# APPENDIX I

## GLOSSARY OF TERMS AND DEFINITIONS

# GLOSSARY

The following terminology is used in this document following the definitions provided in the Mine Site Reclamation Guidelines for the Northwest Territories (INAC 2007) and the DDMI Class “A” Water License [License Number: WL2015L2-0001])

**“A154 Pit”**: The developed open pit and underground mine workings for the mining of the A154 North and South Kimberlite Pipes.

**“A21 Pit”**: The developed open pit for the mining of the A21 Kimberlite Pipe.

**“A418 Pit”**: The developed open pit and underground mine workings for the mining of the A418 Kimberlite Pipe.

**Abandonment**: The permanent dismantlement of a facility so it is permanently incapable of its intended use. This includes the removal of associated equipment and structures.

**Abiotic**: Non-living factors that influence an ecosystem, such as climate, geology and soil characteristics.

**Acid Rock Drainage (ARD)**: The production of acidic leachate, seepage or drainage from underground workings, pits, ore piles, rockwaste, tailings, and overburden that could lead to the release of metals to groundwater and surface water during the life of the mine and after closure.

**Active Layer**: The layer of ground above the permafrost which thaws and freezes annually.

**Alkalinity**: A measure of the buffering capacity of water, or the capacity of bases to neutralize acids.

**Ambient**: The air in the surrounding atmosphere.

**Anthropogenic**: Caused by human activity.

**“Aquatic Effects Monitoring Program” (AEMP)**: A monitoring program designed to determine the short and long-term effects in the water environment resulting from the Project, to evaluate the accuracy of impact predictions, to assess the effectiveness of impact mitigation measures and to identify additional impact mitigation measures to reduce or eliminate environmental effects.

**Aquitard**: A material of low permeability between aquifers. An aquitard allows some measure of leakage between the aquifers it separates.

**Backfill**: Material excavated from a site and reused for filling the surface or underground void created by mining.

**Background**: An area near the site under evaluation not influenced by chemicals released from the site, or other impacts created by onsite activity.

**Baseline**: A surveyed condition and reference used for future surveys.

**Bathymetry**: Measurement of the depth of an ocean or large waterbody.

**Bedrock**: The body of rock that underlies gravel, soil or other subregion material.

**Benthic Invertebrate**: Invertebrate organisms living at, in or in association with the bottom (benthic) substrate of lakes, ponds and streams. Examples of benthic invertebrates include some aquatic insect species (such as caddisfly larvae) that spend at least part of their lifestages dwelling on bottom sediments in the waterbody. These organisms play several important roles in the aquatic community. They are involved in the mineralization and recycling of organic matter produced in the water above, or brought in from external sources, and they are important second and third links in the trophic sequence of aquatic communities. Many benthic invertebrates are major food sources for fish.

**Berm**: A mound of rock or soil used to retain substances or to prevent substances from entering an area.

**Biodiversity**: The variety of plants and animals that live in a specific area.

**Biotic**: The living organisms in an ecosystem.

**Biotite** schist: A metamorphic rock containing a significant proportion of biotite (black) mica flakes, which are aligned in one main direction.

**Boreal Forest**: The northern hemisphere, circumpolar, tundra forest type consisting primarily of black spruce and white spruce with balsam fir, birch and aspen.

**Carat**: A unit weight for precious stones: 1 carat = 200 mg.

**Care and maintenance**: A term to describe the status of a mine when it undergoes a temporary shutdown.

**Closure**: When a mine ceases operations without the intent to resume mining activities in the future.

**Closure Criteria**: Detail to set precise measures of when the objective has been satisfied.

**Conductivity**: A measure of the ability of water to pass an electrical current, which is affected by the presence of inorganic dissolved solids and organic compounds.

**Construction**: Activities undertaken to construct or build any components of, or associated with, the development of the Diavik Diamond Mine.

**Contaminant**: Any physical, chemical, biological or radiological substance in the air, soil or water that has an adverse effect. Any chemical substance with a concentration that exceeds background levels or which is not naturally occurring in the environment.

**Contouring**: The process of shaping the land surface to fit the form of the surrounding land.

**County Rock**: The rock surrounding an intrusive igneous rock such as kimberlite.

**Criteria**: Detail to set precise measures of when an objective has been satisfied.

**Cryoconcentration**: Concentration of solutes due to exclusion by ice.

**Cryosols**: An order of mineral or organic soils that generally have permafrost within 1 m of the ground surface and soil layers that are frequently disrupted by freezing.

**Cryoturbation**: Mixing of soil due to freezing and thawing.

**Decommission**: The process of permanently closing a site and removing equipment, buildings and structures. Reclamation and plans for future maintenance of affected land and water are also included.

**Dewatering**: The removal or draw down of water from any water body or from ground water table by pumping or draining.

**Diabase**: A dark-gray to black, fine-textured igneous rock composed mainly of feldspar and pyroxene.

**Dike**: Temporary water-retaining structure designed for water control to enable safe open-pit and underground mining.

**Dike Seepage**: Any water that passes through a dike.

**Discharge**: The release of any water or waste to the receiving environment.

**Disposal**: The placement, containment, treatment or processing of unwanted materials. This may involve the removal of contaminants or their conversion to less harmful forms.

**Drainage**: Excess surface or ground water runoff from land.

**Drainage Basin**: A region of land that eventually contributes water to a river or lake.

**Dredging**: Excavating and moving lake-bottom sediments and glacial till below the high watermark and from the bottom of Lac de Gras in the area of the footprints of the dikes.

**“East Island”**: The large eastern-most island in Lac de Gras.

**Ecodistrict**: A subdivision of an ecoregion that is characterized by distinctive assemblages of relief, geology, landforms, soils, vegetation, water and fauna.

**Ecoregion**: A subdivision of an ecozone that is characterized by distinctive regional ecological factors, including physiography, climate, soil, vegetation, water and wildlife.

**Ecosystem**: An ecological unit consisting of both biotic (living) and abiotic (nonliving) environment that interacts within a defined physical location.

**Ecozone**: An area at the earth’s surface representative of large and very generalized ecological units characterized by various abiotic (nonliving) and biotic (living) factors.

**Edaphic**: Referring to the soil. The influence of the soil on plant growth is referred to as an edaphic factor.

**Effluent**: Treated or untreated liquid waste material that is discharged into the environment from a treatment plant.

**Conductivity**: The capability of a solution to transmit an electrical current. A capability closely related to the concentration of salts in soils.

**End Land Use**: The allowable use of disturbed land following reclamation. Municipal zoning and/or approval may be required for specific land uses.

**Engineered Structures**: Any constructed facility that was designed and approved by a Professional Engineer registered with the Association of Professional Engineers, Geologists, and Geophysicists of the Northwest Territories.

**Environment**: The components of the Earth, and includes: land, water and air, including all layers of the atmosphere; all organic and inorganic matter and living organisms; and the interacting natural systems that include the aforementioned components.

**Environmental Assessment (EA)**: An assessment of the environmental effects of a project that is conducted in accordance with the Canadian Environmental Assessment Act and its regulations.

**Erosion**: The wearing away of rock, soil or other surface material by water, rain, waves, wind or ice.

**Esker**: Glaciofluvial landform that occurs when meltwater deposits are left behind after glacier melts, resulting in long winding ridges of sediment.

**Evaporation**: The process by which water is changed from a liquid to a vapour.

**Extensometer**: An instrument used to monitor ground displacements.

**Fish**: Fish as defined in the *Fisheries Act*, includes parts of fish, shellfish, crustaceans, marine animals and any parts of shellfish, crustaceans or marine animals and the eggs, sperm, spawn, larvae, spat and juvenile stages of fish, shellfish, crustaceans and marine animals.

**Fish Habitat**: Areas used by fish for spawning, nursery, rearing, foraging and overwintering.

**Footprint**: The proposed development area that directly affects the soil and vegetation components of the landscape.

**Freeboard**: The vertical distance between the water line and the effective water containment crest on a dam's or dike's upstream slope.

**Freshet**: An increase in surface water flow during the late winter or spring as the result of rainfall, and snow and ice melt.

**Geotechnical Engineer**: A professional engineer registered with the Association of Professional Engineers, Geologists and Geophysicists of the Northwest Territories and whose principal field of specialization is the design and construction of earthworks in a permafrost environment.

**Glacial Till**: Unsorted and unlayered rock debris deposited by a glacier.

**Glaciofluvial Deposits**: Material moved by glaciers and subsequently sorted and deposited by flowing glacial meltwater. Consist primarily of course to medium grained sands, gravels, cobbles, and boulders.

**Glaciolacustrine Deposits**: Material moved by glaciers and deposited in glacial lakes. Consist primarily of fine sands, silts and clay.

**Groundwater**: All subsurface water that occurs in rocks, soil and other geologic formations that are fully saturated.

**Groundwater Recharge**: Water that enters the saturated zone by a downward movement through soil and contributes to the overall volume of groundwater.

**Habitat**: The place where an animal or plant naturally lives and grows.

**Habitat Unit**: Generally, used in Habitat Suitability Index models. A habitat is ranked in regards to its suitability for a particular wildlife species. This ranking is then multiplied by the area (hectares) of the particular habitat type to give the number of habitat units (HU) available to the wildlife species in question.

**Home Range**: The area within which an animal normally lives, and traverses as part of its annual travel patterns.

**Hummock**: A bulging mound of soil having a silty of clay core that often develops in wet and/or permafrost conditions and shows evidence of movement due to regular frost action.

**Hydrogeology**: The study of the factors that deal with subsurface water (groundwater) and the related geologic aspects of surface water. Groundwater as used here includes all water in the zone of saturation beneath the earth's surface, except water chemically combined in minerals.

**Hydrology**: The science that deals with water, its properties, distribution and circulation over the Earth's surface.

**Hydraulic Conductivity**: Measure of the capacity of an aquifer to transmit water.

**Igneous Rock**: Rock formed when molten rock cools and solidifies.

**Inclinometer**: A tilt sensor used to monitor the angle of an object with respect to gravity.

**Inspector**: An Inspector designated by the Minister under Section 35(1) of the Northwest Territories *Water Act*.

**Kame**: An irregularly shaped hill or mound composed chiefly of poorly sorted sand and gravel deposited by a sub-glacial stream as an alluvial fan or delta.

**Kimberlite**: A type of ancient rock that travelled up to the earth's surface where it formed mini-volcanoes.

**Kimberlite Pipes**: Volcanic deposits contained in steep-walled, cone-shaped cylinders.

**Landfill**: An engineered waste management facility at which waste is disposed of by placing it on or in land in a manner that minimizes adverse human health and environmental effects.

**Leachate**: Water or other liquid that has washed (leached) from a solid material, such as a layer of soil or water; leachate may contain contaminants.

**Leaching**: The removal, by water, of soluble matter from any solid material lying on top of bedrock (e.g., soil, alluvium or bedrock).

**Lithology**: The systematic description of sediment and rocks, in terms of composition and texture.

**Littoral Zone**: The zone in a lake that is closest to the shore. It includes the part of the lake bottom, and its overlying water, between the highest water level and the depth where there is enough light (about 1% of the surface light) for rooted aquatic plants and algae to colonize the bottom sediments.

**Local Study Area (LSA)**: Defines the spatial extent directly or indirectly affected by the project.

**Metal Leaching**: The mobilization and migration of metals from underground workings, pitwalls, ore piles, waste rock, tailings, and overburden.

**Meteoric Water**: Groundwater that has recently originated from the atmosphere.

**Migration**: The movement of chemicals, bacteria, and gases in flowing water or vapour.

**Mine Design**: The detailed engineered designs for all mine components stamped by a design engineer

**Mine Plan**: The plan for development of the mine, including the sequencing of the development.

**Mine Water**: Any water that accumulates in any underground working or open pits.

**Mitigation**: The process of rectifying an impact by repairing, rehabilitating or restoring, the affected environment, or the process of compensating for the impact by replacing or providing substitute resources or environments.

**Monitoring**: Observing the change in geophysical, hydrogeological or geochemical measurements over time.

**Nitrogen Dioxide**: One of the component gases of oxides of nitrogen, which also includes nitric oxide. In burning natural gas, coal, oil and gasoline, atmospheric nitrogen may combine with molecular oxygen to form nitric oxide, an ingredient in the brown haze observed near large cities. Nitric oxide is converted to nitrogen dioxide in the atmosphere. Cars, trucks, trains and planes are the major source of oxides of nitrogen in Alberta. Other major sources include oil and gas industries and power plants.

**No Net Loss**: A term found in Canada's Fisheries Act. It is based on the fundamental principle of balancing unavoidable losses of fish habitat with habitat replacement on a project-by-project basis in order to prevent depletion of Canada's fisheries resources.

**"North Inlet Facility"**: The containment facility that is constructed within the North Inlet of East Island of Lac de Gras.

**"North Inlet Water Treatment Plant" (NIWTP)**: Includes the treatment plant designated for the treatment of waters associated with the North Inlet Facility and mine workings.

**Nutrient Regime**: The relative supply of nutrients available for plant growth at a given site.

**Objectives**: Objectives describe what select activities are aiming to achieve.

**Oligotrophic**: Trophic state classification for lakes characterized by low productivity and low nutrient inputs (particularly total phosphorus).

**Outliers**: A data point that falls outside of the statistical distribution defined by the mean and standard deviation.

**Parent Material**: Material (generally bedrock) from which soils typically obtain structure and minerals. Consolidated (rock) or unconsolidated (e.g., river deposits) material that has undergone some degree of physical or chemical weathering.

**Particulate Matter**: A mixture if small particles and liquid droplets, often including a number of chemicals, dust and soil particles.

**Passive Treatment**: Treatment technologies that can function with little or no maintenance over long periods of time.

**Pegmatite**: A very coarse-grained igneous rock that has a grain size of 20 mm or more;

**Permafrost**: Ground that remains at or below zero degrees Celsius for a minimum of two consecutive years.

**Permafrost Aggradation**: A naturally or artificially caused increase in the thickness and/or area extent of permafrost.

**Permeability**: The ease with which gases or liquids penetrate or pass through a soil or cover layer.

**pH**: A measure of the alkalinity or acidy of a solution, related to hydrogen ion concentration; a pH of 7.0 being neutral.

**Piezometer**: An instrument used to monitor pore water pressure.

**Pit water**: Water that seeps into and/or is collected within the pit.

**Pore Water Pressure**: The pressure of groundwater held within the spaces between sediment particles.

**Pore Water**: The groundwater present within the spaces between sediment particles.

**Post-Closure**: The period of time after closure of the mine.

**Processed Kimberlite (PK)**: Processed material rejected from the process plant after the recoverable minerals have been extracted.

**Processed Kimberlite Containment (PKC)**: A storage area for the kimberlite remaining after diamonds have been removed during processing.

**Progressive Reclamation**: Actions that can be taken during mining operations before permanent closure, to take advantage of cost and operating efficiencies by using the resources available from mine operations to reduce the overall reclamation costs incurred. Progressive reclamation enhances environmental protection and shortens the timeframe for achieving the reclamation objectives and goals.

**Project**: The Diavik Diamond Mines Project, an unincorporated joint venture between Rio Tinto (60 %) and Dominion Diamond Diavik Limited Partnership (40%) with Rio Tinto being the operating manager..

**Quaternary Glaciation**: Glaciation that occurred during Quaternary period or the geologic time period from the end of the Pliocene Epoch roughly 1.8-1.6 million years ago to the present.

**Rare Plants**: A native plant species found in restricted areas, at the edge of its range or in low numbers within a province, state, territory or country.

**Reclamation**: The process of returning a disturbed site to a condition consistent with the original natural state or one for other productive uses that minimizes any adverse effects on the environment or threats to human health and safety.

**Regional Study Area (RSA)**: Defines the spatial extent related to the cumulative effects resulting from the project and other regional developments.

**Rehabilitation**: Activities to ensure that the land will be returned to a form and productivity in conformity with a prior land use plan, including a stable ecological state that does not contribute substantially to environmental deterioration and is consistent with surrounding aesthetic values.

**Relative Humidity**: The ratio of the amount of water vapour in the atmosphere to the amount necessary for saturation at the same temperature. Relative humidity is expressed in terms of percent and measures the percentage of saturation.

**Remediation**: The removal, reduction, or neutralization of substances, wastes or hazardous material from a site in order to minimize any adverse effects on the environment and public safety now or in the future.

**Restoration**: The renewing, repairing, cleaning-up, remediation or other management of soil, groundwater or sediment so that its functions and qualities are comparable to those of its original, unaltered state.

**Revegetation**: Replacing original ground cover following a disturbance to the land.

**Riparian**: Refers to streams, channels, banks and the habitats associated with them.

**Risk assessment**: Reviewing risk analysis and options for a given site, component or condition. Risk assessments consider factors such as risk acceptability, public perception of risk, socio-economic impacts, benefits, and technical feasibility. It forms the basis for risk management.

**Runoff**: Water that is not absorbed by soil and drains off the land into bodies of water.

**Scarification**: Preparation of a site to make it more amenable to plant growth.

**Security deposit**: Funds held by the Crown that can be used in the case of abandonment of an undertaking to reclaim the site, or carry out any ongoing measures that may remain to be taken after the abandonment of the undertaking.

**Sedge**: Any plant of the genus *Carex*, perennial herbs, often growing in dense tufts in marshy places. They have triangular jointless stems, a spiked inflorescence and long grass-like leaves, which are usually rough on the margins and midrib. There are several hundred species.

**Sediment**: Solid material, both mineral and organic, that has been moved by air, water, gravity, or ice and has come to rest on the earth's surface either above or below sea level.

**Seepage**: Slow water movement in subsurface. Flow of water from constructed retaining structures. A spot or zone, where water oozes from the ground, often forming the source of a small spring.

**Sewage**: All toilet wastes and greywater.

**"Sewage Treatment Plants"**: Comprises the engineered structures that are designed to contain and treat sewage at the North and South Camps during the construction period, and the main accommodations complex during operations,

**Sentinel Species**: Species that can be used as an indicator of environmental conditions.

**Shoals**: A shallow but submerged area isolated from the shorelines of a body of water.

**Shoreline Habitat**: Area extending from the high water mark to the low water mark of a given water body.

**Slurry**: A mixture of fine rock and water that can be pumped.

**Soil**: The naturally occurring, unconsolidated mineral or organic material at least 10 cm thick that occurs at the earth's surface and is capable of supporting plant growth.

**Soil Horizon**: A layer of mineral or organic soil material approximately parallel to the land surface that has characteristics altered by processes of soil formation. A soil mineral horizon is a horizon with 17% or less total organic carbon by weight. A soil organic horizon is a horizon with more than 17% organic carbon by weight.

**Solar Radiation**: The principal portion of the solar spectrum that spans from approximately 300 nanometres (nm) to 4,000 nm in the electromagnetic spectrum. It is measured in $W/m^2$, which is radiation energy per second per unit area.

**Solifluction**: The slow creeping of soil down a slope promoted by the presence of permafrost and caused by a combination of frost creep and the downslope movement of wet, unfrozen soil.

**Spawning Habitat**: A particular type of area where a fish species chooses to produce and deposit its eggs.

**Spillway**: An engineered structure to facilitate the release of water from a water retention facility, often in an emergency. The spillway elevation is the elevation at which water begins to flow through the spillway structure.

**Substrate**: The material that comprises the bottom of a water body.

**Sulphur Dioxide**: Sulphur dioxide is a colourless gas with a pungent odour. In Alberta, natural gas processing plants are responsible for close to half of the emissions of this gas. Oil sands facilities and power plants are also major sources. Others include gas plant flares, oil refineries, pulp and paper mills and fertilizer plants.

**Surficial material**: Deposits on/at the earth's surface.

**Sump**: A catch basin where water accumulates before being pumped elsewhere for storage, treatment or release.

**Surface Waters**: Natural water bodies such as rivers, streams, brooks, ponds and lakes, as well as artificial watercourses, such as drainage ditches and collection ponds.

**Sustainable Development**: The design, development, operation and closure of all mining activities so as to ensure the optimisation of post closure outcomes in terms of social, environmental and economic development needs and expectations.

**Tailings**: Material rejected from a mill after most of the recoverable valuable minerals have been extracted.

**Taliks**: Unfrozen zones that can exist within, below, or above permafrost layers. They are usually located below deep water bodies.

**Temporary Shutdown**: The cessation of mining and diamond recovery for a finite period due to economic or other operational reasons, with the intent to resume operations under more favourable conditions.

**Thermistor**: An instrument used to monitor temperature change.

**Thermokarst**: A landscape characterized shallow pits and depressions caused by selective thawing of ground ice, or permafrost.

**Till**: Sediments laid down by glacial ice.

**Total Dissolved Solids (TDS)**: A measure of the amount of dissolved substances in a waterbody:

**Total Organic Carbon (TOC)**: Total organic carbon is composed of both dissolved and particulate forms. Total organic carbon is often calculated as the difference between Total Carbon (TC) and Total Inorganic Carbon (TIC). Total organic carbon has a direct relationship with both biochemical and chemical oxygen demands, and varies with the composition of organic matter present in the water. Organic matter in soils, aquatic vegetation and aquatic organisms are major sources of organic carbon.

**Total Suspended Particulate (TSP)**: A measure of the total particulate matter suspended in the air. This represents all airborne particles with a mean diameter less than 30 μm (microns) in diameter.

**Total Suspended Solids (TSS)**: A measure of the particulate matter suspended in the water column.

**Traditional Knowledge (TK)**: A cumulative, collective body of knowledge, experience, and values built up by a group of people through generations of living in close contact with nature. It builds upon the historic experiences of a people and adapts to social, economic, environmental, spiritual and political change.

**Trophic**: Pertaining to part of a food chain, for example, the primary producers are a trophic level just as tertiary consumers are another trophic level.

**Turbidity**: The degree of clarity in the water column typically reflected as the amount of suspended particulate matter in a waterbody.

**Understorey**: Trees or other vegetation in a forest that exist below the main canopy level.

**Waste Rock**: All unprocessed rock materials produced as a result of mining operations that have no economic value.

**Waste Rock Storage Areas (WRSA)**: Includes the engineered facilities for the disposal of rock and till, which are designated as the North and South Waste rock piles.

**Waterbody**: A general term that refers to ponds, bays, lakes, estuaries and marine areas.

**Waterfowl Staging Area**: Waterbodies used by waterfowl to gather, rest and feed before or during migration.

**Watershed**: A region or area bordered by ridges of higher ground that drains into a particular watercourse or body of water.

**Wetland**: A swamp. Marsh, bog, fen or other land that is covered by water during at least three consecutive months of the year.

**Wildlife**: Under the *Species at Risk Act*, wildlife is defined as a species, subspecies, variety or geographically or genetically distinct population of animal, plant or other organism, other than a bacterium or virus that is wild by nature and is native to Canada or has extended its range into Canada without human intervention and has been present in Canada for at least 50 years.

# APPENDIX II

## LIST OF ACRONYMS

# LIST OF ACRONYMS

| Acronym | Description |
|---|---|
| A&R | Abandonment and Restoration |
| AANDC | Aboriginal Affairs and Northern Development Canada |
| AEMP | Aquatic Effects Monitoring Program |
| AEP | Alberta Environment and Parks |
| AN | ammonium nitrate |
| ARD | Acid Rock Drainage |
| BHPB | BHP Billiton |
| $CaC0_3$ | calcium carbonate |
| CCME | Canadian Council of Ministers of Environment |
| COPC | constituent of potential concern |
| COSEWIC | Committee on the Status of Endangered Wildlife in Canada |
| CPFS | Canadian Peregrine Falcon Survey |
| CPK | coarse processed kimberlite |
| CRF | cemented rock fill |
| CRP | Closure and Reclamation Plan |
| DDC | Dominion Diamond Corporation |
| DDMI | Diavik Diamond Mines (2012) Inc. |
| DF | dilution factor |
| DFO | Fisheries and Oceans Canada |
| DIAND | Department of Indian Affairs and Northern Development |
| DTC | Diavik Technical Committee |
| DO | dissolved oxygen |
| EA | Environmental Assessment |
| EER | Environmental Effects Report |
| EMAB | Environmental Monitoring Advisory Board |
| EMPR | Department of Energy Mines and Petroleum Resources |
| ENR | Environment and Natural Resources, Government Northwest Territories |
| EQC | Effluent Quality Criteria |
| ESWG | Ecological Stratification Working Group |
| FPK | fine processed kimberlite |

| Acronym | Description |
| --- | --- |
| GNWT | Government of The Northwest Territories |
| HADD | Harmful Alteration, Disruption or Destruction |
| $HCO_3$ | bicarbonate |
| ICRP | Interim Closure and Reclamation Plan |
| INAC | Indigenous and Northern Affairs Canada (previously Indian and Northern Affairs Canada |
| LDG | Lac de Gras |
| LSA | Local Study Area |
| MLch | Metal Leaching |
| MVLWB | Mackenzie Valley Land and Water Board |
| NCRP | North Country Rock Pile |
| NCRP-WRSA | North Country Rock Pile Waste Rock Storage Area |
| N | sample size |
| NI | North Inlet |
| NIWTP | North Inlet Water Treatment Plant |
| Non-PAG | non-potentially acid generating |
| NKSL | Nishi Khon-SNC Lavalin |
| NWT | Northwest Territories |
| PA | Participation Agreement |
| PAH | polycyclic aromatic hydrocarbons |
| PHC | petroleum hydrocarbons |
| PK | processed kimberlite |
| PKC | processed kimberlite containment |
| RA | Responsible Authorities |
| RBRC | risk-based reference criteria |
| RSA | Regional Study Area |
| SNP | Surveillance Network Program |
| SARA | Species at Risk Act |
| SCRP | South Country Rock Pile |
| SSRBCC | Site-Specific Risk-Based Closure Criteria |
| TDS | total dissolved solids |
| TIE | Toxicity Identification Evaluation |
| TK | Traditional Knowledge |

| Acronym | Description |
|---|---|
| TKN | total Kjeldahl nitrogen |
| TN | total nitrogen |
| TOC | total organic carbon |
| TP | total phosphorus |
| TSP | total suspended particulates |
| TSS | total suspended solids |
| UCAF | Underhand Cut and Fill |
| U/G | underground |
| VLC | Vegetation/Land Cover |
| WLWB | Wek'èezhìı Land and Water Board |
| WMP | Wildlife Monitoring Program |
| WTA | Waste Transfer Area |
| WWF | World Wildlife Fund |
| ZOI | Zone of Influence |

# APPENDIX III

## LIST OF ABBREVIATIONS

# LIST OF ABBREVIATIONS

| Abbreviation | Description |
|---|---|
| Acres and Bryant | Acres and Bryant Environmental Consulting |
| Dominion | Dominion Diamond Diavik Limited Partnerships |
| EBA | EBA Engineering Consultants Ltd. |
| AMEC | AMEC Earth and Environmental Ltd. |
| Golder | Golder Associates Ltd. |
| Kennecott | Kennecott Canada Inc. |
| SENES | SENES Consultants |
| The Mine | Diavik Diamond Mine |

# APPENDIX IV

## LIST OF UNITS AND SYMBOLS

# LIST OF UNITS AND SYMBOLS

| Unit | Description |
|---|---|
| % | percent |
| < | less than |
| > | greater than |
| ≥ | greater than or equal to |
| ° ' | degrees, minutes |
| °C | degrees Celsius |
| μg/L | micrograms per litre |
| μg/m$^3$ | microgram per cubic metre |
| μS/cm | microSiemens per centimetre |
| BTU | British Thermal Units |
| cm | centimetre |
| FeSi | ferro-silicon |
| ha | hectare |
| kg $CaCO_3$/tonne | kilograms calcium carbonate per tonne |
| km | kilometre |
| km/hr | kilometres per hour |
| km$^2$ | square kilometres |
| kV | kilovolts |
| m | metre |
| m/s | metres per second |
| m$^3$ | cubic metres |
| m$^3$/day | cubic metres per day |
| m$^3$/s | cubic metres per second |
| masl | metres above sea level |
| mg/dm$^2$/yr | milligrams per square decimetre per year |
| mg/kg | milligrams per kilogram |
| mg-N/L | milligrams of nitrogen per litre |
| mg-P/L | milligrams of phosphorus per litre |
| mg/L | milligrams per litre |
| ML | Million litres |
| mm | millimetre |
| Mm$^3$ | Million cubic metres |
| Mt | Million tonnes (1 tonne = 1,000 kilograms) |
| MW | Megawatts |
| NTU | Nephelometric Turbidity Units |
| v | zonal velocity ratio |
| wt% | percent by weight |
| wt% S | percent by weight sulphur |
| $Z_a$ | acceleration related seismic zone |
| $Z_v$ | velocity related seismic zone |

# APPENDIX V

# DETAILED TABULATION OF CLOSURE OBJECTIVES AND CRITERIA

# Appendix V Detailed Tabulation of Closure Objectives and Criteria

Version 2.0 Revision Notes:

- General update to criteria to include references to new numeric criteria and consistent referencing to Reclamation Completion Reporting as measurement for criteria that as-built is to be comparable to design.
- Removed objective NI-1 (see Section 5.2.1.2)
- Revised Table V-7 based on approach discussed at WLWB Closure Criteria Workshop December 2016 and follow-up discussions.
- Added Tables V-8 through V-13 based on Site Specific Risk Based Closure Criteria (Appendix X-8.2)
- Removed column with reference to Research Plans.

## Table V-1 Closure Objectives and Criteria – Site Wide

| Closure Objective | Closure Criteria | Measurements | Monitoring Reference |
|---|---|---|---|
| SW1. Surface runoff and seepage water quality that is safe for humans and wildlife. | Human – Table V-8;<br>Birds – Table V-9;<br>Mammals Table V-10;<br>or the result of a detailed Risk Assessment. | Post-closure sampling of runoff/seepage at representative locations where human/wildlife consumption is likely. | Appendix VI |
| SW2 Surface runoff and seepage water quality that will not cause adverse effects on aquatic life or water uses in Lac de Gras or the Coppermine River. | Table V-7;<br>or the result of a detailed Risk Assessment. | Post-closure sampling of runoff/seepage at locations where seepage/runoff enters Lac de Gras. | Appendix VI |
| SW3. Dust levels safe for people, vegetation, aquatic life, and wildlife. | Mean TSP concentrations less than 60 *u*g/m$^3$ annual and 120 *u*g/m$^3$ 24 hr maximum acceptable (Canadian Ambient Air Quality Objectives and NWT Ambient Air Quality Standards);<br>or results of a detailed Risk Assessment. | Post-closure TSP and dust deposition/quality measurements taken at same locations as used during operations. | Appendix VI |
| SW4. Dust levels do not affect palatability of vegetation to wildlife. | Monitoring evidence of post-closure wildlife use of area. | Post-closure monitoring of wildlife use in area | Appendix VI |
| SW5. Re-vegetation targeted to priority areas. | ▪ Final re-vegetation procedures applied to priority areas as established with communities and approved by WLWB.<br>▪ Change in biodiversity (richness and diversity units) of Regional Study Area less than 1%. | Reclamation Completion Report.<br>Post-closure assessment of change in biodiversity. | Appendix VI |
| SW6. Ground surface designed to drain naturally follow pre-development drainage patterns. | ▪ Pre-development drainage channels re-established at Ponds 1,2 3,4,5,7,10,11,12,and 13<br>▪ Satisfactory final inspection of drainage construction by a professional engineer. | Reclamation Completion Report.<br>Geotechnical Inspections. | Appendix VI |
| SW7. Areas in and around the site that are undisturbed during operation of the mine should remain undisturbed | Mine footprint area less than 13 km$^2$ post-closure. (Footprint is the directly disturbed area as used in the Wildlife Effects | Post-closure assessment of final mine footprint size. | N/A |

| Closure Objective | Closure Criteria | Measurements | Monitoring Reference |
|---|---|---|---|
| during and after closure. | Monitoring Program for direct habitat/vegetation loss.) | | |
| SW8. No increased opportunities for predation of caribou compared to pre-development conditions. | Caribou predation directly attributable to a landscape feature unique to this area does not result in increased overall predation on the herd. | Post-closure monitoring of wildlife use in area.<br>Post-closure assessment of predation rates. | Appendix VI |
| SW9. Landscape features (topography and vegetation) that match aesthetics and natural conditions of the surrounding natural area. | ▪ Surface of scarified native material (rock or till).<br>▪ Mine footprint area less than 13 $km^2$ post-closure.<br>▪ Final re-vegetation procedures applied to priority areas.<br>▪ Change in biodiversity (richness and diversity units) of Regional Study Area less than 1%.<br>▪ No surface visible buildings, equipment or non-local materials. | Reclamation Completion Report.<br>Post-closure assessment of change in biodiversity.<br>Post-closure assessment of final mine footprint. | Appendix VI |
| SW10. Safe passage and use for caribou and other wildlife. | No repeated harm to caribou as a direct result of passage through or use of the area. (i.e. if a feature/area is confirmed as being a hazard based on more than one incident then objective is not met for that feature/area) | Post-closure monitoring of caribou use in area.<br>Post-closure assessment of area hazards to caribou. | Appendix VI |
| SW11. Mine areas are physically stable and safe for use by people and wildlife. | Satisfactory final inspection by a professional engineer. | Reclamation Completion Report.<br>Geotechnical Inspections. | Appendix VI |

### Table V-2 Closure Objectives and Criteria - Open Pit, Underground and Dike Areas

| Closure Objective | Closure Criteria | Measurements | Monitoring Reference |
|---|---|---|---|
| M1. Water quality in the flooded pit and dike area that is similar to Lac de Gras or at a minimum protective of aquatic life. | AEMP Benchmark;<br>or the result of a detailed Risk Assessment. | Post-closure sampling of water quality in previously diked off areas. | Appendix VI-1 |
| M2. Pit and dike closure do not have adverse effects on water uses in Lac de Gras, the Coppermine River or on groundwater use. | AEMP Benchmark;<br>or the result of a detailed Risk Assessment. | Post-closure sampling of flooded pit area prior to breaching dikes. | Appendix VI-1 |
| M3. Enhanced lake-wide fish habitat to off-set fish habitat temporarily lost during operations. | As-built of fish habitat conforms adequately with designs.<br>Appendix X-1 A154 area<br>Appendix X-2 A418 area<br>Appendix X-3 A21 area | Reclamation Completion Report. | Appendix VI-1 |
| M4. Safe small craft navigation through dike and pit area. | Breaks in dikes to be a minimum of 30m wide by 2 m deep as per Transport Canada approval. | Reclamation Completion Report. | Appendix VI-1 |
| M5. Physically stable pit walls and shorelines to limit risk of a failure impacting people, aquatic life or wildlife. | Satisfactory final inspection by a professional engineer. | Reclamation Completion Report.<br>Geotechnical Inspections. | Appendix VI-1 |
| M6. Pit fill rate that will not cause adverse effects on water levels in Lac de Gras and Coppermine River. | Water levels in Lac de Gras remain above 415 m elevation to ensure Lac de Gras and Coppermine River remain within natural fluctuations. | Monitoring of fill rate and calculation of change to lake level. | N/A |
| M7. Pit fill rate that will not cause adverse effects on fish or fish habitat in Lac de Gras and Coppermine River. | Water levels in Lac de Gras remain above 415 m elevation to ensure Lac de Gras and Coppermine River remain within natural fluctuations. | Monitoring of fill rate and calculation of change to lake level. | N/A |
| M8. Wildlife safe during filling of pits | No mortalities to wildlife VEC caused by filling of pits. | Monitoring of wildlife in pit area during filling. | Appendix VI-1 |

## Table V-4 Closure Objectives and Criteria - Processed Kimberlite Containment Area

| Closure Objective | Closure Criteria | Measurements | Monitoring Reference |
|---|---|---|---|
| P1. No adverse affects on people, wildlife or vegetation. | Table V-8;<br>Table V-9;<br>Table V-10;<br>Table V-11;<br>or the result of a detailed Risk Assessment. | Post-closure sampling of runoff/seepage/vegetation /dust deposition at representative locations where human/wildlife consumption of water/vegetation/dust is likely. | Appendix VI-5 |
| P2. Physically stable processed kimberlite containment area to limit risk of failure that would affect safety of people or wildlife. | As-built conforms adequately with approved design.<br>Final Geotechnical inspection by engineer of Record. | Reclamation Completion Report.<br>Geotechnical Inspections. | Appendix VI-3 |
| P3. Prevent processed kimberlite from entering the surrounding terrestrial and aquatic environments. | As-built conforms adequately with approved design.<br>Final Geotechnical inspection by engineer of Record. | Reclamation Completion Report.<br>Geotechnical Inspections. | Appendix VI-3 |

## Table V-5 Closure Objectives and Criteria - North Inlet Area

| Closure Objective | Closure Criteria | Measurements | Monitoring Reference |
|---|---|---|---|
| NI2. Water quality and sediment quality in the north inlet that is safe for aquatic life, wildlife, and people. | AEMP benchmark for water quality;<br>Table V-12;<br>If sediment quality is within Table V-13 criteria the NI can be rejoined with Lac de Gras;<br>or the result of a detailed Risk Assessment. | Water and sediment monitoring of the North Inlet prior to reconnection. | N/A |
| NI3. Suitable fish habitat in the north inlet. | AEMP benchmark for water quality;<br>Table V-12;<br>If sediment quality is within Table V-13 criteria the NI can be rejoined with Lac de Gras;<br>or the result of a detailed Risk Assessment. | Water and sediment monitoring of the North Inlet prior to reconnection | N/A |
| NI4. Water quality in the north inlet that is as similar to Lac de Gras as possible. | Monitoring results indicate that drawing more Lac de Gras water into the NI and treating and releasing more NI water will not significantly improve water quality. | Monitoring change in NI water quality over time. | Appendix VI-4 |
| NI5. Water and sediment quality in the North Inlet that will not cause adverse effects on aquatic life or water uses in Lac de Gras or the Coppermine River. | AEMP Benchmark;<br>or the result of a detailed Risk Assessment. | Water and sediment monitoring of the North Inlet prior to reconnection | N/A |
| NI6. Physically stable banks of the North Inlet to limit risk of failure that would impact the safety of people or wildlife. | As-built conforms adequately with approved design.<br>Final Geotechnical inspection by engineer of Record. | Reclamation Completion Report.<br>Geotechnical Inspections. | Appendix VI-4 |

### Table V-6 Closure Objectives and Criteria - Mine Infrastructure Areas

| Closure Objective | Closure Criteria | Measurements | Monitoring Reference |
|---|---|---|---|
| I1. Opportunities for communities to re-use infrastructure, allowable under regulation, and where liability is not a significant concern. | Conditions of Socio-Economic Monitoring Agreement and Participation Agreements met. | Third-party post closure audit to confirm. | N/A |
| I2. On-site disposal areas are safe for people, wildlife, and vegetation. | Table V-7;<br>Table V-8;<br>Table V-9;<br>Table V-10;<br>Table V-11;<br>or the result of a detailed Risk Assessment. | Post-closure sampling of runoff/seepage/soil at representative locations where human/wildlife consumption of water/vegetation/soil is likely. | Appendix VI-5 |
| I3. Prevent remaining infrastructure from contaminating land or water. | Table V-7;<br>Table V-8;<br>Table V-9;<br>Table V-10;<br>Table V-11;<br>or the result of a detailed Risk Assessment. | Post-closure sampling of runoff/seepage/soil at representative locations where human/wildlife consumption of water/vegetation/soil is likely. | Appendix VI-5 |

## Table V-7 Surface runoff/seepage closure criteria for protection of aquatic life.

| | | Proposed Closure Criteria | Criteria Note |
|---|---|---|---|
| Silver | mg.L-1 | 0.06 | Achievable |
| Aluminum | mg.L-1 | 8.6 | Back Calculated |
| Arsenic | mg.L-1 | 0.5 | Back Calculated |
| Cadmium | mg.L-1 | 0.01 | Back Calculated |
| Copper | mg.L-1 | 0.4 | Achievable |
| Nitrite | mg.L-1 | 6.1 | Back Calculated |
| Nitrate | mg.L-1 | 310 | Back Calculated |
| Unionized Ammonia | mg.L-1 | 1.0 | MMER (proposed) |
| Nickel | mg.L-1 | 1.0 | MMER |
| Lead | mg.L-1 | 0.1 | Back Calculated |
| Selenium | mg.L-1 | 0.1 | Back Calculated |
| Uranium | mg.L-1 | 1.5 | Back Calculated |
| Zinc | mg.L-1 | 1.0 | MMER |
| Chromium | mg.L-1 | 0.10 | Back Calculated |
| Antimony | mg.L-1 | 3.4 | Back Calculated |
| Tin | mg.L-1 | 7.5 | Back Calculated |
| Thallium | mg.L-1 | 0.1 | Back Calculated |
| pH | units | 5-8.4 | EQC (H26) |

Water Quality Standards for the protection of aquatic life in Lac de Gras form the base for the closure criteria. DDMI proposes to use the approved AEMP Benchmark values as Water Quality Standards. These are listed in Column N of Table A. At this time DDMI has not proposed the use of the Site Specific Risk Based Closure Criteria (Appendix X-8.2) for protection of aquatic life as there seems to be significant reluctance to this approach for water quality given the existence of the AEMP Benchmarks.

