data were collected that relate metals concentrations in the environment (e.g., soils) to tissue burdens of wild mammal game. Given the lack of Project-specific data, literature-based models were reviewed to estimate tissue burdens in subsistence game mammals (e.g., beaver).

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[15] For chickens, a daily feed consumption rate of 0.2 kg $feed_{dw}$ per day) was used (USEPA 2005d).

[16] For chickens, an assumed tissue moisture content of 75 percent was used (USEPA 2005d).

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Soil-to-mammal BAFs are obtained from two widely accepted sources for the following metals of interest:

- Hg — Development and Validation of Bioaccumulation Models for Small Mammals (Sample et al. 1998)
- As — Ecological Soil Screening Levels for Arsenic (USEPA 2005b)
- Sb — Ecological Soil Screening Levels for Antimony (USEPA 2005b)

These soil-to-mammal BAFs are presented in Table 7.

Regional studies and regulatory sources were used to provide context for the BAFs selected for this Project. The Red Devil Mine RI did not propose soil-to-mammals BAFs for Hg, and proposed to use the same soil-to-mammals BAFs for As and Sb as shown in Table 7. No other regional dataset contains data with which to derive soil-to-mammal BAFs. No relevant data or soil-to-mammal BAFs are presented in USEPA (2005d).

TABLE 7: BAFS /MODELS FOR SMALL MAMMALS

Constituent	BAF/Model ($kg_{soil,dw}/kg_{tiss,dw}$)	Source
THg to THg[1]	0.054	Sample et al. 1998[1]
Arsenic	$\ln(C_{mammal}) = 0.8188 \bullet \ln(C_{soil}) - 4.8471$	USEPA 2005b
Antimony	0.050	USEPA 2005c

All BAFs in units of $kg_{soil,dw}/kg_{tiss,dw}$.

1. *Recommended by Sample et al. 1998 because significant regression model fits were not obtained and because data for insectivore and omnivore BAFs were limited.*

2.4.1. *Comparison to Other Datasets*

No other regional or relevant datasets for beaver were found to conduct appropriate comparisons.

2.4.2. *Small Mammal BAF Uncertainty Discussion*

Currently, there is insufficient Project-specific empirical data to reliably characterize the bioaccumulation of metals (including Hg) into mammal tissue. Given the lack of Project-specific empirical data, soil-to-mammal BAFs presented in USEPA (2005b, c) and Sample et al. (1998) were used for the HHRA.

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3. SUMMARY OF BAF REVIEW

Selected BAFs for use in the HHRA are shown in Table 8.

For berry data, Project-specific BAFs for mercury are relatively consistent with other existing regional information. The USEPA (2005d) equation to estimate uptake into plants was used to derive a BAF for As and Sb. To estimate small mammal and waterfowl BAFs, linear regression model-based BAFs developed by USEPA and Sample et al. (1998) were used for these biota endpoints.

For fish data, sculpin tissue burdens were used to develop exposure estimates for fish for use in the HHRA given that: (1) sculpin is a resident fish (likely to spend much of its lifetime in the study area); (2) a large dataset is available (n > 40 samples); and (3) the precedent established by the Red Devil Mine RI in using sculpin tissue data to estimate tissue burdens in subsistence fish. Combining the Project's dataset with other regional studies to obtain a more robust dataset was also considered. However, given the differences and uncertainties associated with combining datasets from other studies, datasets could not be combined. Project-specific sediment-to-fish BAFs were used to estimate constituent concentrations in sculpin. Consistent with USEPA guidance and other assessments conducted in the region, an FCM of 3 was applied to sediment-to-fish BAFs to account for food chain biomagnification of MeHg into pike (McGeer et al. 2004) — for other metals, a FCM of 1 was used.

TABLE 8: BAFS USED IN THE HHRA

Biota	Environ. Medium	THg[1]	MeHg[2]	Arsenic	Antimony
Berry[3]	Soil	0.020	2.9	0.0375	$\ln(C_{plant}) = 0.938 \bullet \ln(C_{soil}) - 3.233$
Sculpin[4]	Sediment	0.23	55	0.016	0.018
Mallard[5]	Soil	0.054	—	$\ln(C_{mammal}) = 0.8188 \bullet \ln(C_{soil}) - 4.8471$	0.05
Beaver[6]	Soil	0.054	—	$\ln(C_{mammal}) = 0.8188 \bullet \ln(C_{soil}) - 4.8471$	0.05

1. *THg in medium to THg in biota.*
2. *MeHg in medium to THg in biota.*
3. *The soil-to-plant BAF for Hg is in units of* $kg_{soil,dw}/kg_{tiss,ww}$.
   The soil-to-plant BAF for As and Sb is in units of $kg_{soil,dw}/kg_{tiss,dw}$.
4. *All sediment-to-fish BAFs are in units of* $kg_{sed,dw}/kg_{tiss,ww}$.
5. *All soil-to-bird BAFs use soil-to-mammal BAFs as surrogate values given the lack of Project-specific and literature-based BAFs/models.*
6. *All soil-to-mammal BAFs are in units of* $kg_{soil,dw}/kg_{tiss,dw}$.

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Figures

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Figure 1. Scatterplot of Mercury Concentrations in Blueberry Plants and Soils

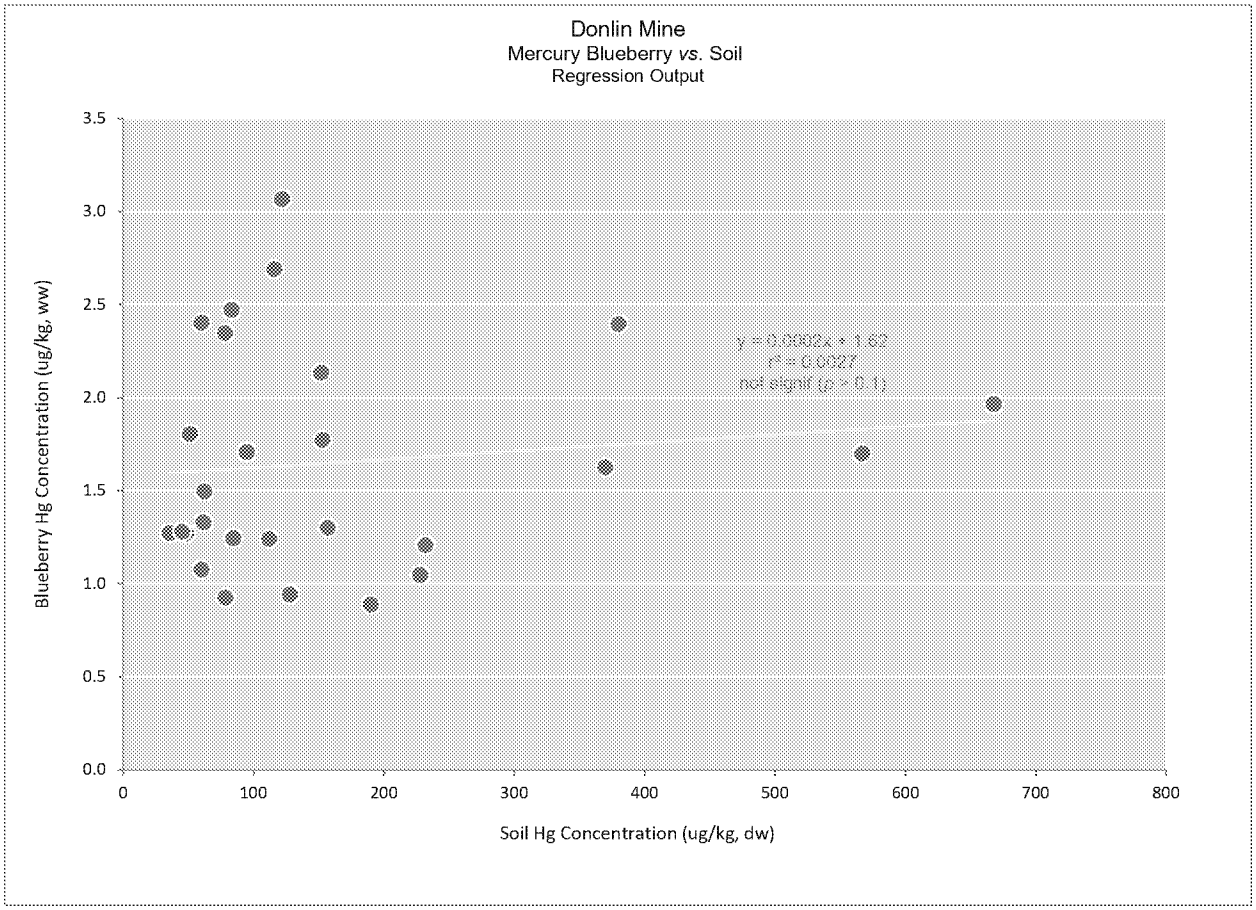


Figure 2. Scatterplot of Mercury Concentrations in Blueberry Plants and Soils with Red Devil Mine Data

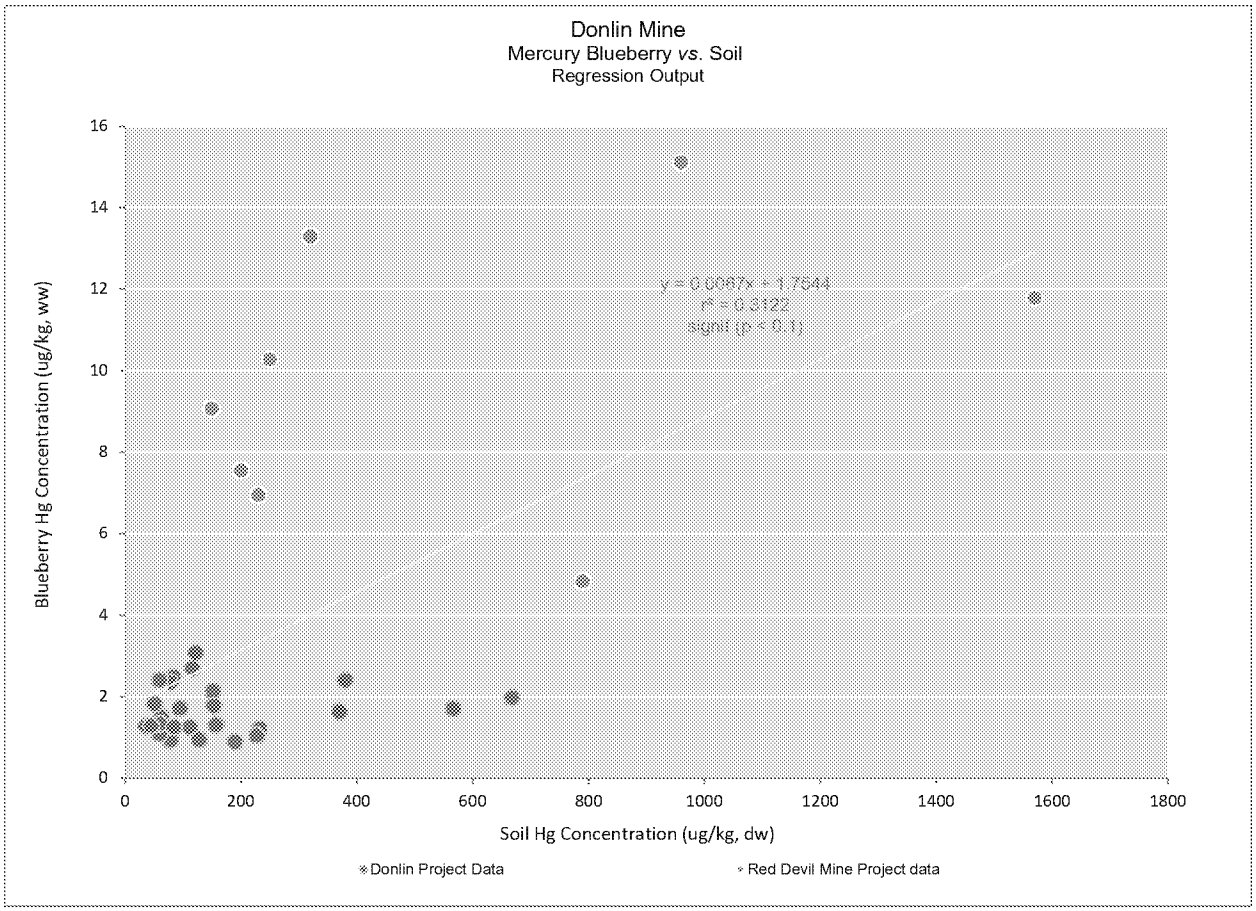
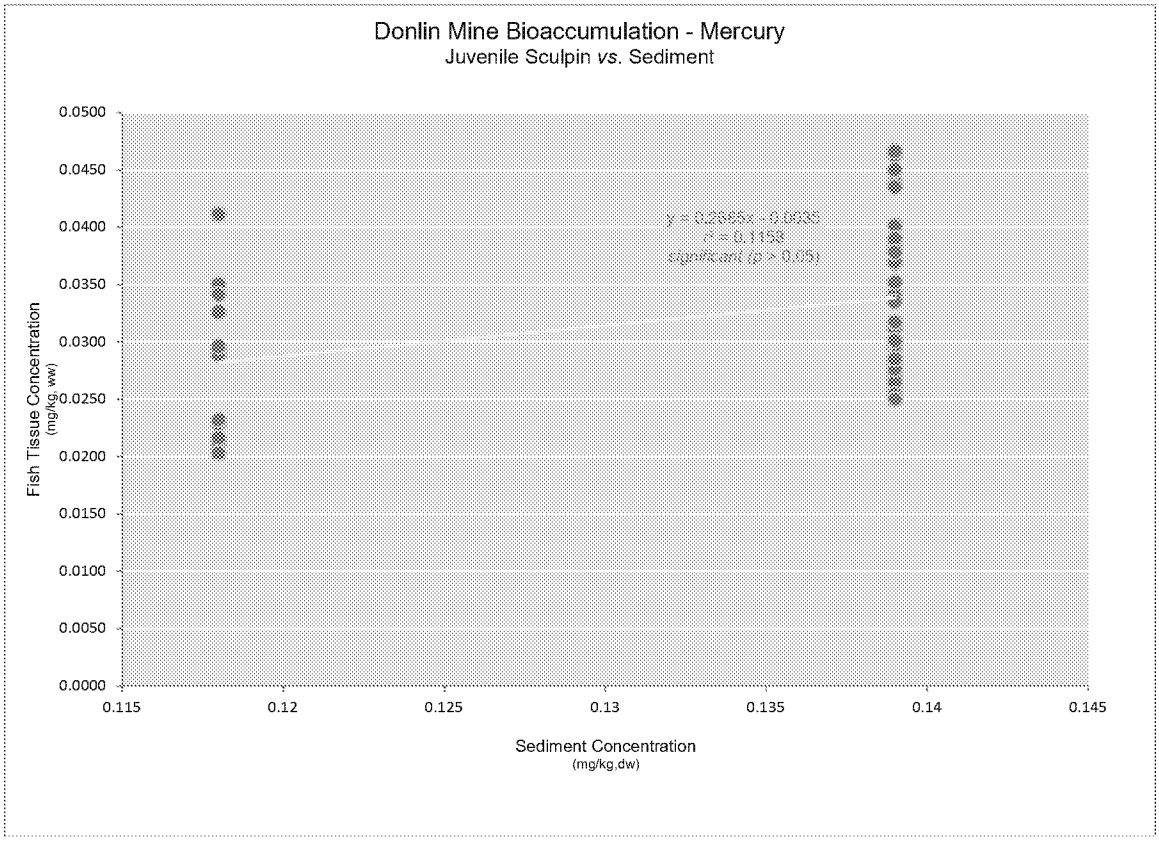


Figure 3. Scatterplot of Mercury Concentrations in Sculpin Juveniles and Sediments



Attachment A
Soil-to-Blueberry / Soil-to-Cranberry BAFs
Project-specific Empirical Data*

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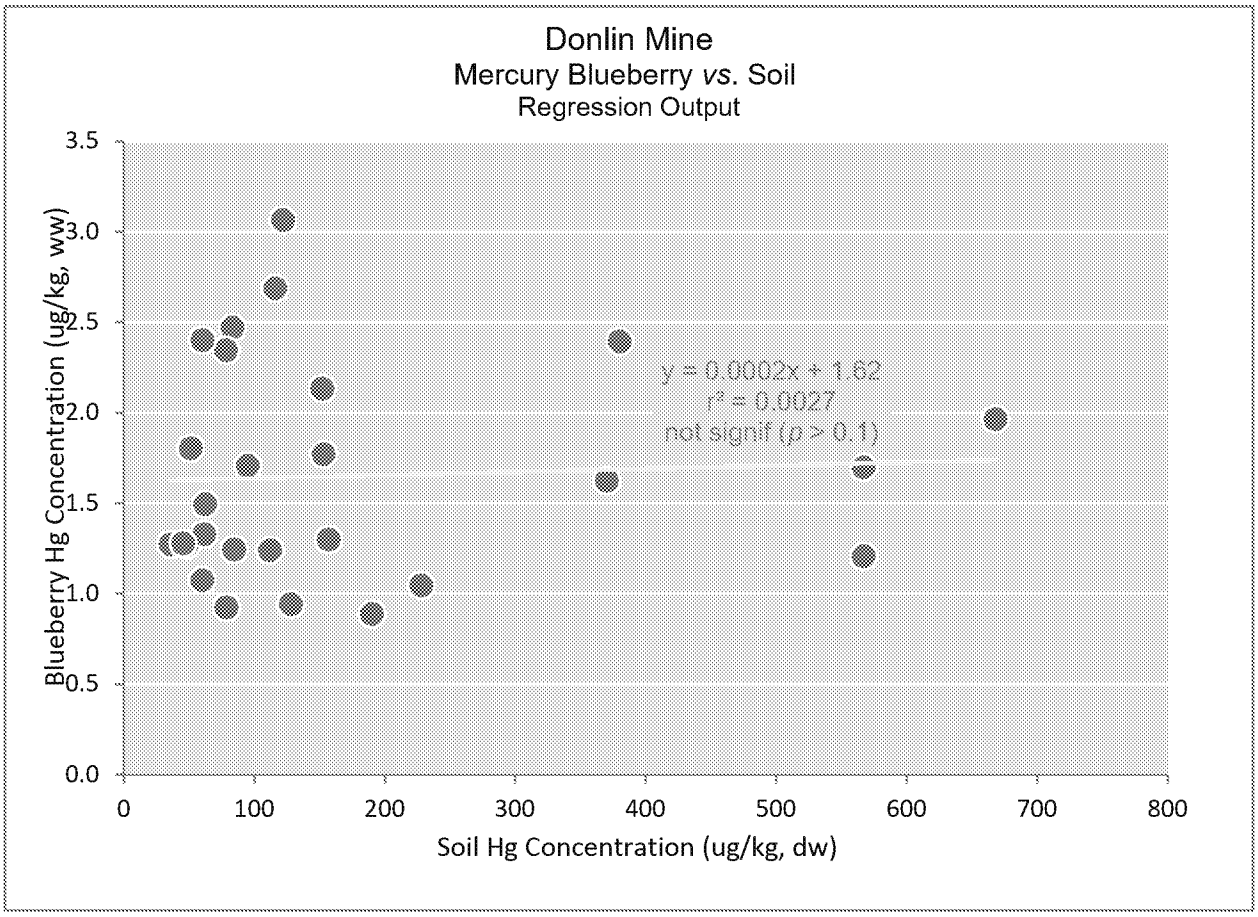
*Figure A-1 Blueberry vs. Soil: Mercury Concentrations**