A back calculation approach was used to estimate the runoff/seepage concentration of each water quality parameter required to anticipate receiving water concentrations below the AEMP benchmark in Lac de Gras at the assessment boundary. The calculation used is:

CC=EM*(DF+1)-(REFO*DF) where:

CC = Closure Criteria (mg/L) (Column T)
EM=Effects Magnitude (mg/L) (Column O)
REFO = Reference Condition – Median Open Water (mg/L) (Column Q)
DF = DF=Dilution Factor (dimensionless)

The Effect Magnitude (Column O) is defined as being 20 percent greater than current AEMP Benchmark (Column N) in Table A. This is the defined High Effects Magnitude from Canada (1999).

Background water quality (REFO) for the calculation was assumed to be the median open water concentration as defined in the AEMP Reference Condition Report (DDMI 2015). These values are listed in Table A for both open-water (Column Q) and ice-cover (Column P).

The dilution factor (DF) has been assumed at 85. This value is from the Environmental Assessment (DDMI 1998- Table A7) and was determined based on modelling of runoff to Lac de Gras and represents the expected level of dilution that would occur within 1 $km^2$. The 1 km assessment boundary is also from the Environmental Assessment (DDMI 1998 Figure 1-4) and is defined as the “local” assessment area in Canada (1999).

The resulting back calculated closure criteria are shown in Column T.

Table A. Values used in the derivation of water quality closure criteria for protection of aquatic life.

| B | C | D | E | M | N | O | P | Q | T | U |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | Median LDG Reference | | | |
| | | Smith (2013) Mean | Smith (2013) Max | EA Prediction | DDMI AEMP Benchmark Aquatic Life | Effects Magnitude | Ice | Open | Back Calculated Criteria | Criteria Note |
| Silver | mg.L-1 | 0.011 | 0.064 | 0.0003 | 0.0001 | 0.00012 | 0.0000025 | 0.0000025 | 0.010 | Calculated |
| Aluminum | mg.L-1 | 0.054 | 0.302 | 0.05 | 0.087 | 0.1044 | 0.0029 | 0.0044 | 8.6 | Calculated |
| Arsenic | mg.L-1 | 0.0060 | 0.0317 | 0.0063 | 0.005 | 0.006 | 0.0002 | 0.00017 | 0.5 | Calculated |
| Boron | mg.L-1 | 0.071 | 0.398 | | 1.5 | 1.8 | 0.0025 | 0.0025 | 155 | Calculated |
| Barium | mg.L-1 | 4.02 | 22.68 | | 1.0 | 1.2 | 0.00193 | 0.00181 | 103 | Calculated |
| Cadmium | mg.L-1 | 0.0003 | 0.0019 | 0.0094 | 0.0001 | 0.00012 | 0.0000025 | 0.0000025 | 0.01 | Calculated |
| Chloride | mg.L-1 | 38.1 | 214.9 | 0.6 | 120 | 144 | 0.8 | 1 | 12299 | Calculated |
| Copper | mg.L-1 | 0.073 | 0.413 | 0.0085 | 0.002 | 0.0024 | 0.0003 | 0.00030 | 0.18 | Calculated |
| Iron | mg.L-1 | 0.071 | 0.401 | 0.0155 | 0.3 | 0.36 | 0.0025 | 0.0025 | 31 | Calculated |
| Nitrite | mg.L-1 | 0.004 | 0.022 | 0.003 | 0.06 | 0.072 | 0.001 | 0.001 | 6 | Calculated |
| Nitrate | mg.L-1 | 1.1 | 6.3 | 0.2 | 3 | 3.6 | 0.0034 | 0.001 | 310 | Calculated |
| Ammonia | mg.L-1 | | | 0.015 | 4.73 | 5.676 | 0.0178 | 0.005 | 488 | Calculated |
| Sodium | mg.L-1 | 70.7 | 398.8 | 16.8 | 52 | 62.4 | 0.64 | 0.63 | 5313 | Calculated |
| Nickel | mg.L-1 | 0.070 | 0.394 | 0.0523 | 0.025 | 0.03 | 0.00097 | 0.00095 | 2.5 | Calculated |
| Lead | mg.L-1 | 0.0024 | 0.0134 | 0.0029 | 0.001 | 0.0012 | 0.0000025 | 0.0000025 | 0.10 | Calculated |
| Sulphate | mg.L-1 | 158.9 | 896.0 | 3.2 | 100 | 120 | 2.2 | 1.9 | 10159 | Calculated |
| Selenium | mg.L-1 | 0.0032 | 0.0181 | 0.0006 | 0.001 | 0.0012 | 0.00002 | 0.00002 | 0.10 | Calculated |
| Silicon | mg.L-1 | 2.9 | 16.6 | | 2.1 | 2.52 | 0.025 | 0.025 | 215 | Calculated |
| Strontium | mg.L-1 | 0.95 | 5.34 | | 30 | 36 | 0.0076 | 0.0073 | 3095 | Calculated |
| Uranium | mg.L-1 | 1.35 | 7.61 | 0.0171 | 0.015 | 0.018 | 0.000028 | 0.000028 | 1.5 | Calculated |
| Zinc | mg.L-1 | 0.070 | 0.398 | 0.0479 | 0.03 | 0.036 | 0.00090 | 0.00075 | 3.0 | Calculated |
| Chromium | mg.L-1 | 0.00032 | 0.00178 | 0.0206 | 0.001 | 0.0012 | 0.00003 | 0.00003 | 0.10 | Calculated |
| Molybdenum | mg.L-1 | 0.016 | 0.089 | | 0.073 | 0.0876 | 0.00007 | 0.00009 | 7.5 | Calculated |
| Antimony | mg.L-1 | 0.00031 | 0.00141 | 0.0214 | 0.033 | 0.0396 | 0.00001 | 0.00001 | 3.4 | Calculated |
| Tin | mg.L-1 | 0.00063 | 0.00356 | | 0.073 | 0.0876 | 0.000005 | 0.000005 | 7.5 | Calculated |
| Thallium | mg.L-1 | 0.00020 | 0.00114 | 0.0031 | 0.0008 | 0.00096 | 0.000001 | 0.000001 | 0.08 | Calculated |
| pH | units | | 6.18 | | | | | | 5-8.4 | EQC (H26) |

Achievability

The next step in the approach was to consider “achievability”. Achievability is a specified consideration in both MVLWB/AANDC (2013) and MVLWB (2011). Achievability is evaluated by reviewing the back calculated closure criteria against available predicted runoff/seepage water quality. Currently achievability has only been considered for NCRP runoff/seepage quality (see NCRP-WRSA Final Closure Plan (April 2017). Appendix V-2 of the NCRP-WRSA Final Closure Plan (April 2017) contains the figures presenting the research data sets in comparison to a) back calculated closure criteria (Column T), b) EA predicted seepage/runoff (Column M), c) range (min/max) of runoff/seepage predictions (Smith 2013) and d) the AEMP Benchmark (Column N).

From this visual assessment DDMI noted two parameters where the back calculated closure criteria appear to present substantive “achievability” concerns; silver and copper.

*Silver*

The back calculated closure criteria for silver of 0.01 mg/L is lower than maximum predicted in Smith (2013) of 0.064 mg/L (Column E) and is within the measured range. DDMI proposes to increase the closure criteria for silver to 0.06 mg/L, the maximum predicted in Smith (2013) to improve achievability. It should be noted that the 0.06 mg/L closure criteria is still within the range of measured seepage from Diavik’s test pile research.

*Copper*

The back calculated closure criteria for copper of 0.18 mg/L is lower than maximum predicted in Smith (2013) of 0.413 mg/L (Column E) and is within the measured range. DDMI proposes to increase the closure criteria for silver to 0.4 mg/L the maximum predicted in Smith (2013) to improve achievability. It should be noted that the 0.4 mg/L closure criteria is still within the range of measured seepage from Diavik’s test pile research.

As runoff/seepage water quality predictions are finalized for other closure areas a similar analysis will be conducted to revise closure criteria.

Other Exceptions

*Nickel and Zinc*

The back calculated closure criteria for nickel and zinc are greater than the current grab limits specified in the Metal Mining Effluent Regulations (MMER). DDMI is recommending that the proposed closure criteria for these two parameters be reduced to equal the MMER grab limits.

*Nitrogen compounds*

The nitrogen compounds (ammonia, nitrate, nitrite) present a unique challenge with regard to achievability. These are not geochemical parameters where runoff/seepage concentrations are influenced by rock type. Nitrogen compounds are the result of explosives residue. While they are expected to be present in early NCRP runoff/seepage, concentrations are expected to decline to very low values quickly relative to metals. For this reason nitrogen compounds have not been evaluated for achievability in the same way as metal parameters. Like nickel and zinc the proposed MMER limit for un-ionized ammonia is likely lower than the back calculated closure criteria and DDMI is recommending the closure criteria for ammonia be equal to the proposed MMER grab limit for un-ionized ammonia once it has been finalized.

*pH*

The back calculation approach described above is not appropriate for pH as it does not mass balance the same way as the other water quality parameters. DDMI proposes that the closure criteria for pH remain as per Part H Item 26 (W2015L2-0001) at between 5 and 8.4.

Criteria not Proposed

MVLWB (2011) includes the principle of waste minimization in setting criteria including setting levels that are lower than what is necessary to meet water quality standards in the receiving environment. DDMI has identified nine parameters where closure criteria could be either lowered following the waste minimization principle or eliminated as being unnecessary for closure. These parameters are boron, barium, chloride, iron, molybdenum, sodium, silicon, sulphate and strontium. For each the back calculated closure criteria are much greater than the expected runoff/seepage water quality from either Smith (2013) or the Diavik research measurements. DDMI proposes that there be no closure criteria for boron, barium, chloride, iron, molybdenum, silicon, sulphate or strontium on the basis that criteria are not necessary.

As runoff/seepage water quality predictions are finalized for other closure areas a similar analysis will be conducted to revise closure criteria.

**Table V8. Drinking water closure criteria.**

| | | SSRBCC (App J with Notes) | |
|---|---|---|---|
| | | Adult | Toddler |
| Antimony | mg.L-1 | 0.113 | 0.00662 |
| Arsenic | mg.L-1 | 0.01 | 0.01 |
| Chromium | mg.L-1 | 0.05 | 0.05 |
| Manganese | mg.L-1 | 0.59 | 0.301 |
| Mercury | mg.L-1 | 0.0011 | 0.0007 |
| Nitrate | mg.L-1 | 30.2 | 17.6 |
| Nitrite | mg.L-1 | 1.89 | 1.0 |
| Selenium | mg.L-1 | 0.05 | 0.05 |
| Sulphate | mg.L-1 | 266 | 669 |
| Uranium | mg.L-1 | 0.02 | 0.02 |

Closure criteria for human drinking water are those specified in Appendix J of the Site Specific Risk Based Closure Criteria (Appendix X-8.2) with application of the notes listed for each parameter. Table V8 above summarizes these values for convenience but the reader should go to Appendix X-8.2 for an explanation of the basis for these criteria. These criteria are applicable where water could be consumed by people. This would include direct consumption of seepage/runoff or consumption of Lac de Gras water in proximity to where the seepage/runoff was released.

Achievability is a specified consideration in MVLWB/AANDC (2013). Achievability was initially considered for the criteria listed in Table V8. DDMI evaluated achievability by reviewing SSRBCC against both the predicted NCRP runoff/seepage quality (Smith 2013) and a graphical compilation of measured seepage results from Diavik's research program.

From this visual assessment it appears that with the exception of uranium all of the SSRBCC will be achieved locally within Lac de Gras but it is unlikely that all SSRBCC would be achieved for direct consumption of the NCRP runoff/seepage based on these predictions. Human health SSCRCC for sulphate and manganese are within the range of expected NCRP runoff/seepage concentrations. Nitrate and nitrite SSRBCC are also within the predicted range for runoff/seepage, but as discussed above these concentrations are not expected to remain long term. Note that achievability has not been assessed for mercury as expected runoff/seepage concentrations are not currently available.

The human health SSRBCC for uranium of 0.02 mg/L is lower that the AEMP Benchmark for the protection of aquatic life (0.015 mg/L). The human health SSRBCC is unlikely to me met in the runoff/seepage water itself. In Lac de Gras the human health SSRBCC for uranium would be achieved before the edge of the local assessment area. If the human health SSRBCC of 0.02 mg/L is approved and runoff/seepage with this quality materializes, measures may be required to restrict human access to the runoff/seepage to avoid direct consumption.

As runoff/seepage water quality predictions are finalized for other closure areas a similar analysis will be conducted to revise closure criteria.

**Table V9. Water closure criteria for birds**

| | | SSRBCC (App I) | | | | |
|---|---|---|---|---|---|---|
| | | Sandpiper | Duck | Ptarmigan | Falcon | Eagle |
| Chromium | mg.L-1 | 2.9 | 9.31 | 8.41 | 47.7 | 83.2 |
| Cobalt | mg.L-1 | 8.28 | 26.6 | 24.1 | 137 | 238 |
| Manganese | mg.L-1 | 1.95 | 626 | 566 | 3213 | 5598 |
| Molybdenum | mg.L-1 | 3.81 | 12.2 | 11.1 | 62.8 | 109 |
| Nickel | mg.L-1 | 7.3 | 23.5 | 21.2 | 120 | 210 |
| Uranium | mg.L-1 | 17.4 | 56 | 50.6 | 287 | 500 |

Water closure criteria for birds are those specified in Appendix I of the Site Specific Risk Based Closure Criteria (Appendix X-8.2). Table V9 above summarizes these values for convenience but the reader should go to Appendix X-8.2 for an explanation of the basis for these criteria. These criteria are applicable where birds would be exposed to water. This would include direct exposure to seepage/runoff and in Lac de Gras in proximity to where the seepage/runoff was released.

Achievability is a specified consideration in MVLWB/AANDC (2013). Achievability was initially considered for the criteria listed in Table V9. DDMI evaluated achievability by reviewing SSRBCC against both the predicted NCRP runoff/seepage quality (Smith 2013) and a graphical compilation of measured seepage results from Diavik's research program. From this visual assessment it appears unlikely that any of the SSRBCC in Table V9 would be realized even with direct exposure to the seepage/runoff.

As runoff/seepage water quality predictions are finalized for other closure areas a similar analysis will be conducted to revise closure criteria.

## Table V10. Water closure criteria for mammals

| | | SSRBCC (App H) | | | |
|---|---|---|---|---|---|
| | | Caribou | Bear | Fox | Vole |
| Chromium | mg.L-1 | 8 | 9.25 | 5.58 | 3.51 |
| Cobalt | mg.L-1 | 24.4 | 28.3 | 17.1 | 10.7 |
| Manganese | mg.L-1 | 172 | 199 | 120 | 75.4 |
| Molybdenum | mg.L-1 | 1 | 1 | 1 | 1 |
| Nickel | mg.L-1 | 5.67 | 6.55 | 3.95 | 2.49 |
| Uranium | mg.L-1 | 10.2 | 11.8 | 7.14 | 4.5 |

Water closure criteria for mammals are those specified in Appendix H of the Site Specific Risk Based Closure Criteria (Appendix X-8.2) with application of the notes listed for molybdenum. Table V10 above summarizes these values for convenience but the reader should go to Appendix X-8.2 for an explanation of the basis for these criteria. These criteria are applicable where mammals would be exposed to water. This would include direct exposure to seepage/runoff and in Lac de Gras in proximity to where the seepage/runoff was released.

Achievability is a specified consideration in MVLWB/AANDC (2013). Achievability was initially considered for the criteria listed in Table V10. DDMI evaluated achievability by reviewing SSRBCC against both the predicted NCRP runoff/seepage quality (Smith 2013) and a graphical compilation of measured seepage results from Diavik's research program. From this visual assessment it appears unlikely that any of the SSRBCC in Table V10 would be realized even with direct exposure to the seepage/runoff.

As runoff/seepage water quality predictions are finalized for other closure areas a similar analysis will be conducted to revise closure criteria.

**Table V11. Soil closure criteria**

| | | SSRBCC (Table 3.1-1) |
|---|---|---|
| Barium | mg/kg dw | 500 |
| Chromium | mg/kg dw | 66.9 |
| Manganese | mg/kg dw | 220 |
| Molybdenum | mg/kg dw | 5 |

Soil closure criteria those specified in Table 3.1-1 of the Site Specific Risk Based Closure Criteria (Appendix X-8.2) with application of the notes listed. Table V11 above summarizes these values for convenience but the reader should go to Appendix X-8.2 for an explanation of the basis for these criteria. These criteria are applicable where humans or wildlife are exposed to a surface material.

## Table V12. Sediment closure criteria for birds

| | | SSRBCC (App J) | |
|---|---|---|---|
| | | Sandpiper | Duck |
| Arsenic | mg/kg | 0.501 | 1.67 |
| Chromium | mg/kg | 3.12 | 11.2 |
| Copper | mg/kg | 0.054 | 0.178 |
| 2-methlynaphthalene | mg/kg | 3,555 | 13828 |
| Acenaphthene | mg/kg | 376 | 1464 |
| Acenaphthylene | mg/kg | 387 | 1506 |
| Naphthalene | mg/kg | 3555 | 13828 |
| Pyrene | mg/kg | 269 | 1046 |

Sediment closure criteria for birds are those specified in Appendix J of the Site Specific Risk Based Closure Criteria (Appendix X-8.2) with application of the notes listed. Table V12 above summarizes these values for convenience but the reader should go to Appendix X-8.2 for an explanation of the basis for these criteria. These criteria are applicable where birds could be exposed to sediment.

### Table V13. Sediment closure criteria for aquatic life

| | | SSRBCC (Table 3.3-1) |
|---|---|---|
| Arsenic | mg/kg | 5.9 |
| Chromium | mg/kg | 37.3 |
| Copper | mg/kg | 35.7 |
| 2-methlynaphthalene | mg/kg | 0.0202 |
| Acenaphthene | mg/kg | 0.00671 |
| Acenaphthylene | mg/kg | 0.00587 |
| Naphthalene | mg/kg | 0.0346 |
| Pyrene | mg/kg | 0.053 |

Sediment closure criteria for aquatic life are those specified in Table 3.3-1 of the Site Specific Risk Based Closure Criteria (Appendix X-8.2) with application of the notes listed. Table V13 above summarizes these values for convenience but the reader should go to Appendix X-8.2 for an explanation of the basis for these criteria. These criteria are applicable where aquatic life could be exposed to sediment.

# APPENDIX VI

# POST-CLOSURE MONITORING AND REPORTING

## Appendix VI Post Closure Monitoring and Reporting

VI-1 Open Pit, Underground and Dike Areas

VI-2 Wasterock and Till Area (See NCRP-WRSA Final Closure Plan V1.1)

VI-3 Processed Kimberlite Containment Area

VI-4 North Inlet Area

VI-5 Mine Infrastructure Areas

## Appendix VI-1 Post Closure Monitoring and Reporting - Open Pit, Underground and Dike Areas

Two types of post-closure monitoring programs are planned: performance monitoring specific to the open pit, underground and dike area and environmental effects monitoring which would include combined effects from all post-closure areas. These are described in Section 1.0 with the type and frequency of reporting described in Section 2.0.

1.0 Performance Monitoring

1.1 Geotechnical

During mining operation the dike, open-pit and underground areas undergo regular geotechnical inspections. As fish habitat work within the dike areas are complete geotechnical inspections will review these areas. Once the underground and pit areas have been flooded inspections will focus on dike and shoreline stability. No geotechnical instrumentation is planned once the back-flooding is complete.

An aerial drone survey will be conducted starting the year prior to back-flooding and then for the following 5 years. The survey before back-flooding will document the constructed fish habitat in each dike area and be submitted separately to Fisheries and Oceans Canada.

1.2 Water Quality

Water quality is monitored during operations at several SNP locations that include underground mine water, open-pit mine water and dike seepage water. This monitoring will cease once back-flooding commences. Immediately following completion of the back-flooding of each of the A154, A418 and A21 dike areas, post-closure SNP monitoring of the dike areas will begin at the following SNP locations:

| SNP Site # | Description |
|---|---|
| 1645-87 (new) | A154 Back-flooded area |
| 1645-88 (new) | A418 Back-flooded area |
| 1645-89 (new) | A21 Back-flooded area |

Water quality will be sampled monthly until water quality is approved to allow breaching of each dike. Samples will be collected from surface, 15m depth and 30m depths. Water samples will be analyzed for the parameters listed below (source W2015L2-0001 – SNP 1645-81). Profiles for temperature, turbidity, conductivity and dissolved oxygen will be recorded over the first 30 m of depth during each sampling event. Twice per year deep water quality samples will be collected from approximately 25 m above the pit bottom, if feasible.

| | |
|---|---|
| Sampling Parameters: | Total Ammonia, Field Parameters[3], ICP-MS Metal Scan[1](Total), Major Ions[2], pH[4], Total Petroleum Hydrocarbons |

After each of the dikes have been breached and rejoined with Lac de Gras the frequency of SNP monitoring will be reduced to twice per year.

1.3 Wildlife

DDMI will employ existing monitoring procedures (as updated from time-to-time) to record wildlife use of the mine and dike areas and observations of behavior when animals are present in these areas. These procedures include:

ENVR-031-0720 – Caribou Road Surveys
ENVR-517-0912 – Caribou Management/Observation
ENVR-531-0812 – Wildlife Monitoring

### 1.4 Dust

DDMI will use the existing Total Suspended Particulate (TSP) monitoring system and procedures (as updated from time-to-time) combined with visual observations to monitoring dust generated from the dike and mine areas post-closure. This monitoring will begin during at the same time as back-flooding.

### 1.5 Environmental Effects Monitoring

DDMI implements two environmental effects monitoring programs:

- Aquatic Effects Monitoring Program (AEMP)
- Wildlife Effects Monitoring Program (WEMP)

These are defined programs, updated or revised as warranted, to monitor mine effects on the Lac de Gras aquatic ecosystem and wildlife within a defined study area. These programs are conducted annually with specific scopes varying from year to year. For example the AEMP has an expanded program every three years and a base program annually. Towards the end of commercial operations, DDMI expects to reduce the scope and/or frequency of these programs as the need to implement operational management responses declines. Near-Field AEMP sampling locations will be adjusted to target runoff/seepage and water quality through dike breaches rather than the NIWTP effluent discharge. The attached Figure VI-1 shows the proposed relocated near-field AEMP stations renamed near-field closure (NFC). After the end of commercial production DDMI will continue these monitoring programs to monitor responses to the cessation of mining operations. The frequency would be reduced to every three years.

## 2.0 Reporting

### 2.1 Reclamation Completion Reporting

At the end of the calendar year following each of the dike breach excavations DDMI and the Engineer of Record will prepare a Reclamation Completion Report. The report shall include:

- Daily construction reports;
- Photographic documentation of construction works;
- Summary of construction problems and resolutions; and
- Completed construction checklist.

This report will be submitted to the WLWB as per Part K Item 5.

### 2.2 Performance Assessment Report.

Once sufficient information is available to evaluate the performance of the back-flooded dike area generally and Closure Objectives and Closure Criteria specifically, DDMI will submit a Performance Assessment Report to the WLWB for approval under Part K Item 6. The Report will be developed in accordance with the Mackenzie Valley Land and Water Board's *Guidelines for the Closure and Reclamation of Advanced Mineral Exploration and Mine Sites within the Northwest Territories*.

3.0 Monitoring and Reporting Schedule

The anticipated monitoring and reporting schedule for the dike area and site wide effects monitoring is shown below. This schedule is subject to change based on actual construction timeline as well as results from inspections and monitoring programs. The number of years of post-construction monitoring required to adequately assess performance is unknown at this time and will depend upon the results obtained. The monitoring duration will be adaptively managed to be responsive to conditions as they are evaluated. DDMI has assumed 3 year of monitoring after the dikes have been breached to provide sufficient information to support an assessment report.

| Activity | 2017 | 2018 | 2019 | 2020 | 2021 | 2022 | 2023 | 2024 | 2025 | 2026 | 2027 | 2028 | 2029 | 2030 | 2031 | 2032 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Geotechnical inspections | | | | | | | ■ | ■ | ■ | ■ | ■ | ■ | ■ | ■ | ■ | ■ |
| Water quality monitoring | | | | | | | | | | ■ | ■ | ■ | ■ | ■ | ■ | ■ |
| Dust Monitoring | ■ | ■ | ■ | ■ | ■ | ■ | ■ | ■ | ■ | ■ | ■ | ■ | ■ | ■ | ■ | ■ |
| Wildlife Use Monitoring | | | | | | | | | ■ | ■ | ■ | ■ | ■ | ■ | ■ | ■ |
| Aquatic Effects Monitoring | | | | | | | | | | ■ | | | ■ | | | ■ |
| Wildlife Effects Monitoring | | | | | | | | | | ■ | | | ■ | | | ■ |
| Annual CRP Progress Reporting | ■ | ■ | ■ | ■ | ■ | ■ | ■ | ■ | | | | | | | | |
| Reclamation Completion Report | | | | | | | | | | | | ■ | | | | |
| Performance Assessment Report | | | | | | | | | | | | ■ | ■ | ■ | ■ | ■ |

## Appendix VI-3 Post Closure Monitoring and Reporting - Processed Kimberlite Containment Area

Two types of post-closure monitoring programs are planned: performance monitoring specific to the Processed Kimberlite Containment (PKC) area and environmental effects monitoring which would include combined effects from all post-closure areas. These are described in Section 1.0 with the type and frequency of reporting described in Section 2.0.

1.0 Performance Monitoring

1.1 Geotechnical

Presently the PKC is inspected weekly to identify any stability issues and to identify seepage/runoff. This inspection frequency will continue until the end of commercial operations after which it will reduce to monthly (November to May) and weekly June to October.

Observation wells, collection wells, thermistors and slope inclinometers have been installed in the PKC area to monitor operational performance. Much of this instrumentation is expected to remain post-closure, however the final determination of post-closure instrumentation will not be made until the final closure plan is prepared.

Annually, visual inspection will include an aerial drone surveys. These surveys will commence with the end of commercial production.

1.2 Seepage/Runoff Water Quality

Seepage/runoff and PKC pond water quality monitoring is proposed at the following SNP locations:

| **SNP Site #** | **Description** |
|---|---|
| 1645-42 | Collection Pond 4 |
| 1645-69 | Collection Pond 5 |
| 1645-44 | Collection Pond 7 |
| 1645-16 | PKC Pond water within the PKC |
| 1645-31 | Groundwater GW4 West of PKC |
| 1645-32 | Groundwater GW4 South of PKC, between the Ammonia Nitrate Storage and Pond 7 |
| 1645-77 | PKC Seepage |
| 1645-78 | PKC Seepage |
| 1645-79 | PKC Seepage |
| 1645-80 | PKC Seepage |

Seepage or runoff quality will be sampled at a weekly frequency if sufficient volumes are identified during the weekly geotechnical inspections. Water samples will be analyzed for the following (source W2015L2-0001 – SNP 1645-81):

| | |
|---|---|
| Sampling Parameters: | Total Ammonia, Field Parameters[3], ICP-MS Metal Scan[1](Total), Major Ions[2], pH[4], Total Petroleum Hydrocarbons |

SNP 1645-42,69 and 1645-44 are currently located within the collection ponds. Once collection ponds are breached, DDMI proposes to relocate these stations to the outlet channel.

Additionally if the estimated flow volume from 1645-42, 69 or 44 is greater than 10 L/s following breaching of the collection ponds then a sample will also be collected quarterly and assessed for acute lethality to rainbow trout, *Oncorhynchus mykiss* as per Environment Canada's Environmental Protection Series Biological Test Method EPS/1/RM/13.

SNP 1645-31 and 1645-32 are currently inactive. DDMI will reactivate them post-closure to either confirm absence of groundwater flow or measure the quality of detected flow.

### 1.3 Wildlife

DDMI will employ existing monitoring procedures (as updated from time-to-time) to record wildlife use of the PKC area and observations of behavior when animals are present in the PKC area. These procedures include:

ENVR-031-0720 – Caribou Road Surveys
ENVR-032-0721 – Caribou PKC & NCRP Use
ENVR-517-0912 – Caribou Management/Observation
ENVR-531-0812 – Wildlife Monitoring

### 1.4 Dust

DDMI will use the existing Total Suspended Particulate (TSP) monitoring system and procedures (as updated from time-to-time) combined with visual observations to monitoring dust generated from the PKC area. This monitoring will begin during erosion cover placement and continue after the end of commercial production.

### 1.5 Environmental Effects Monitoring

DDMI implements two environmental effects monitoring programs:

- Aquatic Effects Monitoring Program (AEMP)
- Wildlife Effects Monitoring Program (WEMP)

These are defined programs, updated or revised as warranted, to monitor mine effects on the Lac de Gras aquatic ecosystem and wildlife within a defined study area. These programs are conducted annually with specific scopes varying from year to year. For example the AEMP has an expanded program every three years and a base program annually. Towards the end of commercial operations, DDMI expects to reduce the scope and/or frequency of these programs as the need to implement operational management responses declines. Near-Field AEMP sampling locations will be adjusted to target runoff/seepage and water quality through dike breaches rather than the NIWTP effluent discharge. The attached Figure VI-1 shows the proposed relocated near-field AEMP stations renamed near-field closure (NFC). After the end of commercial production DDMI will continue these monitoring programs to monitor responses to the cessation of mining operations. The frequency would be reduced to every three years.

## 2.0 Reporting

### 2.1 Reclamation Completion Reporting

Upon completion of construction activities at the end of each calendar year, DDMI and the Engineer of Record will prepare a Construction Record summary report. The report shall include:

- Daily construction reports;
- All testing records including a summary of all test sample locations and test results;

- Photographic documentation of construction works;
- Summary of construction problems and resolutions; and
- Completed construction checklist.

Upon completion of the PKC closure construction, a single comprehensive PKC Reclamation Completion Report will be prepared by the Construction Management team and Engineer of Record for submission to the WLWB as per Part K Item 5.

### 2.2 Performance Assessment Report.

Once sufficient information is available to evaluate the performance of the PKC closure design generally and Closure Objectives and Closure Criteria specifically, DDMI will submit a Performance Assessment Report to the WLWB for approval under Part K Item 6. The Report will be developed in accordance with the Mackenzie Valley Land and Water Board's *Guidelines for the Closure and Reclamation of Advanced Mineral Exploration and Mine Sites within the Northwest Territories*.

## 3.0 Monitoring and Reporting Schedule

The anticipated monitoring and reporting schedule for the PKC and site wide effects monitoring is shown below. This schedule is subject to change based on actual construction timeline as well as results from inspections and monitoring programs. The number of years of post-construction monitoring required to adequately assess performance is unknown at this time and will depend upon the results obtained. The monitoring duration will be adaptively managed to be responsive to conditions as they are evaluated. DDMI has assumed 3 year of monitoring from the time the PKC closure is completed until there is sufficient information to prepare an assessment report.

| Activity | 2017 | 2018 | 2019 | 2020 | 2021 | 2022 | 2023 | 2024 | 2025 | 2026 | 2027 | 2028 | 2029 | 2030 | 2031 | 2032 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Geotechnical inspections | | | | | | | | | | | | | | | | |
| Seepage/Run-off monitoring | | | | | | | | | | | | | | | | |
| Dust Monitoring | | | | | | | | | | | | | | | | |
| Wildlife Use Monitoring | | | | | | | | | | | | | | | | |
| Aquatic Effects Monitoring | | | | | | | | | | | | | | | | |
| Wildlife Effects Monitoring | | | | | | | | | | | | | | | | |
| Annual CRP Progress Reporting | | | | | | | | | | | | | | | | |
| Reclamation Completion Report | | | | | | | | | | | | | | | | |
| Performance Assessment Report | | | | | | | | | | | | | | | | |

## Appendix VI-4 Post Closure Monitoring and Reporting - North Inlet Area

Two types of post-closure monitoring programs are planned: performance monitoring specific to the North Inlet (NI) and environmental effects monitoring which would include combined effects from all post-closure areas. These are described in Section 1.0 with the type and frequency of reporting described in Section 2.0.

1.0 Performance Monitoring

1.1 Geotechnical

Presently the NI is inspected weekly to identify any geotechnical issues. This inspection frequency will continue until the end of commercial operations after which it will reduce to monthly (November to May) and weekly June to October.

Thermistors and slope inclinometers installed for operations monitoring will remain post-closure. Once the NI area has been decommissioned the inspections will focus on the east dam and shoreline stability. No geotechnical instrumentation is planned once the east dam has been breached.

Annually, visual inspection will include an aerial drone survey of the area. These inspections will begin prior to decommissioning and continue until 2032.

1.2 Water Quality

SNP monitoring of the NI and NIWTP will continue as per operations when the NIWTP is operating. Once NIWTP operations are no longer required water quality monitoring is proposed at the following SNP locations:

| SNP Site # | Description |
|---|---|
| 1645-13 | North Inlet – Influent prior to treatment |

Water quality will be monitored monthly and analyzed for the following parameters (source W2015L2-0001 – SNP 1645-81):

| | |
|---|---|
| Sampling Parameters: | Total Ammonia, Field Parameters[3], ICP-MS Metal Scan[1](Total), Major Ions[2], pH[4], Total Petroleum Hydrocarbons |

Once water quality in the NI is approved for breaching of the NI east dam, then the monitoring frequency at 1645-13 will reduce to twice per year.

1.3 Sediment Quality

A sediment quality investigation will be conducted at the end of commercial operations to evaluate the sediment conditions in the NI. The investigation will follow the scope and procedures used in 2015 (Golder 2016 *Consolidated Report: North Inlet Sludge Management Report and North Inlet Hydrocarbon Investigation Report*. February 25, 2016).

1.4 Wildlife

DDMI will employ existing monitoring procedures (as updated from time-to-time) to record wildlife use of the NI area and observations of behavior when animals are present on the NCRP. These procedures include:

ENVR-031-0720 – Caribou Road Surveys
ENVR-517-0912 – Caribou Management/Observation
ENVR-531-0812 – Wildlife Monitoring

### 1.5 Dust

DDMI will use the existing Total Suspended Particulate (TSP) monitoring system and procedures (as updated from time-to-time) combined with visual observations to monitoring dust generated from the NI area. This monitoring will begin during decommissioning of the NI east dam.