Blueberry Regression

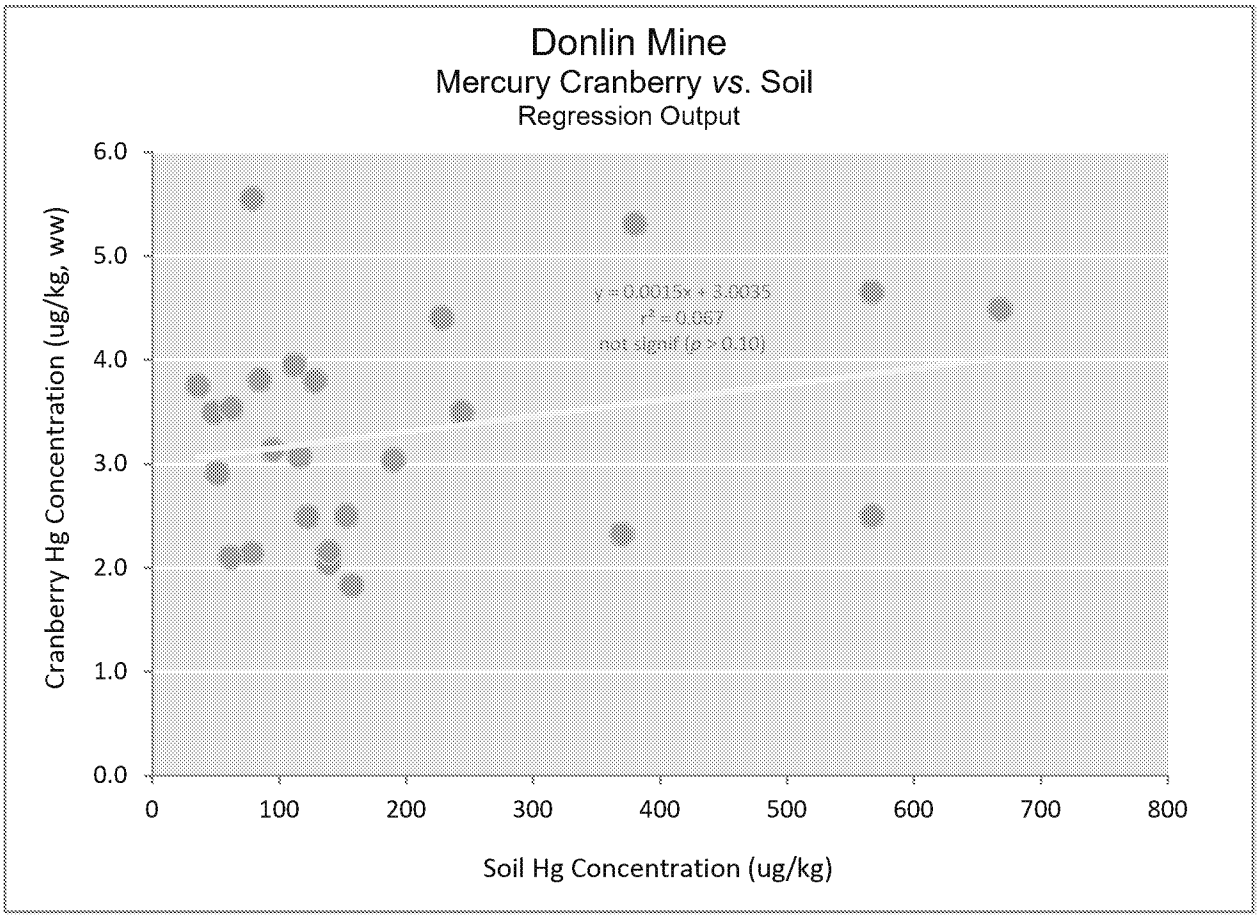
Regression Statistics	
R Square	0.003
Observations	27

ANOVA

	df	*SS*	*MS*	*F*	*Signif F*
Regression	1	0.025	0.025	0.07	0.80
Residual	25	9.22	0.37		
Total	26	9.24			

* Non-significant slope and poor predictability ($r^2 < 0.2$) – does not meet data quality objectives to support regression-based uptake model.

*Figure A-2 Cranberry vs. Soil: Mercury Concentrations**



Cranberry Regression

Regression Statistics	
R Square	0.067
Observations	25

ANOVA

	df	*SS*	*MS*	*F*	*Signif F*
Regression	1	1.7	1.7	1.7	0.21
Residual	23	24	1.0		
Total	24	26			

* Non-significant slope and poor predictability ($r^2 < 0.5$) – does not meet data quality objectives to support regression-based uptake model.

Table A-1 Soil-to-Berry BAF: Descriptive Statistics

Chem	*N*	*%Detect Pairs*	Min	Max	Median	Mean	Std Dev	CV
Blueberry								
Mercury	27	100%	0.0029	0.040	0.015	0.017	0.011	66%
$Mercury_{RD}$[1]	8	100%	0.0061	0.060	0.034	0.030	0.019	63%
MethlylMercury	3	100%	0.43	3.9	2.0	2.1	1.7	81%
Cranberry								
Mercury	25	100%	0.0044	0.10	0.020	0.030	0.025	82%
MethlylMercury	3	100%	0.63	3.1	2.9	2.2	1.4	62%

All uptake factors ($kg_{soil,dw}/kg_{tiss,ww}$)

1 Red Devil Mine blueberry data (Matz 2012)

Use of median uptake factors is recommended, given limited non-significant slopes ($p > 0.1$) and/or poor predictability ($r^2 < 0.2$)

Attachment B
Sediment-to-Fish/Surface Water-to-Fish BAFs
Project-specific Empirical Data

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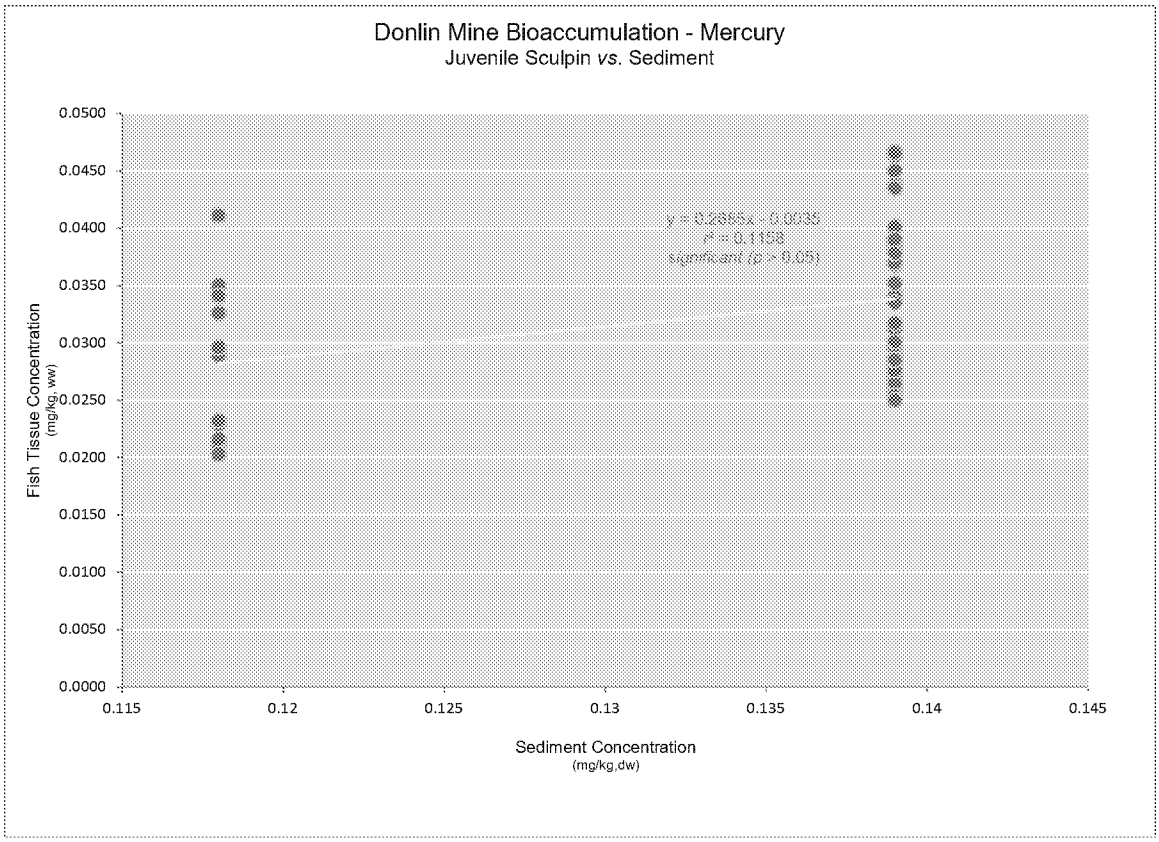
*Figure B-1 Mercury: Sculpin Juvenile vs. Sediment**



Regression Statistics	
Multiple R	0.34
R Square	0.12
Adjusted R Square	0.09
Standard Error	0.01
Observations	44

	df	*SS*	*MS*	*F*	*Signif F*
Regression	1	0.0003	0.0003	5.5	0.02
Residual	42	0.0020	0.00005		
Total	43	0.0023			

* Repeated measures at two surface water concentrations – does not meet data quality objectives to support regression-based uptake model.

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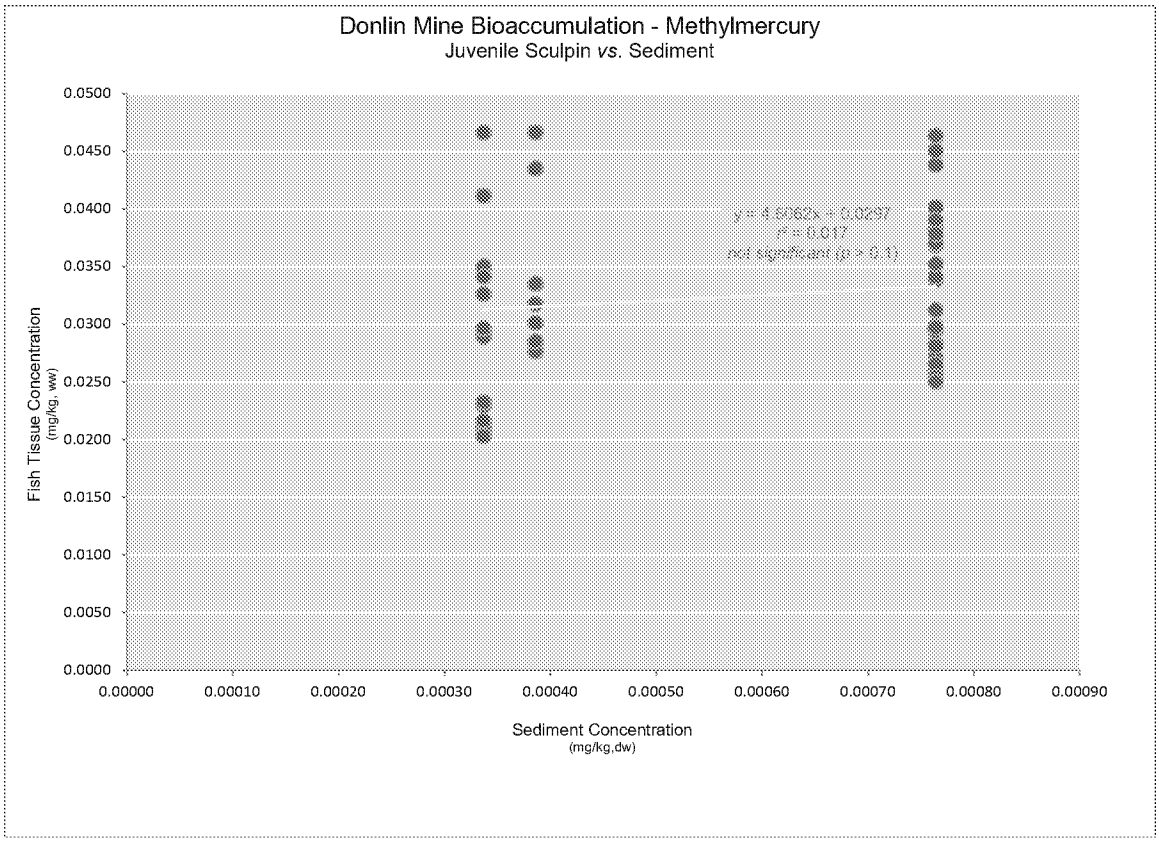
*Figure B-2 Methylmercury: Sculpin Juvenile vs. Sediment**

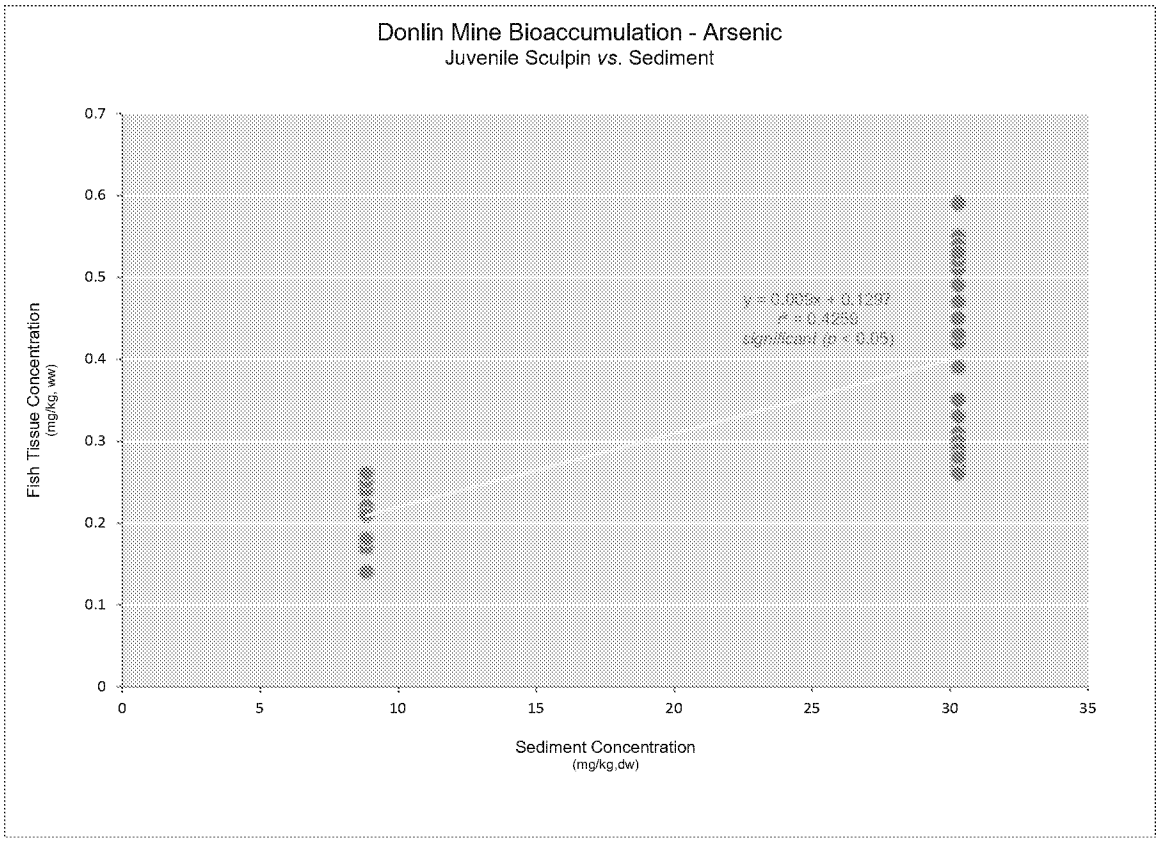


Regression Statistics	
Multiple R	0.13
R Square	0.02
Adjusted R Square	0.01
Standard Error	0.01
Observations	44

	df	*SS*	*MS*	*F*	*Signif F*
Regression	1	3.9E-05	3.9E-05	0.73	0.40
Residual	42	0.002	5.3E-05		
Total	43	0.002			

* Repeated measures at three surface water concentrations – does not meet data quality objectives to support regression-based uptake model.

*Figure B-3 Arsenic: Juvenile Sculpin vs. Sediment**

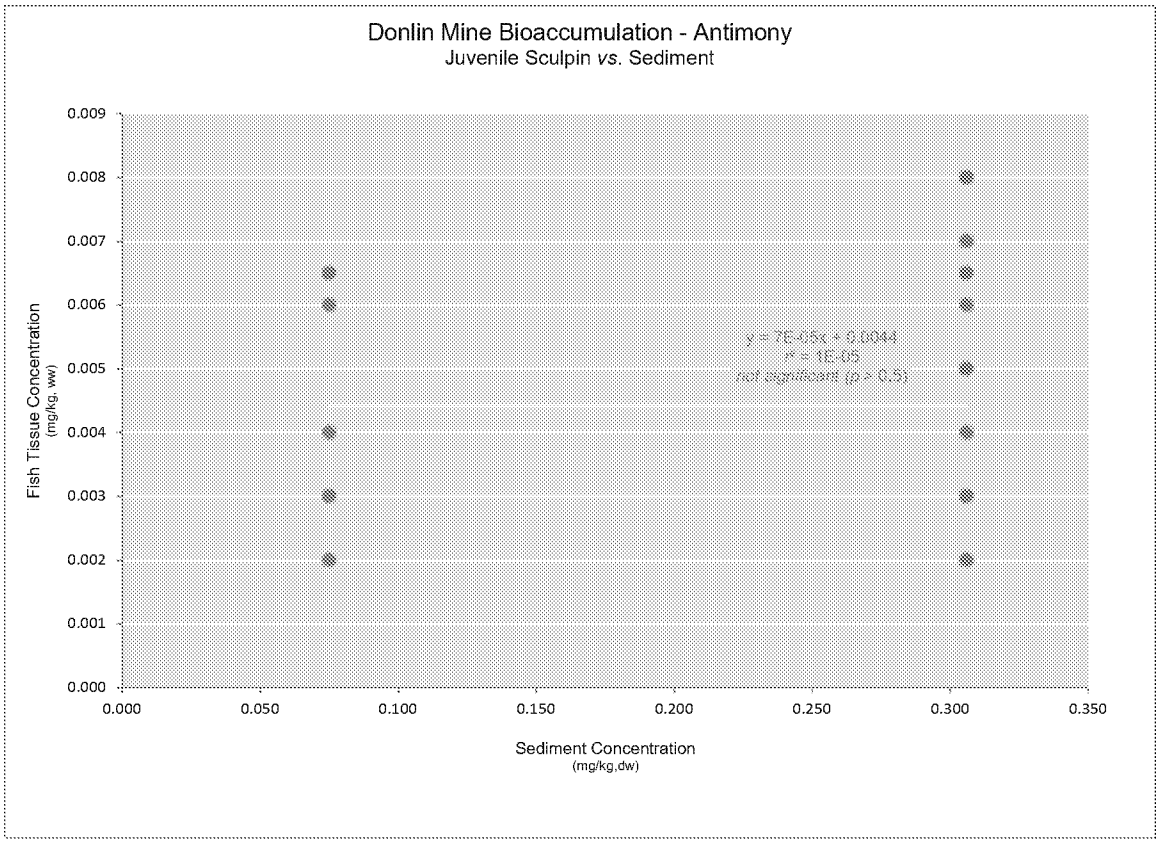


Regression Statistics	
Multiple R	0.65
R Square	0.43
Adjusted R Square	0.41
Standard Error	0.10
Observations	44

	df	*SS*	*MS*	*F*	*Signif F*
Regression	1	0.31	0.31	31	0.000002
Residual	42	0.41	0.01		
Total	43	0.72			

* Repeated measures at two surface water concentrations – does not meet data quality objectives to support regression-based uptake model.

*Figure B-4 Antimony: Juvenile Sculpin vs. Sediment**



Regression Statistics	
Multiple R	0.003
R Square	0.00001
Adjusted R Square	-0.024
Standard Error	0.002
Observations	44

	df	*SS*	*MS*	*F*	*Signif F*
Regression	1	1.89E-09	1.89E-09	0.0005	0.98
Residual	42	0.00016	3.7E-06		
Total	43	0.00016			

* Repeated measures at two surface water concentrations – does not meet data quality objectives to support regression-based uptake model.

Table B-1 Sediment-to-Fish BAF: Descriptive Statistics

Chem	*N*	%Detect Pairs*	Min	Max	Median	Mean	Std Dev	CV
Northern Pike - Adult[1]								
Mercury	1	100%	1.7	1.7	1.7	1.7	--	--
Methylmercury	1	100%	551	551	551	551	--	--
Sculpin - 1+ Yrs Juveniles[2]								
Arsenic	44	100%	0.0086	0.029	0.016	0.016	0.006	37%
Antimony	44	66%	0.0065	0.087	0.018	0.026	0.024	92%
Mercury	44	100%	0.17	0.35	0.23	0.24	0.051	21%
Methylmercury	44	100%	33	138	55	63	28	44%
Sculpin - Unspecified Age[3]								
Arsenic	27	100%	0.0089	0.026	0.011	0.015	0.005	35%
Antimony	27	66%	0.0098	0.160	0.016	0.030	0.039	130%
Mercury	27	100%	0.21	0.33	0.26	0.26	0.039	15%
Methylmercury	27	100%	39	120	49	71	33	46%

All uptake factors ($kg_{sed,dw}/kg_{tiss,ww}$) are:

- wet weight (ww) fish tissue burdens are estimated by the laboratory using a dry weight-to-wet weight conversion based on %moisture of tissue sample
- because sediment-fish data are not precisely co-located, the median sediment concentration for the corresponding creek reach is used to calculate the uptake factor

* %Detect Pairs is based on the lowest %detect of sediment or tissue data

1 Northern Pike Adult uptake factors are based on data from CR-R1 only
- all but one sample are lab MS/MSD (lab QA) samples

2 Sculpin Juvenile uptake factors are based on:
- fish tissue data from 3 reaches: CR-R1, CR-R2, and DO-R1
- given lack of sediment data for CR-R2 and DO-R1, data for CR-R3 and DO-R2 are used

3 Sculpin (unspecified age) uptake factors are based on:
- fish tissue data from 3 reaches: CR-R1, CR-R2, and DO-R1
- given lack of sediment data for CR-R2 and DO-R1, data for CR-R3 and DO-R2 are used

*Mercury in Surface Water-Fish Regression Statistics**

Regression Statistics	
R Square	0.004
Observations	36

ANOVA

	df	*SS*	*MS*	*F*	*Signif F*
Regression	1	0.0006	0.0006	0.14	0.71
Residual	34	0.16	0.0047		
Total	35	0.16			

	Coeffs	*Stnd Err*	*t Stat*	*P-value*
Intercept	0.00	0.10	-0.01	0.99
Slope	26385	71114	0.37	0.71

* Replication at two surface water concentrations (n = 2) – does not meet data quality objectives to support regression-based uptake model.

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Table B-2 Surface Water-to-Fish BAF: Descriptive Statistics

Chem	*N*	%Detect Pairs*	Min	Max	Median	Mean	Std Dev	CV
Northern Pike - Adult[1]								
Mercury[1]	1	100%	271613	271613	271613	271613	--	--
Sculpin - 1+ Yrs Juveniles[2]								
Arsenic	44	65%	56	262	158	155	60	39%
Antimony	44	47%	4.0	17	8.7	9.4	4.1	43%
Mercury	44	100%	16129	33967	21532	22157	4701	21%
Sculpin - Unspecified Age[3]								
Arsenic	27	65%	64	284	158	154	71	46%
Antimony	27	47%	4.0	24	8.7	10	4.7	46%
Mercury	27	100%	19097	29806	24023	24217	3747	15%

All uptake factors ($L/kg_{tiss,ww}$) are:

- wet weight (ww) fish tissue burdens are estimated by the laboratory using a dry weight-to-wet weight conversion based on %moisture of tissue sample
- because surface water-fish data are not precisely co-located, the median surface water concentration for the corresponding creek reach is used to calculate the uptake factor
- all but one sample are lab MS/MSD (lab QA) samples

* %Detect Pairs is based on the lowest %detect of water or tissue data

1 Northern Pike Adult uptake factors are based on data from CR-R1 only

- all but one sample are lab MS/MSD (lab QA) samples

2 Sculpin Juvenile uptake factors based on:

- fish tissue data from 3 reaches: CR-R1,-R2, and DO-R1
- given lack of surface water data for CR-R1, CR-R2, and DO-R1, data for CR-R3 and DO-R2 are used

3 Sculpin (unspecified age) uptake factors based on:

- fish tissue data from 3 reaches: CR-R1,-R2, and DO-R1
- given lack of surface water data for CR-R1, CR-R2, and DO-R1, data for CR-R3 and DO-R2 are used

EVOLUTION
CAPITAL ADVISORS

ASX: NVA

NOVA MINERALS LTD

Equity Research

15th June 2020

SPECULATIVE BUY

Price Target	>$0.200
Share Price	$0.053

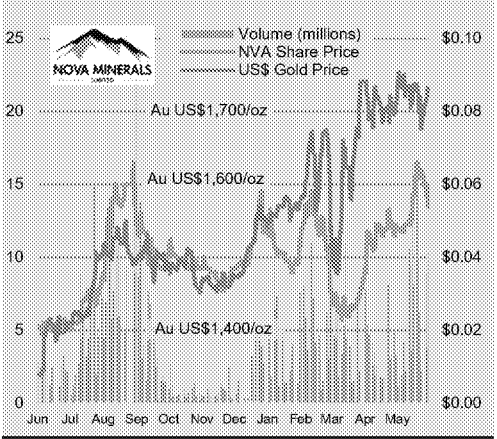
52-Week Range	$0.018 - $0.071
NVA Shares Outstanding	1,074m
NVAO Listed Options (3.25¢, 31 Aug 20)	445m
Unquoted Options (7¢, 2 Jun 2022)	18m
Unquoted Options (4¢, 19 Sep 2022)	61m
Unquoted Options (5.6¢, 28 Nov 2022)	1.5m
Class A Performance Rights	12m
Class B Performance Rights	24m
Market Capitalisation	$56.9m
Cash (31 Mar 2020)	$3.9m
Enterprise Value	$53.0m
Assuming all NVAO options converting by August:	
Market Capitalisation	*$80.5m*
Additional Cash	*$14.5m*

Investments:

1. NVA invested A$413,325 as a convertible note in Torian Resources (ASX:TNR). On conversion, NVA would have a 19.9% interest in TNR.
2. NVA owns 73.8% of Snow Lake Resources Ltd

Major Shareholders:

JP Morgan Nominees	5.2%
Louie Simens	3.6%
Avi Kimelman	3.5%
Top 5 shareholders	17.7%



Nova Minerals Limited (NVA.ASX | NVAAF.OTC | QM3.FSE) is a mineral resource company based in Australia with a current focus on exploration and development in the Tintina Gold Province in Alaska. The Estelle Gold Project (85% NVA) shows strong similarities with adjacent high margin gold mines such as Eagle (Victoria Gold Corporation VGCX.TSX) and Fort Knox (Kinross Gold Corporation K.TSX).

Initiation of Coverage: Don't Mind the Grade When it can be that Big and Highly Profitable

Tintina Gold Belt: The Estelle Gold project is located in a world-class district within the premier Tintina Gold Belt (Alaska) that hosts >220 Moz in mostly bulk tonnage, low grade but high margin deposits.

Geological Model: Estelle is a near-surface Intrusion Related Gold System (IRGS) deposit. The Tintina Gold Belt contains a number of IRGS deposits with low grade multi-million ounces gold mineral resources:

- Fort Knox (5.6 Moz @ 0.3 g/t Au resource) operated by Kinross (K.TSX, market capitalisation $11bn) 8.0 Moz produced 1997-2019
- Golden Summit (2.9 Moz @ 0.7 g/t Au) explored and developed by Freegold Ventures (FVL.TSX, $140m)
- Eagle (5.3 Moz @ 0.6 g/t Au) operated by Victoria Gold Corporation (VGCX.TSX, $820m)

Other types of deposits include very large porphyry copper – gold – silver deposits such as Casino (17.8 Moz @ 0.2 g/t Au, Pebble (106 Moz @ 0.3 g/t Au) and Whistler (6.4 Moz @ 0.5 g/t Au).

Mineral Resource Growth: The maiden mineral resource at Korbel is only a start. At 0.18 g/t Au cut-off, it amounts to 181 Mt at 0.43 g/t Au for 2.5 million ounces. The Korbel mineral resource can easily double by drilling adjacent blocks with identical geophysical signature, likely offset by faulting. The growth of the mineral resource at Korbel is seen as a function of drilling metres. Then Korbel is only one of 15 identified prospects in the Estelle property.

Mining Scenario: With a current average drilling depth of less than 100m, the deposit is shallow and amenable to open pit with a low strip ratio. Preliminary leach recoveries averaging 76% are in line with peer heap leach projects.

Potential Economics: In December 2019, VGCX.TSX released the results of its feasibility study for the Eagle deposit: 2P reserves 3.15 Moz @ 0.66 g/t Au, strip ratio 0.9:1, recovery 76.9%, production 210,000oz p.a. at AISC US$774/oz, capex US$365m, $NPV_{5\%}$ US$756m using US$1,300/oz gold price. Eagle started production in Sep 2019 (first gold pour). In time, NVA could produce similar results for Korbel or some other newly discovered deposits on the Estelle property.

Funding: Beyond the exiting cash, the NVAO listed options with an exercise price of 3.25 cents, expiring 31st August 2020 are well in-the-money and should bring close to $14 million additional cash to NVA.

Exploration Momentum: With about $3m cash and $14m expected from the options conversion, NVA has the opportunity to build momentum in its exploration programs. In addition, NVA aims to setup an all-year round camp removing any seasonality in its exploration efforts and news flow.

News flow: We anticipate several share price catalysts including results from drilling programs at Korbel and two other prospects, geophysical and geochemical surveys, mineral resource estimates and an overall acceleration of exploration results with the potential for new discoveries, some of which could be at a much higher gold grade.

Valuation: While it is still early days for NVA, we can see a relatively low risk high growth potential for the value of the company. Subject to further likely exploration success, our price target is supported by the current market value of peers.

The recommendations and opinions expressed in this research report accurately reflect the research analyst's personal, independent and objective views about any and all the companies and securities that are the subject of this report discussed herein.
For important information, please see the Disclosure & Disclaimer sections at the end of this document.

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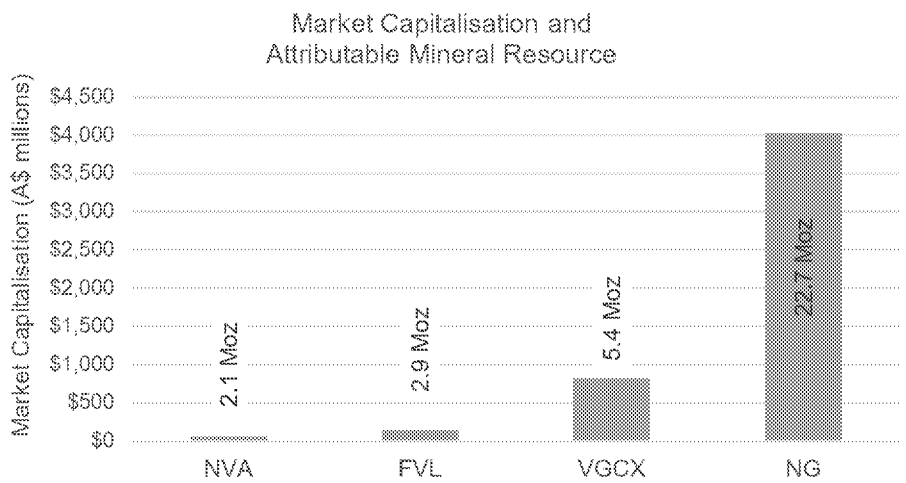
1. NVA Valuation

We see Nova Minerals valuation closely linked to mineral resource growth and progress of development studies.

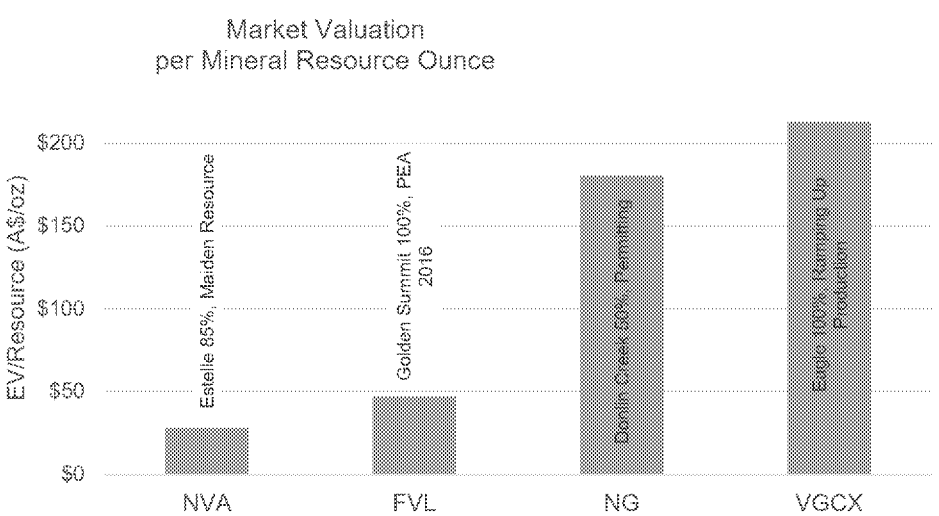
The following charts focus on closely comparable companies:

- One flagship asset (except Nova Gold)
- Same jurisdiction
- Same belt
- Similar geology
- Similar mineralisation
- Expected similar project economics

Figure 1.1 – NVA Comparative Analysis



	NVA	FVL	VGCX	NG
Market Cap	$57m	$140m	$821m	$4,032m



Source: Evolution Capital Advisors. Notes: NVA = Nova Resources, VGCX = Victoria Gold Corp, FVL = Freegold Ventures, NG = Nova Gold Resources, EV = Enterprise Value

NVA market valuation should increase substantially with the delineation of additional resources and the progress of development studies. Over the next 12 months, NVA has the opportunity to at least double the mineral resource at Korbel (and increase its confidence level), delineate additional resources at RPM, and discover some new deposits while confirming the project economics.

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2. Estelle Project

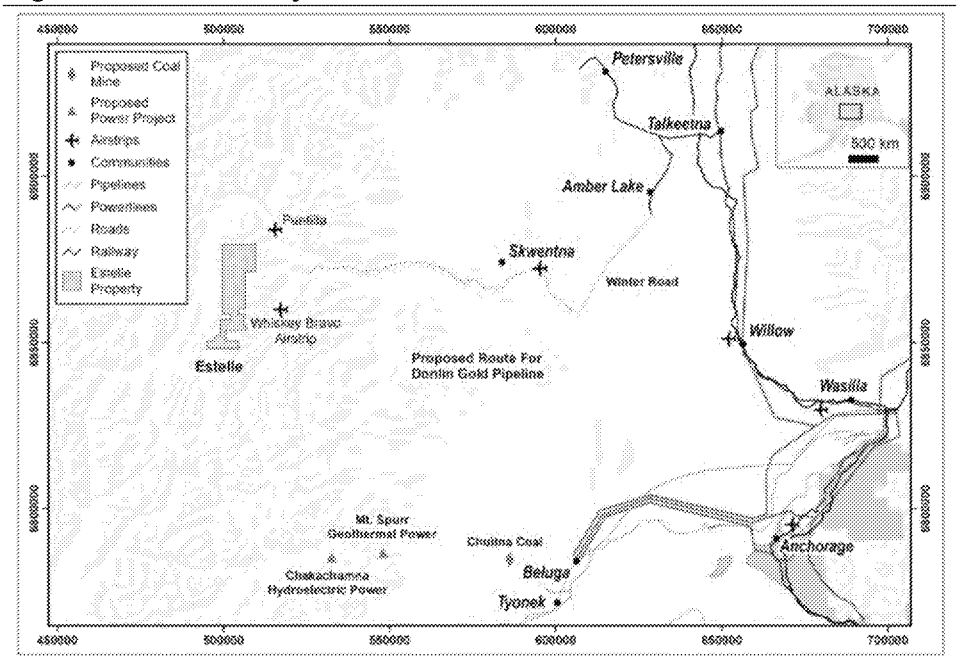
Location and Infrastructure

The Estelle Gold project is located approximately 110 miles (177km) northwest of Anchorage, Alaska's biggest city, which is prosperous and provides all the essential services and a large labour force. Access is via snow road or by air. The Whiskey Bravo airstrip is compliant with DC3 aircraft. To further note Nova Minerals and the Alaska Industrial Development Export Authority (AIDEA) have approved a resolution authorizing an agreement to advance studies of the West Susitna Access Road, which would provide surface access to the resource-rich area of Alaska where Nova's Estelle gold project is located.

Easy access to critical infrastructure

Tier-1 pro-mining jurisdiction

Figure 2.1 - Estelle Project Location



Source: NVA

Water is available throughout the property and permits are in place for five years. Those permits are easily renewable and expandable.

There are multiple options to access power:

No native titles over the project area

- Chakachamna hydro power plant
- Mt. Spurr geothermal project
- Beluga power plant
- Possibly a proposed geothermal power plant 20km from Korbel
- Possibly the LNG Donlin Gold pipeline

The mining property is made of 346 State Mining claims covering 220 km^2. The are no native titles over the project area.

Jurisdiction

Alaska ranked 4th on the Investment Attractiveness Index

Mineral resource projects are integral to the State economy, with a strong and time-tested community support and a government encouraging foreign investment in the mineral sector. The permitting process is well-defined. Alaska is ranked fourth on the Investment Attractiveness Index published by the Fraser Institute (1st Western Australia, 2nd Finland, 3rd Nevada).

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The taxation regime includes 1 3% State royalty based on net income from production as well as a mine license tax after 3-year grace period after production starts: US$4,000 + 7% of taxable income over US$100,000.

Gold in Alaska

Gold was first found in the Kenai River back in 1848 by Russian explorers. Mining never took off until around 1870 when gold was found around the area of Juneau. Soon after that discovery gold was found in both the Fairbanks area and there was the world famous Nome gold rush. Today Alaska has the second most amount of active mines in the USA, second only to Nevada. It is estimated that there is close to 200 active mining operations in the state. Most of these operations are smaller placer operations along with other hard rock shows. There are however some very large mines run by major mining companies. Some of these mines are the largest deposits globally.

Ownership

Nova Minerals Ltd (formerly Quantum Resources Limited) entered into a farm-in agreement in November 2017 with AK Minerals Pty Ltd (AKM), an Australian proprietary company. AKM owns the Estelle project through its Alaskan subsidiary, AK Custom Mining LLC. After spending $3.3 million on exploration to earn 70% of the Estelle project, AKM has now diluted its interest to a minimum of 15% and a 2% net smelter royalty.

3. Geological District and Deposits

Geology

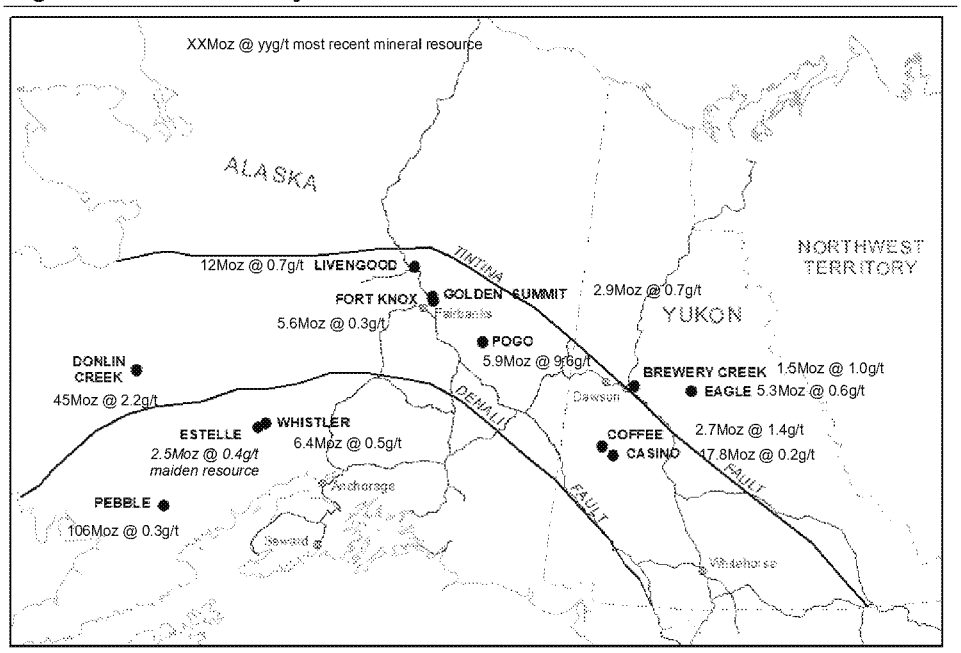
The Estelle Gold project is located in a world-class district within the premier Tintina Gold Belt that hosts >220 Moz in mostly bulk tonnage low grade but high margin deposits.