### 1.6 Environmental Effects Monitoring

DDMI implements two environmental effects monitoring programs:

- Aquatic Effects Monitoring Program (AEMP)
- Wildlife Effects Monitoring Program (WEMP)

These are defined programs, updated or revised as warranted, to monitor mine effects on the Lac de Gras aquatic ecosystem and wildlife within a defined study area. These programs are conducted annually with specific scopes varying from year to year. For example the AEMP has an expanded program every three years and a base program annually. Towards the end of commercial operations, DDMI expects to reduce the scope and/or frequency of these programs as the need to implement operational management responses declines. Near-Field AEMP sampling locations will be adjusted to target runoff/seepage and water quality through dike breaches rather than the NIWTP effluent discharge. The attached Figure VI-1 shows the proposed relocated near-field AEMP stations renamed near-field closure (NFC). After the end of commercial production DDMI will continue these monitoring programs to monitor responses to the cessation of mining operations. The frequency would be reduced to every three years.

## 2.0 Reporting

### 2.1 Reclamation Completion Reporting

Upon completion of NI closure DDMI and the Engineer of Record will prepare a North Inlet Reclamation Completion Report. The report shall include:

- Daily construction reports;
- All testing records including a summary of all test sample locations and test results;
- Photographic documentation of construction works;
- Summary of construction problems and resolutions; and
- Completed construction checklist.

This report will be submitted to the WLWB as per Part K Item 5.

### 2.2 Performance Assessment Report.

Once sufficient information is available to evaluate the performance of the NI generally and Closure Objectives and Closure Criteria specifically, DDMI will submit a Performance Assessment Report to the WLWB for approval under Part K Item 6. The Report will be developed in accordance with the Mackenzie Valley Land and Water Board's *Guidelines for the Closure and Reclamation of Advanced Mineral Exploration and Mine Sites within the Northwest Territories*.

3.0 Monitoring and Reporting Schedule

The anticipated monitoring and reporting schedule for the NI and site wide effects monitoring is shown below. This schedule is subject to change based on actual construction timeline as well as results from inspections and monitoring programs. The number of years of post-construction monitoring required to adequately assess performance is unknown at this time and will depend upon the results obtained. The monitoring duration will be adaptively managed to be responsive to conditions as they are evaluated.

| Activity | 2017 | 2018 | 2019 | 2020 | 2021 | 2022 | 2023 | 2024 | 2025 | 2026 | 2027 | 2028 | 2029 | 2030 | 2031 | 2032 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Geotechnical inspections | | | | | | | | | | | | | | | | |
| NI pond water monitoring | | | | | | | | | | | | | | | | |
| NI sediment investigation | | | | | | | | | | | | | | | | |
| Dust Monitoring | | | | | | | | | | | | | | | | |
| Wildlife Use Monitoring | | | | | | | | | | | | | | | | |
| Aquatic Effects Monitoring | | | | | | | | | | | | | | | | |
| Wildlife Effects Monitoring | | | | | | | | | | | | | | | | |
| Annual CRP Progress Reporting | | | | | | | | | | | | | | | | |
| Reclamation Completion Report | | | | | | | | | | | | | | | | |
| Performance Assessment Report | | | | | | | | | | | | | | | | |

## Appendix VI-5 Post Closure Monitoring and Reporting - Mine Infrastructure Areas

Two types of post-closure monitoring programs are planned: performance monitoring specific to the Infrastructure areas and environmental effects monitoring which would include combined effects from all post-closure areas. These are described in Section 1.0 with the type and frequency of reporting described in Section 2.0.

3.0 Performance Monitoring

3.1 Geotechnical

Aspects of the infrastructure area are inspected weekly during operations to identify any stability and or seepage/runoff. This inspection frequency will continue until the end of commercial operations after which it will reduce to monthly.

Annually, visual inspection will include an aerial drone survey of the infrastructure areas each year starting with the end of commercial production.

3.2 Seepage/Runoff Water Quality

Seepage/runoff water quality monitoring is proposed at the following SNP locations:

| SNP Site # | Description |
|---|---|
| 1645-45 | Collection Pond 10 |
| 1645-46 | Collection Pond 11 |
| 1645-47 | Collection Pond 12 |
| 1645-33 | Groundwater nearest to Bulk Fuel Storage |
| 1645-81 | Surface Runoff during freshet |

Seepage or runoff quality is sampled at a weekly frequency if sufficient volumes are identified during the weekly geotechnical inspections. Water samples will be analyzed for the following (source W2015L2-0001 – SNP 1645-81):

| | |
|---|---|
| Sampling Parameters: | Total Ammonia, Field Parameters[3], ICP-MS Metal Scan[1](Total), Major Ions[2], pH[4], Total Petroleum Hydrocarbons |

SNP 1645-45,45 and 1645-47 are currently located within the collection ponds. Once collection ponds are breached, DDMI proposes to relocate these stations to the outlet channel.

Additionally if the estimated flow volume is greater than 10 L/s once the collection ponds are breached then a sample will also be collected quarterly and assessed for acute lethality to rainbow trout, *Oncorhynchus mykiss* as per Environment Canada's Environmental Protection Series Biological Test Method EPS/1/RM/13.

3.3 Wildlife

DDMI will employ existing monitoring procedures (as updated from time-to-time) to record wildlife use of the NCRP and observations of behavior when animals are present on the NCRP. These procedures include:

ENVR-031-0720 – Caribou Road Surveys

ENVR-517-0912 – Caribou Management/Observation
ENVR-531-0812 – Wildlife Monitoring

### 3.4 Dust

DDMI will use the existing Total Suspended Particulate (TSP) monitoring system and procedures (as updated from time-to-time) combined with visual observations to monitoring dust generated from the Infrastructure areas. This monitoring will begin at the end of commercial production.

### 3.5 Re-Vegetation

- Areas of re-vegetation would be assessed for overall health, including: cover, density, species identification and diversity, seed production, litter and evidence of wildlife grazing. Soils in re-vegetated areas would be sampled and analyzed for structure and texture, pH and organic matter. The need to obtain and analyze plants and soils for metal uptake levels will be evaluated based on risk.

- Additional re-vegetation monitoring items may include shoreline vegetation surveys around collection pond areas, PKC outlet, A154, A418, A21 and the North Inlet as well as documentation of areas of natural recovery, plant ingress/egress or identified invasive species.
- Re-vegetated areas will be inspected annually for two years following initial planting.

### 3.6 Environmental Effects Monitoring

DDMI implements two environmental effects monitoring programs:

- Aquatic Effects Monitoring Program (AEMP)
- Wildlife Effects Monitoring Program (WEMP)

These are defined programs, updated or revised as warranted, to monitor mine effects on the Lac de Gras aquatic ecosystem and wildlife within a defined study area. These programs are conducted annually with specific scopes varying from year to year. For example the AEMP has an expanded program every three years and a base program annually. Towards the end of commercial operations, DDMI expects to reduce the scope and/or frequency of these programs as the need to implement operational management responses declines. Near-Field AEMP sampling locations will be adjusted to target runoff/seepage and water quality through dike breaches rather than the NIWTP effluent discharge. The attached Figure VI-1 shows the proposed relocated near-field AEMP stations renamed near-field closure (NFC). After the end of commercial production DDMI will continue these monitoring programs to monitor responses to the cessation of mining operations. The frequency would be reduced to every three years.

## 4.0 Reporting

### 4.1 Reclamation Completion Reporting

Upon completion of construction activities at the end of each calendar year, DDMI and the Engineer of Record will prepare a Construction Record summary report. The report shall include:

- Daily construction reports;
- All testing records including a summary of all test sample locations and test results;
- Photographic documentation of construction works and any associated re-vegetation efforts;
- Summary of construction problems and resolutions; and

- Completed construction checklist.

Upon completion of the infrastructure closure, a single comprehensive Infrastructure Reclamation Completion Report will be prepared by the Construction Management team and Engineer of Record for submission to the WLWB as per Part K Item 5.

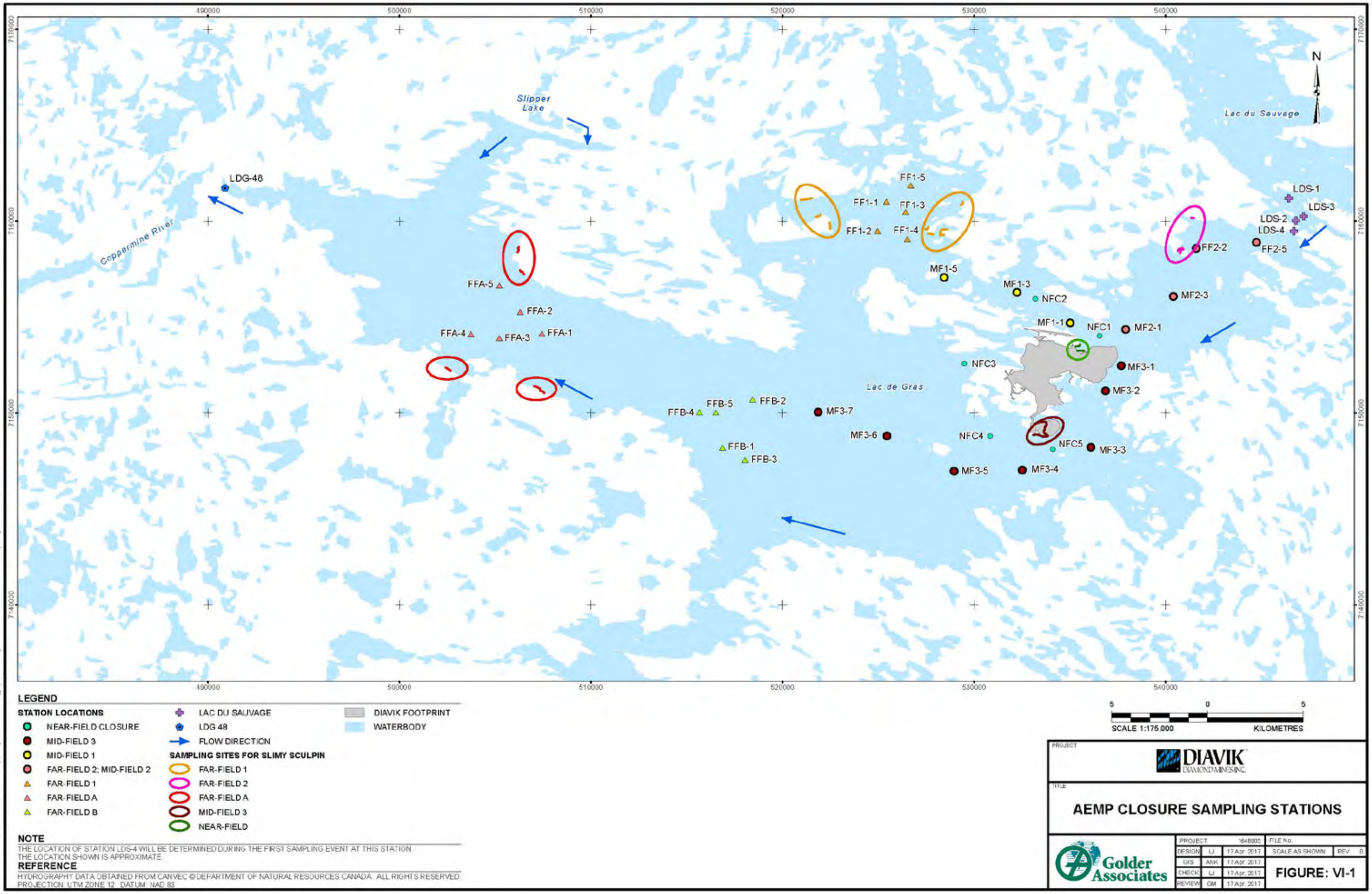
### 4.2 Performance Assessment Report.

Once sufficient information is available to evaluate the performance of the infrastructure area generally and Closure Objectives and Closure Criteria specifically, DDMI will submit a Performance Assessment Report to the WLWB for approval under Part K Item 6. The Report will be developed in accordance with the Mackenzie Valley Land and Water Board's *Guidelines for the Closure and Reclamation of Advanced Mineral Exploration and Mine Sites within the Northwest Territories*.

## 3.0 Monitoring and Reporting Schedule

The anticipated monitoring and reporting schedule for the Infrastructure and site wide effects monitoring is shown below. This schedule is subject to change based on actual construction timeline as well as results from inspections and monitoring programs. The number of years of post-construction monitoring required to adequately assess performance is unknown at this time and will depend upon the results obtained. The monitoring duration will be adaptively managed to be responsive to conditions as they are evaluated.

| Activity | 2017 | 2018 | 2019 | 2020 | 2021 | 2022 | 2023 | 2024 | 2025 | 2026 | 2027 | 2028 | 2029 | 2030 | 2031 | 2032 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Geotechnical inspections | | | | | | | | | ■ | ■ | ■ | ■ | ■ | ■ | ■ | ■ |
| Seepage/Run-off monitoring | | | | | | | | | ■ | ■ | ■ | ■ | ■ | ■ | ■ | ■ |
| Dust Monitoring | ■ | ■ | ■ | ■ | ■ | ■ | ■ | ■ | ■ | ■ | ■ | ■ | ■ | ■ | ■ | ■ |
| Wildlife Use Monitoring | | | | | | | | | ■ | ■ | ■ | ■ | ■ | ■ | ■ | ■ |
| Re-Vegetation Monitoring | | | | | | | | | | ■ | ■ | ■ | ■ | ■ | ■ | ■ |
| Aquatic Effects Monitoring | | | | | | | | | | ■ | | | ■ | | | ■ |
| Wildlife Effects Monitoring | | | | | | | | | | ■ | | | ■ | | | ■ |
| Annual CRP Progress Reporting | ■ | ■ | ■ | ■ | ■ | ■ | ■ | ■ | | | | | | | | |
| Reclamation Completion Report | | | | | | | | | | | | | | ■ | | |
| Performance Assessment Report | | | | | | | | | ■ | ■ | ■ | ■ | ■ | ■ | ■ | ■ |

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# APPENDIX VII

# EXPECTED COST OF CLOSURE AND RECLAMATION

VERSION 4.0 NOTES:

a) NCRP Reslope volumes updated from 1,501,500 $m^3$ to 1,532,500 $m^3$ based on final design.

b) NCRP unit cost for rock cover corrected to WLWB (2014) approved $4.20/$m^3$

c) PKC Cover unit costs for rock cover corrected to WLWB (2014) approved $6.50/$m^3$

d) Updated list and area of buidlings to CRP V4 Table 4-5.

e) Added excavation of 2 caribou ramps in A418 pit wall - shoreline

f) added re-vegetation cost estimate for infrastructure areas, roads-buildings

g) Added costs for cover in Type III rock in CLR (DDMI Letter Oct 16, 2016)

| Total | File Name | Description |
|---|---|---|
| $128,284,831 | WLWB RECLAIM Estimate for DDMI_August 2014.xlsm | WLWB Approved |
| $129,545,615 | WLWB RECLAIM Estimate for DDMI_August 2014 with A21.xlsm | WLWB Approved with addition of A21 open-pit |
| $124,072,323 | DDMI RECLAIM Estimate 2016 V1.xlms | DDMI Proposed:<br>a) NCRP till and rock volumes updated as per Golder (2016) Table 3<br>b) NCRP unit cost for rock cover set to GNWT recommended $3.30 (Letter to WLWB Feb 17, 2016)<br>c) PKC Cover reduced by $1.10 to align with reduced remine unit costs from GNWT (see NCRP)<br>d) updated A21 - one breach volume corrected to be a causeway excavation<br>e) There has been a net removal of buildings since 2011 that has not been credited in this version<br>f) NCRP Contingency to 10% to refelect level of engineerng detail (AANDC Letter to WLWB Oct 23, 2012) |
| $123,122,334 | DDMI RECLAIM Estimate 2017 V1.xlms | DDMI Proposed:<br>a) NCRP Reslope volumes updated from 1,501,500 $m^3$ to 1,532,500 $m^3$ based on final design.<br>b) NCRP unit cost for rock cover corrected to WLWB (2014) approved $4.20/$m^3$<br>c) PKC Cover unit costs for rock cover corrected to WLWB (2014) approved $6.50/$m^3$<br>d) Updated list and area of buidlings to CRP V4 Table 4-5.<br>e) Added excavation of 2 caribou ramps in A418 pit wall - shoreline<br>f) added revegetation cost estimate for infrastructure areas, roads-buildings<br>g) Added costs for cover in Type III rock in CLR (DDMI Letter Oct 16, 2016) |

## SUMMARY OF COSTS

| CAPITAL COSTS | COMPONENT NAME | COST | LAND LIABILITY | WATER LIABILITY |
|---|---|---|---|---|
| OPEN PIT | A514,A418, A21 | $2,851,117 | $97,322 | $2,753,795 |
| UNDERGROUND MINE | | $1,402,419 | $1,365,476 | $36,943 |
| TAILINGS FACILITY | | $25,177,261 | $43,969 | $25,133,292 |
| ROCK PILE | NCRP | $29,643,490 | $832,303 | $28,811,188 |
| BUILDINGS AND EQUIPMENT | | $8,567,896 | $7,479,566 | $1,088,330 |
| CHEMICALS AND CONTAMINATED SOIL MANAGEMEI | | $3,557,553 | $1,758,777 | $1,798,777 |
| SURFACE AND GROUNDWATER MANAGEMENT | | $1,280,539 | - | $1,280,539 |
| INTERIM CARE AND MAINTENANCE | | $0 | - | $0 |
| | **SUBTOTAL: Capital Costs** | **$72,480,275** | **$11,577,411** | **$60,902,863** |
| | **PERCENT OF SUBTOTAL** | | **16%** | **84%** |

| INDIRECT COSTS | | COST | LAND LIABILITY | WATER LIABILITY |
|---|---|---|---|---|
| MOBILIZATION/DEMOBILIZATION | | $9,111,200 | $1,455,349 | $7,655,851 |
| POST-CLOSURE MONITORING AND MAINTENANCE | | $19,508,597 | $3,116,145 | $16,392,452 |
| ENGINEERING | 5% | $3,624,014 | $578,871 | $3,045,143 |
| PROJECT MANAGEMENT | 5% | $3,624,014 | $578,871 | $3,045,143 |
| HEALTH AND SAFETY PLANS/MONITORING & QA/QC | 0.5% | $362,401 | $57,887 | $304,514 |
| BONDING/INSURANCE | 0.5% | $362,401 | $57,887 | $304,514 |
| CONTINGENCY | | | | |
| - Open Pit | 20% | $570,223.37 | $91,083 | $479,141 |
| - Underground Mine | 20% | $280,483.82 | $44,802 | $235,682 |
| - Tailings | 30% | $7,553,178.19 | $1,206,483 | $6,346,695 |
| - Rock Pile | 10% | $2,964,349.00 | $473,501 | $2,490,848 |
| - Buildings and Equipment | 20% | $1,713,579 | $273,713 | $1,439,866 |
| - Chemicals and Soil Management | 20% | $711,510.60 | $113,651 | $597,860 |
| - Water Management | 20% | $256,107.80 | $40,909 | $215,199 |
| MARKET PRICE FACTOR ADJUSTMENT | 0% | $0 | $0 | $0 |
| | **SUBTOTAL: Indirect Costs** | **$50,642,059** | **$8,089,152** | **$42,552,907** |

| | | | |
|---|---|---|---|
| **TOTAL COSTS** | **$123,122,334** | **$19,666,563** | **$103,455,770** |

Complete document can be found at:

**Open Pit Name:** **A514,A418, A21** **Pit # 1**

| ACTIVITY/MATERIAL | Notes | Units | Quantity | Cost Code | Unit Cost | Cost | % Land | Land Cost | Water Cost |
|---|---|---|---|---|---|---|---|---|---|
| CONTROL ACCESS | | | | | | | | | |
| Fence | | m | 450 | FNCH | $203.00 | $91,350 | 100% | $91,350 | $0 |
| Signs | | each | 4.5 | #N/A | $37.08 | $167 | 100% | $167 | $0 |
| Ditch, mat'l A | | m3 | | #N/A | $0.00 | $0 | | $0 | $0 |
| , mat'l B | | m3 | | #N/A | $0.00 | $0 | | $0 | $0 |
| Berm | | m3 | | #N/A | $0.00 | $0 | | $0 | $0 |
| Block roads | | m3 | 1350 | SB1L | $4.30 | $5,805 | 100% | $5,805 | $0 |
| Other | | | | #N/A | $0.00 | $0 | | $0 | $0 |
| STABILITY STUDY | | | | | | | | | |
| Conduct stability and setback study | | allow | | #N/A | $0.00 | $0 | | $0 | $0 |
| STABILIZE SLOPES | | | | | | | | | |
| A154 | | | | | | | | | |
| excavate 4 breaches in dike | | m3 | 48114 | SC1H | $9.30 | $447,460 | | $0 | $447,460 |
| break concrete guides & wall | | m3 | 1288 | SC1H | $9.30 | $11,978 | | $0 | $11,978 |
| construct fish habitat | | m3 | | #N/A | $0.00 | $0 | | $0 | $0 |
| A418 | | | | | | | | | |
| excavate 3 breaches in dike | | m3 | 36086 | SC1H | $9.30 | $335,600 | | $0 | $335,600 |
| break concrete guides & wall | | m3 | 1288 | SC1H | $9.30 | $11,978 | | $0 | $11,978 |
| construct fish habitat | | m3 | | #N/A | $0.00 | $0 | | $0 | $0 |
| excavate 2 shoreline caribou ramps | | m3 | 1500 | RC1H | $17.05 | $25,575 | | $0 | $25,575 |
| A21 | | | | | | | | | |
| excavate 3 breaches in dike and 1 causeway | | m3 | 51086 | SC1H | $9.30 | $475,100 | | $0 | $475,100 |
| break concrete guides & wall | | m3 | 1288 | SC1H | $9.30 | $11,978 | | $0 | $11,978 |
| construct fish habitat | | | | #N/A | $0.00 | $0 | | $0 | $0 |
| COVER/CONTOUR SLOPES | | | | | | | | | |
| Place fill, mat'l A | | m3 | | #N/A | $0.00 | $0 | | $0 | $0 |
| Place fill, mat'l B | | m3 | | #N/A | $0.00 | $0 | | $0 | $0 |
| Rip rap | | m3 | | #N/A | $0.00 | $0 | | $0 | $0 |
| Vegetate slopes | | ha | | #N/A | $0.00 | $0 | | $0 | $0 |
| Vegetate pit floor | | ha | | #N/A | $0.00 | $0 | | $0 | $0 |
| Other | | | | #N/A | $0.00 | $0 | | $0 | $0 |
| CONSTRUCT DIVERSION DITCHES | | | | | | | | | |
| Excavate ditches -soil | | m3 | | #N/A | $0.00 | $0 | | $0 | $0 |
| Excavate ditches -rock | | m3 | | #N/A | $0.00 | $0 | | $0 | $0 |
| Rip rap in channel base | | m3 | | #N/A | $0.00 | $0 | | $0 | $0 |
| CONSTRUCT SPILLWAY | | | | | | | | | |
| Excavate channel | | m3 | | #N/A | $0.00 | $0 | | $0 | $0 |
| Concrete | | m3 | | #N/A | $0.00 | $0 | | $0 | $0 |
| Rip rap | | m3 | | #N/A | $0.00 | $0 | | $0 | $0 |
| Other | | | | #N/A | $0.00 | $0 | | $0 | $0 |
| RECLAIM QUARRIES | | | | | | | | | |
| Contour slopes | | m3 | | #N/A | $0.00 | $0 | | $0 | $0 |
| Place overburden | | m3 | | #N/A | $0.00 | $0 | | $0 | $0 |
| Vegetate | | m3 | | #N/A | $0.00 | $0 | | $0 | $0 |
| FLOOD PIT-Captital | | | | | | | | | |
| Remove stationary equipment (sump pumps) | | each | 4 | #N/A | $5,618.00 | $22,472 | | $0 | $22,472 |
| Remove dewatering pipeline | | m | 14385 | PSRL | $1.00 | $14,385 | | $0 | $14,385 |
| Remove power lines | | m | 8328 | POWRL | $25.50 | $212,364 | | $0 | $212,364 |
| Construct diversion ditches | | m3 | | #N/A | $0.00 | $0 | | $0 | $0 |
| -Ditch, mat'l A | | m3 | | #N/A | $0.00 | $0 | | $0 | $0 |
| -Ditch, mat'l B | | m3 | | #N/A | $0.00 | $0 | | $0 | $0 |
| Construct embankment/dam | | m3 | | #N/A | $0.00 | $0 | | $0 | $0 |
| siphon installation/operation | | each | 9 | #N/A | $119,925.00 | $1,079,325 | | $0 | $1,079,325 |
| silt curtains | | each | 9 | #N/A | $11,731.00 | $105,579 | | $0 | $105,579 |
| Remove pump post-closure | | each | | #N/A | $0.00 | $0 | | $0 | $0 |
| Remove pipeline post-closure | | m | | #N/A | $0.00 | $0 | | $0 | $0 |
| FLOOD PIT-Annual Cost | | | | | | | | | |
| Operate pumps (power) | | m3 | | #N/A | $0.00 | $0 | | $0 | $0 |
| Maintain pump/pipeline | | allow | | #N/A | $0.00 | $0 | | $0 | $0 |
| Labour:fuel management, comissioning/decom | | $/h | | #N/A | $0.00 | $0 | | $0 | $0 |
| Chemical addition, _____ kg/m3 of water | | tonne | | #N/A | $0.00 | $0 | | $0 | $0 |
| Chemicals, purchase and shipping | | tonne | | #N/A | $0.00 | $0 | | $0 | $0 |
| Passive/biological additives | | $/ha | | #N/A | $0.00 | $0 | | $0 | $0 |
| Passive additives purchase and shipping | | tonne | | #N/A | $0.00 | $0 | | $0 | $0 |
| Other | | | | #N/A | $0.00 | $0 | | $0 | $0 |
| | | | | | Annual pumping costs | $0 | | | |
| Number of years of pump flooding | | years | | | | | | | |
| | | | | | Total pumping costs | $0 | | $0 | $0 |
| | | | | | **Total** | $2,851,117 | | $97,322 | $2,753,795 |
| | | | | | **% of Total** | | | 3% | 97% |

1 **Underground Mine Name** **UG Mine #** ***1***

| ACTIVITY/MATERIAL | Notes | Unit | Qty | Code | Unit Cost | Cost | Land | Land Cost | Cost |
|---|---|---|---|---|---|---|---|---|---|
| CONTROL ACCESS | | | | | | | | | |
| Fence | | m | 100 | FNCH | $203.00 | $20,300 | 100% | $20,300 | $0 |
| Signs | | each | 4 | #N/A | $37.08 | $148 | 100% | $148 | $0 |
| Block roads | | m3 | | #N/A | $0.00 | $0 | | $0 | $0 |
| Berm | | m3 | 300 | SB1L | $4.30 | $1,290 | 100% | $1,290 | $0 |
| Block adits | | m3 | 320 | CLFH | $530.25 | $169,680 | 100% | $169,680 | $0 |
| Cap shaft | | m3 | | #N/A | $0.00 | $0 | | $0 | $0 |
| Cap raises at A154/A418 | | m3 | 72 | SRL | $645.00 | $46,440 | 100% | $46,440 | $0 |
| Soil cover on raise caps | | m3 | 708 | SB1L | $4.30 | $3,044 | 100% | $3,044 | $0 |
| Cap raise at A21 | | m3 | | #N/A | $0.00 | $0 | | $0 | $0 |
| Soil cover on raise cap | | m3 | | #N/A | $0.00 | $0 | | $0 | $0 |
| Backfill adit A154 | | m3 | 100 | SCSS | $18.80 | $1,880 | 100% | $1,880 | $0 |
| Contour portal area, A154 | | m3 | 2,500 | SB1L | $4.30 | $10,750 | 100% | $10,750 | $0 |
| Backfill adit A21 | | m3 | | #N/A | $0.00 | $0 | | $0 | $0 |
| Contour portal area, A21 | | m3 | | #N/A | $0.00 | $0 | | $0 | $0 |
| Concrete bulkhead, pit portal, A154 | | allow | 1 | #N/A | $75,000.00 | $75,000 | 100% | $75,000 | $0 |
| Concrete bulkhead, pit portal, A21 | | allow | 0 | #N/A | $75,000.00 | $0 | | $0 | $0 |
| Backfill open stopes | | m3 | | #N/A | $0.00 | $0 | | $0 | $0 |
| Remove decline surface infrastructure | | allow | 1 | #N/A | $1,000,000.00 | $1,000,000 | 100% | $1,000,000 | $0 |
| REMOVE HAZARDOUS MATERIALS | | | | | | | | | |
| Remove hazardous materials, U/G labor | | manhours | 1,440 | lab-usH | $43.98 | $63,331 | 50% | $31,666 | $31,666 |
| Remove/decontam. stationary & elect. equip | | manhours | 240 | lab-usH | $43.98 | $10,555 | 50% | $5,278 | $5,278 |
| Remove/decontam. mobile equipment | | each | | #N/A | $0.00 | $0 | | $0 | $0 |
| Remove misc. haz. mat & explosives | | kg | | #N/A | $0.00 | $0 | | $0 | $0 |
| Other | | | | #N/A | $0.00 | $0 | | $0 | $0 |
| INSTALL BULKHEADS | | | | | | | | | |
| Bulkheads to control water flow | | each | | #N/A | $0.00 | $0 | | $0 | $0 |
| Grout bulkhead | | m3 | | #N/A | $0.00 | $0 | | $0 | $0 |
| FLOOD MINE | | | | | | | | | |
| Supply/install pump | | each | | #N/A | $0.00 | $0 | | $0 | $0 |
| Supply/install piping system | | each | | #N/A | $0.00 | $0 | | $0 | $0 |
| Operate pumps to flood workings | | m3 | | #N/A | $0.00 | $0 | | $0 | $0 |
| Other | | | | #N/A | $0.00 | $0 | | $0 | $0 |
| INSTALL GROUNDWATER COLLECTION SYSTEM | | | | | | | | | |
| Excavate/install sumps | | m2 | | #N/A | $0.00 | $0 | | $0 | $0 |
| Install pumping wells | | m3 | | #N/A | $0.00 | $0 | | $0 | $0 |
| Install pumps/pipelines/power supply | | LS | | #N/A | $0.00 | $0 | | $0 | $0 |
| SPECIALIZED ITEMS | | | | | | | | | |
| Install water quality monitoring pipes | | each | | #N/A | $0.00 | $0 | | $0 | $0 |
| Install permanent pumping system | | each | | #N/A | $0.00 | $0 | | $0 | $0 |
| Other | | | | #N/A | $0.00 | $0 | | $0 | $0 |
| | | | | | **Total** | $1,402,419 | | $1,365,476 | $36,943 |
| | | | | | **% of Total** | | | 97% | 3% |

1 **Tailings Impoundment Name:** **Pond # 1**

| ACTIVITY/MATERIAL | Notes | Units | Quantity | Cost Code | Unit Cost | Cost | % Land | Land Cost | Water Cost | |
|---|---|---|---|---|---|---|---|---|---|---|
| CONTROL ACCESS | | | | | | | | | | |
| Fence | | m | 160 | FNCH | ###### | $32,480 | 100% | $32,480 | $0 | |
| Signs | | each | 8 | #N/A | $37.08 | $297 | 100% | $297 | $0 | |
| Berm | | m3 | | #N/A | $0.00 | $0 | | $0 | $0 | |
| Block roads | | m3 | 1440 | SB1L | $4.30 | $6,192 | 100% | $6,192 | $0 | |
| Other | | | | #N/A | $0.00 | $0 | | $0 | $0 | |
| STABILIZE EMBANKMENT(S) | | | | | | | | | | |
| Toe buttress, drainage layer | | m3 | | #N/A | $0.00 | $0 | | $0 | $0 | |
| Toe buttress, bulk fill | | m3 | | #N/A | $0.00 | $0 | | $0 | $0 | |
| Rip rap | | m3 | | #N/A | $0.00 | $0 | | $0 | $0 | |
| Vegetate | | ha | | #N/A | $0.00 | $0 | | $0 | $0 | |
| Raise crest | | m3 | | #N/A | $0.00 | $0 | | $0 | $0 | |
| Flatten slopes | | m3 | | #N/A | $0.00 | $0 | | $0 | $0 | |
| Other | | | | #N/A | $0.00 | $0 | | $0 | $0 | |
| COVER TAILINGS | | | | | | | | | | |
| Coarse PK, doze to slurry sump | | m3 | | #N/A | $0.00 | $0 | | $0 | $0 | |
| Coarse PK, slurry pumping | | m3 | | #N/A | $0.00 | $0 | | $0 | $0 | |
| Rock for expelled water from N or S dump | | m2 | | #N/A | $0.00 | $0 | | $0 | $0 | |
| Rock for expelled water from roads | | m2 | | #N/A | $0.00 | $0 | | $0 | $0 | |
| Rock for expelled water from new quarry | | m2 | | #N/A | $0.00 | $0 | | $0 | $0 | |
| Soil cover, till | | m3 | | #N/A | $0.00 | $0 | | $0 | $0 | |
| Cover rock from N or S dump | | m3 | 2800000 | SBSH | $6.50 | $18,200,000 | | $0 | $18,200,000 | Note #1 |
| geotextile/geogrid over shoreline | | m2 | 592000 | GSTS | $9.37 | $5,547,040 | | $0 | $5,547,040 | |
| Cover rock from new quarry | | m3 | | #N/A | $0.00 | $0 | | $0 | $0 | |
| Remove & treat pond/seepage | | m3 | 1791000 | OTPL | $0.35 | $626,850 | | $0 | $626,850 | |
| STABILIZE DECANT SYSTEM | | | | | | | | | | |
| Excavate and replace | | m3 | | #N/A | $0.00 | $0 | | $0 | $0 | |
| Plug/backfill with concrete or clay | | m3 | | #N/A | $0.00 | $0 | | $0 | $0 | |
| Other | | | | #N/A | $0.00 | $0 | | $0 | $0 | |
| REMOVE TAILINGS DISCHARGE | | | | | | | | | | |
| Cyclones | | allow | | #N/A | $0.00 | $0 | | $0 | $0 | |
| Pipe | | m | 5000 | PSRL | $1.00 | $5,000 | 100% | $5,000 | $0 | |
| Remove reclaim barge | | allow | | #N/A | $0.00 | $0 | | $0 | $0 | |
| CONSTRUCT DIVERSION DITCHES | | | | | | | | | | |
| Excavate ditches -soil | | m3 | | #N/A | $0.00 | $0 | | $0 | $0 | |
| Excavate ditches -rock | | m3 | | #N/A | $0.00 | $0 | | $0 | $0 | |
| Rip rap in channel base | | m3 | | #N/A | $0.00 | $0 | | $0 | $0 | |
| FLOOD TAILINGS | | | | | | | | | | |
| Doze tailings to final contour | | m3 | | #N/A | $0.00 | $0 | | $0 | $0 | |
| Raise crest of dam | | m3 | | #N/A | $0.00 | $0 | | $0 | $0 | |
| Other | | | | #N/A | $0.00 | $0 | | $0 | $0 | |
| UPGRADE SPILLWAY | | | | | | | | | | |
| Excavate channel, dam | | m3 | 3240 | SC1L | $6.80 | $22,032 | | $0 | $22,032 | |
| Excavate channel, tailings | hydraulic mining of tailings | m3 | 136500 | SCSH | $5.00 | $682,500 | | $0 | $682,500 | |
| Concrete | | m3 | | #N/A | $0.00 | $0 | | $0 | $0 | |
| Rip rap channel to Lac de Gras | | m3 | 6500 | RR3L | $7.00 | $45,500 | | $0 | $45,500 | |
| Geotextile channel to Lac de Gras | | m2 | 1000 | GSTS | $9.37 | $9,370 | | $0 | $9,370 | |
| CONSTRUCT SEEPAGE COLLECTION POND | | | | | | | | | | |
| Excavate seepage collection pond | | m3 | | #N/A | $0.00 | $0 | | $0 | $0 | |
| Doze & spread excavated material | | m3 | | #N/A | $0.00 | $0 | | $0 | $0 | |
| Vegetate spread material | | ha | | #N/A | $0.00 | $0 | | $0 | $0 | |
| Bedding layer | | m3 | | #N/A | $0.00 | $0 | | $0 | $0 | |
| Supply geomembrane | | m2 | | #N/A | $0.00 | $0 | | $0 | $0 | |
| Install geomembrane | | m2 | | #N/A | $0.00 | $0 | | $0 | $0 | |
| Erosion protection layer | | m3 | | #N/A | $0.00 | $0 | | $0 | $0 | |
| INSTALL GROUNDWATER COLLECTION SYSTEM | | | | | | | | | | |
| Excavate/install sumps | | m3 | | #N/A | $0.00 | $0 | | $0 | $0 | |
| Install pumping wells | | m3 | | #N/A | $0.00 | $0 | | $0 | $0 | |
| Install pumps/pipelines/power supply | | LS | | #N/A | $0.00 | $0 | | $0 | $0 | |
| SPECIALIZED ITEMS | | | | | | | | | | |
| Install permanent instrumentation, supply & technican | | each | | #N/A | $0.00 | $0 | | $0 | $0 | |
| Install permanent instrumentation, drilling | | each | | #N/A | $0.00 | $0 | | | $0 | |
| TREAT SEEPAGE - see "Water Management" and "Water Treatment" | | | | | | | | | | |
| TREAT SUPERNATANT | | | | | | | | | | |
| Pump water (to pit, U/G) | | m3 | | #N/A | $0.00 | $0 | | $0 | $0 | |
| Equipment maintenance and parts | | allow | | #N/A | $0.00 | $0 | | $0 | $0 | |
| Supply reagents | | tonne | | #N/A | $0.00 | $0 | | $0 | $0 | |
| | | | Annual treatment costs | | | $0 | | | | |
| Number of years of treatment | | years | | | | | | | | |
| | | | Total treatment costs | | | $0 | | | $0 | |
| | | | | | **Total** | $25,177,261 | | $43,969 | $25,133,292 | |
| | | | | | **% of Total** | | | 0% | 100% | |

* for construction of passive treatment system refer to "Water Management"

Note #1 Unit rate corrected to WLWB (2014) approved rate.