Tintina Gold Belt hosting 220 Moz gold

Mostly bulk tonnage, low grade, high margin deposits

Multi-million ounces deposits are the norm

Figure 3.1 - Estelle Project Location



Source: NVA

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Geological Model

IRGS deposit type

Estelle is a near-surface Intrusion Related Gold System (IRGS) deposit. The Tintina Gold Belt contains a number of IRGS deposits with low grade multi-million ounces:

Project located in giant plutonic gold systems

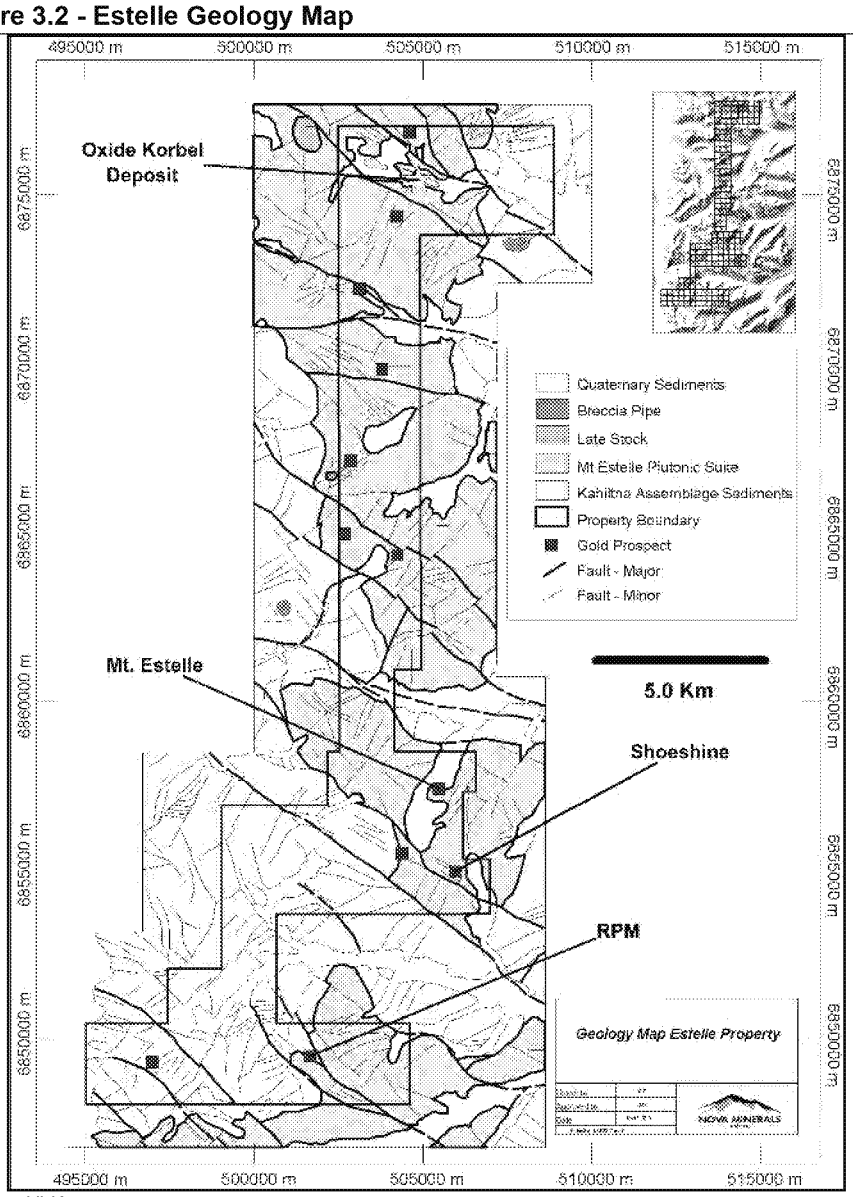
Large mining province attracting majors and large mid-caps looking for long life, low cost mines in a safe and stable jurisdiction

- Fort Knox operated by Kinross (K.TSX, $11bn) 8 Moz produced 1997-2019
- Golden Summit developed by Freegold Ventures (FVL.TSX, $140m)
- Donlin Creek developed (permitting stage) 50/50 by Nova Gold (NG.TSX, $4bn) and Barrick Gold (ABX.TSX, $62bn)
- Eagle (Dublin Gulch) operated by Victoria Gold Corporation (VGCX.TSX, $820m), started production in Sep 2019
- Brewery Creek developed by Golden Predator Mining (GPY.TSX, $44m)

Other types of deposits include very large porphyry copper – gold – silver – (molybdenum) deposits such as Casino, Pebble and Whistler.

Beyond Korbel, 14 targets have been defined at Estelle through geology, mapping, geochemistry, geophysics or historical drilling

Figure 3.2 - Estelle Geology Map



Source: NVA

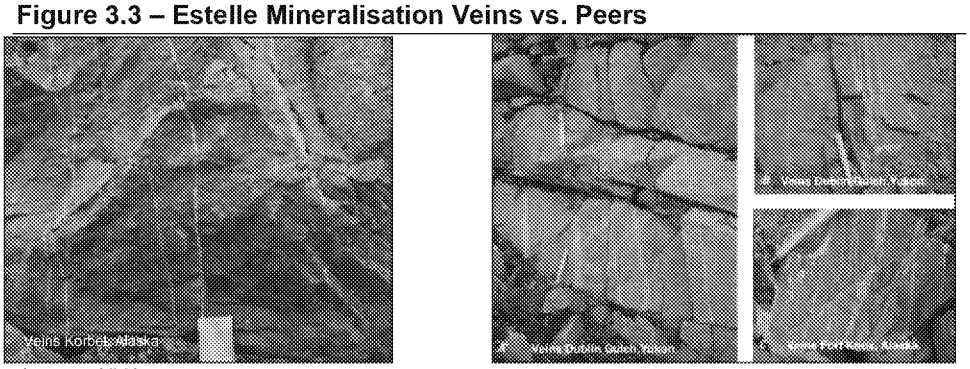
At RPM, SE12-008 hole intersected 177m @ 0.79 g/t Au including 120m @ 1.02 g/t Au

Mineralisation

The mineralization is characterized by a conjugate sets of sub–centimetre scale, commonly sheeted quartz veins.

The mineralized bodies are similar in grade, style of mineralization, deposit type and tonnage potential to the Fort Knox and Eagle deposits which are also located in the Tintina Gold Belt. A direct correlation between gold grade and vein density at Estelle is similarly reported at the Fort Knox (5.6 Moz) and Eagle (5.3 Moz).

Figure 3.3 – Estelle Mineralisation Veins vs. Peers



Source: NVA

4. Korbel Deposit

Geology

Based on mapping data, the main host rock type for the mineralization at Korbel consists dominantly of granite. Cracking and jointing is filled with quartz and other minerals in stacked veining and stockwork that are generally less than 8cm and mostly less than 15cm thick.

Gold mineralisation occurs as native gold in isolated grains or in association with sulphides: arsenopyrite, pyrite and pyrrhotite.

The main geologic characteristics of the Korbel deposit are remarkably similar to those of the Fort Knox and Dublin Gulch gold deposits which are also located in the Tintina Gold Belt.

Mineral Resource

In September 2019, NVA reported a JORC compliant maiden gold resource of 2.5 million ounces for the Korbel deposit.

Table 4.1 - Inferred Mineral Resource – Korbel Deposit

Cut-off Grade	Tonnes	Grade	Au Ounces
0.10	225 Mt	0.37	2.7 Moz
0.15	205 Mt	0.70	2.6 Moz
0.18	181 Mt	0.43	2.5 Moz
0.20	170 Mt	0.45	2.4 Moz
0.30	97 Mt	0.59	1.8 Moz
0.40	67 Mt	0.70	1.5 Moz
0.50	47 Mt	0.82	1.2 Moz

Source: NVA

The Korbel mineral resource estimate was prepared using cut-off grades ranging from 0.10 to 0.50 g/t Au. Similar deposits types to Korbel include the Fort Knox and Dublin Gulch Eagle deposits which have cut-off grades between 0.10 – 0.15 g/t Au (Table 4.2). It is suggested that 0.10 to 0.20g/t

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Au is an appropriate cut-off grade to evaluate the future economics of this project.

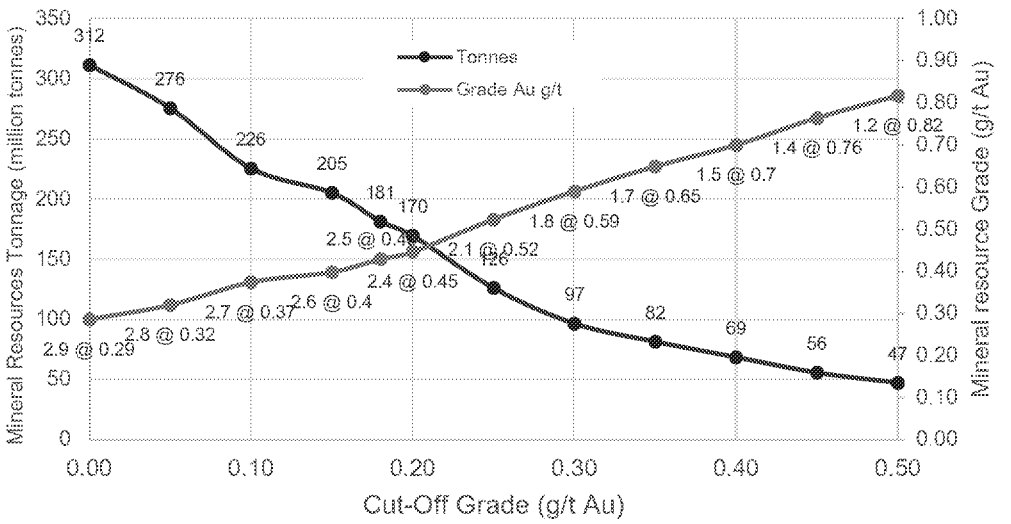
Table 4.2 – Bulk Density and Cut-off Grades of Comparable Deposits

	Fort Knox	Dublin Gulch/ Eagle
Cut-off Grade	0.10	0.15
Density	2.65	2.66

Source: NVA

A rock density of 2.68 was selected for the resource estimate. This estimate for dry bulk density compares favourably for that used in similar deposits types such as Fort Knox and Dublin Gulch.

Figure 4.1 – Estelle Mineral Resource Grade Tonnage Curves



Source: NVA, Evolution Capital Advisors. Read "2.9 @ 0.29" as "2.9 Moz at 0.29 g/t Au"

The mineral resource starts from less than 2m from surface.

Metallurgy

A total of 25 samples were part of a gold cyanidation analysis. The first AuCN analysis was by ALS method AA13, a basic tube leach test utilizing a 30g sample size with a 2 hour leach time, AAS finish. The second AuCN analysis was by ALS method AA14, a more representative bottle roll leach test utilizing a 1kg sample size with a 12 hour leach time, AAS finish. As expected, the 12 hour bottle roll test showed significantly increased recoveries across the board, establishing a clear positive correlation between leach retention time and recovery. Furthermore, the 12 hour bottle roll result provides the most representative data to date reflecting how the Korbel Gold Deposit mineralized material will perform in any future heap leach mining operation scenario.

Summary of initial metallurgical testing

	AuFA Fire Assay	AuCN AA13	AuCN AA14	Au Recovery	Au Recovery
Sample Size		30 g	1 kg		
Leach Time		2 hours	12 hours	2 hours	12 hours
Average of 25 Samples	1.23	0.77	0.91	63.1%	76.8%

Source: NVA

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This result is similar to the recoveries reported at Fort Knox (79%), Eagle (76.9%) and Golden Summit (80%).

Mining Scenario

Considering the size and geometry of the deposit, mining development will consist of a bulk open pit, with a low strip ratio, followed by heap leaching.

5. Exploration Targets

Exploration Tools

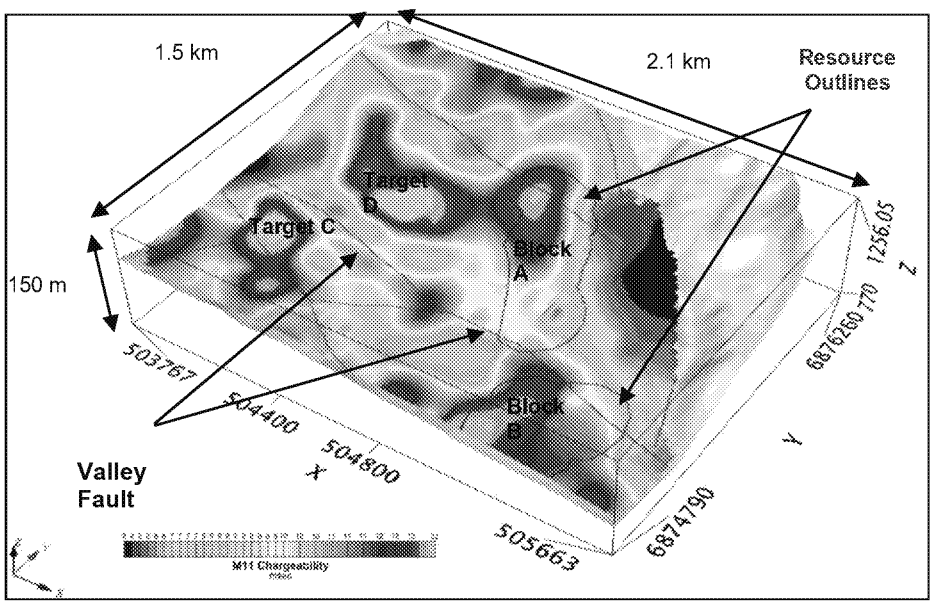
Geophysical surveys such as Induced Polarisation and chargeability are most suited to identify and delineate potential mineralisation.

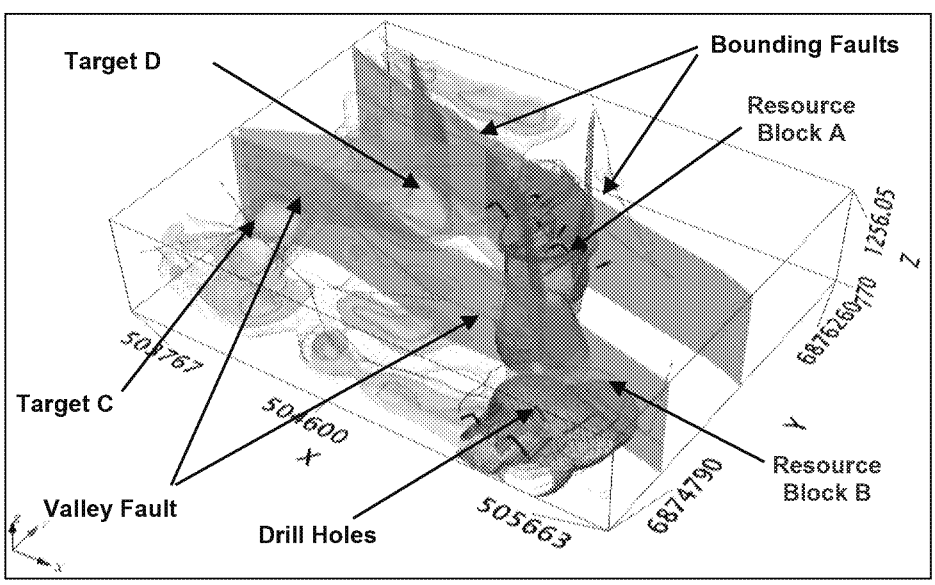
Targets C & D

Resource Blocks A & B are both enveloped by the chargeability anomalies that defined the drill targets. Targets C & D have both larger and stronger chargeability anomalies that have not been drill tested to date.

Targets C & D could easily double the maiden mineral resource

Figure 5.1 – Chargeability Model and Mineral Resource





Source: NVA

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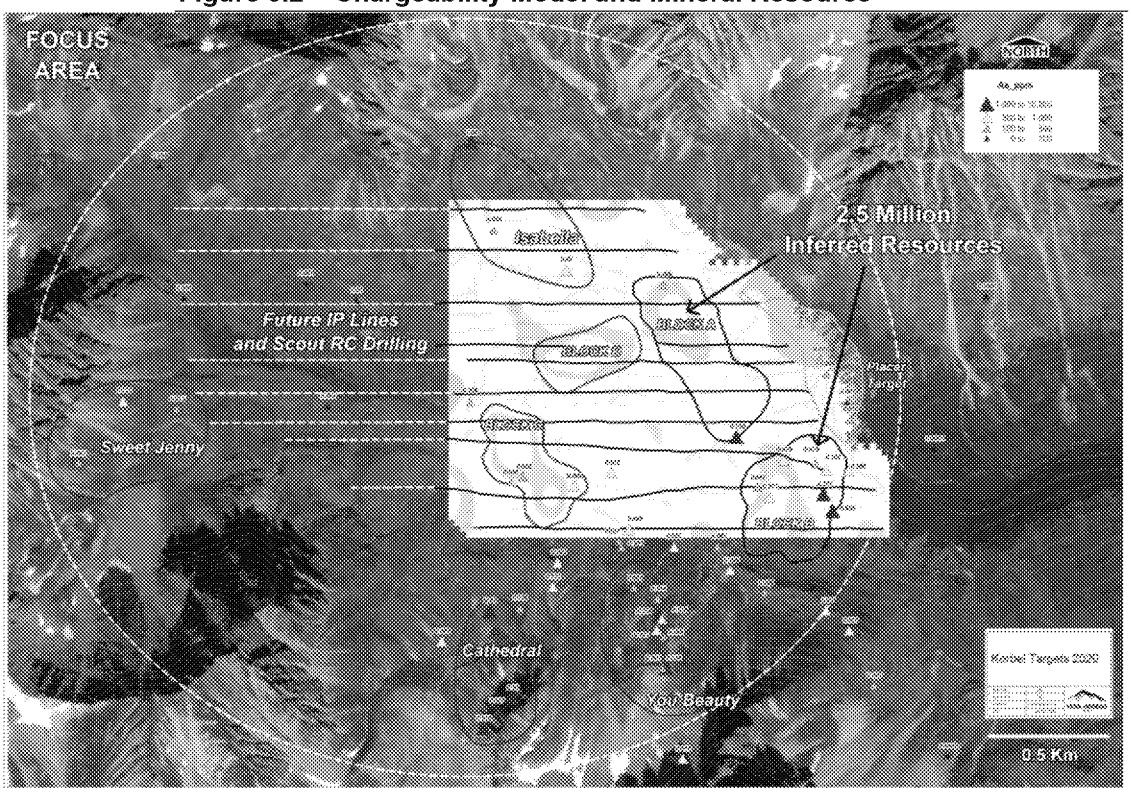
5,000m of exploration is scheduled for Targets C and D as part of the 2020 exploration program.

Targets in the surroundings of Korbel

Figure 5.2 displays some of the targets in the surroundings of the maiden mineral resource estimated at Korbel.

Figure 5.2 – Chargeability Model and Mineral Resource



Source: NVA

Beyond Block C and Block D identified by geophysics and supported by some geochemical samples, four other targets: Cathedral, Isabella, You Beauty and Sweet Jenny have been identified through geochemical surveys. Those are also part of the 2020 drilling program.

Targets at Depth

Induced polarisation/chargeability results show that the mineralisation is present to at least 300m below surface and remains open.

Historical deep drilling results confirms continuous mineralisation beyond 400m depth.

The current program will test down to 500m level.

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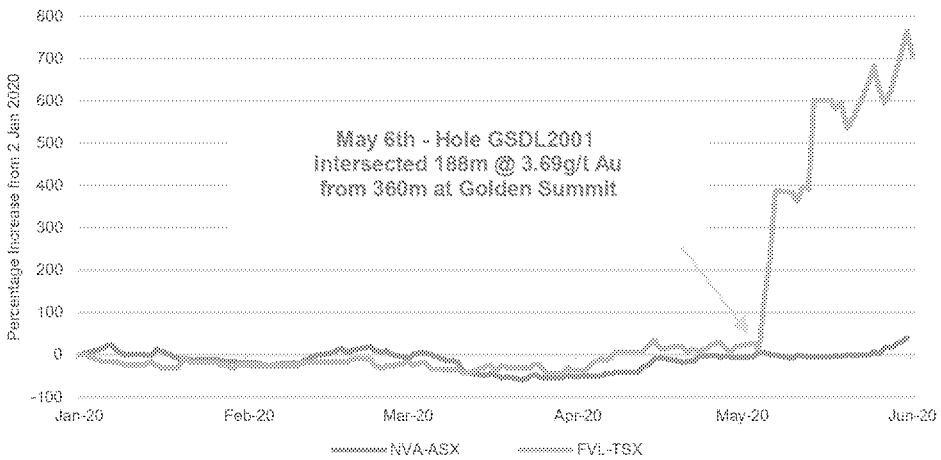
Could NVA potentially replicate the recent drilling success announced by Freegold Ventures (TSX:FVL) at their Golden Summit project: 188m @ 3.69 g/t gold from 360m downhole?

Higher grade could lie below the low grade mineralisation

Figure 5.3 – Recent Share Price Performance of FVL and NVA



Source: NVA

RPM

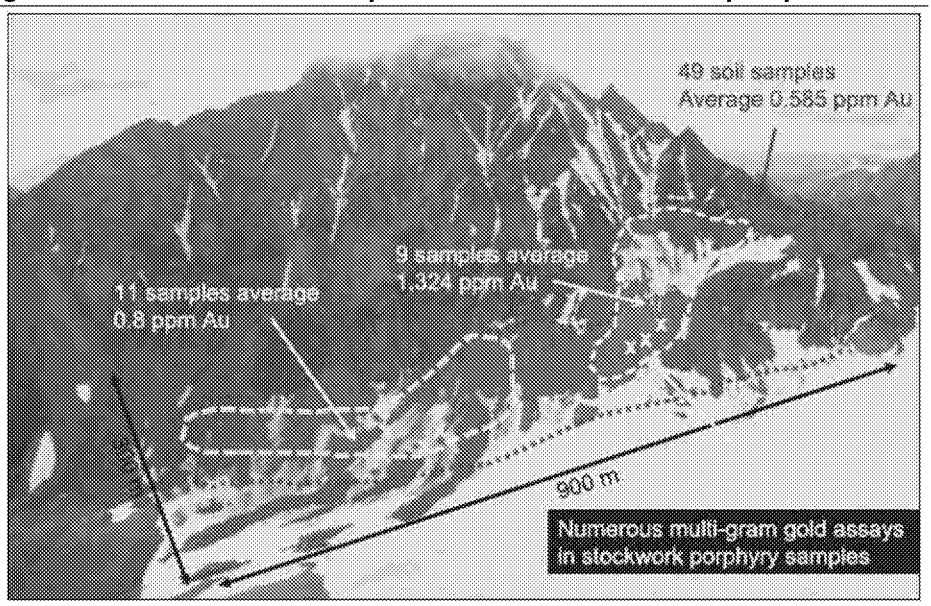
Historical exploration drilling completed by Millrock Resources Inc. in 2012 across the Estelle prospects include diamond drill hole SE12-008 at the RPM prospect. This hole was re-sampled by Nova as part of the 2019 field program. The hole intercepted 177.4m at 0.79 g/t Au from 4.3m, including 120.4m at 1.02 g/t Au from 26m.

The 2020 exploration program includes 5,000m of drilling at RPM.

Shoeshine

At Shoeshine, previous operator Millrock Resources Inc. collected and assayed a number of rock and soil samples with the results summarised in Figure 5.4.

Figure 5.4 – Rock and soil samples collected at Shoeshine prospect



Source: NVA

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6. Potential Project Economics

The table below summarises the key metrics expected or recorded at projects and mines developed or operated in the region. Cowal has been added to provide an additional point of comparison in the Australian context.

Korbel or other deposits at Estelle are likely to display similar project parameters and economics to Eagle

Actually economics returns are significantly higher at current gold prices

Key Metrics of Peer Projects and Mines

Operator		VGC TSX	FVL TSX	Kinross TSX	NST ASX	EVN ASX
Project	Unit	Eagle	Golden Summit	Fort Knox + Gilmore	Pogo	Cowal, NSW
Reference		FS	PEA	FS	AR	AR
Date		Dec-19	May-16	Jun-18	Jun-19	Jun-19
Gold Price	US$/oz	1,300	1,300	1,400	1,262	A$1,765
Mine Life	Years	13	24	12		12
Reserves	Moz	3.15	2.66	3.37	1.47	3.88
Grade	g/t	0.66	0.44 (ox)	0.37	8.1	0.85
Strip Ratio	w:o	0.9	0.9 (ox)	1.2	UG	n/a
Recovery	%	76.9	80	79	89	80
Production	oz	210,000	96,000	205,000	183,555	251,500
AISC	US$/oz	774	n/a	1,005	1,108	647
Initial Capex	US$m	365	88	100	n/a	n/a
NPV 5%	US$m	756	188	348	n/a	n/a
IRR	%	n/a	20	34	n/a	n/a

Source: Evolution Capital Advisors. VGCX = Victoria Gold Corp, FVL = Freegold Ventures, NST = Northern Star Resources, EVN = Evolution Mining. FS = Feasibility Study, AR = Annual Report, ox = oxide, UG = underground, AISC = All-In Sustaining Cost

It is not so much about the grade, but rather the full set of physical and financial parameters delivering the project economics.

Low grade, bulk mining projects can deliver long life, low cost, low risk mining operations appreciated by majors and mid-caps or can be a company maker.

7. Directors & Management Team

The interest of Directors are closely aligned with those of the company.

Interests of Directors are aligned with those from the company

Interest of Directors

Director	Holding Entity	Shares	Options	Rights
Louie Simens	SL Investors	35,551,389	18,333,494	
	Danche Simen	3,173,886	1,884,943	
	Kikceto Pty Ltd		20,000,000	15,000,000[1]
	sub-total	*38,725,275*	*40,218,437*	*15,000,000*
Avi Kimelman	Kushkush Investments	30,700,000	52,391,875	15,000,000[1]
	Advent Management	6,710,096	913,461	
	sub-total	*37,410,096*	*53,305,336*	*15,000,000*
Chris Gerteisen	Christopher Gerteisen	1,000,000	5,000,000	
	AJ Holdings Intl			6,000,000[2]
Avi Geller	Leonite Capital LLC	9,430,769	14,615,385	
	Total	**86,566,140**	**113,139,158**	**36,000,000**

Source: NVA. Performance rights: [1] 5m Class A + 10m Class B; [2] 2m Class A + 4m Class B

Class A Performance Rights convert to fully paid ordinary shares upon the delineation of an Inferred Mineral Resources of at least 5 Moz ounces of gold with average grade of not less than 0.4 g/t for not less than 388 Mt.

Class B Performance Rights convert to fully paid ordinary shares upon the delineation of an Inferred Mineral Resources of at least 10 Moz ounces of gold with average grade of not less than 0.4 g/t for not less than 776 Mt.

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Avi Kimelman, Executive Chairman

Avi Kimelman is the Managing Director and founder of Carraway Corporate, a corporate advisory business. Avi has been a director of a number of publicly listed and unlisted companies in industries including mining exploration and production, property development and investment, technology and education. Mr Kimelman has directly assisted companies in significant capital raisings, mergers and acquisitions, initial public offerings and reverse takeovers. Mr Kimelman is currently Executive Chairman of Nova Minerals Limited and serves as Non-Executive Chairman of Cohiba Minerals Limited (CHK).

Christopher Gerteisen

Mr. Christopher Gerteisen as General Manager controls all aspects of the Estelle Gold project while implementing efficiencies and savings to keep cost per discovery ounce well below industry average. Mr Gerteisen has over 20 years of experience as a professional geologist with an extensive record of managing and advancing complex and challenging resource projects across North America, Australia, and Asia.

His work experience spans Greenfields from discovery through to production stage and other projects with a focus on commodities including gold and copper. He worked as a geologist on the Carlin Trend in Nevada and on exploration in Alaska with Newmont. He has held senior positions within several projects throughout the goldfields of Western Australia.

As a research geologist with Newmont he worked on the Batu Hijau porphyry Cu-Au deposit in Indonesia. Most recently, through his technical contributions and management skills, Mr. Gerteisen played a significant role in the successful start-up, operations, and exploration which resulted in further mine-life extending discoveries at several prominent projects in the Australasian region, including Oxiana's Sepon and PanAust's Phu Bia in Laos. Mr. Gerteisen holds a BSc. Geology from the University of Idaho and a MSc. Economic Geology from the Western Australia School of Mines. He is a dual USA and Australia Citizen based in Alaska and a member of the Australian Institute of Geoscientists.

Louie Simens, Executive Director

Louie Simens has more than decade of experience in micro-cap equities and startup investing, including experience in corporate restructuring, due diligence, and mergers and acquisitions. Prior to entering the junior resources sector, he has owned and operated a successful civil and building construction business, where he gained extensive knowledge of corporate governance and project management. Mr Simens understands the fundamental parameters, strategic drivers and market requirements for growth within the junior resources sector.

Avi Geller, Non-Executive Director

Avi Geller has extensive investment experience and a deep knowledge of corporate finance, including capital markets, venture capital, hybrid, debt and private equity. He served as Chief Investment Officer of Leonite Capital, a family office he co-founded focusing on real estate and capital markets. Mr. Geller also serves as a director of the real estate company Parkit Enterprise Inc (TSX-V: PKT | OTCQX: PKTEF) and the events and technology company Dealflow Financial Products. He previously served as chairman of Axios Mobile Assets.

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Dale Schultz, Technical Lead and Chief Geologist

Dale Schultz has over 30 years of experience in the mining and exploration industry in North and South America. He has a M.Sc. from the University of Saskatchewan and is a registered Professional Geoscientist in the provinces of Manitoba and Saskatchewan. Over the years, Mr. Schultz has been the Qualified Person (QP) for a number of projects including Solex Resources' Pilunani and Macusani projects in Peru, Channel Resources' El Mozo project in Central Ecuador, Aurelians' Bonza-Penus resource campaign on the Condor Project in Central Ecuador, Majescors' Douvray porphyry copper-gold project in Haiti, and spent time at Battle Mountains' Kori Kollo mine in Bolivia. Mr. Schultz has also extensive experience in a number of other gold mining operations in Canada, and brings with him invaluable experience ranging from initial exploration stages through to underground and open pit mine production of large gold systems.

Brian Youngs, Head of Exploration and Logistics

Brian Youngs heads exploration and logistics at Nova. He is a Certified Technician with the Ontario Association of Certified Engineering Technicians and Technologists and a member of the Canadian Institute of Mining, Metallurgy and Petroleum. Mr Youngs completed with Honors a diploma in Mining Engineering Technician and post-diploma in Geographic Information Systems (Applications Specialist Program). He has a robust understanding of geology, mineralogy and mineral processing and was awarded for excellence in the subject of Geology.

Michael Melamed, CFO

Michael is a chartered accountant who has worked in top tier accounting firms and banks, Michael brings to the Company over 20 years of extensive experience in accounting, corporate advisory, M&A, corporate restructuring and acts as a CFO for several listed and unlisted entities. Michael brings to the Company his extensive network and business opportunities.

Since joining Nova, Michael has held several positions within the Finance function. Michael has a strong background in financial reporting, business processes, M&A and investor relations. Michael is a Member of Institute of Chartered Accountants, Australia and has a Bachelor of Business (Accounting & Finance) from the University of Technology, Sydney (UTS).

8. Investment Risks

NVA is exposed to a number of risks including:

- **Geological risk**: the actual characteristics of an ore deposit may differ significantly from initial interpretations.
- **Resource risk:** all resource estimates are expressions of judgment based on knowledge, experience and industry practice. Estimates, which were valid when originally calculated may alter significantly when new information or techniques become available. In addition, by their very nature, resource estimates are imprecise and depend to some extent on interpretations, which may prove to be inaccurate.
- **Commodity price risk:** the revenues NVA will derive through the sale of gold doré expose the potential income to metal price risk. The price of gold fluctuate and are affected by many factors beyond the control of NVA. Such factors include supply and

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demand fluctuations, technological advancements and macro-economic factors.

- **Exchange Rate risk:** The revenue NVA derives from the sale of metal products exposes the potential income to exchange rate risk. International prices of gold and silver as well most of the costs base are denominated in United States dollars, whereas the financial reporting currency of NVA is the Australian dollar, exposing the company to the fluctuations and volatility of the rate of exchange between the USD and the AUD as determined by international markets.
- **Mining risk:** A reduction in mine production would result in reduced revenue.
- **Processing risks:** A reduction in plant throughput would result in reduced revenue. In all processing plants, some metal is lost rather than reporting to the valuable product. If the recovery of metal is less than forecast, then revenue will be reduced.
- **Operational cost risk:** an increase in operating costs will reduce the profitability and free cash generation of the project.
- **Management and labour risk**: an experienced and skilled management team is essential to the successful development and operation of mining projects.

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Tailings facility disclosures reveal stability risks

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GlobalTailingsReview.org

GLOBAL INDUSTRY STANDARD ON TAILINGS MANAGEMENT

AUGUST 2020

ICMM International Council on Mining & Metals

UN environment programme

PRI Principles for Responsible Investment

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PREAMBLE

The Global Industry Standard on Tailings Management (herein 'the Standard') strives to achieve the ultimate goal of zero harm to people and the environment with zero tolerance for human fatality. It requires *Operators* to take responsibility and prioritise the safety of *tailings facilities*, through all phases of a facility's *lifecycle*, including closure and post-closure. It also requires the disclosure of relevant information to support public accountability.

Issues have arisen in the development of the Standard that are difficult to translate into an auditable industry Standard for *Operators*. These issues are more appropriately addressed through national and/or state level regulatory authorities, or through multilateral agencies working with the industry. For example, it is recognised that more work needs to be done by national and/or state level regulators to develop mechanisms that enable the identification, maintenance and/or *restoration* of abandoned or 'orphaned' *facilities*.

The Standard provides a framework for safe *tailings facility* management while affording *Operators* flexibility as to how best to achieve this goal. For auditing and certification purposes, the Standard includes the Preamble, the Requirements, the Glossary and Annexes. Unless otherwise specified, the Requirements of the Standard are directed to the *Operator*. The Requirements apply to individual facilities as defined in the Glossary, and are all intended to apply and be auditable.

Conformance with the Standard does not displace the requirements of any specific national, state or local governmental statutes, laws, regulations, ordinances, or other government directives. *Operators* are expected to conform with the Requirements of the Standard not in conflict with other provisions of law.

The Standard will be supported by implementation protocols which will provide detailed guidance for certification, or assurance as applicable, and for equivalence with other standards. Many activities referenced in this Standard may be found as part of a comprehensive mine-wide *environmental and social management system*. Where credible systems for assuring these requirements are already in place (such as third party audit or verification processes), these should be recognised as equivalent to avoid duplication, to the extent reasonably practicable.

Although the Standard follows a logical sequence arranged around broad topic areas, the Requirements are not presented chronologically. The Principles are intended to summarise the Requirements that follow and are not in themselves auditable. To reduce repetition, the disclosure requirements are grouped under Principle 15. These Requirements support public accountability and protect *Operators* from the need to disclose confidential commercial or financial information.

All terms that appear in *italics* are defined in the Glossary, Annex 1.

GLOBAL INDUSTRY STANDARD ON TAILINGS MANAGEMENT

ACRONYMS

CDIV	Construction versus Design Intent Verification
DBR	Design Basis Report
DSR	Dam Safety Review
EOR	Engineer of Record
EPRP	Emergency Preparedness and Response Plan
ESMS	Environmental and Social Management System
FPIC	Free Prior and Informed Consent
GTR	Global Tailings Review
ICMM	International Council on Mining and Metals
ICOLD	International Commission on Large Dams
IFC	International Finance Corporation
ITRB	Independent Tailings Review Board
OMS	Operations, Maintenance and Surveillance
PRI	Principles for Responsible Investment
RTFE	Responsible Tailings Facility Engineer
TARP	Triggered Action Response Plan
TMS	Tailings Management System
UNEP	United Nations Environment Programme
UNGP	United Nations Guiding Principles on Business and Human Rights

AFFECTED COMMUNITIES

TOPIC I

PRINCIPLE 1 **RESPECT THE RIGHTS OF *PROJECT-AFFECTED PEOPLE* AND *MEANINGFULLY ENGAGE* THEM AT ALL PHASES OF THE *TAILINGS FACILITY LIFECYCLE*, INCLUDING CLOSURE.**

Requirement 1.1 Demonstrate respect for human rights in accordance with the United Nations Guiding Principles on Business and Human Rights (UNGP), conduct human rights due diligence to inform management decisions throughout the *tailings facility lifecycle* and address the human rights risks of *tailings facility credible failure scenarios*.

For existing facilities, the *Operator* can initially opt to prioritise salient human rights issues in accordance with the UNGP.

Requirement 1.2 Where a new *tailings facility* may impact the rights of indigenous or tribal peoples, including their land and resource rights and their right to self-determination, work to obtain and maintain *Free Prior and Informed Consent (FPIC)* by demonstrating conformance to international guidance and recognised *best practice* frameworks.

Requirement 1.3 Demonstrate that *project-affected people* are *meaningfully engaged* throughout the *tailings facility lifecycle* in building the *knowledge base* and in decisions that may have a bearing on public safety and the integrity of the *tailings facility*. The *Operator* shall share information to support this process.

Requirement 1.4 Establish an effective operational-level, non-judicial *grievance* mechanism that addresses complaints and *grievances* of *project-affected people* relating to the *tailings facility*, and provide remedy in accordance with the UNGP.

INTEGRATED KNOWLEDGE BASE

TOPIC II

PRINCIPLE 2 **DEVELOP AND MAINTAIN AN INTERDISCIPLINARY *KNOWLEDGE BASE* TO SUPPORT SAFE *TAILINGS* MANAGEMENT THROUGHOUT THE *TAILINGS FACILITY LIFECYCLE*, INCLUDING CLOSURE.**

Requirement 2.1 Develop and document knowledge about the social, environmental and local economic context of the *tailings facility*, using approaches aligned with international *best practices*. Update this knowledge at least every five years, and whenever there is a *material* change either to the *tailings facility* or to the social, environmental and local economic context. This knowledge should capture uncertainties due to climate change.

Requirement 2.2 Prepare, document and update a detailed site characterisation of the *tailings facility* site(s) that includes data on climate, geomorphology, geology, geochemistry, hydrology and hydrogeology (surface and groundwater flow and quality), geotechnical, and seismicity. The physical and chemical properties of the *tailings* shall be characterised and updated regularly to account for variability in ore properties and processing.

Requirement 2.3 Develop and document a *breach analysis* for the *tailings facility* using a methodology that considers *credible failure modes*, site conditions, and the properties of the slurry. The results of the analysis shall estimate the physical area impacted by a potential failure. When flowable materials (water and liquefiable solids) are present at *tailings facilities* with Consequence Classification of 'High', 'Very High' or 'Extreme', the results should include estimates of the physical area impacted by a potential failure, flow arrival times, depth and velocities, and depth of material deposition. Update whenever there is a *material* change either to the *tailings facility* or the physical area impacted.

Requirement 2.4 In order to identify the groups most at risk, refer to the updated *tailings facility breach analysis* to assess and document potential human exposure and vulnerability to *tailings facility credible failure scenarios*. Update the assessment whenever there is a *material* change either to the *tailings facility* or to the *knowledge base*.

PRINCIPLE 3 USE ALL ELEMENTS OF THE *KNOWLEDGE BASE* - SOCIAL, ENVIRONMENTAL, LOCAL ECONOMIC AND TECHNICAL - TO INFORM DECISIONS THROUGHOUT THE *TAILINGS FACILITY LIFECYCLE*, INCLUDING CLOSURE.

Requirement 3.1 To enhance resilience to climate change, evaluate, regularly update and use climate change knowledge throughout the *tailings facility lifecycle* in accordance with the principles of *Adaptive Management*.