1 **Rock Pile Name:** **NCRP**

| **ACTIVITY/MATERIAL** | **Notes** | **Units** | **Quantity** | **Cost Code** | **Unit Cost** | **Cost** | **% Land** | **Land Cost** | **Water Cost** | |
|---|---|---|---|---|---|---|---|---|---|---|
| STABILIZE SLOPES | | | | | | | | | | |
| Flatten slopes with dozer, rock pile, north | | m3 | 1532500 | DSL | $0.95 | $1,455,875 | 50% | $727,938 | $727,938 | Note #2 |
| Flatten slopes - Type III in CLR Basin | | m3 | 151000 | DSL | $0.95 | $143,450 | 50% | $71,725 | $71,725 | Oct 13, 2016 letter t o WLWB |
| Flatten slopes with dozer, till pile | | m3 | | #N/A | $0.00 | $0 | | $0 | $0 | |
| Flatten slope with dozer, till pile, south | | m3 | | #N/A | $0.00 | $0 | | $0 | $0 | |
| Divert runon, ditch mat'l B | | m3 | | #N/A | $0.00 | $0 | | $0 | $0 | |
| Toe buttress, drain mat'l | | m3 | | #N/A | $0.00 | $0 | | $0 | $0 | |
| Toe buttress, fill mat'l A | | m3 | | #N/A | $0.00 | $0 | | $0 | $0 | |
| Toe buttress, fill mat'l B | | m3 | | #N/A | $0.00 | $0 | | $0 | $0 | |
| Other | | | | #N/A | $0.00 | $0 | | $0 | $0 | |
| COVER ROCK PILE | | | | | | | | | | |
| Till on Type III rock areas | | m3 | 2,000,000 | SB3L | $5.10 | $10,200,000 | | $0 | $10,200,000 | Note #1 |
| Type I rock cover | | m3 | 3,980,000 | SB3S | $4.20 | $16,716,000 | | $0 | $16,716,000 | |
| Till on Type III in CLR Basin | | m3 | 81,150 | SB3L | $5.10 | $413,865 | | $0 | $413,865 | Oct 13, 2016 letter t o WLWB |
| Type I rock on Type III in CLR Basin | | m3 | 162,300 | SB3S | $4.20 | $681,660 | | $0 | $681,660 | Oct 13, 2016 letter t o WLWB |
| till on caribou ramps | | m3 | 6400 | SB3L | $5.10 | $32,640 | 100% | $32,640 | $0 | |
| rock cover from roads etc. | | m3 | | #N/A | $0.00 | $0 | | $0 | $0 | |
| Rip rap drainage channel and chute | | m3 | | #N/A | $0.00 | $0 | | $0 | $0 | |
| Vegetate | | ha | 5,980,000 | #N/A | $0.00 | $0 | | $0 | $0 | |
| Other | | | | #N/A | $0.00 | $0 | | $0 | $0 | |
| VERY LOW PERMEABILITY COVER (in addition to above) | | | | | | | | | | |
| Liner subgrade preparation - compact | | m2 | | #N/A | $0.00 | $0 | | $0 | $0 | |
| Supply geomembrame | | m2 | | #N/A | $0.00 | $0 | | $0 | $0 | |
| Install geomembrane | | m2 | | #N/A | $0.00 | $0 | | $0 | $0 | |
| Protective cover - excavate,haul,spread&compact | | m3 | | #N/A | $0.00 | $0 | | $0 | $0 | |
| Vegetate | | ha | | #N/A | $0.00 | $0 | | $0 | $0 | |
| Install infiltration/seepage instrumentation | | allow | | #N/A | $0.00 | $0 | | $0 | $0 | |
| CONSTRUCT DIVERSION DITCHES | | | | | | | | | | |
| Excavate ditches -soil | | m3 | | #N/A | $0.00 | $0 | | $0 | $0 | |
| Excavate ditches -rock | | m3 | | #N/A | $0.00 | $0 | | $0 | $0 | |
| Rip rap in channel base | | m3 | | #N/A | $0.00 | $0 | | $0 | $0 | |
| CONSTRUCT SEEPAGE COLLECTION POND | | | | | | | | | | |
| Excavate seepage collection pond | | m3 | | #N/A | $0.00 | $0 | | $0 | $0 | |
| Doze & spread excavated material | | m3 | | #N/A | $0.00 | $0 | | $0 | $0 | |
| Vegetate spread material | | ha | | #N/A | $0.00 | $0 | | $0 | $0 | |
| Bedding layer | | m3 | | #N/A | $0.00 | $0 | | $0 | $0 | |
| Supply geomembrane | | m2 | | #N/A | $0.00 | $0 | | $0 | $0 | |
| Install geomembrane | | m2 | | #N/A | $0.00 | $0 | | $0 | $0 | |
| Erosion protection layer | | m3 | | #N/A | $0.00 | $0 | | $0 | $0 | |
| INSTALL GROUNDWATER COLLECTION SYSTEM | | | | | | | | | | |
| Excavate/install sumps | | m3 | | #N/A | $0.00 | $0 | | $0 | $0 | |
| Install pumping wells | | m3 | | #N/A | $0.00 | $0 | | $0 | $0 | |
| Install pumps/pipelines/power supply | | allow | | #N/A | $0.00 | $0 | | $0 | $0 | |
| RELOCATE DUMPS | | | | | | | | | | |
| Load, haul, dump or doze | | m3 | | #N/A | $0.00 | $0 | | $0 | $0 | |
| Add lime | | tonne | | #N/A | $0.00 | $0 | | $0 | $0 | |
| Contour reclaimed area | | ha | | #N/A | $0.00 | $0 | | $0 | $0 | |
| Other | | | | #N/A | $0.00 | $0 | | $0 | $0 | |
| SPECIALIZED ITEMS | | | | | | | | | | |
| Install permanent instrumentation | | each | | #N/A | $0.00 | $0 | | $0 | $0 | |
| Install permanent instrumentation, drilling | | each | | #N/A | $0.00 | $0 | | $0 | $0 | |
| TREAT ROCK PILE SEEPAGE - see "Water Treatment" | | | | | | | | | | |
| collect and treat seepage | | m3 | 848206 | OTPL | $0.35 | $296,872 | | $0 | $296,872 | |
| HEAP LEACH SEEPAGE TREATMENT - Cyanide Detox | | | | | | | | | | |
| Cyanide destruction water treatment pumping | | m3 | | #N/A | $0.00 | $0 | | $0 | $0 | |
| Reagents | | tonnes | | #N/A | $0.00 | $0 | | $0 | $0 | |
| Electrician/mechanic to maintain treatment plant | | allow | | #N/A | $0.00 | $0 | | $0 | $0 | |
| Equipment maintenance and parts | | allow | | #N/A | $0.00 | $0 | | $0 | $0 | |
| | | | | Annual treatment costs | | $0 | | | | |
| Number of years of treatment | | years | | | | | | | | |
| | | | | Total treatment costs | | $0 | | | $0 | |
| HEAP LEACH SEEPAGE TREATMENT - ARD/ML** | | | | | | | | | | |
| Upgrade/modify pumping system - report to WTP | | allow | | #N/A | $0.00 | $0 | | | $0 | |
| | | | | | **Total** | $29,643,490 | | $832,303 | $28,811,188 | |
| | | | | | **% of Total** | | | 3% | 97% | |

* For construction of passive treatment system refer to "Water Management". ARD/ML seepage treatment becomes post-closure water treatment cost

**Heap leach ARD/ML seepage treatment becomes post-closure water treatment cost

| | |
|---|---|
| Note #1 | Volumes Updated from Final Design (Golder 2016 Table 3) |
| | Unit cost corrected to WLWB (2014) approved |
| Note #2 | Volumes updated based on Final Design (Golder 2016) |

1 **Chemicals/Soil Area Name:**

**Note:** The procedures, equipment and packaging for clean up and removal of chemicals or contaminated soils are highly dependent on the nature of the chemicals and their existing state of containment. Government guidelines should be consulted on an individual chemical basis. Any estimate made here should be considered very rough unless specific evaluations have been conducted.

| ACTIVITY/MATERIAL | Notes | Units | Quantity | Cost Code | Unit Cost | Cost | % Land | Land Cost | Water Cost |
|---|---|---|---|---|---|---|---|---|---|
| HAZARDOUS MATERIALS INVENTORY | | | | | | | | | |
| Contaminated soil investigation ESA | | each | 1 | #N/A | $68,393.00 | $68,393 | 50% | $34,197 | $34,197 |
| Contaminated soil drilling and sampling | | each | 1 | #N/A | $277,143.00 | $277,143 | 50% | $138,572 | $138,572 |
| LABORATORY CHEMICALS | | | | | | | | | |
| load, manifest, ship & disposal fee | | pallet | 500 | #N/A | $1,000.00 | $500,000 | 50% | $250,000 | $250,000 |
| PCB hauling | | each | | #N/A | $0.00 | $0 | | $0 | $0 |
| PCB disposal | | each | | #N/A | $0.00 | $0 | | $0 | $0 |
| FUEL | | | | | | | | | |
| Tank decontamination | | allow | 1 | #N/A | $223,737.00 | $223,737 | 50% | $111,869 | $111,869 |
| Type 2 | | litre | | #N/A | $0.00 | $0 | | $0 | $0 |
| Type 3 | | litre | | #N/A | $0.00 | $0 | | $0 | $0 |
| WASTE OIL | | | | | | | | | |
| Oils/lubricants - burn on site | | litre | | #N/A | $0.00 | $0 | | $0 | $0 |
| Oils/lubricants - ship off-site | | litre | 650000 | ORH | $1.20 | $780,000 | 50% | $390,000 | $390,000 |
| Removal glycol | | litre | 20000 | ORH | $1.20 | $24,000 | 50% | $12,000 | $12,000 |
| remove batteries | | kg | 25000 | #N/A | $0.50 | $12,500 | 50% | $6,250 | $6,250 |
| remove paints | | litre | 1500 | #N/A | $0.27 | $405 | 50% | $203 | $203 |
| remove solvents | | litre | 7500 | #N/A | $0.75 | $5,625 | 50% | $2,813 | $2,813 |
| Oils/lubricants - disposal fee | | litre | | #N/A | $0.00 | $0 | | $0 | $0 |
| PROCESS OR TREATMENT CHEMICALS | | | | | | | | | |
| Sulfuric acid transfer to tanker | | litre | 80000 | PCRH | $2.50 | $200,000 | 50% | $100,000 | $100,000 |
| Haul to disposal facility | | loads | 2 | #N/A | $12,000.00 | $24,000 | 50% | $12,000 | $12,000 |
| Disposal fee | | litre | 80000 | #N/A | $1.00 | $80,000 | 50% | $40,000 | $40,000 |
| Type 4 | | kg | | #N/A | $0.00 | $0 | | $0 | $0 |
| EXPLOSIVES | | | | | | | | | |
| | | allow | 1 | #N/A | $10,000.00 | $10,000 | 50% | $5,000 | $5,000 |
| CONTAMINATED SOILS | | | | | | | | | |
| Type 1, light fuel | | m3 | 5000 | CSRH | $146.00 | $730,000 | 50% | $365,000 | $365,000 |
| Type 2, heavy fuel and oil | | m3 | 2500 | CSRH | $146.00 | $365,000 | 50% | $182,500 | $182,500 |
| Type 3, metals | | m3 | 250 | CSRL | $47.00 | $11,750 | 50% | $5,875 | $5,875 |
| HAZARDOUS MAT. TESTING AND ASSESSMENT | | | | | | | | | |
| Technician and analyses | | each | 1 | #N/A | $110,000.00 | $110,000 | 50% | $55,000 | $55,000 |
| Drilling | | each | 1 | #N/A | $75,000.00 | $75,000 | 50% | $37,500 | $37,500 |
| Reporting | | each | 1 | #N/A | $20,000.00 | $20,000 | 50% | $10,000 | $10,000 |
| OTHER | | | | | | | | | |
| Remove nuclear densometers from mill | | each | 10 | #N/A | $4,000.00 | $40,000 | | $0 | $40,000 |
| | | | | | **Total** | $3,557,553 | | $1,758,777 | $1,798,777 |
| | | | | | **% of Total** | | | 49% | 51% |

1 **Building / Equip Name:** **Bldg / Equip #: 1**

| ACTIVITY/MATERIAL | Notes | Units | Quantity | Cost Code | Unit Cost | Cost | % Land | Land Cost | Water Cost |
|---|---|---|---|---|---|---|---|---|---|
| DISPOSE MOBILE EQUIPMENT | | | | | | | | | |
| Decontaminate, ship off-site | | km | | #N/A | $0.00 | $0 | | $0 | $0 |
| Decontaminate, dispose on-site | | each | 5000 | lab-sH | $49.60 | $248,000 | | $0 | $248,000 |
| DISPOSE STATIONARY EQUIPMENT | | | | | | | | | |
| Decontaminate, ship off-site | | km | | #N/A | $0.00 | $0 | | $0 | $0 |
| Decontaminate, dispose on-site | | each | 5000 | lab-sH | $49.60 | $248,000 | | $0 | $248,000 |
| DISPOSE ORE CONCENTRATION EQUIPMENT | | | | | | | | | |
| Decontaminate crushing plant | | each | | #N/A | $0.00 | $0 | | $0 | $0 |
| Decontaminate tanks & plumbing | | each | | #N/A | $0.00 | $0 | | $0 | $0 |
| Remove tanks & plumbing | | each | | #N/A | $0.00 | $0 | | $0 | $0 |
| DISPOSE WATER TREATMENT EQUIPMENT | | | | | | | | | |
| Decontaminate tanks & plumb. | | each | | #N/A | $0.00 | $0 | | $0 | $0 |
| Remove tanks & plumbing | | each | | #N/A | $0.00 | $0 | | $0 | $0 |
| Other | | | | #N/A | $0.00 | $0 | | $0 | $0 |
| DECONTAMINATE BUILDINGS & TANKS | | | | | | | | | |
| site wide allowance | | each | 1 | #N/A | $75,000.00 | $75,000 | 50% | $37,500 | $37,500 |
| clean explosives facility | | each | 1 | #N/A | $50,000.00 | $50,000 | 50% | $25,000 | $25,000 |
| MOTHBALL BUILDINGS | | | | #N/A | $0.00 | $0 | | $0 | $0 |
| Building 1 | | m2 | | #N/A | $0.00 | $0 | | $0 | $0 |
| Building 2 | | m2 | | #N/A | $0.00 | $0 | | $0 | $0 |
| Building 3 | | m2 | | #N/A | $0.00 | $0 | | $0 | $0 |
| Building 4 | | m2 | | #N/A | $0.00 | $0 | | $0 | $0 |
| Building 5 | | m2 | | #N/A | $0.00 | $0 | | $0 | $0 |
| Other | | m2 | | #N/A | $0.00 | $0 | | $0 | $0 |
| REMOVE BUILDINGS - areas are increased to account for height of biuldings | | | | | | | | | |
| 1. Processing Plant | | m2 | 8,525 | BRS1H | $65.00 | $554,125 | 100% | $554,125 | $0 |
| 2. Accommodation Complex | | m2 | 17,285 | BRS1H | $65.00 | $1,123,525 | 100% | $1,123,525 | $0 |
| 3. Maintenance Complex | | m2 | 6,560 | BRS1H | $65.00 | $426,400 | 100% | $426,400 | $0 |
| 4. Backfill Plant | | m2 | 2,655 | BRS1H | $65.00 | $172,575 | 100% | $172,575 | $0 |
| 5. Power House 1 | | m2 | 2,050 | BRS1H | $65.00 | $133,250 | 100% | $133,250 | $0 |
| 6. Power House 2 | | m2 | 2,180 | BRS1H | $65.00 | $141,700 | 100% | $141,700 | $0 |
| 7. Boiler House | | m2 | 540 | BRS1H | $65.00 | $35,100 | 100% | $35,100 | $0 |
| 8. Crusher Building | | m2 | 800 | BRS1H | $65.00 | $52,000 | 100% | $52,000 | $0 |
| 9. Lube Oil Storage | | m2 | 864 | BRS1H | $65.00 | $56,160 | 100% | $56,160 | $0 |
| 10. Batch Plant | | m2 | 646 | BRS1H | $65.00 | $41,990 | 100% | $41,990 | $0 |
| 11. NIWTP Acid Storage | | m2 | 367 | BRS1H | $65.00 | $23,855 | 100% | $23,855 | $0 |
| 12. NIWTP | | m2 | 3,704 | BRS1H | $65.00 | $240,760 | 100% | $240,760 | $0 |
| 13. Tank Farm | | m2 | 8,167 | BRS1H | $65.00 | $530,855 | 100% | $530,855 | $0 |
| 14. SCAP Fab Shop | | m2 | 2,380 | BRS1H | $65.00 | $154,700 | 100% | $154,700 | $0 |
| 15. UG Dry | | m2 | 154 | BRS1H | $65.00 | $10,010 | 100% | $10,010 | $0 |
| 16. ERT Building | | m2 | 336 | BRS1H | $65.00 | $21,840 | 100% | $21,840 | $0 |
| 17. Sewage Treatment Plant | | m2 | 720 | BRS1H | $65.00 | $46,800 | 100% | $46,800 | $0 |
| 18. Emulsion Plant | | m2 | 920 | BRS1H | $65.00 | $59,800 | 100% | $59,800 | $0 |
| 19. Ammonium Nitrate Building | | m2 | 2,850 | BRS1H | $65.00 | $185,250 | 100% | $185,250 | $0 |
| 20. SCAP Warehouses | | m2 | 1,100 | BRS1H | $65.00 | $71,500 | 100% | $71,500 | $0 |
| 21. Potable Water Treatment | | m2 | 81 | BRS1H | $65.00 | $5,265 | 100% | $5,265 | $0 |
| 22. Raw Water Intake | | m2 | 490 | BRS1H | $65.00 | $31,850 | 100% | $31,850 | $0 |
| 23. A21 Offices | | m2 | 570 | BRS1H | $65.00 | $37,050 | 100% | $37,050 | $0 |
| 24. Airport | | m2 | 800 | BRS1H | $65.00 | $52,000 | 100% | $52,000 | $0 |
| 25. Old Site Services | | m2 | 720 | BRS1H | $65.00 | $46,800 | 100% | $46,800 | $0 |
| 26. Enviro Field Lab | | m2 | 200 | BRS1H | $65.00 | $13,000 | 100% | $13,000 | $0 |
| 27. North Inlet Water Intake | | m2 | 102 | BRS1H | $65.00 | $6,630 | 100% | $6,630 | $0 |
| 28. Mine Air Heaters | | m2 | 1,050 | BRS1H | $65.00 | $68,250 | 100% | $68,250 | $0 |
| 29. Windfarm | | m2 | 95 | BRS1H | $65.00 | $6,175 | 100% | $6,175 | $0 |
| 30. Incinerator | | m2 | 455 | BRS1H | $65.00 | $29,575 | 100% | $29,575 | $0 |
| 31. Communications | | m2 | 72 | BRS1H | $65.00 | $4,680 | 100% | $4,680 | $0 |
| 32. Core Storage Area | | m2 | 670 | BRS1H | $65.00 | $43,550 | 100% | $43,550 | $0 |
| BREAK BASEMENT SLABS | | | | | | | | | |
| Buildings - all | | m2 | 4500 | BRCL | $40.00 | $180,000 | 100% | $180,000 | $0 |
| Building 2 | | m2 | | #N/A | $0.00 | $0 | | $0 | $0 |
| Building 3 | | m2 | | #N/A | $0.00 | $0 | | $0 | $0 |
| Building 4 | | m2 | | #N/A | $0.00 | $0 | | $0 | $0 |
| Building 5 | | m2 | | #N/A | $0.00 | $0 | | $0 | $0 |
| Vegetate building footprint | | ha | 68 | VB | $13,000.00 | $885,404 | 100% | $885,404 | $0 |
| REMOVE BURIED TANKS | | | | | | | | | |
| Tank 1, decontaminate | | m3 | | #N/A | $0.00 | $0 | | $0 | $0 |
| , excavate & dispose | | m3 | | #N/A | $0.00 | $0 | | $0 | $0 |
| Tank 2, decontaminate | | m3 | | #N/A | $0.00 | $0 | | $0 | $0 |
| , excavate & dispose | | m3 | | #N/A | $0.00 | $0 | | $0 | $0 |
| Other | | | | #N/A | $0.00 | $0 | | $0 | $0 |
| LANDFILL FOR DEMOLITION WASTE | | | | | | | | | |
| Place rock cover | | m3 | 187500 | SB3S | $4.20 | $787,500 | 50% | $393,750 | $393,750 |
| Vegetate | | ha | | #N/A | $0.00 | $0 | | $0 | $0 |
| Landfill disposal fee | | tonne | | #N/A | $0.00 | $0 | | $0 | $0 |
| GRADE AND CONTOUR | | | | | | | | | |
| Grade mill area | | m2 | 30750 | SB3S | $4.20 | $129,150 | 50% | $64,575 | $64,575 |
| Place rock cover | | m3 | 34050 | SB3S | $4.20 | $143,010 | 50% | $71,505 | $71,505 |
| Rip rap on ditches | | m3 | | #N/A | $0.00 | $0 | | $0 | $0 |
| Vegetate | | ha | | #N/A | $0.00 | $0 | | $0 | $0 |
| Other | | | | #N/A | $0.00 | $0 | | $0 | $0 |
| RECLAIM ROADS | | | | | | | | | |
| Haul roads, A 154 & A418 lease | | ha | 3.71 | SCFYL | $4,300.00 | $15,953 | 100% | $15,953 | $0 |
| Service roads, A154 & A418 lease | | ha | 1.6 | SCFYL | $4,300.00 | $6,880 | 100% | $6,880 | $0 |
| Haul roads, A21 lease | | ha | 0 | SCFYL | $4,300.00 | $0 | 100% | $0 | $0 |
| Service roads, A21 lease | | ha | 1.65 | SCFYL | $4,300.00 | $7,095 | 100% | $7,095 | $0 |
| Haul roads, PKC & dumps lease | | ha | 10.13 | SCFYL | $4,300.00 | $43,559 | 100% | $43,559 | $0 |
| Service roads, PKC & dumps lease | | ha | 23.2 | SCFYL | $4,300.00 | $99,760 | 100% | $99,760 | $0 |
| Haul roads, infrastructure lease | | ha | 14.85 | SCFYL | $4,300.00 | $63,855 | 100% | $63,855 | $0 |
| Service roads, infrastructure lease | | ha | 5.4 | SCFYL | $4,300.00 | $23,220 | 100% | $23,220 | $0 |
| Haul roads, airstrip lease | | ha | 0 | SCFYL | $4,300.00 | $0 | 100% | $0 | $0 |
| Service roads, airstrip lease | | ha | 2.9 | SCFYL | $4,300.00 | $12,470 | 100% | $12,470 | $0 |
| Vegetate roads | | ha | 63 | VB | $13,000.00 | $824,720 | 100% | $824,720 | $0 |
| SPECIALIZED ITEMS | | | | | | | | | |
| Reclaim airstrip | | ha | 11 | SCFYL | $4,300.00 | $47,300 | 100% | $47,300 | $0 |
| Yellowknife landfill disposal fee | | allow | 1 | #N/A | $250,000.00 | $250,000 | 100% | $250,000 | $0 |
| | | | | | **Total** | $8,567,896 | | $7,479,566 | $1,088,330 |
| | | | | | **% of Total** | | | 87% | 13% |

1 **Capital Expenditures and Short Term Water Treatment identified in 'Instructions' worksheet**

| ACTIVITY/MATERIAL | Notes | Units | Quantity | Cost Code | Unit Cost | Cost |
|---|---|---|---|---|---|---|
| STABILIZE EMBANKMENT | | | | | | |
| Toe buttress, drain mat'l | | m3 | | #N/A | $0.00 | $0 |
| , fill mat'l A | | m3 | | #N/A | $0.00 | $0 |
| , fill mat'l B | | m3 | | #N/A | $0.00 | $0 |
| Rip rap | | m3 | | #N/A | $0.00 | $0 |
| Vegetate | | ha | | #N/A | $0.00 | $0 |
| Raise crest | | m3 | | #N/A | $0.00 | $0 |
| UPGRADE SPILLWAY IN NORTH INLET BERM | | | | | | |
| Excavate channel | | m3 | 680 | SC1L | $6.80 | $4,624 |
| Place rip rap | | m3 | 190 | RR3L | $7.00 | $1,330 |
| STABILIZE SEDIMENT CONTAINMENT PONDS | | | | | | |
| Place soil cover | | m3 | | #N/A | $0.00 | $0 |
| Place geotextile | | m2 | | #N/A | $0.00 | $0 |
| Vegetate | | ha | | #N/A | $0.00 | $0 |
| BREACH EMBANKMENT | | | | | | |
| Remove fill | | m3 | | #N/A | $0.00 | $0 |
| COLLECTION PONDS | | | | | | |
| Breach 4 dams | | m3 | 2200 | SB1L | $4.30 | $9,460 |
| place geotextile, 4 by 15,000 m2 | | m2 | 60000 | #N/A | $10.00 | $600,000 |
| place rock over geotextile | | m3 | 60000 | SBSH | $6.50 | $390,000 |
| BREACH DITCHES | | | | | | |
| Excavate | | m3 | 7875 | SB1L | $4.30 | $33,863 |
| Backfill/recontour | | m3 | 2625 | SC1H | $9.30 | $24,413 |
| Vegetate | | ha | | #N/A | $0.00 | $0 |
| REMOVE PIPELINES | | | | | | |
| Remove pipes | | m | | #N/A | $0.00 | $0 |
| Concrete plug deep pipes | | m3 | | #N/A | $0.00 | $0 |
| Install pumps/pipelines/power supply | | LS | | #N/A | $0.00 | $0 |
| NORTH INLET EAST DIKE | | | | | | |
| Excavate/construct spillway | | m3 | 4500 | SC1H | $9.30 | $41,850 |
| Excavate & backfill | | m3 | | #N/A | $0.00 | $0 |
| COLLECT DRAINAGE FOR TREATMENT | | | | | | |
| Excavate collection ditches | | m3 | | #N/A | $0.00 | $0 |
| Rip rap ditches | | m3 | | #N/A | $0.00 | $0 |
| Pipes | | m | | #N/A | $0.00 | $0 |
| Pumps | | each | | #N/A | $0.00 | $0 |
| Collect'n pond, exc. mat'l A | | m3 | | #N/A | $0.00 | $0 |
| , exc. mat'l B | | m3 | | #N/A | $0.00 | $0 |
| Collect'n pond, fill mat'l A | | m3 | | #N/A | $0.00 | $0 |
| , fill mat'l B | | m3 | | #N/A | $0.00 | $0 |
| Collect'n pond, liner | | m2 | | #N/A | $0.00 | $0 |
| COLLECT DRAINAGE FOR TREATMENT | | | | | | |
| Remove and treat north inlet water | | m3 | 500000 | OTPL | $0.35 | $175,000 |
| SHORT TERM WATER TREATMENT* | | | | | | |
| Annual water treatment cost, from "Water Treatment" | | | | | | $0 |
| | | | | | **Total** | $1,280,539 |

## 1 Post-Closure Monitoring & Maintenance:

| ACTIVITY/MATERIAL | Notes | Units | Quantity | Cost Code | Unit Cost | Cost |
|---|---|---|---|---|---|---|
| MONITORING & INSPECTIONS | | | | | | |
| Annual geotechnical inspection | | each | 7 | RPTH | $20,000.00 | $140,000 |
| Survey inspection | | each | 7 | #N/A | $50,000.00 | $350,000 |
| Performance monitoring (water, dust, wildlife, etc.) | | each | 10 | #N/A | $250,000.00 | $2,500,000 |
| Reporting | | each | 10 | #N/A | $100,000.00 | $1,000,000 |
| person, labour, equipment, logistics, etc | | each | 1 | #N/A | $6,237,680.00 | $6,237,680 |
| INTERIM CARE AND MAINTENANCE | | | | | | |
| annual C&M | | yrs | 3 | #N/A | $2,223,639.00 | $6,670,917 |
| fish consumption advisory signage | | allow | 1 | #N/A | $10,000 | $10,000 |
| POST-CLOSURE EFFECTS MONITORING AND COMMUNITY ENGAGEMNT | | | | | | |
| Aquatic Effects Monitoring and Reporting | | yrs | 3 | #N/A | $250,000 | $750,000 |
| Wildlife Effects Monitoring and Reporting | | yrs | 3 | #N/A | $50,000 | $150,000 |
| Traditional Knowledge Monitoring and Review (at site) | | yrs | 10 | #N/A | $120,000 | $1,200,000 |
| Environmental Monitoring Advisory Board | Unique to Diavik Environmental Agreemen | yrs | | #N/A | | $0 |
| Community Engagement (at communities) | | yrs | 10 | #N/A | $50,000 | $500,000 |
| Subtotal, Annual post-closure costs | | | | | | $19,508,597 |
| Discount rate for calculation of net present value of post-closure cost, % | | | | 0.00% | | |
| Number of years of post-closure activity | | | | | years | |
| **Present Value of payment stream** | | | | | | $19,508,597 |

*Regulatory costs - annual reporting, management plans, progress reports etc.
Include water treatment cost from "Water Treatment" worksheet if treatment is considered long term, such as ARD/ML.

ANNUAL INTERIM CARE & MAINTENANCE

| | | | | | |
|---|---|---|---|---|---|
| | No. | hrs/yea | Rate | Annual Cost | |
| Site supervisor | 1 | 3650 | $61.20 | $223,380 | |
| laborers | 3 | 3650 | $38.76 | $141,474 | |
| equipment operators | 2 | 3650 | $56.10 | $204,765 | |
| mechanic | 1 | 3650 | $61.20 | $223,380 | |
| electrician | 1 | 3650 | $70.00 | $255,500 | |
| envir. coodinator | 1 | 3650 | $61.20 | $223,380 | |
| | | | | $1,271,879 | total staff |
| Fuel, power & heat | L/hr | mon/yr | fuel | | |
| | 50 | 3 | 108000 | | |
| | 40 | 7 | 201600 | | |
| | 25 | 2 | 36000 | | |
| Fuel, mobile equipment | 15 | 12 | 129600 | | |
| | | | 475200 | total fuel | |
| air charter | flights/yr | | cost/flight | | |
| | 52 | | 4500 | 234000 | |
| camp costs | 108 | m-mont | 1320 | 142560 | |
| misc. supplies, allowance | | | | 50000 | |
| reagents | | | | 50000 | |
| | | Total annual C&M | | $2,223,639 | |

## 1 Mobilization/Demobilization:

| ACTIVITY/MATERIAL | Notes | Units | Quantity | Cost Code | Unit Cost | Cost | |
|---|---|---|---|---|---|---|---|
| MOBILIZE HEAVY EQUIPMENT | | | | | | | |
| Excavators -2 | | km | 4800 | MHERH | 10.25 | $49,200 | |
| Dump trucks - 15 | | km | 120000 | MHERH | 10.25 | $1,230,000 | |
| Dozers - 4 | | km | 16000 | MHERH | 10.25 | $164,000 | |
| Demolition shears - 2 | | km | 9600 | MHERH | 10.25 | $98,400 | |
| Crane - 2 | | km | 1600 | MHERH | 10.25 | $16,400 | |
| Loader - 2 | | km | 4800 | MHERH | 10.25 | $49,200 | |
| Compactor | | km | | MHERH | 10.25 | $0 | |
| Service vehicles - 10 | | km | 16000 | MHERH | 10.25 | $164,000 | |
| MOBILIZE MISC. EQUIPMENT | | | | | | | |
| Pump shipping | | each | | #N/A | 0 | $0 | |
| Pipe shipping | | m | | #N/A | 0 | $0 | |
| Minor tools and equipment | | allow | 1 | #N/A | 500000 | $500,000 | |
| Truck tires | | allow | 1 | #N/A | 500000 | $500,000 | |
| Other | | | | #N/A | 0 | $0 | |
| MOBILIZE CAMP | | | | | | | |
| Reclamation activities | | allow | 1 | #N/A | 150000 | $150,000 | |
| Long term reclamation activities (eg pump flooding) | | allow | | #N/A | 0 | $0 | |
| MOBILIZE WORKERS | | | | | | | |
| Rotations over reclamation period | | manhours | 26000 | #N/A | 45 | $1,170,000 | |
| Reclamation activities - transport | | each | | #N/A | 0 | $0 | |
| Reclamation activities - travel time | | manhours | | #N/A | 0 | $0 | |
| Long term reclamation activities (eg pump flooding) - transport | | each | | #N/A | 0 | $0 | |
| Long term reclamation activities (eg pump flooding) - travel time | | each | | #N/A | 0 | $0 | |
| Monitoring Airfare | | each | | #N/A | 0 | $0 | |
| WORKER ACCOMODATIONS | | | | | | | |
| Reclamation activities 20800 mandays | | mandays | 20800 | ACCML | 100 | $2,080,000 | |
| Long term reclamation activities (eg pump flooding) | | manmonths | | #N/A | 0 | $0 | |
| MOBILIZE FUEL | | | | | | | |
| Fuel freight - reclamation activities | | litre | | #N/A | 0 | $0 | |
| Fuel freight - long term reclamation activities | | litre | 7000000 | FCMH | 0.42 | $2,940,000 | |
| Fuel freight accomodations | | litre | | #N/A | 0 | $0 | |
| WINTER ROAD | | | | | | | |
| Construction and operation - 400km | once for C&M, twice for contractor mob/dem | km | | WRCH | 11500 | $0 | tabled pending A21 pit development plans |
| Limited winter use | | km | | #N/A | 0 | $0 | |
| Winter road tarriff | | km | | #N/A | 0 | $0 | |
| DEMOBILIZE HEAVY EQUIPMENT | | | | | | | |
| Excavators | | km | | #N/A | 0 | $0 | |
| Dump trucks | | km | | #N/A | 0 | $0 | |
| Dozers | | km | | #N/A | 0 | $0 | |
| Demolition shears | | km | | #N/A | 0 | $0 | |
| Crane | | km | | #N/A | 0 | $0 | |
| Loader | | km | | #N/A | 0 | $0 | |
| Compactor | | each | | #N/A | 0 | $0 | |
| Light duty vehicles | | km | | #N/A | 0 | $0 | |
| Other | | km | | #N/A | 0 | $0 | |
| DEMOBILIZE CAMP | | | | | | | |
| | | allow | | #N/A | 0 | $0 | |
| DEMOBILIZE WORKERS | | | | | | | |
| crew travel time | | mandays | | #N/A | 0 | $0 | |
| crew transportation | | each | | #N/A | 0 | $0 | |
| WINTER ROAD | | | | | | | |
| Construction and operation | | km | | #N/A | 0 | $0 | |
| Limited winter use | | km | | #N/A | 0 | $0 | |
| Winter road tarriff | | km | | #N/A | 0 | $0 | |
| | | | | | **Total** | **$9,111,200** | |

| Equipment Mobilization | # of machines | | loads/ machine | round trip km | total road mileage |
|---|---|---|---|---|---|
| excavator | | 2 | 3 | 800 | 4800 |
| dump trucks | | 15 | 10 | 800 | 120000 |
| dozers | | 4 | 5 | 800 | 16000 |
| demolition shears | | 2 | 6 | 800 | 9600 |
| front end loader | | 2 | 3 | 800 | 4800 |
| cranes | | 2 | 1 | 800 | 1600 |
| service vehicles | | 10 | 2 | 800 | 16000 |