Requirement 3.2 For new *tailings facilities*, the *Operator* shall use the *knowledge base* and undertake a multi-criteria *alternatives analysis* of all feasible sites, technologies and strategies for *tailings* management. The goal of this analysis shall be to: (i) select an alternative that minimises risks to people and the environment throughout the *tailings facility lifecycle*; and (ii) minimise the volume of *tailings* and water placed in external *tailings facilities*. This analysis shall be reviewed by the *Independent Tailings Review Board (ITRB)* or a *senior independent technical reviewer*.

For existing *tailings facilities*, the *Operator* shall periodically review and refine the *tailings* technologies and design, and management strategies to minimise risk and improve environmental outcomes. An exception applies to facilities that are demonstrated to be in a state of *safe closure*.

Requirement 3.3 For new *tailings* facilities, use the *knowledge base*, including uncertainties due to climate change, to assess the social, environmental and local economic impacts of the *tailings facility* and its potential failure throughout its *lifecycle*. Where *impact assessments* predict *material* acute or chronic impacts, the *Operator* shall develop, document and implement impact mitigation and management plans using the *mitigation hierarchy*.

Requirement 3.4 Update the assessment of the social, environmental and local economic impacts to reflect a *material* change either to the *tailings facility* or to the social, environmental and local economic context. If new data indicates that the impacts from the *tailings facility* have changed *materially*, including as a result of climate change knowledge or long-term impacts, the *Operator* shall update *tailings facility* management to reflect the new data using *Adaptive Management best practices*.

DESIGN, CONSTRUCTION, OPERATION AND MONITORING OF THE TAILINGS FACILITY

TOPIC III

PRINCIPLE 4 **DEVELOP PLANS AND DESIGN CRITERIA FOR THE *TAILINGS FACILITY* TO MINIMISE RISK FOR ALL PHASES OF ITS *LIFECYCLE*, INCLUDING CLOSURE AND POST-CLOSURE.**

Requirement 4.1 Determine the consequence of failure classification of the *tailings facility* by assessing the downstream conditions documented in the *knowledge base* and selecting the classification corresponding to the highest Consequence Classification for each category in Annex 2, Table 1. The assessment and selection of the classification shall be based on *credible failure modes*, and shall be defensible and documented.

Requirement 4.2 With the objective of maintaining flexibility in the development of a new *tailings facility* and optimising costs while prioritising safety throughout the *tailings facility lifecycle*:

A. Develop *preliminary designs* for the *tailings facility* with external loading design criteria consistent with both the consequence of failure classification selected based on current conditions and higher Consequence Classifications (including 'Extreme').

B. Informed by the range of requirements defined by the *preliminary designs*, either:

1. Implement the design for the 'Extreme' Consequence Classification external loading criteria; or
2. Implement the design for the current Consequence Classification criteria, or a higher one, and demonstrate that the feasibility, at a proof of concept level, to upgrade to the design for the 'Extreme' classification criteria is maintained throughout the *tailings facility lifecycle*.

C. If option B.2 is implemented, review the consequence of failure classification at the time of the *Dam Safety Review (DSR)* and at least every five years, or sooner if there is a *material* change in the social, environmental and local economic context, and complete the upgrade of the *tailings facility* to the new Consequence Classification as determined by the *DSR* within three years. This review shall proceed until the *tailings facility* has been *safely closed* according to this Standard.

D. The process described above shall be reviewed by the *Independent Tailings Review Board (ITRB)* or the *senior independent technical reviewer*, as appropriate for the *tailings facility* Consequence Classification.

Subject to Requirement 4.7, Requirements 4.2.C and 4.2.D shall also apply to existing *tailings facilities*.

Requirement 4.3	The *Accountable Executive* shall take the decision to adopt a design for the current Consequence Classification criteria and to maintain flexibility to upgrade the design for the highest classification criteria later in the *tailings facility lifecycle*. This decision shall be documented.
Requirement 4.4	Select, explicitly identify and document all design criteria that are appropriate to minimise risk for all *credible failure modes* for all phases of the *tailings facility lifecycle*.
Requirement 4.5	Apply design criteria, such as factors of safety for slope stability and seepage management, that consider estimated operational properties of materials and expected performance of design elements, and quality of the implementation of risk management systems. These issues should also be appropriately accounted for in designs based on deformation analyses.
Requirement 4.6	Identify and address brittle failure modes with conservative design criteria, independent of trigger mechanisms, to minimise their impact on the performance of the *tailings facility*.
Requirement 4.7	Existing *tailings facilities* shall conform with the Requirements under Principle 4, except for those aspects where the *Engineer of Record (EOR)*, with review by the *ITRB* or a *senior independent technical reviewer*, determines that the upgrade of an existing *tailings facility* is not viable or cannot be retroactively applied. In this case, the *Accountable Executive* shall approve and document the implementation of measures to reduce both the probability and the consequences of a *tailings facility* failure in order to reduce the risk to a level *as low as reasonably practicable (ALARP)*. The basis and timing for addressing the upgrade of existing *tailings facilities* shall be risk-informed and carried out as soon as reasonably practicable.
Requirement 4.8	The *EOR* shall prepare a *Design Basis Report (DBR)* that details the design assumptions and criteria, including operating constraints, and that provides the basis for the design of all phases of the *tailings facility lifecycle*. The *DBR* shall be reviewed by the *ITRB* or *senior independent technical reviewer*. The *EOR* shall update the *DBR* every time there is a *material* change in the design assumptions, design criteria, design or the *knowledge base* and confirm internal consistency among these elements.

PRINCIPLE 5 **DEVELOP A *ROBUST DESIGN* THAT INTEGRATES THE *KNOWLEDGE BASE* AND MINIMISES THE RISK OF FAILURE TO PEOPLE AND THE ENVIRONMENT FOR ALL PHASES OF THE *TAILINGS FACILITY LIFECYCLE*, INCLUDING CLOSURE AND POST-CLOSURE.**

Requirement 5.1 For new *tailings facilities*, incorporate the outcome of the multi-criteria *alternatives analysis* including the use of *tailings* technologies in the design of the *tailings facility*.

For expansions to existing *tailings facilities*, investigate the potential to refine the *tailings* technologies and design approaches with the goal of minimising risks to people and the environment throughout the *tailings facility lifecycle*.

Requirement 5.2 Develop a *robust design* that considers the technical, social, environmental and local economic context, the *tailings facility* Consequence Classification, site conditions, water management, mine plant operations, *tailings* operational and construction issues, and that demonstrates the feasibility of *safe closure* of the *tailings* facility. The design should be reviewed and updated as performance and site data become available and in response to *material* changes to the *tailings facility* or its performance.

Requirement 5.3 Develop, implement and maintain a water balance model and associated water management plans for the *tailings facility*, taking into account the *knowledge base* including climate change, upstream and downstream hydrological and hydrogeological basins, the mine site, mine planning and overall operations and the integrity of the *tailings facility* throughout its *lifecycle*. The water management programme must be designed to protect against unintentional releases.

Requirement 5.4 Address all potential failure modes of the structure, its foundation, abutments, reservoir (*tailings* deposit and pond), reservoir rim and appurtenant structures to minimise risk to *ALARP*. Risk assessments must be used to inform the design.

Requirement 5.5 Develop a design for each stage of construction of the *tailings facility*, including but not limited to start-up, partial raises and interim configurations, final raise, and all closure stages.

Requirement 5.6 Design the closure phase in a manner that meets all the Requirements of the Standard with sufficient detail to demonstrate the feasibility of the closure scenario and to allow implementation of elements of the design during construction and operation as appropriate. The design should include progressive closure and *reclamation* during operations.

Requirement 5.7 For a proposed new *tailings facility* classified as 'High', 'Very High' or 'Extreme', the *Accountable Executive* shall confirm that the design satisfies *ALARP* and shall approve additional *reasonable steps* that may be taken downstream, to further reduce potential consequences to people and the environment. The *Accountable Executive* shall explain and document the decisions with respect to *ALARP* and additional consequence reduction measures.

For an existing *tailings facility* classified as 'High', 'Very High' or 'Extreme', the *Accountable Executive*, at the time of every *DSR* or at least every five years, shall confirm that the design satisfies *ALARP* and shall seek to identify and implement additional *reasonable steps* that may be taken to further reduce potential consequences to people and the environment. The *Accountable Executive* shall explain and document the decisions with respect to *ALARP* and additional consequence reduction measures, in consultation with external parties as appropriate.

Requirement 5.8 Where other measures to reduce the consequences of a *tailings facility credible failure* mode as per the *breach analysis* have been exhausted, and pre-emptive resettlement cannot be avoided, the Operator shall demonstrate conformance with international standards for *involuntary resettlement*.

PRINCIPLE 6 PLAN, BUILD AND OPERATE THE *TAILINGS FACILITY* TO MANAGE RISK AT ALL PHASES OF THE *TAILINGS FACILITY LIFECYCLE*, INCLUDING CLOSURE AND POST-CLOSURE

Requirement 6.1 Build, operate, monitor and close the *tailings facility* according to the design intent at all phases of the *tailings facility lifecycle*, using qualified personnel and appropriate methodology, equipment and procedures, data acquisition methods, the *Tailings Management System (TMS)* and the overall *Environmental and Social Management System (ESMS)* for the mine and associated infrastructure.

Requirement 6.2 Manage the quality and adequacy of the construction and operation process by implementing Quality Control, Quality Assurance and *Construction vs Design Intent Verification (CDIV)*. The *Operator* shall use the *CDIV* to ensure that the design intent is implemented and is still being met if the site conditions vary from the design assumptions.

Requirement 6.3 Prepare a detailed *Construction Records Report* ('as-built' report) whenever there is a *material* change to the *tailings facility*, its infrastructure or its monitoring system. The *EOR* and the *Responsible Tailings Facility Engineer (RTFE)* shall sign this report.

Requirement 6.4 Develop, implement, review annually and update as required an *Operations, Maintenance and Surveillance (OMS) Manual* that supports effective risk management as part of the *TMS*. The *OMS Manual* should follow *best practices*, clearly provide the context and *critical controls* for safe operations, and be reviewed for effectiveness. The *RTFE* shall provide access to the *OMS Manual* and training to all levels of personnel involved in the *TMS* with support from the *EOR*.

Requirement 6.5 Implement a formal *change management system* that triggers the evaluation, review, approval and documentation of changes to design, construction, operation or monitoring during the *tailings facility lifecycle*. The *change management system* shall also include the requirement for the *EOR* to prepare a periodic *Deviance Accountability Report (DAR)*, that provides an assessment of the cumulative impact of the changes on the risk level of the as-constructed facility. The *DAR* shall provide recommendations for managing risk, if necessary, and any resulting updates to the design, *DBR*, *OMS* and the monitoring programme. The *DAR* shall be approved by the *Accountable Executive*.

Requirement 6.6 Include new and emerging technologies and approaches and use the evolving knowledge in the refinement of the design, construction and operation of the *tailings facility*.

PRINCIPLE 7 DESIGN, IMPLEMENT AND OPERATE MONITORING SYSTEMS TO MANAGE RISK AT ALL PHASES OF THE FACILITY LIFECYCLE, INCLUDING CLOSURE.

Requirement 7.1 Design, implement and operate a comprehensive and integrated performance monitoring programme for the *tailings facility* and its appurtenant structures as part of the *TMS* and for those aspects of the *ESMS* related to the *tailings facility* in accordance with the principles of *Adaptive Management*.

Requirement 7.2 Design, implement and operate a comprehensive and integrated engineering monitoring system that is appropriate for verifying design assumptions and for monitoring potential failure modes. Full implementation of the *Observational Method* shall be adopted for non-brittle failure modes. Brittle failure modes are addressed by conservative design criteria.

Requirement 7.3 Establish specific and measurable performance objectives, indicators, criteria, and performance parameters and include them in the design of the monitoring programmes that measure performance throughout the *tailings facility lifecycle*. Record and evaluate the data at appropriate frequencies. Based on the data obtained, update the monitoring programmes throughout the *tailings facility lifecycle* to confirm that they remain effective to manage risk.

Requirement 7.4 Analyse technical monitoring data at the frequency recommended by the *EOR*, and assess the performance of the *tailings facility*, clearly identifying and presenting evidence on any deviations from the expected performance and any deterioration of the performance over time. Promptly submit evidence to the *EOR* for review and update the risk assessment and design, if required. Performance outside the expected ranges shall be addressed promptly through *Trigger Action Response Plans (TARPs)* or *critical controls*.

Requirement 7.5 Report the results of each of the monitoring programmes at the frequency required to meet company and regulatory requirements and, at a minimum, on an annual basis. The *RTFE* and the *EOR* shall review and approve the technical monitoring reports.

MANAGEMENT AND GOVERNANCE

TOPIC IV

PRINCIPLE 8 ESTABLISH POLICIES, SYSTEMS AND ACCOUNTABILITIES TO SUPPORT THE SAFETY AND INTEGRITY OF THE *TAILINGS FACILITY*.

Requirement 8.1 The *Board of Directors* shall adopt and publish a policy on or commitment to the safe management of *tailings facilities*, to emergency preparedness and response, and to recovery after failure.

Requirement 8.2 Establish a *tailings governance framework* and a performance based *TMS* and ensure that the *ESMS* and other critical systems encompass relevant aspects of the *tailings facility* management.

Requirement 8.3 For roles with responsibility for *tailings facilities*, develop mechanisms such that incentive payments or performance reviews are based, at least in part, on public safety and the integrity of the *tailings facility*. These incentive payments shall reflect the degree to which public safety and the integrity of the *tailings facility* are part of the role. Long-term incentives for relevant executive managers should take *tailings* management into account.

Requirement 8.4 Appoint one or more *Accountable Executives* who is/are directly answerable to the CEO on matters related to this Standard. The *Accountable Executive(s)* shall be accountable for the safety of *tailings facilities* and for avoiding or minimising the social and environmental consequences of a *tailings facility* failure. The *Accountable Executive(s)* shall also be accountable for a programme of *tailings* management training, and for emergency preparedness and response. The *Accountable Executive(s)* must have scheduled communication with the *EOR* and regular communication with the *Board of Directors*, which can be initiated either by the *Accountable Executive(s)*, or the *Board*. The *Board of Directors* shall document how it holds the *Accountable Executive(s)* accountable.

Requirement 8.5 Appoint a site-specific *Responsible Tailings Facility Engineer (RTFE)* who is accountable for the integrity of the *tailings facility*, who liaises with the *EOR* and internal teams such as operations, planning, regulatory affairs, social performance and environment, and who has regular two-way communication with the *Accountable Executive*. The *RTFE* must be familiar with the *DBR*, the design report and the construction and performance of the *tailings facility*.

Requirement 8.6 Identify appropriate qualifications and experience requirements for all personnel who play safety-critical roles in the operation of a *tailings facility*, including, but not limited to the *RTFE*, the *EOR* and the *Accountable Executive*. Ensure that incumbents of these roles have the identified qualifications and experience, and develop succession plans for these personnel.

Requirement 8.7 For *tailings facilities* with Consequence Classification of 'Very High' or 'Extreme', appoint an *Independent Tailings Review Board (ITRB)*. For all other facilities, the *Operator* may appoint a *senior independent technical reviewer*. The *ITRB* or the reviewer shall be appointed early in the project development process, report to the *Accountable Executive* and certify in writing that they follow *best practices* for engineers in avoiding conflicts of interest.

PRINCIPLE 9 APPOINT AND EMPOWER AN *ENGINEER OF RECORD*.

Requirement 9.1 Engage an engineering firm with expertise and experience in the design and construction of *tailings facilities* of comparable complexity to provide *EOR* services for operating the *tailings facility* and for closed facilities with 'High', 'Very High' and 'Extreme' Consequence Classification, that are in the active closure phase. Require that the firm nominate a senior engineer, approved by the *Operator*, to represent the firm as the *EOR*, and verify that the individual has the necessary experience, skills and time to fulfil this role. Alternatively, the *Operator* may appoint an in-house engineer with expertise and experience in comparable facilities as the *EOR*. In this instance, the *EOR* may delegate the design to a firm ('*Designer of Record*') but shall remain thoroughly familiar with the design in discharging their responsibilities as *EOR*. Whether the *EOR* or the *DOR* is in-house or external, they must be competent and have experience appropriate to the Consequence Classification and complexity of the *tailings facility*.

Requirement 9.2 Empower the *EOR* through a written agreement that clearly describes their authority, role and responsibilities throughout the *tailings facility lifecycle*, and during change of ownership of mining properties. The written agreement must clearly describe the obligations of the *Operator* to the *EOR*, to support the effective performance of the *EOR*.

Requirement 9.3 Establish and implement a programme to manage the quality of all engineering work, the interactions between the *EOR*, the *RTFE* and the *Accountable Executive*, and their involvement in the *tailings facility lifecycle* as necessary to confirm that both the implementation of the design and the design intent are met.

Requirement 9.4 Given its potential impact on the risks associated with a *tailings facility*, the selection of the *EOR* shall be decided by the *Accountable Executive* and informed, but not decided, by procurement personnel.

Requirement 9.5 Where it becomes necessary to change the *EOR* (whether a firm or an in-house employee), develop a detailed plan for the comprehensive transfer of data, information, knowledge and experience with the construction procedures and materials.

PRINCIPLE 10 **ESTABLISH AND IMPLEMENT LEVELS OF REVIEW AS PART OF A STRONG QUALITY AND RISK MANAGEMENT SYSTEM FOR ALL PHASES OF THE *TAILINGS FACILITY LIFECYCLE*, INCLUDING CLOSURE.**

Requirement 10.1 Conduct and update risk assessments with a qualified multi-disciplinary team using *best practice* methodologies at a minimum every three years and more frequently whenever there is a *material* change either to the *tailings facility* or to the social, environmental and local economic context. Transmit risk assessments to the *ITRB* or *senior independent technical reviewer* for review, and address with urgency all unacceptable *tailings facility* risks.

Requirement 10.2 Conduct regular reviews of the *TMS* and of the components of the *ESMS* that refer to the *tailings facility* to assure the effectiveness of the management systems. Document and report the outcomes to the *Accountable Executive*, *Board of Directors* and *project-affected people*. The review shall be undertaken by *senior technical reviewers* with the appropriate qualifications, expertise and resources. For *tailings facilities* with 'High', 'Very High' or 'Extreme' Consequence Classification, conduct the review at least every three years.

Requirement 10.3 Conduct internal audits to verify consistent implementation of company procedures, guidelines and *corporate governance* requirements consistent with the *TMS* and aspects of the *ESMS* developed to manage *tailings facility risks*.

Requirement 10.4 The *EOR* or *senior independent technical reviewer* shall conduct *tailings facility* construction and performance reviews annually or more frequently, if required.

Requirement 10.5 Conduct an independent *DSR* at least every five years for *tailings facilities* with 'Very High' or 'Extreme' Consequence Classifications and at least every 10 years for all other *facilities*. For *tailings facilities* with complex conditions or performance, the *ITRB* may recommend more frequent *DSRs*. The *DSR* shall include technical, operational and *governance* aspects of the *tailings facility* and shall be completed according to *best practices*. The *DSR* contractor cannot conduct consecutive *DSRs* on the same *tailings facility* and shall certify in writing that they follow *best practices* for engineers in avoiding conflicts of interest.

Requirement 10.6 For *tailings facilities* with 'Very High' or 'Extreme' Consequence Classifications, the *ITRB*, reporting to the *Accountable Executive* shall provide ongoing senior independent review of the planning, siting, design, construction, operation, water and mass balance, maintenance, monitoring, performance and risk management at appropriate intervals across all phases of the *tailings facility lifecycle*. For *tailings facilities* with other Consequence Classifications, this review can be done by a *senior independent technical reviewer*.

Requirement 10.7 The amount of estimated costs for planned closure, early closure, *reclamation*, and post-closure of the *tailings facility* and its appurtenant structures shall be reviewed periodically to confirm that adequate financial capacity (including insurance, to the extent commercially reasonable) is available for such purposes throughout the *tailings facility lifecycle*, and the conclusions of the review shall be publicly disclosed annually. Disclosure may be made in audited financial statements or in public regulatory filings.

Subject to the provisions of local or national regulations on this matter, *Operators* shall use best efforts to assess and take into account the capability of an acquirer of any of its assets involving a *tailings facility* (through merger, acquisition, or other change in ownership) to maintain this Standard for the *tailings facility lifecycle*.

PRINCIPLE 11 DEVELOP AN ORGANISATIONAL CULTURE THAT PROMOTES LEARNING, COMMUNICATION AND EARLY PROBLEM RECOGNITION.

Requirement 11.1 Educate personnel who have a role in any phase of the *tailings facility lifecycle* about how their job procedures and responsibilities relate to the prevention of a failure.

Requirement 11.2 Establish mechanisms that incorporate workers' experience-based knowledge into planning, design and operations for all phases of the *tailings facility lifecycle*.

Requirement 11.3 Establish mechanisms that promote *cross-functional* collaboration to ensure effective data and knowledge sharing, communication and implementation of management measures to support public safety and the integrity of the *tailings facility*.

Requirement 11.4 Identify and implement lessons from internal incident investigations and relevant external incident reports, paying particular attention to human and organisational factors.

Requirement 11.5 Establish mechanisms that recognise, reward and protect from retaliation, employees and contractors who report problems or identify opportunities for improving *tailings facility* management. Respond in a timely manner and communicate actions taken and their outcomes.

PRINCIPLE 12 ESTABLISH A PROCESS FOR REPORTING AND ADDRESSING CONCERNS AND IMPLEMENT WHISTLEBLOWER PROTECTIONS.

Requirement 12.1 The *Accountable Executive* shall establish a formal, confidential and written process to receive, investigate and promptly address concerns from employees and contractors about possible permit violations or other matters relating to regulatory compliance, public safety, *tailings facility* integrity or the environment.

Requirement 12.2 In accordance with international *best practices* for whistleblower protection, the *Operator* shall not discharge, discriminate against, or otherwise retaliate in any way against a whistleblower who, in good faith, has reported possible permit violations or other matters relating to regulatory compliance, public safety, *tailings facility* integrity or the environment.

EMERGENCY RESPONSE AND LONG-TERM RECOVERY

TOPIC V

PRINCIPLE 13 **PREPARE FOR EMERGENCY RESPONSE TO *TAILINGS FACILITY* FAILURES.**

Requirement 13.1 As part of the *TMS*, use *best practices* and emergency response expertise to prepare and implement a site-specific tailings facility *Emergency Preparedness and Response Plan (EPRP)* based on *credible flow failure scenarios* and the assessment of potential consequences. Test and update the *EPRP* at all phases of the *tailings facility lifecycle* at a frequency established in the plan, or more frequently if triggered by a *material* change either to the *tailings facility* or to the social, environmental and local economic context. *Meaningfully engage* with employees and contractors to inform the *EPRP*, and co-develop community-focused emergency preparedness measures with *project-affected people*.

Requirement 13.2 Engage with *public sector agencies*, first responders, local authorities and institutions and take *reasonable* steps to assess the capability of emergency response services to address the *hazards* identified in the *tailings facility EPRP*, identify gaps in capability and use this information to support the development of a collaborative plan to improve preparedness.

Requirement 13.3 Considering community-focused measures and *public sector* capacity, the *Operator* shall take all *reasonable steps* to maintain a shared state of readiness for *tailings facility credible flow failure scenarios* by securing resources and carrying out annual training and exercises. The *Operator* shall conduct emergency response simulations at a frequency established in the *EPRP* but at least every 3 years for *tailings facilities* with potential loss of life.

Requirement 13.4 In the case of a *catastrophic tailings facility failure*, provide immediate response to save lives, supply humanitarian aid and minimise environmental harm.

PRINCIPLE 14 PREPARE FOR LONG-TERM RECOVERY IN THE EVENT OF *CATASTROPHIC FAILURE*.

Requirement 14.1 Based on *tailings facility credible flow failure scenarios* and the assessment of potential consequences, take *reasonable steps* to *meaningfully engage* with *public sector agencies* and other organisations that would participate in medium- and long-term social and environmental post-failure response strategies.

Requirement 14.2 In the event of a *catastrophic tailings facility failure*, assess social, environmental and local economic impacts as soon as possible after people are safe and short-term survival needs have been met.

Requirement 14.3 In the event of a *catastrophic tailings facility failure*, work with *public sector agencies* and other *stakeholders* to develop and implement reconstruction, *restoration* and recovery plans that address the medium- and long-term social, environmental and local economic impacts of the failure. The plans shall be disclosed if permitted by public authorities.

Requirement 14.4 In the event of a *catastrophic tailings facility failure*, enable the participation of affected people in reconstruction, *restoration* and recovery works and ongoing monitoring activities.

Requirement 14.5 Facilitate the monitoring and public reporting of post-failure outcomes that are aligned with the thresholds and indicators outlined in the reconstruction, *restoration* and recovery plans and adapt activities in response to findings and feedback.

PUBLIC DISCLOSURE AND ACCESS TO INFORMATION

TOPIC VI

PRINCIPLE 15 **PUBLICLY DISCLOSE AND PROVIDE ACCESS TO INFORMATION ABOUT THE *TAILINGS FACILITY* TO SUPPORT PUBLIC ACCOUNTABILITY.**

Requirement 15.1 Publish and regularly update information on the *Operator's* commitment to safe *tailings facility* management, implementation of its *tailings governance framework*, its organisation-wide policies, standards or approaches to the design, construction, monitoring and closure of *tailings facilities*.

A. For new *tailings facilities* for which the regulatory authorisation process has commenced, or that are otherwise approved by the *Operator*, the *Operator* shall publish and update, in accordance with Principle 21 of the UNGP, the following information:

1. A plain language summary of the rationale for the basis of the design and site selected as per the multi-criteria *alternatives analysis*, *impact assessments*, and mitigation plans (Information may be obtained from the output of multiple Requirements including, but not limited to, Requirements 3.2, 3.3, 5.1, 5.3, 6.4, 6.6, 7.1 and 10.1); and
2. The Consequence Classification. (Requirement 4.1).

B. For each existing *tailings facility* and in accordance with Principle 21 of the UNGP, the *Operator* shall publish and update at least on an annual basis, the following information:

1. A description of the *tailings facility* (Information may be obtained from the output of Requirements 5.5 and 6.4);
2. The Consequence Classification (Requirement 4.1);
3. A summary of risk assessment findings relevant to the *tailings facility* (Information may be obtained from the output of Requirement 10.1);
4. A summary of *impact assessments* and of human exposure and vulnerability to *tailings facility credible flow failure scenarios* (Information may be obtained from the output of Requirements 2.4 and 3.3);
5. A description of the design for all phases of the *tailings facility lifecycle* including the current and final height (Information may be obtained from the output of Requirement 5.5);
6. A summary of *material* findings of annual performance reviews and *DSR*, including implementation of mitigation measures to reduce risk to *ALARP* (Information may be obtained from output of Requirements 10.4 and 10.5);
7. A summary of *material* findings of the environmental and social monitoring programme including implementation of mitigation measures (Requirement 7.5);
8. A summary version of the *tailings facility EPRP* for facilities that have a *credible failure mode(s)* that could lead to a flow failure event that: (i) is informed by *credible flow failure scenarios* from the *tailings facility breach analysis*; (ii) includes emergency response measures that apply

to *project affected people* as identified through the *tailings facility breach analysis* and involve cooperation with *public sector agencies*; and (iii) excludes details of emergency preparedness measures that apply to the *Operator's* assets, or confidential information (Requirements 13.1 and 13.2);

9. Dates of most recent and next independent reviews (Requirement 10.5); and
10. Annual confirmation that the *Operator* has adequate financial capacity (including insurance to the extent commercially reasonable) to cover estimated costs of planned closure, early closure, *reclamation*, and post-closure of the *tailings facility* and its appurtenant structures (Requirement 10.7).

Such disclosures shall be made directly, unless subject to limitations imposed by regulatory authorities.

C. Provide local authorities and emergency services with sufficient information derived from the *breach analysis* to enable effective disaster management planning (Information may be obtained from the output of Requirement 2.3);

Requirement 15.2 Respond in a systematic and timely manner to requests from interested and affected *stakeholders* for additional information *material* to the public safety and integrity of a *tailings facility*. When the request for information is denied, provide an explanation to the requesting *stakeholder*.

Requirement 15.3 Commit to cooperate in credible global transparency initiatives to create standardised, independent, industry-wide and publicly accessible databases, inventories or other information repositories about the safety and integrity of *tailings facilities*.

GLOSSARY

ANNEX 1

Terms shown throughout the Standard appear in italics and are explained below.

Accountable Executive	One or more executive(s) who is/are directly answerable to the CEO on matters related to this Standard, communicates with the Board of Directors, and who is accountable for the safety of tailings facilities and for minimising the social and environmental consequences of a potential tailings facility failure. The Accountable Executive(s) may delegate responsibilities but not accountability.
Adaptive Management	A structured, iterative process of robust decision-making with the aim of reducing uncertainty over time via system monitoring. It includes the implementation of mitigation and management measures that are responsive to changing conditions, including those related to climate change, and the results of monitoring throughout the tailings facility lifecycle. The approach supports alignment on decisions about the tailings facility with the changing social, environmental and economic context and enhances opportunities to develop resilience to climate change in the short and long term.
As Low As Reasonably Practicable	ALARP requires that all reasonable measures be taken with respect to 'tolerable' or acceptable risks to reduce them even further until the cost and other impacts of additional risk reduction are grossly disproportionate to the benefit.
Alternatives Analysis	An analysis that should objectively and rigorously consider all available options and sites for mine waste disposal. It should assess all aspects of each mine waste disposal alternative throughout the project life cycle (i.e. from construction through operation, closure and ultimately long-term monitoring and maintenance). The alternatives analysis should also include all aspects of the project that may contribute to the impacts associated with each potential alternative. The assessment should address environmental, technical and socio-economic aspects for each alternative throughout the project life cycle.
Best Practices	A procedure that has been shown by research and experience to produce optimal results and that is established or proposed as a standard suitable for widespread adoption.
Board of Directors	The ultimate governing body of the Operator typically elected by the shareholders of the Operator. The Board of Directors is the entity with the final decision-making authority for the Operator and holds the authority to, among other things, set the Operator's policies, objectives, and overall direction and oversee the firm's executives. As the term is used here, it encompasses any individual or entity with control over the Operator, including, for example, the owner or owners. Where the State serves as the Operator, the Board of Directors shall be understood to mean the government official with ultimate responsibility for the final decisions of the Operator.

Breach Analysis	A study that assumes a failure of the tailings facility and estimates its impact. Breach Analyses must be based on credible failure modes. The results should determine the physical area impacted by a potential failure, flow arrival times, depth and velocities, duration of flooding, and depth of material deposition. The Breach Analysis is based on scenarios which are not connected to probability of occurrence. It is primarily used to inform emergency preparedness and response planning and the consequence of failure classification. The classification is then used to inform the external loading component of the design criteria.
Catastrophic Failure	A tailings facility failure that results in material disruption to social, environmental and local economic systems. Such failures are a function of the interaction between hazard exposure, vulnerability, and the capacity of people and systems to respond. Catastrophic events typically involve numerous adverse impacts, at different scales and over different timeframes, including loss of life, damage to physical infrastructure or natural assets, and disruption to lives, livelihoods, and social order. Operators may be affected by damage to assets, disruption to operations, financial loss, or negative impact to reputation. Catastrophic failures exceed the capacity of affected people to cope using their own resources, triggering the need for outside assistance in emergency response, restoration and recovery efforts.
Change Management System	Changes in projects are inevitable during design construction and operation and must be managed to reduce negative impacts to quality and integrity of the tailings facility. The impact and consequences of changes vary according to the type and nature of changes, but most importantly according to how they are managed. Managing changes effectively is crucial to the success of a project. A change management system has the objective of disciplining and coordinating the process, and should include an evaluation of the change, a review and formal approval of the change followed by detailed documentation including drawings and, where required, changes to equipment, process, actions, flow, information, cost, schedule or personnel.
Construction versus Design Intent Verification	Intended to ensure the design intent is implemented and still being met if the site conditions vary from the design assumptions. The CDIV identifies any discrepancies between the field conditions and the design assumptions, such that the design can be adjusted to account for the actual field conditions.
Construction Records Report	Describes all aspects of the 'as-built' product, including all geometrical information, materials, laboratory and field test results, construction activities, schedule, equipment and procedures, Quality Control and Quality Assurance data, CDIV results, changes to design or any aspect of construction, non-conformances and their resolution, construction photographs, construction shift reports, and any other relevant information. Instruments and their installation details, calibration records and readings must be included in the CRR. Roles, responsibilities and personnel, including independent review should be documented. Detailed construction record drawings are fundamental.
Corporate Governance	Refers to the organisational structures and processes that a company puts in place to ensure effective management, oversight and accountability.

Credible Failure Modes / Scenarios	Refers to technically feasible failure mechanisms given the materials present in the structure and its foundation, the properties of these materials, the configuration of the structure, drainage conditions and surface water control at the facility, throughout its lifecycle. Credible failure modes can and do typically vary during the lifecycle of the facility as the conditions vary. A facility that is appropriately designed and operated considers all of these credible failure modes and includes sufficient resilience against each. Different failure modes will result in different failure scenarios. Credible catastrophic failure modes do not exist for all tailings facilities. The term 'credible failure mode' is not associated with a probability of this event occurring and having credible failure modes is not a reflection of facility safety.
Critical Controls	A control that is critical to preventing a potential undesirable event or mitigating the consequences of such an event. The absence or failure of a critical control would disproportionately increase the risk despite the existence of the other controls.
Cross-functional	A system or a practice whereby people from different areas of an organisation share information and work together effectively as a team.
Dam Safety Review	A periodic and systematic process carried out by an independent qualified review engineer to assess and evaluate the safety of a dam or system of dams (or in this case a tailings facility) against failure modes, in order to make a statement on the safety of the facility. A safe tailings facility is one that performs its intended function under both normal and unusual conditions; does not impose an unacceptable risk to people, property or environment; and meets applicable safety criteria.
Design Basis Report	Provides the basis for the design, operation, construction, monitoring and risk management of a tailings facility.
Designer of Record	A qualified professional engineer designated by the Engineer of Record to design the tailings facility in the case where the Engineer of Record is an internal professional.
Deviance Accountability Report	Provides an assessment of the cumulative impact of changes to the tailings facility on the risk level of the achieved product and defines the potential requirement for updates to the design, DBR, OMS or the monitoring programme.
Emergency Preparedness and Response Plan	A site-specific plan developed to identify hazards, assess capacity and prepare for an emergency based on tailings facility credible flow failure scenarios, and to respond if it occurs. This may be part of operation-wide emergency response planning and includes the identification of response capacity and any necessary coordination with off-site emergency responders, local communities and public sector agencies. The development of the EPRP includes a community-focused planning process to support the co-development and implementation of emergency response measures by those vulnerable to a tailings facility failure.

Engineer of Record	The qualified engineering firm responsible for confirming that the tailings facility is designed, constructed, and decommissioned with appropriate concern for integrity of the facility, and that it aligns with and meets applicable regulations, statutes, guidelines, codes, and standards. The Engineer of Record may delegate responsibility but not accountability. In some highly-regulated jurisdictions, notably Japan, the role of EOR is undertaken by the responsible regulatory authorities.
Environmental and Social Management System	A methodological approach which draws on the elements of the established process of 'Plan, Do, Check, Act', and is used to manage environmental and social risks and impacts in a structured way in the short and longer term. An effective ESMS, appropriate to the nature and scale of the operation, promotes sound and sustainable environmental and social performance, and can also lead to improved financial outcomes. The ESMS helps companies integrate the procedures and objectives for the management of social, environmental (and, local economic) impacts into core business operations, through a set of clearly defined, repeatable processes. An ESMS is a dynamic and continuous process initiated and supported by management, and involves engagement between the Operator, its employees and contractors, project-affected people and, where appropriate, other stakeholders. The interaction of the ESMS with the TMS facilitates alignment of decisions about the tailings facility with the changing social, environmental and local economic context and reflects the fact that a tailings facility is situated within a complex and dynamic local and global environment.
Free, Prior and Informed Consent	A mechanism that safeguards the individual and collective rights of indigenous and tribal peoples, including their land and resource rights and their right to self-determination. The minimum conditions that are required to secure consent include that it is 'free' from all forms of coercion, undue influence or pressure, provided 'prior' to a decision or action being taken that affects individual and collective human rights, and offered on the basis that affected peoples are 'informed' of their rights and the impacts of decisions or actions on those rights. FPIC is considered to be an ongoing process of negotiation, subject to an initial consent. To obtain FPIC, 'consent' must be secured through an agreed process of good faith consultation and cooperation with indigenous and tribal peoples through their own representative institutions. The process should be grounded in a recognition that the indigenous or tribal peoples are customary landowners. FPIC is not only a question of process, but also of outcome, and is obtained when terms are fully respectful of land, resource and other implicated rights.
Grievance	A perceived injustice, which may be based on law, contract, explicit or implicit promises, customary practice, or general notions of fairness of aggrieved communities.
Hazard	Any substance, human activity, condition or other agent that may cause harm, loss of life, injury, health impacts, loss of integrity of natural or built structures, property damage, loss of livelihoods or services, social and economic disruption, or environmental damage.

Impact Assessment	A decision-making and management support instrument for identifying, predicting, measuring and evaluating the impact of development proposals, both prior to major decisions being made, and throughout the lifecycle of a project. While impact assessments typically focus on a single project, assessments can be scoped at the landscape level, and consider strategic implications of a change. Depending on the context, the circumstances, and the issues at hand, impact assessments may be discipline-specific, or conducted as part of an integrated set of studies. Assessments can be conducted in advance of impacts, or retrospectively. In this context, impacts are consequences to people, built infrastructure or the natural environment caused by a tailings facility or its failure, including impacts to the human rights of workers, communities, or other rights holders and including sensitive ecological receptors and ecosystem services. Impacts can be positive or adverse, tangible or intangible, direct or indirect, acute, chronic or cumulative, and measurable quantitatively or qualitatively.
Independent Tailings Review Board	A board that provides independent technical review of the design, construction, operation, closure and management of tailings facilities. The independent reviewers are third-parties who are not, and have not been directly involved with the design or operation of the particular tailings facility. The expertise of the ITRB members shall reflect the range of issues relevant to the facility and its context and the complexity of these issues. In some highly regulated jurisdictions, notably Japan, the role of ITRB is undertaken by the responsible regulatory authorities.
Involuntary Resettlement	Resettlement can be either voluntary or involuntary, and may involve either physical or economic displacement. Involuntary resettlement occurs when project-affected people do not have the right to refuse resettlement. This includes cases where a company has the legal right to expropriate land. Voluntary resettlement occurs when resettled households have a genuine choice to move. When the voluntary nature of resettlement cannot be confirmed, resettlement should be treated as involuntary.
Knowledge Base	The sum of knowledge required to support the safe management of a tailings facility throughout its lifecycle. The knowledge base has an iterative nature and needs to be updated as the need arises and the context changes. Fundamental elements would include a detailed site characterisation and baseline knowledge of the social and environmental context. As design, construction and performance monitoring proceeds additional data are collected and required and the knowledge base evolves.
Material (adj)	Important enough to merit attention, or having an effective influence or bearing on the determination in question. For the Standard, the criteria for what is material will be defined by Operator, subject to the provisions of local regulations, and evaluated as part of any audit or external independent assessment that may be conducted on implementation.