## Unit Cost Table (for refining unit costs see "Estimator" worksheet)

**Filter by unit**

| ITEM | Detail | COST CODE | UNITS | LOW $ | HIGH $ | SPECIFIED $ | COMMENTS |
|---|---|---|---|---|---|---|---|
| **Accomodation** | | | | | | | |
| | | ACCM | manday | 100.00 | 175.00 | | |
| **Buildings - Decontaminate** | | | | | | | |
| | Asbestos | BDA | m2 | 25.60 | 51.20 | | Low: removal of asbestos siding & flooring; High: removal of insulated pipes |
| **Buildings - Remove** | | | | | | | Unit costs are based on 3m high, single storey building. Scale areas accorc |
| | Wood | BRW | m2 | 27.50 | 41.00 | | |
| | Concrete | BRC | m2 | 40.00 | 65.00 | 6.00 | Specified: puncture concrete foundation slabs |
| | Steel - teardown | BRS1 | m2 | 45.00 | 65.00 | | |
| | Steel - for salvage | BRS2 | m2 | 67.00 | 100.00 | | |
| **Concrete work** | | | | | | | |
| | Small pour | CSF | m3 | 426.50 | 639.75 | | Low: YK; High=1.5xLow |
| | Large pour | CLF | m3 | 353.50 | 530.25 | 2,130.00 | Specified: concrete crown pillar |
| **Contaminated Soils** | | | | | | | |
| | ESA Phase 1 | CS1 | each | 7500.00 | | | Low: small, "clean" site |
| | ESA Phase 1 | CS2 | each | 50000.00 | | | Low: small, "clean" site |
| | Remediate on site | CSR | m3 | 47.00 | 146.00 | | |
| **Dozing** | | | | | | | |
| | doze rock piles | DR | m3 | 1.05 | 2.40 | | Low cost: doze crest off dump |
| | doze overburden/soil piles | DS | m3 | 0.95 | 3.80 | | High cost: push up to 300 m |
| **Excavate Rock; Low Spec's and QA/QC** | | | | | | | |
| | drill/blast/load/short haul | RB1 | m3 | 11.40 | 17.05 | | Low:quarry operations for bulk fill |
| | drill/blast/load/long haul | RB2 | m3 | 12.05 | 17.80 | | |
| | RB1 + spread and compact | RB3 | m3 | 12.05 | 17.80 | | |
| | RB2 + spread and compact | RB4 | m3 | 12.50 | 30.75 | | |
| | Specified activity | RBS | m3 | | | | |
| **Excavate Rock; High Spec's and QA/QC** | | | | | | | (e.g. ditch/spillway excavation) |
| | drill/blast/load/short haul | RC1 | m3 | 12.05 | 17.80 | | Low:foundation excavation;High:spillway excavation |
| | drill/blast/load/long haul | RC2 | m3 | 12.70 | 18.40 | | |
| | RC1 + spread and compact | RC3 | m3 | 12.70 | 18.40 | | e,g, cover construction |
| | RC2 + spread and compact | RC4 | m3 | 13.50 | 19.20 | | e,g, cover construction |
| | Specified activity | RCS | m3 | | | 175.00 | Specified-drift excavation |
| **Excavate Rip Rap** | | | | | | | |
| | drill/blast/load/short haul/place | RR1 | m3 | 13.50 | 17.75 | | High: quarry & place rip rap in channel |
| | drill/blast/load/long haul/place | RR2 | m3 | 14.20 | 20.65 | | |
| | source is waste dump/short haul | RR3 | m3 | 7.00 | | | cost includes sorting |
| | source is waste dump/long haul | RR4 | m3 | 7.60 | | | |
| | Specified activity | RRS | m3 | | | | |
| **Excavate Soil; Low Spec's and QA/QC** | | | | | | | |
| | clear & grub | SBC | m2 | 3.40 | 5.00 | | |
| | excavate/load/short haul | SB1 | m3 | 4.30 | 5.90 | | |
| | excavate/load/long haul | SB2 | m3 | 4.60 | 7.30 | | |
| | SB1 + spread and compact | SB3 | m3 | 5.10 | 8.90 | 4.20 | Low: non-engineered; High:engineered; specified 2011 $3.96 adjusted for ir |
| | SB2 + spread and compact | SB4 | m3 | 5.50 | 11.00 | | Low: non-engineered; High:engineered |
| | Specified activity | SBS | m3 | 3.20 | 6.50 | | Low: rehandle waste rock dump by dozing; High:rehandle waste rock by hau |
| | Tailings | SBT | m3 | 1.35 | 3.70 | 15.50 | High:contour surface - wet or frozen; Specified:haul/place wet infill |
| **Excavate Soil, High Spec's and QA/QC** | | | | | | | |
| | excavate/load/short haul | SC1 | m3 | 6.80 | 9.30 | | |
| | excavate/load/long haul | SC2 | m3 | 7.10 | 11.75 | | |
| | SC1 + spread and compact | SC3 | m3 | 8.90 | 14.20 | | Low: non-engineered; High:engineered |
| | SC2 + spread and compact | SC4 | m3 | 9.30 | 23.20 | | Low: non-engineered; High:engineered (e.g. complex covers, low volume da |
| | Specified activity | SCS | m3 | | 5.00 | 18.80 | High:hydraulic mining; Specified:Backfill adit with waste rock |
| **Fence** | | | | | | | |
| | | FNC | m | 13.55 | 203.00 | | |
| **Fuel and Electricity** | | | | | | | |
| | Fuel cost - gas | FCG | litre | 1.05 | 1.40 | | |
| | Fuel cost - diesel | FCD | litre | 0.99 | 1.39 | | |
| | Fuel mobilization | FCM | litre | 0.22 | 0.42 | | High: winter road usage |
| | Electricity | FCE | kW-h | 0.17 | 0.19 | 0.49 | Low and High:Yellowknife; Specified:diesel generator |
| **Geo-Synthetics** | | | | | | | |
| | geotextile | GST | m2 | 3.44 | | 9.37 | Supply and install |
| | geogrid | GSG | m2 | 5.75 | | | |
| | liner, HDPE | GSHDPE | m2 | 7.95 | | | Supply and install; large quantity |
| | liner, ES3 | GSES3 | m2 | 20.20 | | | FOB Yellowknife |
| | geosynthetic installation | GSI | m2 | 3.16 | 14.00 | | Low:geotextile; High:ES3 or HDPE |

## Unit Cost Table (for refining unit costs see "Estimator" worksheet)

| | **Filter by unit** | | | | | |
|---|---|---|---|---|---|---|
| bentonite soil ammendment | GSBA | tonne | 308.30 | 348.50 | | FOB Edmonton, add shipping & mixing |
| **Grouting (/m3 of rock grouted)** | | | | | | |
| | grout | m3 | 236.55 | 286.75 | | High: cement, FOB Yellowknife |
| **Labour & Equipment Rates** | | | | | | |
| Site manager | sman | $/hr | 125.00 | 152.00 | | |
| Supervisor | super | $/hr | 52.00 | 91.84 | | |
| Registered engineer | eng | $/hr | 95.00 | 220.00 | | |
| Environmental coordinator | envco | $/hr | 74.16 | 130.00 | | |
| Evironmental technologist | envtech | $/hr | 36.00 | | | |
| Electrician | elec | $/hr | 74.00 | 95.00 | | |
| Journeyman - various | journey | $/hr | 44.00 | 71.79 | | |
| Labour - skilled | lab-s | $/hr | 41.00 | 49.60 | | |
| Labour - unskilled | lab-us | $/hr | 31.00 | 43.98 | | |
| Equipment operator | oper | $/hr | 41.00 | 65.00 | | |
| Heavy duty mechanic | mech | $/hr | 49.00 | 72.85 | | |
| Water treatment plant operator | oper-wt | $/hr | 41.00 | 59.86 | | |
| Security / first aid | safety | $/hr | 36.00 | 66.97 | | |
| Administative staff | admin | $/hr | 38.00 | 57.89 | | |
| | | | | | | |
| Equipment rates include operator and fuel | | | | | | |
| Loader - 4 cu.yd (3.06m3) | load-s | $/hr | 175.00 | | | |
| Loader - 7 cu.yd (5.35m3) | load-l | $/hr | 315.00 | | | |
| Excavator - 26.76-30.84 tonnes | exc-s | $/hr | 190.00 | | | |
| Excavator - 68.95+tonnes | exc-l | $/hr | 420.00 | | | |
| Grader | grad | $/hr | 190.00 | | | |
| Dump truck off hwy 30-50 tonnes | truck-s | $/hr | 225.00 | | | |
| Dump truck off hwy 55-75 tonnes | truck-l | $/hr | 300.00 | | | |
| dozer, small | dozers | $/hr | 205.00 | 260.00 | | |
| dozer, large | dozerl | $/hr | 490.00 | 565.00 | | |
| smooth drum compactor | comp | $/hr | 155.00 | | | |
| scooptram, 6 yd3 bucket | scoop | $/hr | 170.00 | | | |
| flat bed truck with hiab | hiab | $/hr | 155.00 | | | |
| fuel truck | ftruck | $/hr | 150.00 | | | |
| water truck | wtruck | $/hr | 58.00 | 150.00 | | |
| **Mobilize Heavy Equipment** | | | | | | |
| Road access | MHER | kmtonne | 3.40 | 10.25 | | |
| Air access | MHEA | kmtonne | 12.00 | | | cargo rate>500lb |
| **Mobilize Camp** | | | | | | |
| Road access | MCR | each | 50000.00 | | | refurbish existing camp |
| **Mobilize Workers** | | | | | | |
| flight | MW | each | 4500.00 | 9100.00 | | Low:e.g. 8 passenger; High: Dash 7 |
| **Oil Removal** | | | | | | |
| oil removal | OR | litre | 0.43 | 1.20 | | Low:waste oil heater; High: ship offsite |
| **PCB Removal** | | | | | | |
| Remove from site | PCBR | litre | 40.20 | 46.90 | | Low: shipping, handling & disposal from Yellowknife |
| **Pipes, small (<6in dia.)** | | | | | | |
| remove/dispose on site | PSR | m | 1.00 | 24.00 | | Low: remove/dispose on site; High: remove/re-use |
| supply | PSS | m | 6.10 | 11.10 | | Low:supply; High:supply and ship |
| install | PSI | m | 25.00 | | | |
| **Pipes, large (>6in dia.)** | | | | | | |
| remove/dispose on site | PLR | m | 22.00 | 72.00 | | Low: remove/dispose on site; High: remove/re-use |
| supply | PLS | m | 129.00 | 143.00 | | Low:supply; High:supply and ship |
| install | PLI | m | 50.00 | | | |
| **Power Lines** | | | | | | |
| remove/dispose on site | POWR | m | 25.50 | | | |
| **Process Chemicals** | | | | | | |
| Remove from site | PCR | kg | 0.45 | 2.50 | | Low: shipping, handling & disposal from Yellowknife |
| **Pumps** | | | | | | |
| Pump capital cost | PC | each | 195000.00 | | | |
| Pump shipping | PS | each | 2500.00 | | | |
| Pump operating cost | POC | m3 | 0.12 | | | pump operating costs should be calculated based on pump capacity, fuel cc |
| Pump maintenance | PM | allow | 25000.00 | | | |
| **Pump sand BackFill** | | | | | | |
| | PBF | m3 | 85.00 | 300.00 | | |
| **Scarify - road/mine site** | | | | | | |
| | SCFY | ha | 4300 | 6030 | 2150 | |
| **Shaft, Raise & Portal Closures** | | | | | | |

## Unit Cost Table (for refining unit costs see "Estimator" worksheet)

**Filter by unit**

| | | | | | | |
|---|---|---|---|---|---|---|
| Shaft & Raises | SR | m2 | 645.00 | 2132.00 | | Low:pre-cast concrete slabs, little site prep. Area=shaft+>1m all around |
| Portals | POR | m3 | 18.80 | 250.00 | 1200.00 | Low:unit cost code SCS;High:excavate & backfill collapsed portal;Spec: inst |
| **Site Inspection Report** | | | | | | |
| | RPT | each | 10000.00 | 20000.00 | | |
| **SpillWay - Clear** | | | | | | |
| | SW | each | 3000.00 | 7000.00 | | |
| **Survey/Instrumentation** | | | | | | |
| | SI | each | 1800.00 | 3600.00 | | 2 person crew |
| **Treatment Plant - Construct** | | | | | | |
| Small (< 1000 m3/d) | TPS | lump sum | 9000000 | 15000000 | | |
| Large (> 1000 m3/d) | TPL | lump sum | 15000000 | 46000000 | | |
| Constructed Wetland | CWTS | ha | 200000 | 300000 | | |
| **Treatment Plant - Operate** | | | | | | |
| | OTP | m3 | 0.35 | 2.00 | | |
| **Treatment Chemicals** | | | | | | |
| ferric sulphate | ferric | kg | 1.19 | | | |
| ferrous sulphate | ferrous | kg | 1.32 | | | |
| lime | lime | kg | 0.56 | | | |
| hydrogen peroxide, 35% | hperox | kg | 1.50 | | | |
| Sodium Metabisulfate | Nametab | kg | 1.18 | | | |
| Caustic soda, 50% | caustic | kg | 0.74 | | | |
| Sulfuric acid, 93% | sulfuric | kg | 0.31 | | | |
| flocculant | flocc | kg | 6.00 | | | |
| copper sulphate | copper | kg | | | | |
| shipping | shipping | kg | 0.20 | | | |
| **Vegetation** | | | | | | |
| Hydroseed, Flat | VHF | ha | 4000.00 | | | |
| Hydroseed, Sloped | VHS | ha | 4500.00 | | | |
| Veg. blanket/erosion mat | VB | ha | 13000.00 | | | |
| Tree planting | VT | ha | 2600.00 | 6000.00 | | |
| Wetland species | VW | ha | | | 47.72 | Specified= /m3, Wetland Growth Media Substrate mixed and installed (sanc |
| **Water Sampling/Analysis/Reporting** | | | | | | |
| | WS | each | 7000.00 | 10000.00 | | |
| **Winter Road** | | | | | | |
| Construction | WRC | km | 2000.00 | 11500.00 | | |
| Usage | WRU | kmtonne | 0.29 | | | |

# APPENDIX VIII

# RECLAMATION RESEARCH

# APPENDIX VIII-1

## Research Status Tracking Table

CRP V4 - Appenidx VIII-1. Research plan tracking table.

| Research Area | Topic | Scope | Status | Original ICRP V3.2 Research Plan (V1.1) Reference or New | Work to begin in Next 3 Years? (Y/N) | Detailed Scope of Work Provided? (Y/N) | Timeline Updated? |
|---|---|---|---|---|---|---|---|
| **1. Traditional Knowledge and Community Engagement** | 1.1 Wildlife Movement | 1.1.1 Desktop study to review available TK for caribou and other wildlife in the Slave Geological Province | Complete. *Literature Review of Traditional Ecological Knowledge Related to the Resource Sector.* July 2011. | **VIII-1 TK** 3.2.3.1 5.1.1.1 | **Complete** | | **Y** |
| | | 1.1.2 More detailed discussions with members from each of the Aboriginal organizations to obtain more specific recommendations on preferred options and where/how to best incorporate these recommendations in the final closure design, while still taking into account technical considerations. | On-going. TK/IQ Panel discussions continue to evolve on this topic (Appendix I-1) and community updates should provide further insight into each Aboriginal organization's preferences. | **VIII-1 TK** 3.2.3.2 3.2.3.3 3.2.3.4 3.2.3.5 3.2.4.3 5.1.1.2 | **Y** | **na[1]** | **Y** |
| | | 1.1.3 DDMI hopes to discuss these topics in community-based workshops and with the TK Panel. | On-going. TK/IQ Panel discussions continue to evolve on this topic (Appendix I-1) and community updates should provide further insight into each Aboriginal organization's preferences. | **VIII-1 TK** 5.1.1.3 | **Y** | **na[1]** | **Y** |
| | 1.2 Re-vegetation | 1.2.1 Desktop study to review available TK for vegetation in the Slave Geological Province | Complete. Documented in Appendix I-3 *Literature Review: Traditional Knowledge of Plant Life at the Diavik Diamond Mine.* October 2014. | **VIII-1 TK** 3.2.4.1 5.1.2.1 | **Complete** | | **Y** |
| | | 1.2.2 A summary of DDMI 5-year research on re-vegetation is to be provided to Aboriginal organizations and combined with TK views on which of those species are suited to re-vegetation or are beneficial for wildlife. | Completed. Summaries of the Phase I and II studies have been provided in annual Wildlife Monitoring Program reports. A full summary of both phases, including plans to continue re-vegetation research, was included in the 2012 Environmental Agreement report. Appendix C of the 2014 Literature Review (Appendix I-3) identified species valued by Aboriginal organizations and noted which of these species have been tested in DDMI's re-vegetation research. | **VIII-1 TK** 3.2.4.2 3.2.4.6 5.1.2.2 | **Complete** | | **Y** |
| | | 1.2.3 DDMI hopes to discuss these topics in community-based workshops and with the TK Panel. | Ongoing. The TK Panel site visit of 20 August 2012 included a visit to the re-vegetation plots and a discussion of results to date. The Panel expressed an interest in further re-vegetation discussions and this was conducted from 14-18 August 2014. Recommendations relating to re-vegetation are included in Section 2 and Appendix II-2. DDMI is working with PA organizations to arrange community visits where the results of this Panel session would be shared (Q4 2014). | **VIII-1 TK** 3.2.4.4 3.2.4.5 3.2.4.7 5.1.2.3 | **Y** | **na[1]** | **Y** |
| | 1.3 Landforms | 1.3.1 DDMI to work with Aboriginal organizations to begin developing more detailed images of what the mine will look like post-closure to assist community members in understanding what the mine site might look like. These images can incorporate different rock features, vegetation, or wildlife trails that community members may recommend. | Complete - DDMI Closure Visualization Tool | **VIII-1 TK** 3.2.5.1 5.1.3.1 | **Complete** | | **Y** |

| Research Area | Topic | Scope | Status | Original ICRP V3.2 Research Plan (V1.1) Reference or New | Work to begin in Next 3 Years? (Y/N) | Detailed Scope of Work Provided? (Y/N) | Timeline Updated? |
|---|---|---|---|---|---|---|---|
| | | 1.3.2 DDMI will assess the technical feasibility and material availability to meet Aboriginal organizations recommendations for key landforms. A model that best represents the final look of the land will be constructed and shared with each of the Aboriginal organizations to obtain any further feedback. | Ongoing | **VIII-1 TK**<br>3.2.5.2<br>3.2.5.3<br>5.1.3.2 | **Y** | **N** | **Y** |
| | | 1.3.3 DDMI hopes to discuss the models in community-based workshops and with the TK/IQ Panel. | Ongoing | **VIII-1 TK**<br>3.2.5.4<br>3.2.5.5<br>5.1.3.3 | **Y** | **na**[1] | **Y** |
| | 1.4 Community Engagement - TK | 1.4.1 Development of a TK/IQ Panel under the Environmental Agreement | Panel established under EMAB in 2012. Administration of the Panel was transferred to DDMI in August 2013. The TK Panel has completed a total of 7 sessions since its inception, with results from the most recent session summarized in Section 2. | **VIII-1 TK**<br>3.2.2.1<br>3.2.2.2<br>3.2.6.2<br>5.1.4.2 | **Complete** | | **Y** |
| | | 1.4.2 Formalize community engagement protocols with each of the Aboriginal organizations. | Ongoing. | **VIII-1 TK**<br>3.2.1.1<br>3.2.1.2<br>3.2.1.3<br>3.2.1.4<br>3.2.6.1<br>5.1.4.1 | **Y** | **na**[1] | **Y** |
| | 1.5 Semi-Fluid Processed Kimberlite Study | 1.5.1 Initiate an independent toxicological and chemical assessment of semi-fluid PK material. | Complete - Documented in 2015 ICRP Progress Report - Appendix II-5: *Characterization of Extra Fine Processed Kimberlite Tailings from the Diavik Processed Kimberlite Containment Pond*. | **VIII-1 TK**<br>New 5.2.2 | **Complete** | | **Y** |
| | 1.6 Fish Habitat Design | 1.6.1 engage TK Panel and communities on fish habitat designs for pit shelf areas | Complete - documented in 2015 ICRP Progress Report - Appendix I-2: *DDMI Traditional Knowledge Panel Session #8 - Focus on Fish Habitat.* | **VIII-1 TK**<br>3.3.1<br>3.3.2<br>5.2.1 | **Complete** | **na**[1] | **Y** |

| Research Area | Topic | Scope | Status | Original ICRP V3.2 Research Plan (V1.1) Reference or New | Work to begin in Next 3 Years? (Y/N) | Detailed Scope of Work Provided? (Y/N) | Timeline Updated? |
|---|---|---|---|---|---|---|---|
| 2. Open Pit, Underground and Dike Area Research | Pit Water Quality | 2.1 Geochemical loadings from the walls of the pit and underground workings are expected to be greater from areas with exposed biotite schist than areas with granite. The walls of the open pit represent the largest surface area of rock that will be washed by the flooding of the pit. The relative areas of granite versus biotite schist will be measured using photo imagery techniques and the results will be available for future updates to flooded pit water quality predictions. | Complete – documented in 2013 ICRP Progress Report. | **VIII-2 Pit-Dike**<br>3.1<br>5.1 | **Complete** | | **Y** |
| | Pit Water Quality | 2.2 Actual geochemical loading rates from pit or underground walls during flooding will be measured by spraying water over small sections of exposed granite and biotite schist and collecting and analysing the wash water. These results will be compared with estimates from waste rock geochemical testing. The results will be available for future updates to flooded pit water quality predictions. | Complete – documented in 2013 ICRP Progress Report. | **VIII-2 Pit-Dike**<br>3.2<br>5.2 | **Complete** | | **Y** |
| | Fish Use of Dike Exterior | 2.3 DDMI is working with Fisheries and Oceans Canada on a survey method for verifying fish use of the exterior slopes of the A418 and A154 dikes. This work may also be an opportunity to combine TK approaches. The information will be used to verify expected post-closure fish habitat use. | Complete – documentation in 2013 ICRP Progress Report. | **VIII-2 Pit-Dike**<br>3.3<br>3.4<br>5.3 | **Complete** | | **Y** |
| | Revised Predictions | 2.4 Beyond 2013 the anticipated tasks relate to applying the results of reclamation research to update predictions of flooded pit water quality using the established mathematical modelling framework. The model is also expected to be used to evaluate the effect of different fill rates on flooded pit water quality and effects of post-closure groundwater flows on flooded pit water quality. | Initiated - CRP V4 Appendix X7.1 and X-7.2 documents work completed on fill rates and pumping methods.<br>Further modelling of flooded pit quality is pending preferred closure options such as disposal of PK in underground/open pit are resolved. Updated Task description is include in CRP V4 - Appendix VIII-2 | **VIII-2 Pit-Dike**<br>3.5<br>3.6<br>3.7<br>3.8<br>5.4 | **Y** | **Y** | **Y** |
| | Risk Assessment | 2.5 Predicted water quality conditions would then be used as the basis for a screening level risk assessment to determine if the predicted water quality is expected to pose an unacceptable risk to aquatic life. Outcomes from the assessment could include revisions to closure criteria, identification of additional research tasks and/or the need for a more detailed risk assessment (See Appendix VIII Introduction). | Not started - assessment is pending the results of final pit water quality modelling (see 2.4 above). Updated Task description is include in CRP V4 - Appendix VIII-2 | **VIII-2 Pit-Dike**<br>3.9<br>5.5 | **Y** | **Y** | **Y** |

| Research Area | Topic | Scope | Status | Original ICRP V3.2 Research Plan (V1.1) Reference or New | Work to begin in Next 3 Years? (Y/N) | Detailed Scope of Work Provided? (Y/N) | Timeline Updated? |
|---|---|---|---|---|---|---|---|
| 3. Waste Rock Research | 3.0 Field data collection from the Test Piles, laboratory measurement and characterization of thermal, hydrological, gas transport and geochemical processes. | | Complete | **VIII-3 Wasterock** 3.2.1/3.3.1 3.2.2/3.3.3 3.2.3/3.3.4 3.2.4/3.3.5 3.2.5/3.3.6 3.2.6/3.3.7 3.3.2 5.2.4 | **Complete** | | **Y** |
| | 3.1 Thermal | 3.1.1 Based on the monitoring results from the test piles and waste rock as well as possible mathematical modelling, provide an estimate of the depth of annual thaw for the waste rock pile. | Complete – Documented in 2012 ICRP Progress Report. | **VIII-3 Wasterock** 5.1.1.1 | **Complete** | | **Y** |
| | | 3.1.2 Provide this estimate for scenarios assuming both a cover and no cover. | Complete – Documented in 2012 ICRP Progress Report. | **VIII-3 Wasterock** 5.1.1.2 | **Complete** | | **Y** |
| | | 3.1.3 Determine the effect of a climate change scenario on these initial estimates. | Complete – Documented in 2012 ICRP Progress Report. | **VIII-3 Wasterock** 5.1.1.3 | **Complete** | | **Y** |
| | | 3.1.4 Revise estimates with any changes in monitoring information, mathematical modelling or cover design parameters. | Pending any changes. | **VIII-3 Wasterock** 5.1.1.4 | **N** | **N** | **Y** |
| | 3.2 Hydrological | 3.2.1 Based on the monitoring results from the test piles and thermal analysis provide an interim estimate of the fraction of rainfall and snow melt expected to travel within the annual thaw zone and exit the rock pile as seepage. | Complete – Documented in 2013 ICRP Progress Report. | **VIII-3 Wasterock** 5.1.2.1 | **Complete** | | **Y** |
| | | 3.2.2 Provide this estimate for scenarios assuming both a cover and no cover. | Complete - Documented in 2013 ICRP Progress Report. | **VIII-3 Wasterock** 5.1.2.2 | **Complete** | | **Y** |
| | | 3.2.3 Determine the effect of a climate change scenario on these initial estimates. | Complete - Documented in 2013 ICRP Progress Report. | **VIII-3 Wasterock** 5.1.2.3 | **Complete** | | **Y** |
| | | 3.2.4 Revise estimates with any changes in monitoring information or cover design parameters. | Pending any changes. | **VIII-3 Wasterock** 5.1.2.4 | **N** | **N** | **Y** |
| | 3.3 Geochemical | 3.3.1 Based on the monitoring results from the test pile, thermal analysis and hydrological analysis provide an interim estimate of the geochemical loading rates in seepage from the waste rock. | Complete – Documented in 2013 ICRP Progress Report. | **VIII-3 Wasterock** 3.2.7/3.3.8 5.1.3.1 | **Complete** | | **Y** |
| | | 3.3.2 Provide this estimate for scenarios assuming both a cover and no cover. | Complete - Documented in 2013 ICRP Progress Report. | **VIII-3 Wasterock** 3.2.7/3.3.8 5.1.3.2 | **Complete** | | **Y** |
| | | 3.3.3 Determine the effect of a climate change scenario on these initial estimates. | Complete - Documented in 2013 ICRP Progress Report. | **VIII-3 Wasterock** 3.2.7/3.3.8 5.1.3.3 | **Complete** | | **Y** |
| | | 3.3.4 Revise estimates with any changes in monitoring information or cover design parameters. | Pending any changes. | **VIII-3 Wasterock** 5.1.3.4 | **N** | **N** | **Y** |
| | 3.4 Finalize estimates of post-closure thermal, hydrological and geochemical conditions for the waste rock pile. Final evaluation of the expected performance of a Type I and till cover, as compared with no cover, on seepage water quality and quantity. Evaluation of cost-benefit of a waste rock pile cover. | | Complete - Documented in *WRSA-NCRP Final Closure Plan* (DDMI 2017). Evaluation of cost-benefits not required at this time. | **VIII-3 Wasterock** 5.2.1 5.2.2 5.2.3 | **Complete** | | **Y** |

| Research Area | Topic | Scope | Status | Original ICRP V3.2 Research Plan (V1.1) Reference or New | Work to begin in Next 3 Years? (Y/N) | Detailed Scope of Work Provided? (Y/N) | Timeline Updated? |
|---|---|---|---|---|---|---|---|
| **4. Processed Kimberlite Containment Area Reclamation Research** | 4.1 Geotechnical | 4.1.1 Interpretation and analysis of piezocone testing of the PKC slimes to determine consolidation rates and magnitudes. An estimation of consolidation rates and magnitudes can provide an indication of final landscape topography, and the volume of pore water that may be expelled during consolidated. | Complete. Documented in 2012 ICRP Progress Report. | **VIII-4 PKC**<br>3.2.1.1<br>5.1.1.1 | **Complete** | | **Y** |
| | | 4.1.2 Laboratory tests for additional slimes characterization, could contribute to estimates of consolidation rates and magnitudes. | Complete. Documented in 2012 ICRP Progress Report. | **VIII-4 PKC**<br>3.2.1.2<br>5.1.1.2 | **Complete** | | **Y** |
| | | 4.1.3 Installation of thermistors in the beaches and/or slimes and collection of thermal data can provide an indication of permafrost development and the propensity for thermokarst topography. | Installation complete. Data collection and interpretation is on- going. To-date results are described in Appendix II-1 *Four-Year Hydrochemical Field Investigation of Processed Kimberlite Weathering.* | **VIII-4 PKC**<br>3.2.1.3<br>5.1.1.3 | **Complete** | | **Y** |
| | | 4.1.4 Contract a qualified engineer to review the 2001 cover design for the PKC. Specifically to provide expert opinion on the expected performance of the till layer as an impermeable layer over an unconsolidated PK material and provide a written report. | Complete. Documented in 2013 ICRP Progress Report. | **VIII-4 PKC**<br>3.2.1.4<br>5.1.1.4 | **Complete** | | **Y** |
| | 4.2 Geochemical | 4.2.1 Annual or semi-annual sample collection from surviving/accessible piezometers (as accessible) to monitor changes to pore water chemistry and identify any potential elements of concern. | On-going. See 2015 ICRP Progress Report - Appendix II-1 *Four-Year Hydrochemical Field Investigation of Processed Kimberlite Weathering.* | **VIII-4 PKC**<br>3.2.2.1<br>5.1.2.1<br>3.3.6<br>5.2.5 | **Y** | **Y** | **Y** |
| | | 4.2.2 Pore water chemistry trend analysis and interpretation; to identify any changes in pore water chemistry over time and identify any potential elements of concern. | On-going. See 2015 ICRP Progress Report - Appendix II-1 *Four-Year Hydrochemical Field Investigation of Processed Kimberlite Weathering.* | **VIII-4 PKC**<br>3.2.2.2<br>5.1.2.2 | **Y** | **Y** | **Y** |
| | | 4.2.3 Laboratory and/or small scale field leaching experiments to monitor accelerated and in situ weathering of FPK and the resultant water quality. | Ongoing. See 2015 ICRP Progress Report - Appendix II-2 *Technical Memorandum – PK Tank 2014 Progress Report* and Appendix II-3 *Technical Memorandum – PK Static and Kinetic Tests.* | **VIII-4 PKC**<br>3.2.2.3<br>5.1.2.3 | **Y** | **Y** | **Y** |
| | | 4.2.4 Pore water chemistry modelling based on pore water chemistry trends, and laboratory experiments and/or small-scale field experiments that may include predictive/reactive transport modelling. | On-going. An initial interpretive report is included in 2015 ICRP Progress Report *Appendix II-1: Sources of Dissolved Ions to the Process Kimberlite Containment Facility at Diavik Diamond Mines Inc.* | **VIII-4 PKC**<br>5.1.2.4 | **N** | **Y** | **Y** |
| | | 4.2.5 A screening level risk assessment using available PKC pond monitoring (SNP 1645-16) information, pore water chemistry information, and laboratory and/or field experiment preliminary results to estimate possible outlet seepage water quality. This risk assessment will identify parameters of potential concern and may help focus characterization of sources (e.g. pore water, beach runoff) or processes (e.g. freezing, oxidation) governing the concentrations in the outlet and seepage water. | Complete. Documented in CRP V4 Appenidx X-8.1 and X-8.2 | **VIII-4 PKC**<br>5.1.2.5 | **Complete** | | **Y** |
| | 4.3 Water quality criteria | 4.3.1 A screening level risk assessment will be completed based on initial estimates of probable ranges of outlet water quality and quantity. Water quality criteria from Appendix V, Table V7 will be used as the basis for screening. Areas where exposure concentrations will be estimated include streams and or inland lakes along any seepage pathway and areas of Lac de Gras. | Complete. Documented in CRP V4 Appenidx X-8.1 and X-8.2 | **VIII-4 PKC**<br>3.2.3.1<br>5.1.3.1 | **Complete** | | **Y** |
| | | 4.3.2 Update water quality criteria, if required | Complete. Documented in CRP V4 Appenidx X-8.1 and X-8.2; with proposed criteria in Appendix V | **VIII-4 PKC**<br>3.2.3.2<br>5.1.3.2 | **Y** | | **Y** |
| | | 4.4.1 Thermal modelling including modelling of climate change scenario. | Not started. | **VIII-4 PKC**<br>3.3.1<br>5.2.1 | **N** | **N** | **Y** |
| | | 4.4.2 Hydrological modelling. | Not started. | **VIII-4 PKC**<br>3.3.2<br>5.2.2 | **N** | **N** | **Y** |

| Research Area | Topic | Scope | Status | Original ICRP V3.2 Research Plan (V1.1) Reference or New | Work to begin in Next 3 Years? (Y/N) | Detailed Scope of Work Provided? (Y/N) | Timeline Updated? |
|---|---|---|---|---|---|---|---|
| | 4.4 Final Evaluation | 4.4.3 Predictions of seepage and outlet water quality. | Not started. | **VIII-4 PKC** 3.3.3 5.2.3 | **N** | **N** | **Y** |
| | | 4.4.4 Conduct and document detailed level risk assessment, if required. | Not started. | **VIII-4 PKC** 3.3.4 5.2.4 | **N** | **N** | **Y** |
| | | 4.4.5 Update closure criteria. | Not started. | **VIII-4 PKC** 3.3.6 5.2.6 | **N** | **na**[2] | **Y** |

| Research Area | Topic | Scope | Status | Original ICRP V3.2 Research Plan (V1.1) Reference or New | Work to begin in Next 3 Years? (Y/N) | Detailed Scope of Work Provided? (Y/N) | Timeline Updated? |
|---|---|---|---|---|---|---|---|
| 5. North Inlet Reclamation Research | 5.1 Follow-up studies and testing from 2010 characterization program to isolate the source of measured biological responses | 5.1.1 Estimate leaching potential of contaminants from NI sediment | Complete – Documented in 2013 ICRP Progress Report. | **VIII-5 NI** 3.1.1 5.1.1a | **Complete** | | **Y** |
| | | 5.1.2Confirm sediment chemistry and toxicity in NI sediment | Complete - Documented in 2012 ICRP Progress Report. | **VIII-5 NI** 3.1.1 5.1.1b | **Complete** | | **Y** |
| | | 5.1.3 Conduct additional chemical and toxicological testing on NIWTP sludge | Complete - Documented in 2012 ICRP Progress Report. | **VIII-5 NI** 3.1.1 5.1.1c | **Complete** | | **Y** |
| | | 5.1.4 Conduct zooplankton sampling in NI | Complete - Documented in 2012 ICRP Progress Report. | **VIII-5 NI** 3.1.1 5.1.1d | **Complete** | | **Y** |
| | | 5.1.5 Conduct preliminary Toxicity Identification Evaluation (TIE) | Complete – Documented in 2013 ICRP Progress Report. | **VIII-5 NI** **NEW** | **Complete** | | **Y** |
| | | 5.1.6 Model acceptable NI water quality conditions for a partial breach to Lac de Gras as a closure alternative | Pending outcome of Task 5.2 | **VIII-5 NI** 5.1.1e | **Not Required** | | **Y** |
| | 5.2 Conduct and document screening level risk assessment for NI water and sediment quality | | Complete - Documented in *Consolidated Report: North Inlet Sludge Management Report and North Inlet Hydrocarbon Investigation Report* (Golder 2016) approved by the WLWB as a requirement of W2015L2-0001-Part H | **VIII-5 NI** 3.1.2 3.2.2 5.1.2 | **Complete** | | **Y** |
| | 5.3 Conduct and document detailed level risk assessment, if required | | Not Required | **VIII-5 NI** 3.1.3 3.2.3 5.1.3 | **Not Required** | | **Y** |
| | 5.4 Develop risk management strategy, if required | | Complete - Documented in *Consolidated Report: North Inlet Sludge Management Report and North Inlet Hydrocarbon Investigation Report* (Golder 2016) approved by the WLWB as a requirement of W2015L2-0001-Part H | **VIII-5 NI** 3.1.4 5.1.4 | **Complete** | | **Y** |
| | 5.5 Update water and sediment closure criteria | | Complete - Documented in CRP V4 Appenidx V. | **VIII-5 NI** 3.1.5 3.2.4 5.1.5 | **Complete** | | **Y** |
| | 5.6 Sediment Characterization Update | | Complete - Documented in *Consolidated Report: North Inlet Sludge Management Report and North Inlet Hydrocarbon Investigation Report* (Golder 2016) approved by the WLWB as a requirement of W2015L2-0001-Part H | **VIII-5 NI** 5.2.1 | **Complete** | | **Y** |

| Research Area | Topic | Scope | Status | Original ICRP V3.2 Research Plan (V1.1) Reference or New | Work to begin in Next 3 Years? (Y/N) | Detailed Scope of Work Provided? (Y/N) | Timeline Updated? |
|---|---|---|---|---|---|---|---|
| **6. Infrastructure Area Reclamation Research** | 6.1 Re-vegetation | 6.1.1 Continue monitoring of re-vegetation research plots | Ongoing – progress reports included as CRP V4 - Appendix VIII-1A and VIII-1B: *Reclamation of Disturbed Sites at Diavik Diamond Mine – 2016 Annual Report* and *Preliminary Assessment of Plant Uptake of Metals from Processed Kimberlite Used as a Reclamation Substrate.* | **VIII-6 Infrastructure**<br>3.2.1.1<br>5.1.1 | **Y** | **Y** | **Y** |
| | | 6.1.2 Interpretation and documentation of field and laboratory monitoring results | See 6.1.1 above. Final re-vegetation research report expected at end of 2017. | **VIII-6 Infrastructure**<br>3.2.1.2<br>5.1.1 | **Y** | **Y** | **Y** |
| | | 6.1.3 Assess information availability and applicability from Ekati | Complete. Documented in Appendix II-4 *Reclamation of Disturbed Sites in the North – Implications for Diamond Mines – A Literature Review.* | **VIII-6 Infrastructure**<br>3.2.1.3<br>5.1.1 | **Complete** | | **Y** |
| | | 6.1.4 Assess confidence in developing re-vegetation procedures | Planned for inclusion in the 2018 Annual CRP Progress Report. | **VIII-6 Infrastructure**<br>3.2.1.4<br>5.1.1 | **Y** | **Y** | **Y** |
| | | 6.1.5 Identify any additional research that may be required and long-term monitoring scope for existing re-vegetation plots. | See 6.1.1 above | **VIII-6 Infrastructure**<br>3.2.1.5<br>5.1.1 | **Y** | **Y** | **Y** |
| | | 6.1.6 Finalize specific procedures for site-wide re-vegetation | Planned for inclusion in the 2018 Annual CRP Progress Report. | **VIII-6 Infrastructure**<br>3.3.1<br>5.2.1 | **Y** | **Y** | **Y** |
| | 6.2 Contaminated soils | 6.2.1 Conduct and document risk assessment for options for management and disposal of petroleum hydrocarbon contaminated materials. | Complete – Documented in 2012 ICRP Progress Report. | **VIII-6 Infrastructure**<br>3.2.2.1<br>5.1.2 | **Complete** | | **Y** |
| | | 6.2.2 Finalize procedures for management/disposal of hydrocarbon contaminated material. | Preferred aproach is described in Task 6.2.1. More specific description of procedures will be provided with Final CRP. | **VIII-6 Infrastructure**<br>3.3.2<br>5.2.2 | **N** | **N** | **Y** |
| | 6.3 Closure Reference Concentrations | 6.3.1 Develop site-specific, risk-based closure reference concentrations; document and distribute for review | Complete - Documented in CRP V4 Appendix X-8.1 and X-8.2. | **VIII-6 Infrastructure**<br>3.2.3.1<br>3.2.3.2<br>5.1.3 | **Complete** | | **Y** |
| | | 6.3.2 Update closure criteria | Complete - Documented in CRP V4 Appenidx V. | **VIII-6 Infrastructure**<br>3.2.3.3<br>5.1.3 | **Complete** | | **Y** |
| | | 6.3.3 if expected exposure concentrations of metals in water, soil, dust, plants or prey are identified as posing an unacceptable risk to wildlife or people, then specific research plans may need to be developed to address associated uncertainties | No unacceptable risks identified to date. | **VIII-6 Infrastructure**<br>3.3.3 | **Not Required** | | **Y** |
| | 6.4 Post Closure Vegetation Metals Level Risk | 6.4.1 Literature and field studies to determine metals levels in plant tissue from test plots. | Ongoing - prelimnary results are reported in the attached CRP V4 Appenidx VIII-1A. Additional field work is planned. | **VIII-6 Infrastructure**<br>3.2.4.1<br>5.1.4<br>5.2.3 | **Y** | **Y** | **Y** |
| | | 6.4.2 Compare these literature values with risk-based reference concentrations. | Ongoing - premliminary results prelimnary results are reported in the attached CRP V4 Appenidx VIII-1A. Final comparisons with SSRBCC will be conducted with final results from 6.4.1 | **VIII-6 Infrastructure**<br>3.2.4.2<br>5.1.4<br>5.2.3 | **Y** | **Y** | **Y** |
| | | 6.4.3 Determine if there is a need to further research this potential contaminant pathway. | Results from 6.4.1 identified the need for additional field work. CRP V4 Appendix VIII-2 includes a description of this updated task. | **VIII-6 Infrastructure**<br>3.2.4.3<br>5.1.4<br>5.2.3 | **Y** | **Y** | **Y** |
| | | 6.4.4 if metals levels in post-closure vegetation remains a high risk contaminant pathway, determine appropriate post-closure monitoring methods as per Water License Part L, Item 3f. | Premiminary results do not indicate the need for a post-closure monitoring method. Confirmation is pending final results from 6.4.2 | **VIII-6 Infrastructure**<br>3.3.4 | **N** | **N** | **Y** |

| Research Area | Topic | Scope | Status | Original ICRP V3.2 Research Plan (V1.1) Reference or New | Work to begin in Next 3 Years? (Y/N) | Detailed Scope of Work Provided? (Y/N) | Timeline Updated? |
|---|---|---|---|---|---|---|---|
| | Notes | 1. Community and/or TK Panel engagement tasks do not lend themselves to conventional work scope definitions.<br>2. The methods used to update criteria are described in the previous tasks. Updated criteria would be one of the deliverables. | | | | | |

# APPENDIX VIII-1A

## Plant Uptake of Metals from PK

# PRELIMINARY ASSESSMENT OF PLANT UPTAKE OF METALS FROM PROCESSED KIMBERLITE USED AS A RECLAMATION SUBSTRATE AT DIAVIK DIAMOND MINE, NORTHWEST TERRITORIES, CANADA


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# 1. BACKGROUND

Trace metals in the arctic are a primary concern for environmental and human health (Macdonald et al 2000, AMAP 2005, Fisk et al 2005, Van Oostdam et al 2005). Trace metals have been found in air, soil and marine and terrestrial wildlife. Sources of these metals are not known, although anthropogenic activities have been implicated with long distance transport considered a primary source of contaminants (Elkin and Bethke 1995, Shotyk et al 2005). In the Canadian north, metal and non metal mining and transportation emissions contribute to metal pollution. Some metals, including those that are potentially toxic to wildlife, are naturally abundant in the environment due to the geomorphology of an area. However, even in regions where natural abundance of metals is high in the environment, anthropogenic concentrations are reported to rival or exceed natural ones (Macdonald et al 2000). Some of these metals are transferred through the food web and bioaccumulate in higher trophic levels and some are toxic to wildlife and humans. Cadmium, lead, mercury and selenium have been the focus of human health risks in the north (Van Oostdam et al 2005).