Meaningful Engagement	A process of mutual dialogue and decision-making whereby Operators have an obligation to consult and listen to stakeholder perspectives, and integrate those perspectives into their business decisions. Meaningful engagement involves measures to overcome structural and practical barriers to the participation of diverse and vulnerable groups of people. Strategies for addressing barriers must be appropriate to the context and the stakeholders involved, and may include, for example, logistics and other support to enable participation. Preconditions to meaningful engagement include: access to material information that can be reasonably understood; a structure that enables transparent communication; and accountability for engagement processes and outcomes.
Mitigation Hierarchy	Identifies a series of essential, sequential steps that Operators must follow through the project lifecycle in order to limit negative impacts and to enhance opportunities for positive outcomes. It describes a process to anticipate and avoid adverse impacts on workers, communities and the environment from a proposed action. Where avoidance is not possible, actions must be taken to minimise, and where residual impacts remain, to compensate fairly or offset for the risks and impacts.
Observational Method	A continuous, managed, integrated, process of design, construction control, monitoring and review that enables previously defined modifications to be incorporated during or after construction as appropriate. All of these aspects must be demonstrably robust. The key element of the Observational Method is the proactive assessment at the design stage of every possible unfavourable situation that might be disclosed by the monitoring programme and the development of an action plan or mitigative measure to reduce risk in case the unfavourable situation is observed. This element forms the basis of a performance-based risk management approach. The objective is to achieve greater overall safety. See Peck, R.B. (1969) "Advantages and Limitations of the Observational Method in Applied Soil Mechanics" Geotechnique 19, No2., pp.171-187.
Operations, Maintenance and Surveillance Manual	Describes the performance indicators and criteria for risk controls and critical controls, and the ranges of performance linked to specific pre-defined management actions. An OMS manual also describes the procedures for collecting, analysing and reporting surveillance results in a manner consistent with the risk controls and critical controls and that supports effective, timely decision-making. The link between OMS activities and critical controls management underscores the fact that it is essential that OMS Manuals be developed to reflect site-specific conditions and circumstances. An OMS Manual cannot be purchased 'off-the-shelf'. To be effective, it must be tailored to the site.
Operator	An entity that singly, or jointly with other entities, exercises ultimate control of a tailings facility. This may include a corporation, partnership, owner, affiliate, subsidiary, joint venture, or other entity, including any State agency, that controls a tailings facility.

Preliminary Design	For the purpose of Requirement 4.2 of the Standard , preliminary design is a design performed to a level of detail sufficient to determine the differences between viable designs that adopt different external loading design criteria in terms of required footprints, volumes and drainage requirements.
Project-affected People	People who may experience impacts from a tailings facility. People affected by a tailings facility may include, for example, people who live nearby; people who hear, smell or see the facility; or people who might own, reside on, or use the land on which the facility is to be located or may potentially inundate.
Public Sector Agencies	All governmental agencies at the State, regional, and/or local level with some responsibility or authority for regulating mining activities that occur within or impact their jurisdictions.
Reasonable Steps	Steps taken to achieve a specific objective such that any negative impact on people, social systems, environment, local economy or costs is not out of balance with the intended benefits.
Reclamation	The process of restoring the mine site to a natural or economically useable state as provided in a reclamation plan. Reclamation results in productive and sustainable landscapes to meet a range of conditions that might allow for biodiversity conservation, recreational or agriculture uses, or various forms of economic development.
Responsible Tailings Facility Engineer	An engineer appointed by the Operator to be responsible for the tailings facility. The RTFE must be available at all times during construction, operations and closure. The RTFE has clearly defined, delegated responsibility for management of the tailings facility and has appropriate qualifications and experience compatible with the level of complexity of the tailings facility. The RTFE is responsible for the scope of work and budget requirements for the tailings facility, including risk management. The RTFE may delegate specific tasks and responsibilities for aspects of tailings management to qualified personnel but not accountability.
Restoration	The process of assisting recovery of the social, environmental and local economic systems that have been degraded, damaged or destroyed.
Robust Design	The robustness of a tailings facility design depends on each particular situation and it may be associated with various aspects including, for example, the factor of safety against each of the potential failure modes, the presence or absence of materials with brittle behaviour, the degree of brittleness of these materials, the degree of variability of the materials and the potential for thresholds of deformation that materially affect the facility performance. The degree of robustness is related to the facility maintaining its overall integrity despite less than ideal performance of one or more of its components.
Safe closure	A closed tailings facility that does not pose ongoing material risks to people or the environment which has been confirmed by an ITRB or senior independent technical reviewer and signed off by the Accountable Executive.

Senior Independent Technical Reviewer	An independent professional with in-depth knowledge and at least 15 years' experience in the specific area of the review requirements, e.g. tailings design, operations and closure, environmental and social aspects or any other specific topic of concern. The independent reviewer is a third-party who is not, and has not been directly involved with the design or operation of the particular tailings facility.
Senior Technical Reviewer	A professional who is either an in-house employee or an external party with in-depth knowledge and at least 15 years' experience in the specific area of the review requirements, e.g. tailings design, operations and closure, environmental and social aspects or any other specific topic of concern.
Stakeholder	Persons or groups who are directly or indirectly affected by a project, as well as those who may have interests in a project and/or the ability to influence its outcome, positively or negatively. Stakeholders may include workers, trade unions, project-affected people or communities and their formal and informal representatives, national or local government authorities, politicians, religious leaders, civil society organisations and groups with special interests, the academic community, or other businesses. Different stakeholders will often have divergent views, both within and across stakeholder groupings.
Tailings	A by-product of mining, consisting of the processed rock or soil left over from the separation of the commodities of value from the rock or soil within which they occur.
Tailings Facility	A facility that is designed and managed to contain the tailings produced by the mine. Although tailings can be placed in mined-out underground mines, for the purposes of the Standard, tailings facilities refer to facilities that contain tailings in open pit mines or on the surface ('external tailings facilities'). For the purposes of the Standard, tailings facilities are higher than 2.5 m measured from the elevation of the crest to the elevation of the toe of the structure, or have a combined water and solids volume more than 30,000 m3, unless the Consequence Classification is 'High', 'Very High' or 'Extreme', in which case the structure is considered a tailings facility regardless of its size. For the purposes of this Standard, existing tailings facilities are facilities that are accepting new mine tailings on the date that the Standard takes effect or not currently accepting new mine tailings but are not in a state of safe closure. All other facilities will be treated as New for the purposes of this Standard.

Tailings Facility Lifecycle	The phases in the life of a facility, which may occur in linear or cyclical succession, consisting of: 1. Project conception, planning and design; 2. Initial construction; 3. Operation and ongoing construction (may include progressive reclamation); 4. Interim closure (including care and maintenance); 5. Closure (regrading, demolition and reclamation); 6. Post-closure (including relinquishment, reprocessing, relocation, removal)
Tailings Governance Framework	A framework that focusses on the key elements of management and governance necessary to maintain the integrity of TSFs and minimise the risk of catastrophic failures. The six key elements of this TSF governance framework are: 1. Accountability, Responsibility and Competency; 2. Planning and Resourcing; 3. Risk Management; 4. Change Management; 5. Emergency Preparedness and Response; 6. Review and Assurance.
Tailings Management System	The site-specific TMS comprises the key components for management and design of the tailings facility and is often referred to as the 'framework' that manages these components. The TMS sits at the core of the Standard and is focused on the safe operation and management of the tailings facility throughout its lifecycle (see above). The TMS follows the well-established Plan-Do-Check-Act cycle. Each Operator develops a TMS that best suits their organisation and tailings facilities. A TMS includes elements such as: establishing policies, planning, designing and establishing performance objectives, managing change, identifying and securing adequate resources (experienced and/or qualified personnel, equipment, scheduling, data, documentation and financial resources), conducting performance evaluations and risk assessments, establishing and implementing controls for risk management, auditing and reviewing for continual improvement, implementing a management system with clear accountabilities and responsibilities, preparing and implementing the OMS and EPRP. The TMS, and its various elements, must interact with other systems, such as the environmental and social management system (ESMS), the operation-wide management system, and the regulatory system. This systems interaction is fundamental to the effective implementation of the Standard.
Trigger Action Response Plan	A TARP is a tool to manage risk controls, including critical controls. TARPs provide pre-defined trigger levels for performance criteria that are based on the risk controls and critical controls of the tailings facility. The trigger levels are developed based on the performance objectives and risk management plan for the tailings facility. TARPs describe actions to be taken if trigger levels are exceeded (performance is outside the normal range), to prevent a loss of control. A range of actions is pre-defined, based on the magnitude of the exceedance of the trigger level.

CONSEQUENCE CLASSIFICATION TABLES

ANNEX 2

Table 1: Consequence Classification Matrix

Dam Failure Consequence Classification			
	Potential Population at Risk	Potential Loss of Life	
Low	None	None expected	
Significant	1–10	Unspecified	
High	10–100	Possible (1–10)	
Very High	100–1,000	Likely (10 – 100)	
Extreme	> 1,000	Many (> 100)	

Incremental Losses		
Environment	Health, Social and Cultural	Infrastructure and Economics
Minimal short-term loss or deterioration of habitat or rare and endangered species.	Minimal effects and disruption of business and livelihoods. No measurable effect on human health. No disruption of heritage, recreation, community or cultural assets.	Low economic losses: area contains limited infrastructure or services. <US$1M.
No significant loss or deterioration of habitat. Potential contamination of livestock/fauna water supply with no health effects. Process water low potential toxicity. Tailings not potentially acid generating and have low neutral leaching potential. Restoration possible within 1 to 5 years.	Significant disruption of business, service or social dislocation. Low likelihood of loss of regional heritage, recreation, community, or cultural assets. Low likelihood of health effects.	Losses to recreational facilities, seasonal workplaces, and infrequently used transportation routes. <US$10M.
Significant loss or deterioration of critical habitat or rare and endangered species. Potential contamination of livestock/ fauna water supply with no health effects. Process water moderately toxic. Low potential for acid rock drainage or metal leaching effects of released tailings. Potential area of impact 10 km^2 – 20 km^2. Restoration possible but difficult and could take > 5 years.	500-1,000 people affected by disruption of business, services or social dislocation. Disruption of regional heritage, recreation, community or cultural assets. Potential for short term human health effects.	High economic losses affecting infrastructure, public transportation, and commercial facilities, or employment. Moderate relocation/compensation to communities. <US$100M.
Major loss or deterioration of critical habitat or rare and endangered species. Process water highly toxic. High potential for acid rock drainage or metal leaching effects from released tailings. Potential area of impact > 20 km^2. Restoration or compensation possible but very difficult and requires a long time (5 years to 20 years).	1,000 people affected by disruption of business, services or social dislocation for more than one year. Significant loss of national heritage, community or cultural assets. Potential for significant long-term human health effects.	Very high economic losses affecting important infrastructure or services (e.g., highway, industrial facility, storage facilities, for dangerous substances), or employment. High relocation/ compensation to communities. < US$1B.
Catastrophic loss of critical habitat or rare and endangered species. Process water highly toxic. Very high potential for acid rock drainage or metal leaching effects from released tailings. Potential area of impact > 20 km^2. Restoration or compensation in kind impossible or requires a very long time (> 20 years).	5,000 people affected by disruption of business, services or social dislocation for years. Significant National heritage or community facilities or cultural assets destroyed. Potential for severe and/or long- term human health effects.	Extreme economic losses affecting critical infrastructure or services, (e.g., hospital, major industrial complex, major storage facilities for dangerous substances) or employment. Very high relocation/compensation to communities and very high social readjustment costs. >US$1B.

The intention of this guidance is to provide a consistent manner to establish minimum external loading design criteria for the safe design of *tailings facilities*. Alternative guidance exists, for example, by reputable national dam associations, which, in turn, form the basis of jurisdictional regulatory requirements. These alternative guidances can be considered by the *EOR*, *RTFE* and *ITRB* or independent technical reviewer and adopted, if appropriate and approved by the *Accountable Executive*.

There is a distinction between Operations and Post-Closure (also referred to as Passive Care Closure) where Operations involves all phases of construction and operation, periods of temporary cessation of operations, and the Closure phase (transition phase into post-closure also referred to as active care closure). Post-Closure refers to permanently closed facilities that have been configured for their perpetual form/state and thereby will be subjected to the maximum time of exposure irrespective of the Consequence Classification for the facility.

Table 2: Flood Design Criteria

Consequence Classification	Flood Criteria[1] – Annual Exceedance Probability	
	Operations and Closure (Active care)	Passive-Closure (Passive Care)
Low	1/200	1/10,000
Significant	1/1,000	1/10,000
High	1/2,475	1/10,000
Very High	1/5,000	1/10,000
Extreme	1/10,000	1/10,000

The term "Maximum Probable Precipitation" (PMP) or "Probable Maximum Flood" (PMF) are terms sometimes used to denote extreme hydrological events. The concepts of PMP and PMF are acceptable for assigning flood loading if they meet, or exceed, the requirements above for Extreme Consequence Classification facilities and/or facilities at the Post-Closure (or Passive Care Closure) phase.

Table 3: Seismic Design Criteria

Consequence Classification	Seismic Criteria[2,3] – Annual Exceedance Probability	
	Operations and Closure (Active care)	Passive-Closure (Passive Care)
Low	1/200[2]	1/10,000[2]
Significant	1/1,000[2]	1/10,000[2]
High	1/2,475[2]	1/10,000[2]
Very High	1/5,000[2]	1/10,000[2]
Extreme	1/10,000[2]	1/10,000[2]

1. For existing *tailings facilities* the *EOR*, with review by the *ITRB* or a *senior independent technical reviewer*, may determine that the upgrade to this design criteria is not feasible or cannot be retroactively applied. In this case, the *Accountable Executive* shall approve and document the implementation of measures to reduce both the probability and the consequences of a *tailings facility* failure in order to reduce the risk to a level *as low as reasonably practicable (ALARP)*. The basis and timing for addressing the upgrade of existing *tailings facilities* shall be risk-informed and carried out as soon as reasonably practicable (see Requirement 4.7).

2. The selection of the design ground motion should consider the seismic setting and the reliability and applicability of the probabilistic and deterministic methods for seismic *hazard* assessment. The Maximum Credible Earthquake (MCE) is part of a deterministic approach that can govern in some areas. The method that produces the most appropriate ground motion for the facility safety should be used for the design.

3. For existing *tailings facilities* the *EOR*, with review by the *ITRB* or a *senior independent technical reviewer*, may determine that the upgrade to this design criteria is not feasible or cannot be retroactively applied. In this case, the *Accountable Executive* shall approve and document the implementation of measures to reduce both the probability and the consequences of a *tailings facility* failure in order to reduce the risk to a level *as low as reasonably practicable (ALARP)*. The basis and timing for addressing the upgrade of existing *tailings facilities* shall be risk-informed and carried out as soon as reasonably practicable (see Requirement 4.7).

SUMMARY TABLES

ANNEX 3

Table 4: Summary of Key Roles and Functions mentioned in the Standard

Key Role	Function Items listed below are either expressly requested in the Standard OR are listed against those roles which typically undertake these activities. It is understood that this may vary depending on the operation.
Responsible Tailings Facility Engineer (RTFE)	• Accountable for the integrity of the *tailings facility* (Requirement 8.5). • Responsible for liaising with *EOR*, operations, planning, regulatory affairs, social performance and environment teams (Requirement 8.5). • Responsible for implementation of the design. • Accountable for the establishment of a *change management system* (Requirement 6.5). • Responsible for the monitoring system and communication of the results to the *EOR*, including performance reviews (Requirements 7.2, 7.3). • Responsible, with the *EOR*, for the *Construction Records Report* (Requirement 6.3). • Responsible for the *OMS Manual* (Requirement 6.4).
Engineer of Record (EoR)	• Responsible for the *Design Basis Report* (Requirement 4.8). • Responsible for the design (Requirement 9.1). • Responsible for the design report. • Responsible for construction and performance reviews (Requirement 10.4). • Responsible for the *Deviance Accountability Report* (Requirement 6.5). • Responsible, with the *RTFE*, for the *Construction Records Report* (Requirement 6.3). • Support the *RTFE* on the *OMS Manual* (Requirement 6.4).
Accountable Executive	• Accountable for the safety of the *tailings facility* and for environmental and social performance (Requirements 7.1, 8.2, 8.3, 8.4). • Approval of the adopted design criteria and measures to reduce the risk of failure of existing facilities to *ALARP* (Requirements 4.3, 4.7, 5.7). • Accountable for *tailings* management training, emergency preparedness and response (Requirement 8.4). • Selection of the *RTFE* (Requirements 8.5, 8.6) and the *EOR* (Requirements 9.1 to 9.5, 8.6). • Appointment of the *ITRB* or a *senior independent technical reviewer* (Requirement 8.7). • Establishment of a process for addressing concerns (Requirement 12.1).
Independent Tailings Review Board (ITRB) or senior technical reviewer	• Review of the design, construction, risk assessments, *governance* systems and other risk management matters that can affect the *tailings facility*, ensuring that the required expertise and skill sets are involved. • Review of the adopted external loading design criteria and measures to reduce the risk of failure of existing facilities to *ALARP* (Requirements 4.2, 4.7, 5.7). • Review of the *alternatives analysis* (Requirement 3.2), design, construction, risk assessments (Requirements 10.1), governance systems and other risk management matters (Requirement 10.6) that can affect the *tailings facility*. • Review the *Design Basis Report* (Requirement 4.8). • Determine the frequency of *Dam Safety Review* (Requirement 10.5).

Table 5: Summary of Key Documents mentioned in the Standard

Key Documents	Description
Design Basis Report	Details the design assumptions and criteria, including operational constraints to provide a basis for all phases of the *tailings facility lifecycle*.
Design Report	Includes among other items: documentation of the relevant aspects of *knowledge base*, the consequence classification, multi-criteria *alternatives analysis*, water balance modelling, design analyses and evaluation of their results, design of all stages of the facility including monitoring requirements, construction requirements and specifications, operational constraints and construction drawings. The Design Report typically includes constuction drawings.
Construction Records Report	Includes among other items: survey data and drawings, field reports, QC and QA reports, *CDIV* reports, changes required during construction, drilling and field test data, instrumentation installation details and calibration reports, instrumentation monitoring data, description of field procedures and equipment, photographic records (Requirements 6.2, 6.3, 6.5).
Operation, Maintenance and Surveillance Manual	Provides the context and *critical controls* for the safe operation of the *tailings facility* to support effective risk management. Includes among other items: description of the facility, (Requirements 6.4, 6.5). It includes the *Trigger Action Response Plan (TARP)*.
Deviance Accountability Report	Provides an assessment of the cumulative impact of the individual changes assessed, approved and documented in the *change management system*, on the risk level of the as-constructed *tailings facility* and provides recommendations for managing the risk, if required.
Annual Performance Report	Provides the results of the annual performance review and typically includes results of visual inspection, instrumentation monitoring and assessment. Some *Operators* may conduct internal performance reports on a more frequent basis.
Dam Safety Review Report	Provides the results of a review of the safety of a *tailings facility* covering technical, operational and governance aspects, conducted by an independent technical specialist according to established *best practices*.
Emergency Preparedness and Response Plan (EPRP)	Provides a detailed, site-specific plan developed to identify *hazards* of the *tailings facility*, assess capacity internally and externally to respond, and prepare for an emergency and to respond if it occurs.
Impact Assessments and Mitigation Plans	Assessments of the social, environmental and local economic impacts from a *tailings facility* or its failure, and the associated impact mitigation and management plans.

Table 6: Summary of Levels of Review mentioned in the Standard

Key Documents	Description
Internal Reviews	Includes reviews of company processes, procedures, guidelines and *corporate governance* requirements and systems (including *TMS*, *ESMS*) (Requirement 10.3).
EoR Review	Engineering firms typically have internal review systems for all engineering work to manage the accuracy and quality of the technical product and provide mentoring and training to staff. This is also good practice for technical work done in-house by the *Operator* (Requirement 9.3).
Annual Performance Reviews	Conducted by the *EOR* or an independent reviewer. Regular performance reviews are typically mandated in many jurisdictions, often annually or twice a year. Some *Operators* may conduct internal performance reviews more frequently. These reviews typically involve visual inspection, review of construction and operation practices and review and assessment of the instrumentation monitoring data.
Dam Safety Review (DSR)	Independent review of the safety of a *tailings facility* covering technical, operational and governance aspects, conducted by an independent technical specialist according to established *best practices*. It should be conducted at intervals based on the Consequence Classification and the complexity of its condition or performance. It is regulatory requirement in many jurisdictions.
Independent Tailings Review Board (ITRB) or Senior Technical Reviewer	Provides ongoing senior independent review of the planning, siting, design, construction, operation, maintenance, monitoring, performance, risk management at appropriate intervals across all phases of the *tailings facility lifecycle* (Requirement 8.8).

Co-convened by the International Council on Mining and Metals (ICMM), United Nations Environment Programme (UNEP) and Principles for Responsible Investment (PRI), the Global Tailings Review has established a robust, fit-for-purpose international standard for the safer management of tailings storage facilities.

GlobalTailingsReview.org

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Notes

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