One potential exposure pathway is through country or traditional foods, including caribou, muskox, small mammals, seal, walrus, whale and fish. Bioaccumulation has been linked to sources of forage and browse for terrestrial wildlife (Crete et al 1989, Gamberg and Scheuhammer 1995, Larter and Nagy 2000). Moderately high concentrations of cadmium were reported in caribou (*Rangifer tarandus*) across the Canadian arctic (Crete et al 1989, Elke and Bethke 1995) with lower metal accumulation in the western arctic than eastern regions (Elke and Bethke 1995, Roubillard et al 2002, Van Oostdam et al 2005). Accumulation is most concentrated in caribou in the kidney and liver and varies with sex and age (Crete et al 1989, Roubillard et al 2002, Pedersen and Lierhagen 2006). Other metals including aluminum, arsenic, copper, iron, lead, manganese, molybdenum, nickel and zinc have been assessed but not identified as a concern in caribou (Elkin and Bethke 1995, Gamberg and Scheuhammer 1995, Larter and Nagy 2000).

Few studies have been conducted on other terrestrial species of importance for traditional food. Gamberg and Scheuhammer (1995) found metal concentrations where considerably greater in caribou tissue than muskox (*Ovibos moschatus*) tissue, both herbivores from the same region; this suggests species specific accumulation and/or metabolization of metals. Amuno et al (2016) found higher concentrations of cadmium and lead in arctic hare (*Lepus arcticus*) livers near a lead-zinc mine than those from unmined reference areas. However, no detrimental effects to the hares were reported. Soil metal concentrations were significantly higher than reference areas, and cadmium in tissue strongly positively correlated with that in soil. In another study on arctic hare, metals measured (copper, mercury, lead, zinc) were not at concentrations of concern, with the exception of cadmium (Pedersen and Lierhagen 2006). As found in caribou, metal accumulation was greater in kidneys and livers than muscle and greater with age of the animal. Researchers suggest hares are more likely to reflect local contaminant distribution as their ranges are small relative to caribou. In a study on arctic ground squirrels (*Spermophilus parryi*), arsenic, cadmium, mercury, nickel and lead were found in livers but concentrations were very low and considered not of concern (Allen-Gill et al 1997).

On diamond mine disturbances in the north, one of the reclamation goals is to reestablish a native vegetation cover as quickly as possible to provide habitat including forage and browse for wildlife. At Diavik Diamond Mine specifically, arctic hares, arctic ground squirrels and barren ground caribou rely on tundra vegetation as a food source. Processed kimberlite is a by product of diamond processing and is a desirable reclamation material. It has a sandy loam texture which can improve the structure of gravel substrates commonly requiring reclamation, and its use in reclamation would reduce costs required to transport it off site for disposal. Processed kimberlite is known to contain trace metals including aluminum, cadmium, chromium, cobalt, copper and nickel (Bakker et al 2001, Drozdowski et al 2012). It is not known if plants growing on processed kimberlite uptake these metals and if they do, whether they present a potential risk to wildlife and human consumers.

## 2. RESEARCH OBJECTIVES

The purpose of this research is to determine if vegetation on reclamation sites poses a risk to wildlife that may graze on these sites. The specific objectives were to determine if plants uptake metals from processed kimberlite when this material is used as a reclamation substrate, and if they do, to determine the range of metals and their concentrations.

## 3. MATERIALS AND METHODS

In 2016 metal uptake by plants grown in processed kimberlite was assessed in plant growth facilities at the University of Alberta using a complete randomized experimental design. The experiment investigated six substrates and four plant species, each replicated eight times.

Reclamation substrates were 100 % processed kimberlite, 75 % processed kimberlite with 25 % lakebed sediment (75:25), 50 % processed kimberlite with 50 % lakebed sediment (50:50), 25 % processed kimberlite with 75 % lakebed sediment (25:75) and 100 % lakebed sediment. Commercial potting soil was used as a reference (control). Mixes were included as they are the more plausible scenarios for reclamation substrates, since plant growth in 100 % processed kimberlite has consistently been poor in the field and under controlled conditions. Processed kimberlite and lakebed sediment were obtained from Diavik Diamond Mine in August 2013. The fine processed kimberlite was collected from the containment facility, where it had been placed as a slurry to dry. The lakebed sediment was removed from a stockpile where it had been placed during pit excavation after diking and drainage.

Four grass species, *Agropyron pauciflorum* (slender wheat grass), *Poa glauca* (glaucous blue grass), *Agrostis scabra* (tickle grass) and *Deschampsia caespitosa* (tufted hair grass), were selected for study. These species are native to subarctic tundra and commonly used in reclamation; two are known to be tolerant of adverse soil chemistry (*Agrostis scabra* and *Deschampsia caepitosa*). A forb was not chosen for inclusion as a goal was to obtain sufficient plant biomass for laboratory analyses in eight to twelve weeks. Forbs are often slower growing and produce less biomass than grasses. Germination tests were conducted in the laboratory prior to seeding pots as the basis for seeding rates.

Substrates were analyzed to determine the source of any metals that might be found in plant tissue. Three random samples from each substrate were collected at the beginning of the experiment and submitted to a commercial laboratory for metal determination. Samples were analyzed for aluminum, antimony, arsenic, barium, beryllium, bismuth, cadmium, chromium, cobalt, copper, iron, lead, lithium, magnesium, manganese, molybdenum, nickel, phosphorus, potassium, selenium, silver, sodium, strontium, thallium, tin, titanium, uranium, vanadium, zinc and zirconium concentrations. Samples were digested with nitric and hydrochloric acids, followed with analysis by collision reaction cell inductively coupled plasma mass spectrometry (EPA 200.2/6020A). Mercury analysis required an additional procedure and was not included in our study due to budget constraints. Extensive sampling and analysis of processed kimberlite and other reclamation substrates in 2004, 2005 and 2009 found mercury was consistently below detection limits (0.050 mg $kg^{-1}$) so it was not of concern for this study (Drozdowski et al 2012, Naeth and Wilkinson 2014).

Pots, with 6 inch diameters and 6 inch depths, were filled with each substrate, seeded with the designated grass species and randomly placed on a greenhouse bench. Greenhouse conditions were set for 21 $^{o}$C with a 16 hour photoperiod. Pots were watered to maintain approximate field capacity for 12 weeks. Plant density per pot was assessed regularly. After 12 weeks many pots did not have sufficient biomass for analysis; however, there had been no new growth within the past 2 to 3 weeks and in some treatments plants were showing signs of stress.

Above ground plant biomass was collected from each pot by clipping as close to the substrate surface as possible. Biomass from the eight replicates (pots) of each plant species on each substrate was combined to form one species-substrate composite sample. Biomass was air dried for 48 hours, then weighed. Three samples of equal dry weight were created from each species-substrate composite. For some composites there was insufficient biomass for more than one sample; specifically for most species grown in 100 % processed kimberlite except *Agropyron pauciflorum*, and for any composite from *Poa glauca*.

Twenty nine samples of sufficient volume for analyses were produced, including three replicates from each substrate for *Agropyron pauciflorum* (18 samples). The remaining samples were three reference samples for each of the other species, two lakebed sediment samples with species combined and one sample of a mix of 50:50 and 25:75 for species combined. Samples were analysed for the same 33 metals as in soil. Although analyzing plant tissue for 33 metals was unnecessary, it was considerably less expensive than analyzing for the metals of concern alone due to laboratory fee structures. Tissue samples were homogenized and sub-sampled prior to hotblock digestion with nitric and hydrochloric acids, with addition of hydrogen peroxide (EPA 200.3). Instrumental analysis was by collision cell inductively coupled plasma mass spectrometry (modified from EPA 6020A) (Austin 2015).

Soil and tissue data were tested for normality and homogeneity of variance using standard tests. One way analysis of variance (ANOVA) was performed to determine if soil and tissue metal concentrations differed among substrates. Pearson’s correlations were conducted to determine association between soil and tissue metal concentrations. Data analyses were conducted in SPSS Version 23.0 (IBM Corp, Armonk, NY) using an alpha value of 0.05.

## 4. RESULTS AND DISCUSSION

### 4.1. Trace Metals In Reclamation Substrates

Results for select metals in reclamation substrates are presented in Table 1 and others provided in appendices. Silver and tin were below detection limits in all samples. Antimony was below detection limits in all samples except 100 % processed kimberlite; selenium in all samples except 100 % processed kimberlite and 75 % processed kimberlite with 25 % lakebed sediment, and bismuth in all samples except 100 % lakebed sediment. As expected, processed kimberlite had significantly higher concentrations of all metals than the reference except for boron, calcium, molybdenum, phosphorus and sodium. Processed kimberlite had significantly higher (at least two fold) concentrations of barium, calcium, chromium, cobalt, iron, magnesium, manganese and strontium than 100 % lakebed sediment. Metals with Canadian Council of Ministers of Environment (CCME) soil quality guidelines were below values of concern in most substrates (CCME 2007). Boron, chromium and nickel were consideraly higher than the CCME guideline in all substrates containing processed kimberlite. Barium and cobalt were higher than CCME guidelines in 100 % processed kimberlite and 75 % processed kimberlite with 25 % lakebed sediment. Metal concentrations in samples were similar to those from previous research (Drozdowski et al 2012, Naeth and Wilkinson 2014), with the exception that barium and arsenic were 2 to 2.5 times greater in our processed kimberlite.

### 4.2 Trace Metals In Plant Tissue

Results for selected metals in *Agropyron pauciflorum* shoot tissue are presented in Table 2 and others provided in appendices. In all samples, antimony, beryllium, bismuth, tin and zirconium were below detection limits. There were no differences in chromium, iron, lead and tin among plant tissue samples from substrates and reference potting soil. Thus these metals are not likely to bioaccumulate in plants. Lead is a priority metal of concern as it is highly toxic to wildlife and humans. Cadmium, copper, molybdenum, selenium and strontium in plant tissue from processed kimberlite was significantly higher than from the reference. Arsenic, barium and calcium were significantly and unexpectedly lower in plant tissue from 100 % processed kimberlite than in tissue from the reference substrate. The greater uptake of arsenic and barium by plants in the reference substrate may be due to improved overall health of the plants. These metals in processed kimberlite may be more limiting in early stages of development, thereby preventing vigorous seedling establishment. Barium was above CCME soil quality guidelines in processed kimberlite, however barium toxicity to plants has not been well documented (Kabata-Pendias 2011). The lower uptake of calcium, even though substrate and control concentrations were similar, also suggests poor plant health may be a factor.

Relative to lakebed sediment, plant tissue from processed kimberlite had significantly greater molybdenum (10 times) and strontium (2.5 times). Plant tissue from lakebed sediment had significantly greater arsenic (7 times), cadmium (2.5 times), copper (2 times), phosphorus (3 times), manganese (2.5 times), thallium (4.5 times), uranium (6 times) and zinc (3.5 times). In general these elements were in the same concentration or less than that of processed kimberlite, however, uptake was greater in lakebed sediment. Similarily, elements that were in signifcantly higher concentration in processed kimberlite, did not result in increased plant uptake from them. Even though barium was 7 times greater in processed kimberlite than in lakebed sediment, and above CCME soil quality guidelines, there was no difference in plant uptake. This trend is confirmed by the lack of significant positive correlations between substrate and plant tissue metal concentrations with the exception of arsenic, chromium and copper.

Differences between soil and plant tissue concentrations can be affected by many factors including depth of rooting zone and biomass production (Mertens et al 2005), substrate texture and pH (Kabata-Pendias 2011) and plant species specific metal accumulation (Eriksson et al 1990). While rooting depth was constant in this controlled study, plants were larger and healthier when grown in lakebed sediment than in processed kimberlite, which may result in increased capacity to uptake metals. Differences in plant vigour and growth between reclamation substrates will always exist as processed kimberlite is more limiting to plant growth (Drozdowski et al 2012, Naeth and Wilkinson 2014, Miller unpublished).

Differences in soil physical properties affect metal retention and mobility (Kabata-Pendias 2011). Some metals such as barium, cadmium and chromium readily bind to fine clay particles, which are absent in sandy processed kimberlite. In sandy substrates metals can be readily leached through the profile and out of reach of the plant rooting zone. Plant uptake of cadmium, nickel, manganese and zinc is greater in acidic soils (Chaney 1994, Zabata-Pendias 2011). Processed kimberlite is alkaline (mean 8.0 to 8.2) with lower pH in lakebed sediment (mean 5.7 to 6.5) (Drozdowski et al 2012, Naeth and Wilkinson 2014). Alkaline soils, however, increase the update of molybendum and selenium (Chaney 1994).

### 4.3 Potential For Bioaccumulation

Higher accumulation of metals in wildlife tissue with age are generally hypothesized to be due to ongoing consumption of plants (Crete et al 1989, Parker and Hamr 2001, Roubillard et al 2002, Pedersen and Lierhagen 2006). Only a few studies have directly investigated the relationship between forage or browse metal concentrations and those in tissue of wildlife that consume them. Tissue from elk (*Cervus canadensis*) and browse species were analyzed for cadmium, cobalt, chromium, copper, iron, lead, nickel and zinc near a nickel and iron mine in northern

Ontario. Relative to a reference site, nickel and iron were elevated in browse, although values were much lower than in our study. Researchers found higher concentrations of cadmium and iron in tissue of adult elk than juvenile elk and attributed this increase to dietary sources based on their work and that of others studying cervids. They concluded histological exams were necessary to determine if metal concentrations were detrimental to elk. In Lapland, the range of metals at elevated levels in caribou forage near a mine were the same ones as those found in caribou tissue in the region (Eriksson et al 1990). Metal uptake was plant species and/or group specific. The authors conclude there was no implied health hazard even though some concentrations were high.

Cadium concentrations in arctic hare liver and kidney tissue near a mine in Nunavut were strongly correlated with soil concentrations and researchers propose the likely pathway of exposure was through diet (Amuno et al 2016). This may not be true for all metals such as those that have reduced mobility in soils by binding with organic matter or soil particles. Concentrations of cadmium in soil (0.2 to 6.2 mg $kg^{-1}$) and tissue (0.1 to 1.9 mg $kg^{-1}$) were greater than for the reference site, but were not considered to result in significant pathological changes. Effects on wildlife may be indirect as excessive cadmium has been reported to change willow ptarmigan behaviour, which in turn increased predation (Pedersen and Saether 1999).

There are no published guidelines for metal concentrations in plant tissue. Guidelines for metals in human and livestock food and water focus primarily on cadmium, lead and mercury, as these metals are known to be highly toxic (World Health Organization 1995, National Research Council 2005, European Commission 2006). The Canadian Food Inspection Agency (CFIA) routinely analyzes animal feed and forages for metal contaminants of concern. Action levels, a concentration at which if exceeded may present a health risk, have been established for aluminum, arsenic, cadmium and lead; chromium is considered of concern although does not have an action level and is assessed on a case by case basis. Action levels are presented in Table 2. Some lakebed sediment plant samples exceeded Canadian Food Inspection Agency action levels for aluminum and cadmium for horse consumption and some processed kimberlites samples for cadmium only.

Metal concentration thresholds for wildlife species in the north have not been widely established. Extrapolating data from non arctic species is not recommended due to significant differences in environmental conditions which cause much uncertainty in data (AMAP 2005). Reliance on livestock data, which is more abundant than that on wildlife, therefore may be an unreliable approach. There are a few guidelines for marine life but the applicability of these guidelines to terrestrial organisms is unknown. Aquatic organisms are reported to be more sensitive to pollutants and differences in feeding habits and physiology can affect accumulation. AMAP (2005) reports that ground squirrels accumulate heavy metals in the arctic, however, at less than 1 mg $kg^{-1}$ weight basis (ww), concentrations of arsenic, cadmium, mercury, nickel and lead were below toxicity thresholds. Caribou tissue concentrations of cadmium and lead were also below terrestrial mammal thresholds (cadmium 40 to 100 mg $kg^{-1}$ ww, lead 2 to 15 mg $kg^{-1}$ ww). Small rodents may be most at risk as they consume soil invertebrates which are known to be sensitive to soil metal concentrations.

## 5. SUMMARY, CONCLUSIONS AND RECOMMENDATIONS

This is a preliminary study, the sample size was small and growing conditions were controlled. Results of this study show that plants uptake some metals from processed kimberlite and lakebed sediment. Uptake by *Agropyron pauciflorum* of chromium, cobalt and nickel was not different from that of the reference potting soil, suggesting these metals are not of concern. High substrate concentrations did not necessarily result in high plant uptake. The limited association between substrate and plant tissue metal concentrations for the 33 metals analyzed suggest that substrate concentrations are not an effective method for predicting trace metal accumulation in plants. Uptake by plants was greater when plants were larger and healthier and was dependent on metal species. Few guidelines for maximum metal concentrations in plant tissue exist and none specifically exist for wildlife forage. Although some processed kimberlite and lakebed sediment plant samples exceeded Canadian Food Inspection Agency action levels for aluminum and cadmium for horse consumption, the applicability of these guidelines to wildlife is not well understood. Even if processed kimberlite and lakebed sediment are sources of some metals of concern, the reclamation area is small relative to the ranges of caribou and would contribute a very small percent of an animal's daily forage. Small mammals may rely more heavily on reclamation plant species on East Island for forage.

It is not possible from this research to directly determine if the reported metal concentrations in *Agropyron pauciflorum* could result in bioaccumulation in herbivores such as arctic hares, ground squirrels and caribou. Bioaccummulation varies with amount of plant biomass that is consumed on a daily basis and with wildlife species (eg Gamberg and Scheuhammer 1995) and the consumed plant species (eg Parker and Hamr 2001). Implications for wildlife health and for human consumption and health via the food web are even more complex, as where in the organism (muscle or organs) metals accumulate can vary with wildlife and with metal species. Northern contaminant research to date has focused on concentrations and trends of accumulation in wildife, with few studies on biological effects of contaminant exposure (Fisk et al 2005). Recent research suggests that lichen, as the main component of the caribou winter diet, may have a greater impact on metal bioaccumulation in their tissue in the Canadian arctic than spring forage (Crete et al 1989, Larter and Nagy 2000). Pedersen and Lierhagen (2006) suggest that while individual metal concentrations may not constitute a risk, the combined concentration of metals may.

Further research is recommended to confirm the range of metals and concentrations plants uptake from reclamation substrates and then to assess the potential risk to wildlife who consume this vegetation. Research needs to consider more species of plants due to variability of uptake. Collection and analysis of plant samples from aready established sites, that have well established vegegetation cover, will ensure sufficient biomass and diversity of species and provide confirmation of the range of metals and relative concentrations relative to plants growing in natural soils. Collection of plant tissue samples from amended and unamended substrates is recommended as sewage sludge and waste water treatment sludge previously used in reclamation research contain metals, including mercury, which could be taken up by plants on reclamation sites. Plant tissue analyses will narrow the list of metals that are present and at elevated concentrations; however, concomitmant studies on metals in tissue of wildlife species of interest, particularly small mammals, must be conducted to conclude if metals in plants are a concern for wildlife and potentially human health.

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Table 1. Select metal concentrations (mg $kg^{-1}$) in reclamation substrates composed of processed kimberlite, lakebed sediment and combinations of the two diamond mine by products.

| Substrate | Aluminum | Arsenic | Barium | Boron | Cadmium | Chromium | Cobalt | Copper | Lead | Nickel | Selenium | Zinc |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Processed kimberlite | 10,313 (311) | 3.12 (0.40) | 789 (33) | 10 (0) | 0.16 (0.01) | 483 (19) | 77 (1) | 29.13 (1.60) | 4.72 (0.11) | 1363 (23) | 0.34 (0.01) | 9.50 (0.26) |
| 75:25 | 10,637 (1143) | 3.60 (0.38) | 678 (77) | 9 (1) | 0.13 (0.01) | 419 (47) | 75 (8) | 27.57 (3.11) | 4.63 (0.46) | 1300 (130) | 0.23 (0.07) | 9.23 (0.97) |
| 50:50 | 10,167 (448) | 4.53 (0.20) | 400 (25) | 7 (0) | 0.08 (0.00) | 248 (12) | 49 (3) | 22.33 (1.24) | 3.73 (0.16) | 819 (46) | 0.10 (0.00) | 7.80 (0.36) |
| 25:75 | 12,000 (1124) | 6.63 (0.47) | 306 (37) | 7 (1) | 0.08 (0.01) | 176 (20) | 32 (4) | 25.47 (2.52) | 4.16 (0.29) | 448 (70) | 0.10 (0.00) | 8.40 (0.80) |
| Lakebed sediment | 13,100 (100) | 7.53 (0.43) | 110 (2) | 7 (0) | 0.07 (0.00) | 52 (0) | 11 (0) | 23.13 (0.23) | 3.63 (0.03) | 35 (1) | 0.10 (0.00) | 7.93 (0.18) |
| Control | 879 (112) | 0.59 (0.09) | 32 (5) | 8 (0) | 0.08 (0.01) | 3 (0) | 1 (0) | 4.92 (0.90) | 1.95 (0.66) | 2 (0) | 0.10 (0.00) | 0.50 (0.00) |
| Undisturbed soil[1] | - | 3.15 | 61 | - | <0.50 | 26 | 5 | 13.48 | <5.00 | 18 | 0.29 | 29.33 |
| CCME guideline | - | 12 | 500 | 2 | 10 | 64 | 40 | 63 | 70 | 50 | 1.00 | 200 |
| Crustal abundance[2] | 8.23 % | 1.80 | 425 | 10 | 0.20 | 100 | 25 | 55 | 15 | 75 | 0.05 | 70 |

Number is mean $\pm$ standard error in brackets.
Mixed treatments are processed kimberlite (first number proportion by volume) and lakebed sediment (second number proportion by volume).
Reference is potting soil.
[1] Data from samples collected in 2009 at Diavik Diamond Mine.
[2] From Taylor 1964.

Table 2. Select metal concentrations in *Agropyron pauciflorum* shoot tissue (mg $kg^{-1}$ dry weight) grown in processed kimberlite, lakebed sediment and combinations of the two diamond mine by products.

| Element | Aluminum | Arsenic | Barium | Boron | Cadmium | Cobalt | Chromium | Copper | Lead | Nickel | Selenium | Zinc |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Processed kimberlite | 133.5 (50.2) | 0.08 (0.02) | 15.4 (1.0) | 5.57 (0.35) | 0.10 (0.01) | 0.87 (0.27) | 9.94 (5.32) | 6.81 (0.23) | 0.20 (0.11) | 16.00 (5.10) | 0.61 (0.01) | 9.10 (0.00) |
| 75:25 | 197.7 (135.5) | 0.27 (0.03) | 11.0 (3.7) | 7.83 (0.35) | 0.22 (0.02) | 0.77 (0.38) | 6.53 (3.89) | 11.63 (0.60) | 0.17 (0.02) | 12.40 (6.42) | 0.64 (0.08) | 19.45 (0.54) |
| 50:50 | 135.7 (47.0) | 0.37 (0.05) | 8.7 (0.3) | 7.57 (0.61) | 0.29 (0.01) | 0.42 (0.10) | 5.74 (0.69) | 13.27 (0.38) | 0.10 (0.02) | 6.73 (1.74) | 0.41 (0.03) | 18.13 (0.31) |
| 25:75 | 87.0 (12.0) | 0.38 (0.04) | 9.1 (0.7) | 7.93 (0.15) | 0.28 (0.03) | 0.27 (0.02) | 4.60 (0.12) | 12.13 (0.68) | 0.08 (0.01) | 4.16 (0.12) | 0.39 (0.03) | 20.23 (1.20) |
| Lakebed sediment | 318.3 (115.0) | 0.59 (0.03) | 16.3 (0.8) | 17.67 (3.51) | 0.25 (0.01) | 1.43 (0.05) | 8.26 (3.74) | 14.27 (0.32) | 0.35 (0.36) | 6.79 (1.0) | 0.52 (0.04) | 34.53 (1.42) |
| Control | 35.7 (32.6) | 0.38 (0.06) | 36.7 (2.1) | 5.47 (0.47) | 0.03 (0.00) | 0.07 (0.03) | 3.06 (1.13) | 5.04 (0.62) | 0.08 (0.02) | 1.89 (0.50) | bdl | 45.40 (1.80) |
| CFIA[1] | 200-1000 | 8 | | | 0.20-0.40 | | | | 8 | | | |
| NRC[2] | 200-1000 | 30 | 100-250 | 150 | 10 | 25 | 100 | 15-500 | 10 | 50-250 | 3-5 | 300-500 |

Number is mean ± standard error in brackets.
Mixed treatments are processed kimberlite (first number proportion by volume) and lakebed sediment (second number proportion by volume).
[1] Canadian Food Inspection Agency RG-8 Regulatory Guidance: Contaminants in Feed. Maximum allowable value based on total diet.
[2] National Research Council Mineral Tolerances of Animals. Maximum tolerable limit based on chronic exposure.

# APPENDIX VIII-1B

## 2016 University of Alberta Annual Research Report

# RECLAMATION OF DISTURBED SITES AT DIAVIK DIAMOND MINE

## 2016 ANNUAL REPORT

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## 1. BACKGROUND

Exploration and mining for metals and minerals has been increasing at a rapid rate in Canada and around the world. Industrial development is often occurring at a faster pace than reclamation techniques, especially in the arctic. Following their discovery in the mid 1990s, diamonds have been mined in the Canadian north, which has led to various disturbances, including removal of soil, road construction, infrastructure development and creation of waste rock piles. These activities leave areas partially or completely devoid of soil and vegetation, making them unstable, visually unappealing, vulnerable to wind and water erosion and unable to provide food or habitat for fauna.

Concerns over mining impacts on wildlife, human health and the environment have prompted government agencies to require reclamation of mining disturbances to viable and sustainable ecosystems to protect resource function and integrity. Without reclamation, these areas could take hundreds to thousands of years to recover naturally due to the harsh environmental conditions (eg short growing season, high winds, low temperature, low rainfall) (Billings 1987, Forbes and Jefferies 1999). Despite decades of research, knowledge of effective reclamation strategies for severely disturbed sites is poor. Development of innovative, cost effective and sustainable methods to reclaim disturbed land is imperative.

From 2004 to 2009, research was conducted at Diavik Diamond Mine, examining effectiveness of amendments and substrates for improving soil and native plant community development (Drozdowski et al 2012, Naeth and Wilkinson 2014). In northern environments with limited access, reclamation must maximize use of onsite waste materials and minimize use of external materials. Anthroposols are soils that have been altered or created by human activity, often during land reclamation (Naeth et al 2012). Several materials and amendments showed promise for soil building, others were less successful. Organic matter or fertilizer enhanced revegetation on some substrates. Planting native propagules was essential as native species are slow growing with low colonization rates (Drozdowski et al 2012, Naeth and Wilkinson 2014). Micro topographic variability enhanced reclamation but little quantitative research has addressed mechanisms by which it affects germination, establishment, recruitment and plant community development. Processed kimberlite contained high levels of metals including cadmium, chromium and nickel and it is not known if native plants, potential forage for wildlife, growing in this substrate uptake metals into their tissue. Research is needed to better understand the mechanisms associated with these successes and failures as they relate to ecological process development in the naturally harsh conditions and substrates of the north. Whether these changes are sustainable beyond the first few years after reclamation must be addressed, particularly whether management is required.

Assisted revegetation is a common reclamation technique to accelerate plant establishment and growth on disturbed sites. However, effective methods for arctic environments have yet to be developed, as revegetation in the north is often complicated by limited access to equipment and lack of available resources. Only a few suppliers carry native seeds for arctic and alpine species, and they are often of too small quantities and/or consist of grasses and legumes which lack the diversity necessary for large scale revegetation projects (Forbes and Jefferies 1999, Matheus and Omtzigt 2012). To develop self sustaining communities that are structurally and functionally integrated with surrounding heath-lichen tundra, new revegetation techniques are required for shrub, moss and lichen species.

Erect and dwarf shrubs provide most of the vegetation cover in many tundra communites. Shrub cuttings have potential to provide a more consistent source of plant material than seed for reclaiming large areas in a timely manner. However, methods are required to reliably root large quantities of cuttings under arctic conditions. Few comprehensive studies have rigourously tested a variety of factors for multiple shrub species to determine the most practical methods to induce root development on a species specific basis (eg Houle and Babeux 1998, Holloway and Peterburs 2009). Improved method development for shrub cuttings could be used to inform and improve current reclamation and revegetation guidelines in the north as use of shrubs is currently limited by high costs and lack of understanding of their requirements.

Cryptogamic species, mosses and lichens, are critical in northern ecosystems. Moss and lichen are important components of tundra biological crusts, regulating surface temperature and water and providing erosion control and slope stability (Gold 1998, Van der Wal et al 2001). Moss and lichen crusts may be most important early in succession with benefits in surface layers for seed and seedlings and may act as nurse species, directly facilitating later communities (Gold 1998, Forbes and Jeffries 1999, Bowker 2007). They are important indicators of ecosystem health whose presence or absence can indicate level of disturbance, hydrologic regime, acidity and nutrient concentrations (Gignac et al 1991, Forbes 1994). They provide critical habitat and forage for northern fauna, including birds, rodents and caribou (Batzli and Sobaski 1980, Thompson and McCourt 1981). Mosses and lichens are of cultural importance; First Nations have been using them for thousands of years (Andre and Fehr 2002). Despite their significance, little is known about revegetation methods.

## 2. RESEARCH GOAL AND OBJECTIVES

The goal of this research program is to build on past research to develop methods to reclaim disturbed sites at Diavik Diamond Mine in the Canadian subarctic. The program has three focus areas: patch revegetation to maximize limited resources such as micro sites and organic matter; native shrub, moss and lichen propagation to build diverse plant communities for wildlife food and habitat; and long term monitoring of reclamation success. Results from reclamation research over the past decade, at Diavik Diamond Mine and other disturbed sites such as oil sands and limestone quarries, will add to the collective findings and expedite results at Diavik.

### 2.1. Development Of Anthroposols For Revegetation

The objective of this research program component is to develop suitable reclamation substrates for sustainable soil and plant community development on disturbed sites at Diavik Diamond Mine. Substrates provide the foundation for plant establishment and growth and long term soil and plant community development. Research is being conducted by PhD student Valerie Miller in the field and greenhouse.

Specific objectives are as follows.

- Evaluate substrate amendment combinations for anthroposols.
- Evaluate micro topographic influences on revegetation.
- Evaluate short term management options for erosion.
- Evaluate amendments for potential to enhance soil water content and retention.
- Evaluate plant uptake of metals from processed kimberlite used as a reclamation substrate.
- Elucidate mechanisms by which ecosystem development triggers and trajectories are influenced by reclamation choices of substrate, management and plant species selection.

### 2.2. Development Of Plant Material For Revegetation

The objective of this research program component is to develop and improve methods for collection, propagation and dispersion of native shrub, moss and lichen species for revegetation of disturbances at Diavik Diamond Mine. Research is being conducted by PhD student Sarah Ficko and MSc student Jasmine Lamarre in growth chambers and in the field.

Specific objectives are as follow for shrubs

- Evaluate time of collection on shoot and root development.

- Evaluate soaking length and rooting hormones on shoot and root development.
- Evaluate willow water and smoke water on shoot and root development.
- Evaluate the ability of shrub cuttings to develop and survive in reclamation substrates.
- Develop recommendations for reclamation methods to improve shrub establishment.

Specific objectives are as follows for biological crust (lichen and moss).

- Evaluate growth media for common lichen and bryophyte species.
- Evaluate propagation techniques for lichen and bryophyte establishment and growth.
- Evaluate erosion control material effects on lichen and bryophyte establishment and growth.
- Recommend collection and propagation techniques for lichens and mosses for reclamation.

### 2.3. Long Term Development of Reclaimed Communities

2014 marked ten years since reclamation plots were established at Diavik Diamond Mine as part of a long term research program. The research site was last monitored in 2009, providing sufficient time for significant changes in soil and plant communities. Five years after reclamation, major changes in soil properties and plant abundance and diversity occurred. At the last monitoring, many reclamation treatments were on a trajectory to a self sustaining tundra community, while others were in arrested successional stages and the likelihood of further significant changes was low (Drozdowski et al 2012, Naeth and Wilkinson 2014).

Assessing and quantifying long term ecosystem development trajectories will enhance the knowledge base for northern reclamation and facilitate assessment of reclamation sustainability. Specific objectives of this research program component are to determine if best performing treatments five years after reclamation are still best after ten years, if plant abundance and diversity are increasing, if phytotoxic soil properties are being ameliorated, and if a soil biological crust is developing and evolving.

## 3. RESEARCH ACTIVITIES IN 2016 AND PRELIMINARY RESULTS

### 3.1. Development Of Anthroposols For Revegetation

#### 3.1.1. Greenhouse experiments

The first greenhouse experiment was conducted in 2013 to assess effectiveness of substrates and substrate amendment combinations for plant establishment and growth. A manuscript was submitted to the Canadian Journal of Soil Science in November 2016 following review by Diavik. The primary issues identified for successful use of waste materials in reclamation were substrate structure, metals and lack of nutrients. Crushed rock and processed kimberlite had little fine material and lakebed sediment was compacted. Processed kimberlite and sewage had metal concentrations (barium, chromium, cobalt, copper, molybdenum, nickel, selenium and zinc) above guidelines. Vegetation established on all combinations of substrates and amendments, with plant growth and density greatest with crushed rock, followed by 25 % processed kimberlite with 75 % lakebed sediment and 100 % lakebed sediment. The long term suitability of these substrates is uncertain without addition of organic amendments. Substrates amended with peat and/or soil had greatest plant density and below ground biomass; substrates amended with sewage and sewage/soil had greatest above ground biomass. Amendment selection depends on the final reclamation goal, whether high plant density or large plants are desired. Fertilizer had a limited effect on plant growth and no effect on plant density. Site waste materials can support plant establishment and growth especially when combined with organic amendments. These can be used to select appropriate organic amendment addition based on characteristics of waste materials on site and amendment availability.

The second greenhouse experiment comprised three small scale water holding capacity experiments. The first two investigated hydrogel application to reclamation substrates and its effects on maximum water holding capacity and water retention; the third assessed ability of organic amendments and hydrogel to increase soil water content and retention. These experiments were completed in fall 2014; in 2016 data analyses began. Preliminary results show processed kimberlite held most water and crushed rock and lakebed sediment were similar (Figure 1). Higher water application rates resulted in greater water retention. Hydrogel application method influenced water retention with dry substrates more successful than wet substrates or no hydrogel (Figure 2). Amendment addition improved water retention with wet hydrogel most successful, followed by peat and dry hydrogel (Figure 3).

In 2016, no further work on the third greenhouse experiment to assess vegetation response under water limited conditions was conducted. Results of this experiment are being analyzed and a manuscript is under development.

### 3.1.2. Field experiments

The primary field experiment was established in 2013 and 2014 on the old magazine storage site at Diavik Diamond Mine to examine the role of micro topography, erosion control and amendments in developing substrates to enhance and sustain native plant species. In 2016, the experimental plots were assessed during the last two weeks of July and the first week of August; this is the third year of assessment. Species density, health, physiological stage, height and cover were assessed in 0.75 x 0.75 m quadrats. Cover was visually assessed as live, dead, moss and lichens, litter, bare ground and rocks. Evidence of wildlife use such as feces, tracks and chewed plants was recorded. Three soil samples were taken from each treatment and reference tundra to a depth of 10 cm for characterization. Samples were submitted to a commercial laboratory and analyzed for pH, electrical conductivity, cation exchange capacity, total and organic carbon, total nitrogen and texture using standard methods of the Canadian Soil Science Society (Carter and Gregorich 2008).

Data analysis is currently underway. Field observations from summer 2016 show similar results to previous years. Crushed rock had the most plants followed by lakebed sediment, then processed kimberlite with plants only in low areas (Photos 1, 2, 3). Plants appeared to grow larger and more densely in depressions and furrows; sewage resulted in greatest plant cover and density (Photo 4). Soil Lynx had no observable plant response. Processed kimberlite plots had significant erosion, with depressions and furrows filling and mounds flattening (Photo 5). Valerie presented a poster on preliminary results from this experiment at the Circumpolar Student Association Northern Research Day at the University of Alberta, 30 March 2016.

The small scale field experiment established in 2014 to examine erosion control methods was assessed for the second year in early August 2016. Treatments were Soil Lynx™, jute treated with Soil Lynx™, Soil Lynx™ and treated jute, coconut erosion control blanket and an untreated control. Plots were 1 by 1 m on substrates processed kimberlite, lakebed sediment and crushed rock. Plots were seeded with six native grass species. Plots were assessed using the same methods as in the primary field experiment.

Field observations do not indicate major differences among treatments; however, erosion control blanket appears to have slightly more plants (Photo 6) potentially due to greater plant protection. Erosion control blankets and jute in processed kimberlite plots are beginning to be buried by loose processed kimberlite. Some erosion control blankets and jute have been disturbed by animals with holes ripped in the material.

### 3.1.3. Metal assessment greenhouse experiment

In 2016 metal uptake by plants grown in processed kimberlite was assessed in plant growth facilities at the University of Alberta. Four grass species, *Agropyron pauciflorum* (slender wheat grass), *Poa glauca* (glaucous blue grass), *Agrostis scabra* (tickle grass) and *Deschampsia caespitosa* (tufted hair grass), were used for this study. The species are native to subarctic tundra and commonly used in reclamation; two are known to be tolerant of adverse soil chemistry (*Agrostis scabra* and *Deschampsia caepitosa*). A forb was not chosen for inclusion as a goal was to obtain sufficient plant biomass for laboratory analyses in 8 to 12 weeks. Forbs are often slower growing and produce less biomass than grasses. Germination tests were conducted in the laboratory prior to seeding pots as the basis for seeding rates.

Substrates were processed kimberlite, 75 % processed kimberlite with 25 % lakebed sediment, 50 % processed kimberlite with 50 % lakebed sediment, 25 % processed kimberlite with 75 % lakebed sediment and lakebed sediment. Commercial potting soil was used as a control. Mixes were included as they are more plausible reclamation scenarios, since plant growth in pure processed kimberlite has consistently been poor in the field and under ambient conditions. Each species and substrate treatment was replicated eight times.

Soil was analyzed to determine the source of any metals in plant tissue. Substrates were sampled at the beginning of the experiment and submitted to a commercial laboratory for metal determination. Samples were digested with nitric and hydrochloric acids, followed by analysis by collision reaction cell inductively coupled plasma mass spectrometry (Environmental Protection Agency 200.2/6020A).

Greenhouse conditions were 21 $^{o}$C with a 16 hour photoperiod. Pots were watered to maintain approximate field capacity for 12 weeks. Many pots did not have sufficient biomass after 12 weeks; however, there had been no new growth within the past 2 to 3 weeks and in some treatments plants were showing signs of stress. Above ground plant biomass was collected from each pot by clipping as close to the substrate surface as possible. Biomass from each species and treatment combination was combined and air dried for 48 hours. Three composite samples of equal dry weight were created for each species and treatment combination. In some treatments and/or for some species there was insufficient biomass for more than one sample; specifically for most species grown in processed kimberlite alone, except *Agropyron pauciflorum*, and any treatment for *Poa glauca*.

Thirty samples of sufficient volume for analyses were produced, including three replicates from each substrate for *Agropyron pauciflorum* (18 samples). The remaining samples were mixes of biomass from the other three species. Samples were analyzed for aluminum, antimony, arsenic, barium, beryllium, bismuth, cadmium, chromium, cobalt, copper, iron, lead, lithium, magnesium, manganese, molybdenum, nickel, phosphorus, potassium, selenium, silver, sodium, strontium, thallium, tin, titanium, uranium, vanadium, zinc and zirconium concentrations. Tissue samples were homogenized and sub-sampled prior to hotblock digestion with nitric and hydrochloric acids, with addition of hydrogen peroxide (Environmental Protection Agency 200.3). Instrumental analysis is by collision cell inductively coupled plasma mass spectrometry (modified from Environmental Protection Agency 6020A) (Austin 2015).

Results for select metals in reclamation substrates are presented in Table 1. Silver and tin were below detection limits in all samples. Antimony was below detection limits in all samples except processed kimberlite alone; selenium in all samples except processed kimberlite alone and 75 % processed kimberlite with 25 % lakebed sediment, and bismuth in all samples except lakebed sediment alone. Metals with Canadian Council of Ministers of Environment (CCME) soil quality guidelines were below values of concern in most substrates. Boron, chromium and nickel were consideraly higher in all substrates except lakebed sediment and reference soil. Barium and cobalt was higher than CCME guidelines in processed kimberlite and 75 % processed kimberlite with 25 % lakebed sediment. Relative to lakebed sediment, processed kimberlite had considerably higher (at least two fold) concenrations of barium, calcium, chromium, cobalt, iron, magnesium, maganese and strontium.

Reciept of laboratory results for plant tissue were delayed due to the complexity of the samples and small volumes. The results are expected to be provided by the end of 2016 and a summary will then be provided to Diavik by 31 January 2017.

### 3.2. Development Of Plant Material For Revegetation

#### 3.2.1. Shrub cutting experiments

Growth chamber experiments were conducted to investigate methods to accelerate root initiation and development on cuttings from eight dominant tundra species at Diavik procured at different times of year. Cuttings were collected in 2013, 2014 and 2015 for two experiments. In experiment 1, cuttings from each species were collected in summer, fall or spring, and treated with one of six soaking lengths (0, 1, 3, 5, 10, 20 days) and one of four rooting hormone concentrations (0, 0.1, 0.4, 0.8 %), prior to planting in commercial potting soil. In experiment 2, cuttings were collected in summer and fall, and treated with one of four rooting hormone concentrations (0, 0.1, 0.4, 0.8 %), one of three concentrations of willow water (1/2x, x, 2x), or one of three dilutions of smoke water (1, 1:10, 1:20). Cuttings were assessed for shoot health after 30 and 60 days and for number of roots and root growth patterns after 60 days.

Data analyses were conducted in 2016 to determine trends and patterns in root initiation and development to improve revegetation success. Preliminary results indicate all species have capacity to develop roots and there are species specific factors, including time of year, influencing rooting behavior (Figure 4). Sarah Ficko presented preliminary results from this research at the Canadian Land Reclamation Association conference in Timmins Ontario in June 2016 and at the Land Reclamation International Graduate School Lecture Series in Edmonton.

### 3.2.2. Biological soil crust experiments

A field experiment was established in summer 2014 to investigate methods of dispersing and containing biological soil crust material when transplanted onto crushed rock, lakebed sediment and processed kimberlite. In 2016, research plots were assessed for the second year. Data analyses are currently being conducted to determine differences between treatments over time. From field observations, plots with jute appeared to have a more even distribution of lichens (Photo 7). Lichens from most species had blown onto control plots (small quantities). Micro topography is likely an important factor in retention of lichens and biological soil crust material on all substrates but especially those with less micro topographic variability such as processed kimberlite (Photo 8). Plots with erosion control blanket alone had lichens mostly in dips and not on any bumps. Lichens were frequently associated with tundra soil, when present, even if some had blown away and were often observed around the rock borders of the plots. For the biological soil crust growth chamber experiment completed in 2015, data exploration and preliminary analyses were conducted in 2016.

### 3.2.3. Biological soil crust multiple field site experiment

Jasmine Lamarre completed her graduate student program in winter 2016. Below is a summary of her research findings. Results and recommendations for reclamation will be included in the final report for the research program.

Research was conducted in the laboratory and in the field at Diavik and Heiðmörk Iceland to address the need for use of bryophytes in reclamation of northern ecosystems. Research objectives were to determine effectiveness of bryophyte fragment size (small < 1 mm, medium < 2 mm, large < 40 mm), slurry mixtures (beer, buttermilk, water) and cheesecloth as an erosion control material in promoting bryophyte regeneration and revegetation. Research was conducted on substrates of crushed rock, lakebed sediment and processed kimberlite at Diavik and road material and plateau material at Heiðmörk. Capacity of bryophyte species for effective propagation and the influence of different environments on reclamation success were assessed.

Results of the two experiments showed that in the short term (12 weeks in laboratory, 2 growing seasons in field), fragmentation promoted bryophyte growth. Medium bryophyte fragments produced higher density and cover than small or large fragments in the laboratory and highest density, species abundance and species diversity when in direct contact with soil in the field. Large fragments were less susceptible to effects of wind and rain and yielded higher total and live cover. Greater live cover was likely due to greater retention of material on the substrates.

Erosion control material effects on bryophyte cover and species abundance was positive, varying with substrate and climate. At Heiðmörk, erosion control cloth frayed after one growing season, likely due to wind and jagged substrates. At Diavik, erosion control cloth remained intact and had a positive effect on bryophyte retention and propagation. The most striking effect was promotion of colonization under the cloth in all but one substrate. This was likely due to the minimization of wind erosion and reduced variability of soil water content and temperature. Erosion control material had a tempering effect on soil volumetric water content and temperature, narrowing ranges of recorded values. Early stage cloth decomposition was observed after two growing seasons in three of five substrates.

Slurry significantly impacted bryophyte propagation. Beer and water had higher bryophyte cover and density than buttermilk, although buttermilk generated considerable protonemal growth by week 12. Beer and water did not differ significantly; thus beer is not recommended for large scale bryophyte propagation in reclamation. Slurry effect was stronger early in the experiment, indicating more importance for short term propagation than long term reclamation success.

Substrates with more heterogeneous surfaces (crushed rock at Diavik; plateau and road at Heiðmörk) had greater live cover, volume retention, density and spontaneous colonization of bryophytes. More material was retained in erosion control material on relatively homogeneous substrates (processed kimberlite, lakebed sediment at Diavik), due to better contact between material and soil particles. However, retained material did not yield much regeneration. Results of an observational turf transplantation experiment were inconclusive, as it was only replicated on an unfavourable substrate.

Environment invariably impacts reclamation outcomes. The factors that had the most impact on experiment results were climate related. Regeneration (live cover and density of new individuals) was higher at Heiðmörk, where there is more precipitation and less variation in temperature. Retention of planted material was higher at Diavik, where wind speeds were lower. These factors considerably impacted the outcome of fragment sizes, due to their impact on material displacement and bryophyte species specific regeneration requirements.

### 3.3. Long Term Development Of Reclaimed Communities

Data analyses were conducted in 2016 and a manuscript is currently being prepared for a peer reviewed journal. Anticipated submission date is March 2017 following Diavik review.

## 4. RESEARCH PLANS FOR 2017

2017 is the final year of the research program and the focus will be on analyzing remaining data from all greenhouse and field experiments. With these results we will prepare the final report, which includes conclusions and recommendations for reclamation and future research at Diavik Diamond Mine, to be submitted to Diavik by 31 December 2017.

Valerie Miller will collect soil water and temperature data from the HOBO data loggers on site in June. This will provide her with fall and spring data which are critical to understanding plant establishment and survival. Once plant tissue metal results are received from the laboratory a summary will be provided to Diavik by 31 January 2017. Based on results of these analyses, plant tissue may be collected from the same species in the plots established in 2004 and/or 2014 on weathered fine processed kimberlite. Once known if there is uptake, these samples could provide an understanding of the period of time over which metal uptake from processed kimberlite may remain an issue.

There is no further anticipated field work as part of this research program unless during data analyses it is determined minor follow up assessments or sample collection would be beneficial and then this would be conducted in summer 2017. We encourage continued assessment of the field research plots as from previous work at Diavik, much ecological change can occur beyond two years. In the north, two years is just the establishment phase for native plants. Longer term data are not available for mine disturbances in the north, although collection of this type of data is inexpensive and timely. Besides simple yet informative measures of plant community development, measures of soil development, in particular biological parameters, can further inform Diavik's reclamation program.

From all components of the research program, manuscripts will be prepared and submitted to peer reviewed scientific journals, following review by Diavik. A manuscript from the long term development of plant communities component of the research program will be completed and submitted to a peer reviewed scientific journal by end of March 2017. At least an additional two manuscripts will be submitted by end of 2017 with the remainder in 2018.

Valerie will complete her PhD program in early 2018. Sarah is expected to complete her PhD program at the end of 2018. Copies of both dissertations will be provided to Diavik once they are completed and approved by the University of Alberta.

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Table 1. Select metal concentrations (mg $Kg^{-1}$) in reclamation substrates.

| Substrate | Barium | Boron | Chromium | Cobalt | Nickel |
|---|---|---|---|---|---|
| Processed Kimberlite | 789 (57) | 10 (1) | 483 (32) | 77 (2) | 1363 (40) |
| 75:25 | 678 (134) | 9 (2) | 419 (81) | 75 (14) | 1300 (226) |
| 50:50 | 400 (44) | 7 (0) | 248 (21) | 49 (4) | 819 (79) |
| 25:75 | 306 (63) | 7 (1) | 176 (35) | 32 (8) | 448 (121) |
| Lakebed Sediment | 110 (3) | 7 (0) | 52 (0) | 11 (0) | 35 (2) |
| Reference | 32 (9) | 8 (1) | 3 (1) | 1 (0) | 2 (1) |
| CCME Guideline | 500 | 2 | 64 | 40 | 50 |

Number is mean ± standard deviation in brackets.

Mixed treatments contain processed kimberlite (first number proportion by volume) and lakebed sediment (second number proportion by volume)

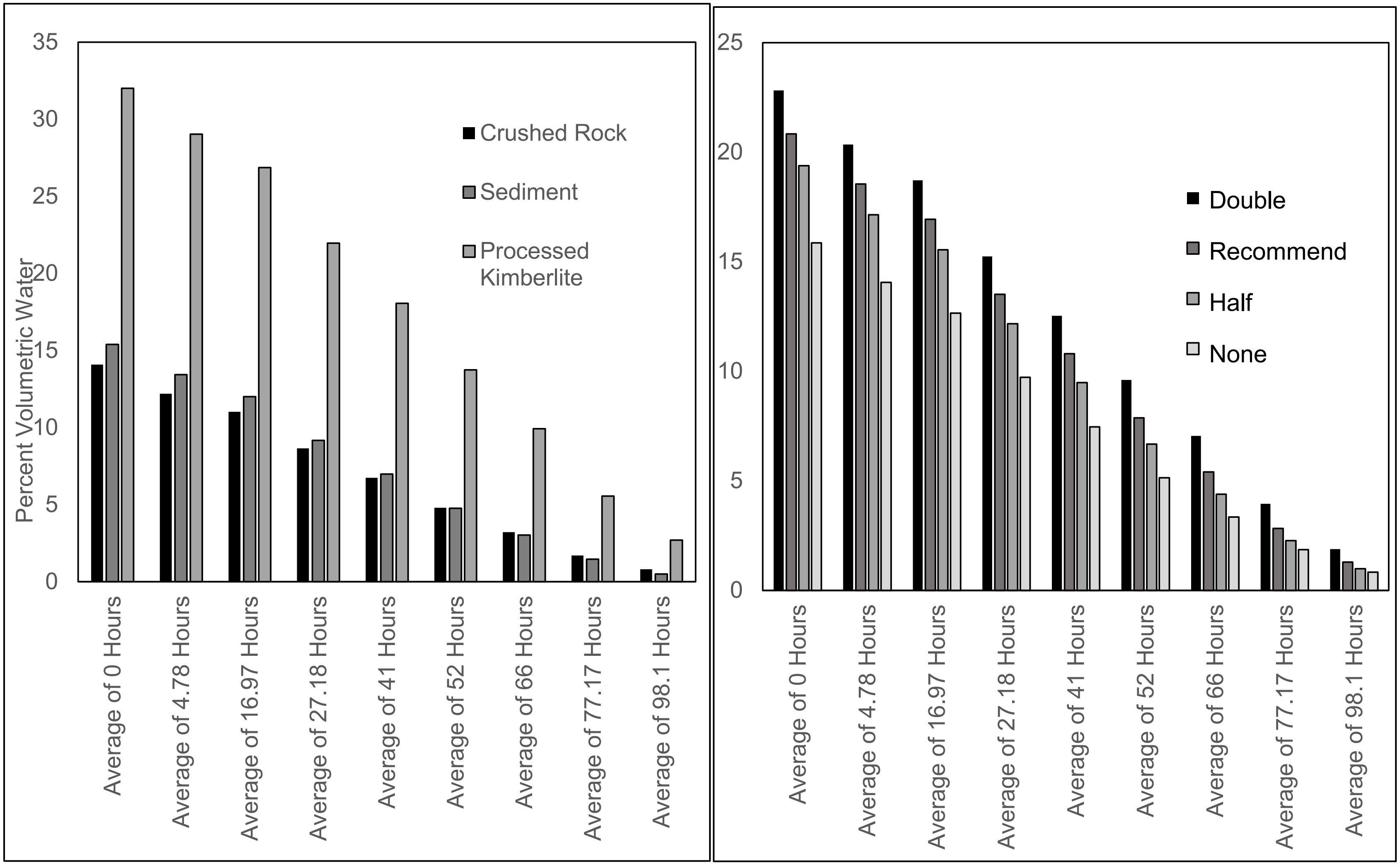


Figure 1. Volumetric water content by substrates (left) and application rate (right).

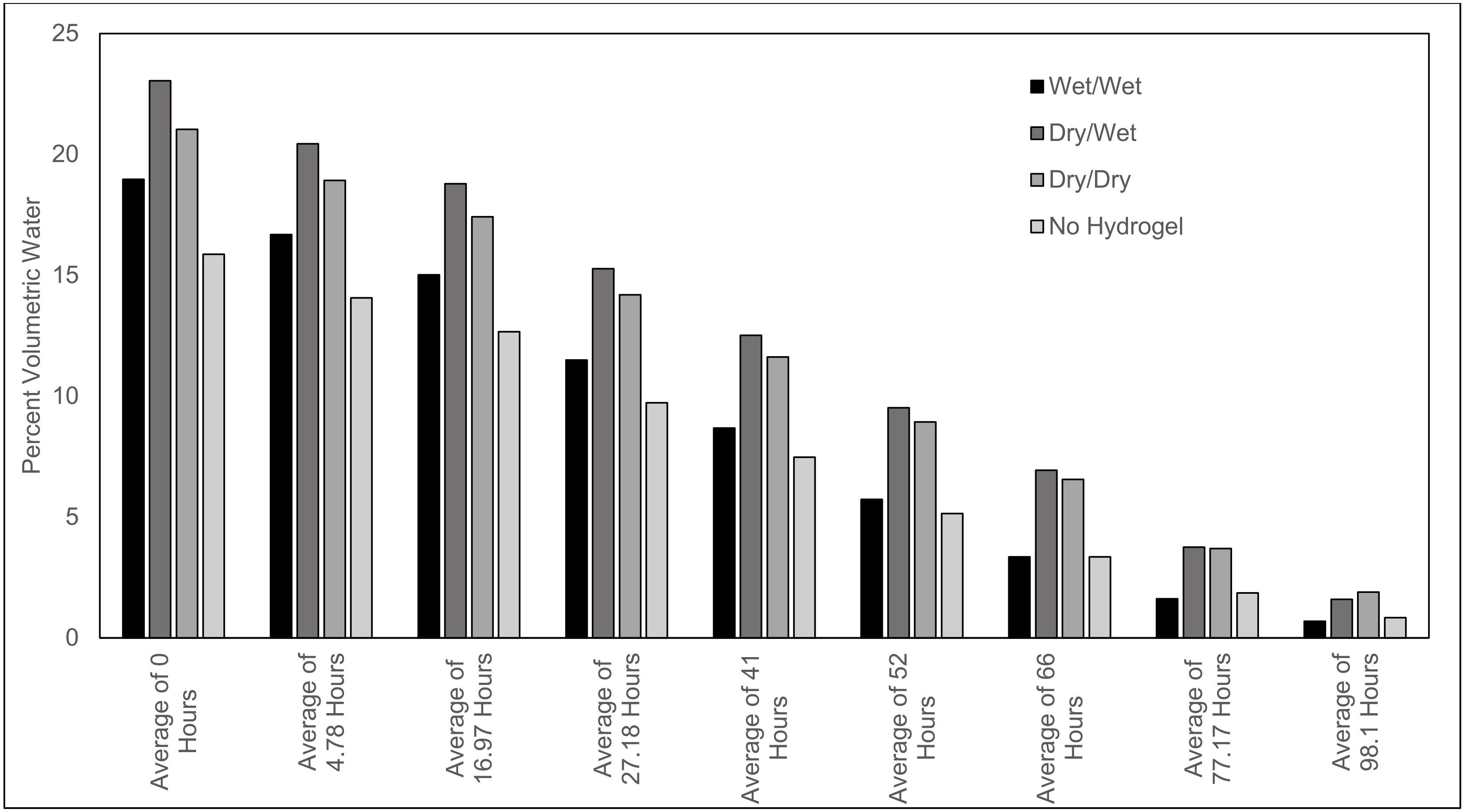


Figure 2. Effect of application method on water retention.

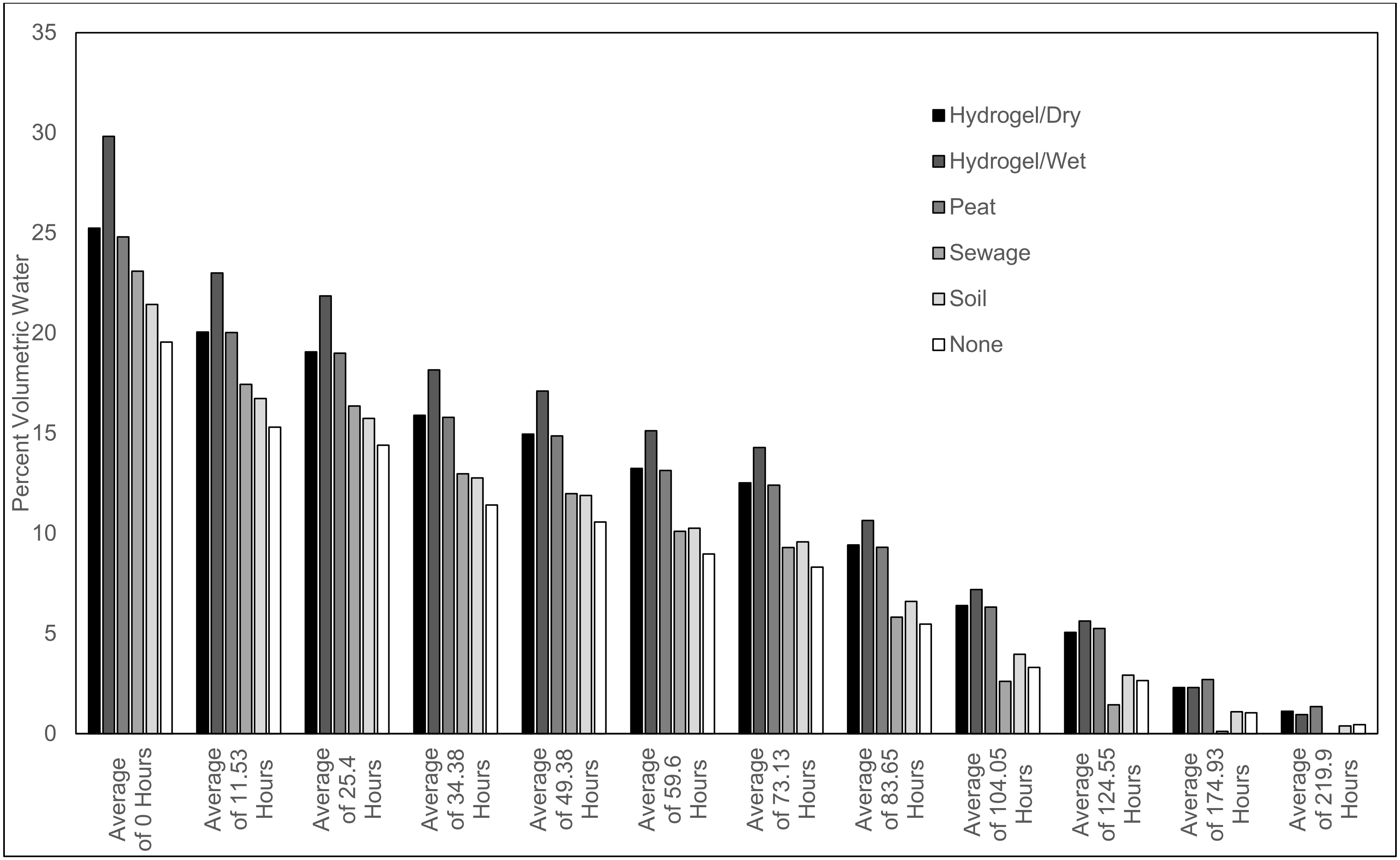


Figure 3. Volumetric water content for organic and hydrogel amendments.

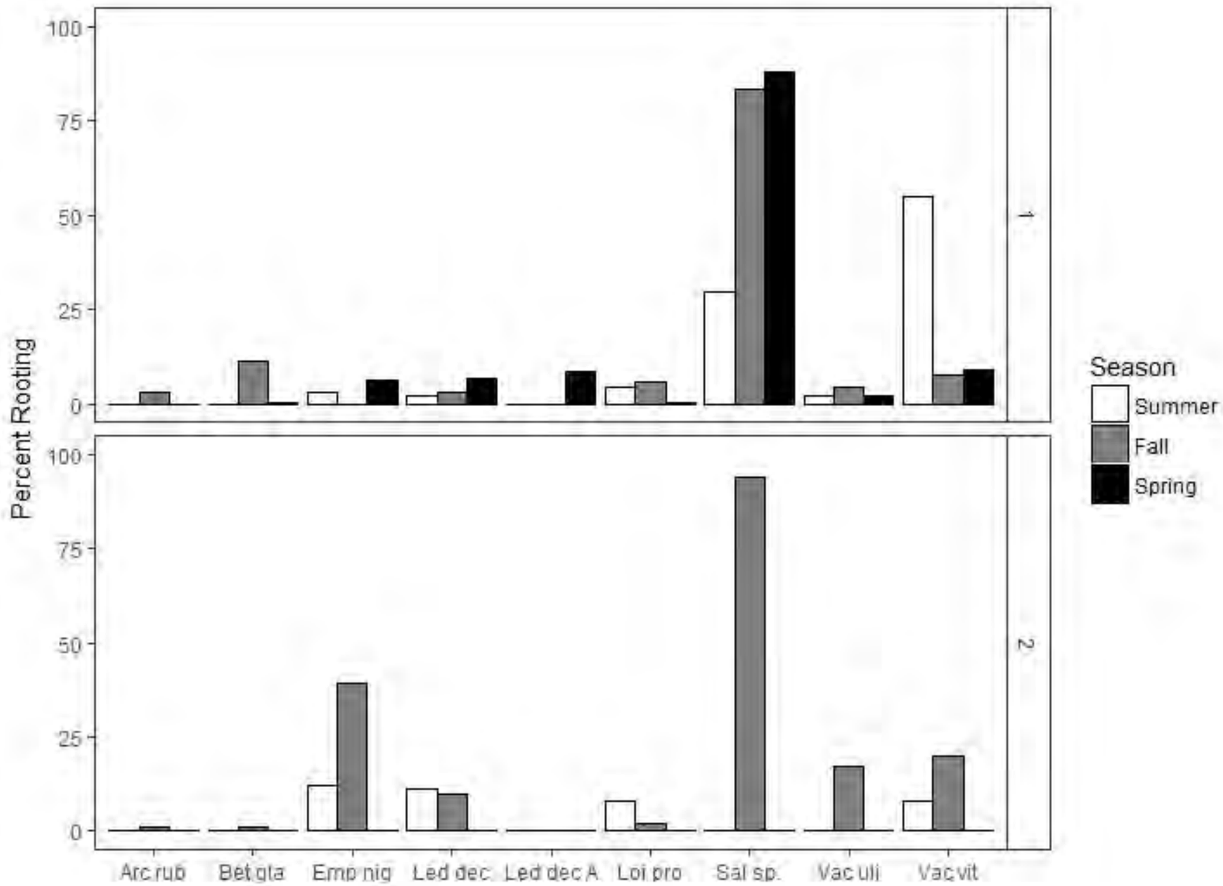


Figure 4. Cuttings that rooted after 60 days for summer, fall and spring collections across treatments. Arc rub = Arctostaphylos rubra, Bet gla – Betula glandulosa, Emp nig = Empetrum nigrum, Led dec = Ledum decumbens, Loi pro = Loiseleuria procumbens, Sal sp = Salix species, Vac uli = Vaccinium uliginosum, Vac vit = Vaccinium vitis idaea.

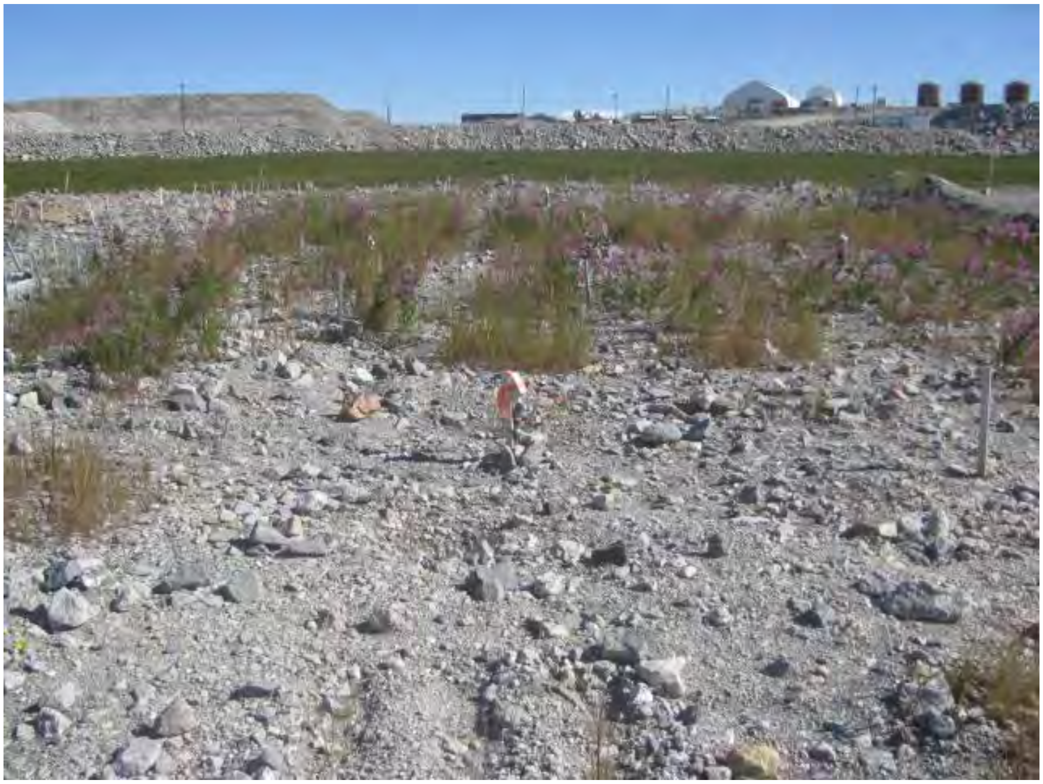
Photo 1. Good plant growth in crushed rock.


Photo 2. Moderate plant growth in lakebed sediment.

Photo 3. Limited plant growth in processed kimberlite.

Photo 4. Abundant growth in low parts of furrows in crushed rock.


Photo 5. Furrows almost completely eroded in processed kimberlite.


Photo 6. Plant growth on erosion control blankets.

Photo 7. Good retention of lichen and soil biological crust with jute and erosion control blanket.

Photo 8. Lichen and soil biological crust research plots on processed kimberlite.

# APPENDIX VIII-2

## Reclamation Research Plan V2

# Appendix VIII-2 Introduction

## 1. Introduction

This Appendix contains Version 2.0 of the Diavik Closure and Reclamation Research Plan. Appendix VIII-1 provides a summary table with the status of research tasks identified in Version 1.1 of this research plan along with references for where results have been documented.

Within the remaining three years before the Final Closure and Reclamation Plan is to be submitted (W2015L2-0001 Part K Item 7) DDMI will focus on completing research in three areas:

- PKC Geochemistry (Research Topic 4.2)
- Prediction of final water quality in flooded pit area (Research Topic 2.4)
- Re-vegetation procedures (Research Topic 6.1 and 6.4)

Research Plan Version 1.1 included Traditional Knowledge and Community Engagement as a research area. While this work will continue, including continued sessions with the TK Panel, this has not been included as a research plan in Version 2.0. DDMI will instead continue the current practice of working with the TK Panel to identify focus areas collaboratively between DDMI and the TK Panel. DDMI will continue to report outcomes from TK Panel and community engagement in the Annual Closure and Reclamation Plan Progress Reports and ultimately within the Final Closure and Reclamation Plan.

# Research Area: Open Pit, Underground and Dike Area Reclamation Research Plan

## 1. Uncertainty

Final water quality in the flooded A418, A154 and A21 pits were calculated to be similar to Lac de Gras water quality (Blowes and Logsdon 1998) based on information available at that time. Final water quality was governed by the water quality of Lac de Gras because the very large volume of this water reduced any influence from other contributing sources. The other contributing sources are primarily groundwater inflow and geochemical loading from the exposed pit wall surfaces and underground mine workings. Refinements have been made to estimates of geochemical loading and preliminary modelling and design of the flooding methods completed. Mathematical modelling is required to describe the expected water quality conditions that will remain post-closure. This is the key uncertainty remaining for this closure research area.

## 2. Research Objectives

The research objective is to answer the following questions:

- What is the expected water quality of the pit and dike area a) after filling but before breaching the dikes and b) post-closure?

## 3. Overview of Tasks

### 3.1 Completed Tasks

*Initial water quality predictions*

Blowes and Logsdon (1998) predicted water quality for the flooded open pits. These initial estimates showed that the predicted water quality in the flooded pits is similar to Lac de Gras.

*Modelling of vertical mixing conditions*

Initially mathematical modelling was completed of the vertical mixing processes that are expected to drive vertical mixing conditions in the pit area post-closure. Key findings were that the depth of vertical mixing was shallow relative to the pit depths and that the surface waters (top 20 m) became very similar to Lac de Gras water quality, effectively isolating the deep water in the pit area. It appears unlikely that events would occur where deep pit water would mix with surface water.

*Ongoing monitoring of mine water inflow water quality and quantity*

Ongoing monitoring results from mine water inflows are included with the Surveillance Network Monitoring (SNP) regulatory reporting and Annual Water License Reports. Results continue to support initial estimates that show that mine inflow water will not be a significant determinant of surface water quality in a flooded pit. Ongoing monitoring will determine any changes from contact with underground mine workings, including Type III cemented backfill. Initial estimates indicate that the effect of using Type III versus Type I rock for backfill on water quality is minimal (DDMI 2010).

*Task 3.1 - Complete pit wall lithology maps*

Exposed surface areas of granite and metasediments in the A154 and A418 pit were obtained using I-Site 3D Laser Scanner to map the pit wall (DDMI 2011a and 2011b).

*Task 3.2 - Measure geochemical loading from pit wall*

Field sampling was completed to measure amounts of accumulated geochemical reaction products that can be flushed from the pit walls during final closure flooding. Results showed that Lac de Gras water dominates the final pit water quality (Smith 2013a).

*Task 3.3 Review science and possible Traditional Knowledge methods to evaluate fish use of dike exterior slopes*

*Task 3.4 Evaluate fish use of exterior slopes of A154 and A418 dikes.*

There was a lack of detectable lake trout spawning at both the dikes and adjacent unaffected habitat even though both appeared to have appropriate attributes for lake trout spawning. There does not appear to be a compelling reason for enhancing the habitat quality of the dikes (Fitzsimons 2013).

*Task 3.7 - Use model to evaluate impact of fill rate on water quality.*

Water balance modelling was conducted to estimate fill rates for flooding underground workings and open pits (Golder 2017a) with results used to complete a scoping level back-flooding design (Golder 2017b). Results indicate that it would be practical to fill both the A154 and A418 pit/underground within 6 months.

## 3.2 Remaining Tasks and Scopes of Work

Tasks 3.5, 3.6 and 3.8 from Version 1.1 of the Reclamation Research Plan (ICRP V3.2 Appendix VIII) remain. These have been combined into the following updated Research Tasks:

**Research Task 5.4 – Updated predictions of flooded pit water quality.**

Recently Dominion Diamond Corporation (DDC) completed extensive modelling of pit lake water quality, in particular the internal wind driven mixing conditions and maintenance of stratification conditions, as part of the Jay Project Environmental Assessment. DDMI intends to build from these modelling learnings and apply them to models of water quality for each of the A21, A418 and A154 pits. Estimates of initial flooded water quality will be updated by applying the results of the wall washing experiments, pit wall lithology mapping and ongoing mine water inflow and quality and quantity monitoring. A range of lake fill rate and initial groundwater fill level scenarios will be considered. The model will be configured to represent the preferred closure option for this area with consideration for use of underground/open-pit for disposal of processed kimberlite and inert building materials.

**Research Task 5.5 – Screening level risk assessment of flooded pit water quality.**

Estimates of water quality conditions in each of the flooded open-pit areas from Task 5.5 will be screened against AEMP Benchmark criteria to identify any parameters of potential concern. Outcomes from the assessment are expected to describe the extent of any closure risk to Lac de Gras from dike breaching and/or need for contingency plans.

## 4. Linkages to Other Research

This research plan builds on the results from completed tasks described above in Section 3.1 as well as:

- Feasibility study of option to dispose processed kimberlite in completed underground and/or open-pit mine (CRP V4 – Section 5.2.6.3.5).
- Feasibility study of option to dispose of inert building material in completed underground and/or open-pit mine (CRP V4 – Section 5.2.6.3.5).
- Development of Site-Specific Risk-Based Closure Criteria (CRP V4 Appendix X-8.1 and Appendix X-8.2).
- Water quality evaluation of underground backfill (DDMI 2010).

## 5. Project Research Schedule

Projects are tracked by task. The expected task schedule is shown in Table 1.

**Table 1 Planned Project Activities**

| Year | Activities |
|---|---|
| 2018 | • Evaluate feasibility of processed kimberlite disposal in completed underground and/or open-pit mine<br>• Evaluate feasibility of inert building material disposal in completed underground and/or open-pit mine.<br>• Configure water quality model to A154, A418 and A21 areas. |
| 2019 | • Conduct modelling analysis of mine area flooding.<br>• Document |

## 6. Costs

Expected cost to complete the tasks described above is $250,000.

## 7. References


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DDMI. 2011a. *I-Site 3D Laser Scanner pit wall mapping of exposed metasedimentary (Type 3) Rock in A154.* 1 December 2011. Internal Report

DDMI. 2011b. *I-Site 3D Laser Scanner pit wall mapping of exposed metasedimentary (Type 3) Rock in A418*. 1 December 2011. Internal Report

Fitzsimons, J.D. 2013. *Assessment of the Use of Dikes at Diavik Diamond Mine Lac de Gras for Lake Trout Spawning 2011.*

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Golder. 2017a. *Description of Underground and Pit Filling Rates Estimate*. Submitted to Diavik Diamond Mines (2012) Inc. January 5, 2017.

Golder. 2017b. *Scoping-Level Back-Flooding Design Description for Interim Closure and Reclamation Plan.* Submitted to Diavik Diamond Mines (2012) Inc. January 5, 2017.

# Research Area: Processed Kimberlite Containment Area Reclamation Research Plan

## 1. Uncertainty

This research plan is designed to improve understanding of the expected geochemical performance of the Processed Kimberlite Containment (PKC) preferred closure plan. The remaining area of uncertainty is:

- quality of the water that will be released through both the design outlet and seepage; and

Completing the geochemical characterization and finalizing the preferred closure plan for the facility will permit a more accurate prediction of closure performance. A more accurate prediction will enable a more complete assessment of risks that the closed PKC facility will may pose to people, wildlife or aquatic life.

## 2. Research Objectives

The objective of this research plan is to address the following questions:

- What is the expected water quality of surface water that travels through the unsaturated PK beaches and exits the facility as seepage?
- What is the expected water quality in the engineered outlet and any seepage pathways?

## 3. Overview of Tasks

### 3.1 Completed Tasks

- Geochemical characterization of Diavik kimberlites (Blowes and Logsdon 1998);
- Sampling and instrument installation in fine processed kimberlite (FPK) for pore water chemistry characterization (Task 3.2.2.1)
- Water sample collection from standpipe piezometers (Task 3.2.2.1);
- Core sample collection for pore water sampling and mineralogical studies (task 3.2.2.1);
- FPK mineralogical characterization related to *in situ* geochemical reactions and porewater chemistry (Task 3.2.2.1);
- Porewater sampling from FPK beach sediments (core squeezing) (Task 3.2.2.1);

- Initial mineralogical evaluation of beach FPK for primary and secondary mineralogy Task 3.2.2.2).

- Multi-year sample collection from surviving/accessible standpipe piezometers (as accessible) (Task 3.2.2.1);

- Laboratory static and kinetic experiments from FPK and coarse PK (CPK)(Task 3.2.2.3);

- Construction and monitoring of six 2 m –scale field leaching experiments (ongoing) (Task 3.2.2.3); and

- Interpretation of results, including geochemical equilibrium modelling (ongoing)(Task 5.1.2.4).

Results from the completed tasks indicate that the kimberlite material contains 2-5% xenoliths of sedimentary mudstone and siltsone, with the remainder being comprised of olivine, pyroxene, and their weathering products (e.g lizardite, saponite and an amorphous magnesian-silica-aluminum phase), with lesser biotite, calcite, quartz and garnet. Whole rock analyses indicated that the kimberlite contained concentrations of Ni, Co, Cr and Mg that were higher than the country rock. The sulfide content in various PK samples had a mean of 0.34 wt. %S with most pyrite present as framboids, which can release sulfate, iron and trace metals when exposed subaerially. However, the abundant calcite (4-8 wt. %) neutralizes acidity and the PK is non- acid generating; the pH >8.5 suggest some dissolution of the mafic alumniosilicate minerals is contributing the neutralization potential.

The evaluation of PK porewater evolution is on-going but results to date suggest that the unsaturated zone of the PKC is oxidizing, with the lowest pH (though still greater than pH 7) and elevated concentrations of dissolved sulfate , Zn, Cu, Cd, Mg, Mo, and Mn at some locations (Moncur and Smith 2012), consistent with the 2-m scale field experiments, and the laboratory experiments. Concentrations of trace metals and sulfate in the unsaturated zone are higher than concentrations from the PK pond or samples from below the saturated/frost zones. Secondary mineral formation has been both modelled and observed *in situ*, which acts to reduce the porewater concentration of some ions. Stable isotopes of sulfur indicate that the primary source of dissolved sulfate in the porewater is sulfide oxidation (Moncur and Smith 2012).

Reports and research papers related to the geochemical characterization of kimberlite at Diavik include:

- Mineralogy of the Diavik Lac de Gras Kimberlite and Host Rocks (Jambor, 1997)

- Mineralogical investigation of Diavik Lac de Gras rocks after column leaching tests (Jambor, 1998)

- Diavik Geochemistry Baseline Report (Blowes and Logsdon 1998)

- Diavik Geochemistry Review (Blowes and Logsdon 2000)

- Environmental geochemistry of kimberlite materials: Diavik Diamonds Project, Lac de Gras, Northwest Territories, Canada (Baker et al. 2001)

- Characterization of Processed Kimberlite Samples, Diavik Mine, NWT: Petrography and Rietveld XRD Analysis (PetraScience 2006)

- Quantifying carbon fixation in trace minerals from processed kimberlite: A comparative study of quantitative methods using X-ray powder diffraction data with applications to the Diavik Diamond Mine, Northwest Territories, Canada (Wilson et al. 2009)

- PKC Mass Balance Study, Diavik Diamond Mines Inc. Diavik Northwest Territories (Moncur Groundwater 2009)

- Quantitative Mineralogy of Processed Kimberlite and Waste Rock Samples from the Diavik Diamond Mines (Paktunc and Thibault, 2010)

- Hydrogeochemical Investigation of the Processed Kimberlite Facility at Diavik Diamond Mines Inc. Final Report (Moncur et al., 2011)

- Subarctic weathering of mineral wastes provides a sink for atmospheric $CO_2$ (Wilson et al., 2011)

- Processed kimberlite porewater geochemistry from Diavik Diamond Mines Inc. (Moncur and Smith, 2012)

- Mineralogical Characterization of Nine Samples from the Diavik Diamond Mines (Thibault and Paktunc 2012)

- Construction and Preliminary Results of the Processed Kimberlite Test Tanks, Diavik Diamond Mines Inc. (Moncur 2012)

- 2012 Progress Summary for Hydrogeochemical Investigations of the Processed Kimberlite Facility at Diavik Diamond Mines Inc. (Moncur 2012).

- Mineralogy and porewater geochemistry of processed kimberlite: Implications for acid rock drainage and metal releases (Smith et al. 2012)

- 2013 Progress Summary for Hydrogeochemical Investigations of the Processed Kimberlite Facility at Diavik Diamond Mines Inc. (Moncur 2013).

- Technical Memorandum: PK Static and Kinetic Tests. (Smith 2014)

- Technical Memorandum: PK Tank 2014 Progress Update (Smith and Moncur, 2014)

- Four-Year Hydrogeochemical Field Investigation of Processed Kimberlite Weathering at Diavik Diamond Mines Inc. (Moncur and Smith 2014).

- Technical Memorandum: CPK Tank Construction (Smith 2015)
- Sources of Dissolved Ions to the Processed Kimberlite Containment Facility at Diavik Diamond Mines Inc (Moncur et al. 2015)
- Comparison of laboratory and field-scale predictions of processed kimberlite effluent in the Arctic (Moncur et al. 2015)
- 2016 Summary of Hydrogeochemical Investigations of Processed Kimberlite at Diavik Diamond Mines Inc. (Moncur 2017)

### 3.1 Remaining Tasks and Scopes of Work

**Research Task 5.2.3 Prediction of Outlet and Seepage Water Quality**

Sampling of the 2m scale field experiment will continue with the addition of the collection of core samples to enable more detailed porewater evaluation. Results from recently completed laboratory experiments will also be evaluated. Once complete, this information will be used in support of post-closure PKC water quality predictions.

PKC water quality predictions will be dependent upon the preferred final closure configuration. Ongoing CPK:FPK trials and feasibility study of depositing PK in completed underground and/or in pit mine areas will determine this preferred final configuration.

## 4. Linkages to Other Research

This research plan builds on the results from completed tasks described above in Section 3.1 as well as:

- Updated closure concept for the PKC (CRP V4 – Appendix X-5)
- Feasibility study of option to dispose processed kimberlite in completed underground and/or open-pit mine (CRP V4 – Section 5.2.6.3.5).
- Ongoing CPK:FPK Change Trials (DDMI 2017).
- Development of Site-Specific Risk-Based Closure Criteria (CRP V4 Appendix X-8.1 and Appendix X-8.2).

## 5. Project Tracking and Schedule

Projects are tracked by task. The expected task schedule is shown in Table 1.

**Table 1 Planned Project Activities**

| Year | Activities |
|---|---|
| 2017 | • Collection of core samples from 2m scale experiments.<br>• Interpretation of results from the laboratory column experiments<br>• Ongoing collection and interpretation of data from the 2m scale field experiments |
| 2018 | • Ongoing collection and interpretation of data from the 2m scale field experiments. |
| 2019 | • Prediction of seepage and/or outlet water quality. |

## 6. Costs

Expected costs to complete the required tasks are:

- 2m scale experiments – annual data collection (field work and analyses): $30,000/year
- 2m scale experiments – 2017 coring and mineralogical analyses (field work and analyses): $30,000
- Data interpretation, including field and laboratory results: $20,000-$30,000/year
- Prediction of seepage and/or outlet water quality: $100,000;

## 7. References


Baker, M.J., Blowes, D.W., Logsdon, M.J., Jambor, J.L. 2001. Environmental geochemistry of kimberlite materials: Diavik Diamonds Project, Lac de Gras, Northwest Territories, Canada. Exploration and Mining Geology, 10, 155-163.

Blowes, D.W. and M.J. Logsdon. 1998. Diavik Geochemistry Baseline Report. Prepared for Diavik Diamond Mines Inc. September 1998.

DDMI. 2017. *CPK:FPK Change Trial Update for the Diavik Diamond Mine – Month 10.* Submitted to WLWB April 11, 2017.

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Moncur, M.C., Birks, S.J., Taylor, E. 2015. Sources of Dissolved Ions to the Processed Kimberlite Containment Facility at Diavik Diamond Mines Inc. Prepared for Diavik Diamond Mines Inc. September 2015.

Paktunc, D. and Thibault, Y. 2010. Quantitative Mineralogy of Processed Kimberlite and Waste Rock Samples from the Diavik Diamond Mine. Report number CANMET-MMSL 10-019(CR). Report to Diavik Diamond Mines Inc., April 2010.

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# Research Area: Infrastructure Area Reclamation Research Plan

## 1. Uncertainty

### 1.1 Re-vegetation Methods

Complementary field and laboratory (greenhouse) studies lead by the University of Alberta have been conducted since 2004 and are scheduled for completion by the end of 2017. The research has focused on improving knowledge of soil and plant characteristics and processes essential for re-establishing vegetation on disturbed sites, and determining ecologically and economically effective re-vegetation methods to implement at closure. Progress has been made in refining preferred materials, species and methods. While longer-term monitoring results of the Phase I plots may yet identify new information, the remaining areas of uncertainty relates to a preferred re-vegetation method.

### 1.2 Post-Closure Vegetation Metals Level Risk

Communities and the Environmental Monitoring Advisory Board identified a potential concern that post-closure vegetation may accumulate metals to a level that would pose an unacceptable risk to wildlife or people. Substrates that may have elevated metals levels include Processed Kimberlite (PK), till/lakebed sediments and treated sewage. Research to date has found reduced metals levels if materials such as treated sewage are allowed to sit for a period of time prior to use, Additional studies to confirm if plants uptake metals from PK and, if so, at which concentrations, was conducted by the University of Alberta and a summary of preliminary results is included with this report as Appendix VIII-1A (Naeth 2017). These preliminary results are uncertain and require confirmation.

## 2. Research Objectives

This research plan is designed to address the following remaining research items.

### 2.1 Re-vegetation Methods

- Developing site-specific re-vegetation methods; and
- Integrating methods with the most suitable locations for re-vegetation efforts obtained from Traditional Knowledge perspectives.

### 2.2 Post-Closure Vegetation Metals Level Risk

- Confirmation of metals levels in plants and soils within the Phase I and Phase II re-vegetation research plots;
- Evaluate risks associated with wildlife or human consumption against risk-based closure reference concentrations for the types and range of metals identified in the research; and
- Determine if there is a need to establish a procedure for testing metals uptake in plants, or identify suitable alternative methods for determining such levels.

# 3. Overview of Tasks

## 3.1 Completed Tasks

A list of tasks completed for re-vegetation research are outlined below and Appendix VIII-1 summarizes many of the re-vegetation research findings to date. As noted above, a final research report is planned for the end of 2017.

Phase I of DDMI's re-vegetation research program was designed to develop a general understanding of which substrates and amendments were most effective for enhancing soil properties and native plant community development, as well as determining which species would establish and thrive (Naeth and Wilkinson 2011a). A total of 15 plots were established and 5 substrates, 4 amendments and 10 seed mixes were applied throughout the site in various combinations. Results to date indicate that the performance of each substrate improves when mixed with another substrate and/or with the addition of an amendment. Gravel has proven to be one of the most effective substrates in the short-term; however its long-term ability to provide water and nutrients is limited without the addition of another substrate (e.g. till) or an amendment. This result supports scarification of gravel surfaces of road and laydown areas to enhance microhabitats for vegetation and integrate better with the surrounding landscape. Treated sewage performed best of the amendments, despite reduced plant densities in the first few years of the study that were linked to an initial increase in salinity. It was during the Phase I study that the importance of microsites for vegetation establishment was observed and identified for future study during Phase II of the research program. Plant community development is inherently slow in northern environments and seeding is recommended for more rapid reclamation. Spring and fall seeding efforts resulted in similar establishment, though spring conditions were identified as more favourable due to lighter winds and warmer weather. Grass dominated seed mixes and species consistently performed better than forb species. While forbs are often slower to establish, their inclusion is important for longer-term plant community diversity and nitrogen fixation from legumes. Improving reclamation substrates with fine material and organic matter, combined with seeding, accelerates natural processes within 5 years facilitating initial tundra plant community development (Naeth and Wilkinson 2014). The species with the highest performance and therefore recommended for use in re-vegetation include:

- Grasses in a seed mix: *Poa glauca* (glaucous bluegrass), *Poa alpina* (alpine bluegrass), *Puccinellia nuttalliana* (Nuttall's alkaligrass), *Agropyron violaceum* (wheatgrass), *Agropyron pauciflorum* (slender wheat grass), *Arctagrostis latifolia* (narrow leaved polar grass), *Festuca saximontana* (rocky mountain fescue), *Deschampsia caespitosa* (tufted hairgrass) and *Trisetum spicatum* (spike trisetum).

- Forbs in a seed mix: *Hedysarum mackenzii* (bear root, sweet pea/sweetvetch), *Hedysarum alpinium* (liquorice root), *Oxytropsis splendens* (showy locoweed) and *Oxytropis deflexa* (nodding locoweed).
- Shrub cuttings and seed collection: *Betula glandulosa* (bog birch), *Salix glauca* (grey leaf willow), *Salix planifolia* (diamond leaf willow), *Loiseleuria procumbens* (alpine azalea), *Vaccinium vitis-idaea* (mountain cranberry), *Vaccinium uliginosum* (bog

bilberry), *Empetrum nigrum* (crowberry) and *Ledum palustre decumbens* (labrador tea).

Phase II of DDMI's re-vegetation research program was designed to refine the options for successful re-vegetation and determine the effect of microtopography, methods for establishing native shrubs from wild seed and stem cuttings and the potential to use salvaged topsoil as an amendment and source of native propagules. Research results identified difficulties with establishing shrubs from seed or cuttings in all substrate types. Survival was highest for the species *Vaccinium vitis-idaea* and in gravel and till depression substrates. As in Phase I, microsites were observed to influence erosion and survival, but the low shrub survival rates did not allow for determination of specific effects of this methodology. Salvaged topsoil is only available in limited amounts on site, therefore 2 to 3 cm thick patches were added to select substrates as an amendment, but these patches eroded within the first year.

With the completion of Phase I and II research, efforts since 2013 are summarized in the University of Alberta's annual reports (Naeth et al. 2013, 2015a, 2015b, 2016), which are shared as part of DDMI's CRP Annual Progress Reports and an overview is provided here. Greenhouse experiments and an overview of results to date are outlined below and in Table VIII-1.

- Assess effectiveness of substrates and substrate amendment combinations for plant establishment and growth, including alternative amendments not available on site or native to the area (e.g. peat, commercial products).
    - All plant species established and survived in most treatments. Plant emergence was most successful in unamended crushed rock. Amendment selection depends on the final reclamation goal, whether high plant density or large plants are desired. Addition of fertilizer does not appear to have an effect on plant density but it does affect plant growth, especially when peat is used as the amendment. Some commercial amendments were ineffective in the greenhouse (biochar, Black Earth).
- Evaluate maximum water holding capacity and water retention for substrates with Hydrogel (a commercial amendment).
    - Amendment addition improved water holding capacity; the more amendment added, the greater the water holding capacity. Hydrogel appeared to increase water holding capacity the most.
- Assess effects of water stress on vegetation growth and germination.
    - There did not appear to be major differences between amendments, but all were greater with amendment than without. Sewage increased density and growth the most and hydrogel seemed to have no effect.
- Encourage shrub root and shoot development and assess survival in various reclamation substrates.

    - Preliminary results from different times of year (spring, summer, fall) indicate all species have capacity to develop roots and there are species-specific factors, including time of year, influencing rooting behavior. Analysis is underway to determine trends and patterns in root initiation and development.

- Evaluate dispersal and propagation technique effects on composition and function of biological soil crusts.

    - Preliminary results indicate watering every three days and mixed biological soil crust material had better survival compared to more frequent watering and use of just one individual lichen species.

Field experiments have also been conducted and include the following topics.

- Examine the role of micro topographic variability, erosion control and amendments in developing substrates to enhance and sustain native plant species.

    - Crushed rock had the most plants followed by lakebed sediment, then processed kimberlite with plants only in low areas. Plants appeared to grow larger and more densely in depressions and furrows; sewage resulted in greatest plant cover and density. Soil Lynx (an erosion control product) had no observable plant response. Processed kimberlite plots had significant erosion, with depressions and furrows filling and mounds flattening.

    - Field observations do not indicate major differences among erosion control treatments; however, erosion control blankets appear to have slightly more plants potentially due to greater plant protection. Erosion control blankets and jute nets in processed kimberlite plots are beginning to be buried and some erosion control blankets and jute have been disturbed by animals, with holes ripped in the material.

- Investigate methods of dispersing and containing biological soil crust material when transplanted.

    - Microtopography is likely an important factor in retention of lichens and biological soil crust material on all substrates, but especially those with less variability. Plots with erosion control blanket alone had lichens mostly in dips and not on any bumps. Lichens were frequently associated with tundra soil when present even if some had blown away and were often observed around the rock borders of the plots.

- Investigate bryophyte (moss) propagation methods.

    - Most new growth occurred on crushed rock substrate. Large size fragmentation showed the most regrowth, followed by medium then small;

however, results do not differ greatly. Survival of material varied and further analysis is required.

- Re-evaluate plant and soil condition at all research plots, including Phase I plots that were planted in 2004.
    - This work is scheduled to be completed during the summer of 2014.

DDMI also requested additional analysis of metal uptake by plants (four grass species) grown in processed kimberlite (Naeth and Wilkinson 2017). Both field and greenhouse experiments were attempted but species in the field did not grow sufficiently for samples to be obtained. Samples from plants grown in the greenhouse were collected and analyzed for aluminum, antimony, arsenic, barium, beryllium, bismuth, cadmium, chromium, cobalt, copper, iron, lead, lithium, magnesium, manganese, molybdenum, nickel, phosphorus, potassium, selenium, silver, sodium, strontium, thallium, tin, titanium, uranium, vanadium, zinc and zirconium concentrations. Metals with Canadian Council of Ministers of Environment (CCME) soil quality guidelines were below values of concern in most substrates. Boron, chromium and nickel were consideraly higher in all substrates except lakebed sediment and reference soil. Barium and cobalt was higher than CCME guidelines in processed kimberlite and 75:25 processed kimberlite to lakebed sediment. High substrate concentrations did not necessarily result in high plant uptake. The limited association between substrate and plant tissue metal concentrations for the 33 metals analyzed suggests that substrate concentrations are not an effective method for predicting trace metal accumulation in plants. Uptake by plants was greater when plants were larger and healthier and was dependent on metal species. It is not possible from this research to directly determine if the reported metal concentrations could result in bioaccumulation in herbivores such as arctic hares, ground squirrels and caribou. Collection and analysis of plant samples from already established sites that have a well-established vegetation cover, planned for summer 2017, will ensure sufficient biomass and diversity of species and provide confirmation of the range of metals and concentrations relative to plants growing in natural soils.

An Annual CRP Progress Report was not required to be submitted for 2016, therefore copies of the University of Alberta's Preliminary Assessment of Plant Uptake of Metals from Processed Kimberlite and 2016 Annual Report and the have been included as Appendices VIII-1A and VIII-1B, respectively. A final research report to summarize findings and contribute to the development of a re-vegetation procedure for the Diavik mine is planned for the end of 2017.

## 3.2 Remaining Tasks and Scopes of Work

Work Scopes 6.1.1 through 6.1.6 from Reclamation Research Plan V1.1 (ICRP V3.2 Appendix VIII) are now supersede by the following Tasks:

**Research Task 5.1 – 2017 Field Work**

Complete 2017 field work and sample requirements, followed by interpretation and documentation of field and laboratory monitoring results. This task includes weather and soil data collection from the final research plots, in addition to soil microbiology and metals samples in vegetation and soils at each of the re-vegetation research areas. Data analysis from greenhouse and field experiments will be summarized in a final re-vegetation research report by the end of 2017. A copy of the University of Alberta's final research report will be submitted to the WLWB.

**Research Task 5.2 – Natural Recovery**

Identify plant species and site conditions at mine site areas that have experienced natural recovery. The purpose of this research is to identify and better understand soil, hydrologic and plant conditions on disturbed sites at Diavik Diamond Mine that promote successful natural recovery of native tundra plant communities to better emulate these conditions on future disturbed sites. Specific objectives are to:

- Identify plant species which can readily establish on disturbed sites naturally; Characterize hydrologic conditions, soil and micro topography of disturbed sites on which native plants have naturally established.
- Use multivariate data analyses to determine site factors and soil properties that contribute most to successful natural re-vegetation including plant abundance, species richness and species evenness.
- Develop recommendations for how these conditions can cost effectively be emulated on future disturbed sites to enhance natural recovery.

**Research Task 5.3 – Target Areas for Re-vegetation**

As site closure plans develop, it becomes easier for TK holders and community members to link site plans with preferences for wildlife habitat, safety and movement. It is important to re-visit the concepts that have been discussed to date and verify which are still applicable and identify any recommended changes. The outcome of this task will be the distribution of a re-vegetation procedure for review as part of DDMI's Annual CRP Progress Report.

Work Scopes 6.4.1 through 6.4.4 from Reclamation Research Plan V1.1 (ICRP V3.2 Appendix VIII) are now supersede by the following Tasks:

**Research Task 5.4 – 2017 Plant and Soil Sampling**

Obtain and evaluate the results of plant and soil metals samples from the 2017 sampling program to determine metal uptake levels. The purpose of this task is to confirm the range of metals and concentrations in re-vegetated species and substrates relative to plants growing in natural soils. Once this is completed, it should be possible to determine a process for evaluating exposure risks for humans or wildlife.

**Research Task 5.5 – Assess Risks**

Assess metals levels in relation to the site-specific risk-based criteria being developed for ecological receptors, or other applicable guidelines. Results from metals samples obtained from re-vegetation plots would be compared with site-specific risk-based closure criteria, or other applicable criteria, to identify potential parameters or levels of concern.

**Research Task 5.6 – Post-Closure Monitoring Method (if required)**

If metals levels in post-closure vegetation is confirmed to be a high risk contaminant pathway, appropriate post-closure monitoring methods will be determined as per Water License Schedule 9 Item 1(f).

## 4. Linkages to Other Research

This research plan builds on the results from completed tasks described above in Section 3.1 as well as:

- Results from Traditional Knowledge Panel and community engagement sessions relating to re-vegetation;
- Development of Site-Specific Risk-Based Closure Criteria (CRP V4 Appendix X-8.1 and Appendix X-8.2);
- On-going stakeholder and community engagement for re-vegetation plans and procedures;
- Closure plans and schedules for site infrastructure; and

## 5. Project Research Schedule

Projects are tracked by task. The expected task schedule is shown in Table 1.

**Table 1 Planned Project Activities**

| Year | Activities |
|---|---|
| 2017 | • Continued monitoring of re-vegetation research plots, including metals levels in plants and soil.<br>• Interpretation and documentation of field and laboratory monitoring results.<br>• Complete and submit a final re-vegetation research report.<br>• Conduct and document risk assessment for options for management and disposal of petroleum hydrocarbon contaminated materials. |
| 2018 | • Evaluate metals data in relation to site-specific, risk-based closure reference concentrations, or other applicable criteria.<br>• Determine if post-closure vegetation is likely to pose an unacceptable risk to people or wildlife.<br>• Develop a re-vegetation procedure and monitoring plan for review with stakeholders.<br>• Conduct stakeholder engagement on re-vegetation procedure. |
| 2019 | • Review and finalize the re-vegetation procedure and monitoring plan.<br>• If applicable, include a suitable monitoring program that can measure metal levels in plants, either directly or indirectly. |

## 6. Costs

Expected cost to complete the tasks described above is $150,000.

## 7. References


Naeth, M.A. and Wilkinson, S.R. 2011a. *Diamond Mine Reclamation in the NWT: Substrates, Soil Amendments and Native Plant Community Development, Phase I Final Report*.

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Naeth, M.A., V.S. Miller, S.A. Ficko and S.R. Wilkinson. 2014. *Reclamation of Disturbed Sites at Diavik Diamond Mine: 2013 Annual Report.*

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Naeth, M.A., V.S. Miller, S.A. Ficko, J. Lamarre and S.R. Wilkinson. 2014. *Reclamation of Disturbed Sites in the North: Implications for Diamond Mines, A Literature Review.*

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Naeth, M.A. and Wilkinson, S.R. 2017. *Preliminary Assessment of Plant Uptake of Metals from Processed Kimberlite Used as a Reclamation Substrate at Diavik Diamond Mine, NT, Canada.*

Thorpe Consulting Services. 2014. *DDMI Traditional Knowledge Panel Session #7: Focus on Re-vegetation.*

Thorpe, N., J. Barnaby and M. Lockhart. 2014. *Literature Review: Traditional Knowledge of Plant Life at the Diavik Diamond Mine.*

**Table VIII-1. Summary of Re-Vegetation Results**

| Material | Summary | Recommend (Y/N/U) | Benefits | Limitations | Supplemental Requirements | Outstanding Questions |
|---|---|---|---|---|---|---|
| ***Substrates*** | | | | | | |
| **Processed Kimberlite (PK)** | Mine waste material (processed ore); chemical & physical properties not conducive to plant establishment or development | Yes, if mixed with other substrates, or a substrate with an amendment. | Texture, increased surface temperature for seed germination; water holding capacity; 25:75 or 50:50 PK:Till mix is recommended | Heavy metal content, results of plant metal uptake and toxicological impacts to ecological receptors is preliminary; public perception; ineffective on own; difficult to recover material for use | Amendment(s) to increase nutrients; regulatory approvals to place PK in reclamation areas | - Confirm longer-term performance with results from 2014 samples at Phase I plots<br>- What is the preferred ratio & areas/substrates for application? |
| **Till/Lake Bed Sediment** | Mine waste material (pre-stripping); | Yes, mixed with amendments | Fine texture is beneficial for mixing with coarse materials (PK or gravel); improves water holding capacity and nutrient retention;; material accessible for re-mining | High silt content can result in compaction; low infiltration capacity; some metals elevated; ineffective on own without amendments such as inorganic fertilizer, topsoil or sewage. | Amendment(s) to increase nutrients; | - Confirm longer-term performance with results from 2014 samples at Phase I plots<br>- Volumes/depth/ ratios required for blending with coarse materials |
| **Gravel/Crushed Rock** | Mine waste material (waste rock) | Yes | Microsites good for seed germination, enhance coarse substrates, uneven surface, used across the site, lichen establish well on rock; placement on & adjacent to tundra encourages ingress. | Low nutrient and water availability, long-term effectiveness is limited without an amendment | Amendment(s) to increase nutrients; additional fine-textured substrate to improve structure and water holding capacity | - Confirm longer-term performance with results from 2014 samples at Phase I plots |

| Material | Summary | Recommend (Y/N/U) | Benefits | Limitations | Supplemental Requirements | Outstanding Questions |
|---|---|---|---|---|---|---|
| **Local Topsoil** | Native soil cover stripped from tundra in areas of mine development | Y | May contain propagules of local plants in particular shrubs, properties and characteristics typical of the region to support native plants; adds organic matter which is absent in other substrates but needed for soil water and nutrient retention. | Limited availability, avoid harvesting from nearby native tundra to prevent further area impacts, difficulty obtaining in past due to runoff concerns | Propagule supply reduced with stockpiling; re-classify as an amendment due to limited quantities | - Can topsoil from SCRP or other A21 development be salvaged & stock-piled for use in reclamation?<br>- If so, is it worth considering seeding it so propagules are available when used for reclamation? |
| ***Amendments*** | | | | | | |
| **NI Sludge** | Waste material from water treatment plant | N | May contain nutrients that are limited in anthroposols; available on site; increased soil water content initially. | No significant or sustaining effect on plant response; toxicity and contaminant concerns in NI have changed since initial studies | Regulatory approvals to place in reclamation areas | |
| **Sewage Sludge** | Waste material from sewage treatment plant | Y, mixed with other organic amendments such as soil to ameliorate limitations and maximize use. | Contains nutrients limited in anthroposols; improves soil properties and plant cover response; available on site; consistently positive field test results; increases water retention | Increases salinity immediately after application, metals present in sewage, faecal coliforms present in sewage; short-term reduction of plant density possible and species diversity | Outdoor stockpiling of sewage reduces faecal coliforms (sunlight); metals and salinity leach over time; let product site one season prior to use; Regulatory approvals to place in reclamation areas | - Assessment of soil/plant uptake and toxicological impacts to ecological receptors, including runoff<br>- What is the preferred ratio & areas/substrates for application? |

| Material | Summary | Recommend (Y/N/U) | Benefits | Limitations | Supplemental Requirements | Outstanding Questions |
|---|---|---|---|---|---|---|
| **Peat** | Externally-supplied product purchased for application | Y | Contains nutrients limited in anthroposols; improves soil and plant response; consistently positive greenhouse results; increases water retention | Not available on site; public perception (not native), potential for invasive species in soil; cost; | Use for in combination with substrates and nutrient source (e.g. sewage, fertilizer) to facilitate soil building and vegetation succession | - What is the preferred ratio & areas/substrates for application?<br>- Under which scenarios is its use advised?<br>- Costs?<br>- Local (northern) product & supplier? |
| **Inorganic Fertilizer** | Externally-supplied product purchased for application | Y, applied with amendments to improve soil structure. | Contains nutrients limited in anthroposols; improves short-term soil and plant response; | Less nitrogen and phosphorous addition than sewage; short-term effectiveness; public perception (not native); cost | Use for initial establishment in combination with gravel and peat to address short-term nutrient limitations | - Under which scenarios is its use advised?<br>- What is the preferred ratio & frequency of application for establishment versus long-term sustainability?<br>- Cost/benefit |
| **Local Topsoil** | Native soil cover stripped from tundra in areas of mine development | Y | May contain propagules of local plants in particular shrubs, properties and characteristics typical of the region to support native plants; increases plant diversity & production; source of organic matter to improve structure; ameliorates pH in anthroposols | Poor source of nutrients, limited availability, avoid harvesting from undeveloped areas to prevent further impacts, difficulty obtaining in past due to seasonal runoff concerns | Propagule supply reduced with stockpiling; apply immediately after salvaging; considered an amendment due to limited quantities. Appropriate timing of salvage | - Can topsoil from SCRP or other A21 development be salvaged & stock-piled for use in reclamation?<br>- If so, is it worth considering seeding or turning material so propagules are available when used for reclamation? |

| Material | Summary | Recommend (Y/N/U) | Benefits | Limitations | Supplemental Requirements | Outstanding Questions |
|---|---|---|---|---|---|---|
| **Hydrogel** | Polyacrylamide crystals that absorb water | U | Improve hydrologic properties of soils including increased water content & retention; improved water holding capacity in greenhouse | Can limit plant access to water and pose toxicity issues for northern species; appeared to have no benefit to plant growth under water limited conditions in a greenhouse; purchased product; public perception (not native) | More information and field trials required to determine if beneficial for use | - Cost/benefit |
| **Biochar** | Commercial product made of charcoal derived from biomass via pyrolysis | N | Stimulate microorganisms in soil; improve soil fertility | Little to no benefit based on short term greenhouse trials; purchased material | In the long term, mixed with other amendments may be beneficial. | |
| **Black Earth** | Commercial product made of humalite (80% humic acid) | N | Microbial growth promoter; addition of organic matter and carbon. | Little to no benefit based on short term greenhouse trials;; purchased material | In the long term, mixed with other amendments may be beneficial. | |
| ***Species*** | | | | | | |
| **Grasses** | Native grasses and seed harvested locally or purchased from supplier | Y | Soil building through litter development; hardy species tolerant of northern growing conditions, densely tufted species to retain precipitation and withstand the elements; seed can be harvested locally, field trials have identified suitable species; relatively quick to establish, seeding increases recovery rates | Some are pioneer species; northern commercial supply and suppliers are limited; grass cover and litter can reduce opportunities for natural colonization; metal uptake rates from PK unknown | Balance benefits of rapid establishment of a vegetation cover with room for natural colonization; consider species unfavourable to wildlife if metals levels expected to be high | - Community employment/ business opportunities for seed harvest & supply<br>- Confirm optimal species/mix |

| Material | Summary | Recommend (Y/N/U) | Benefits | Limitations | Supplemental Requirements | Outstanding Questions |
|---|---|---|---|---|---|---|
| **Forbs** | Native plants and seed harvested locally or purchased from supplier | Y | Soil building, hardy species tolerant of northern growing conditions, seed can be harvested locally, field trials have identified suitable species; slower to establish but beneficial for nitrogen fixation and succession over long term | Many are pioneer species; northern commercial supply and suppliers are limited; metal uptake rates unknown; limited establishment of forb species from seed mixes during field trials | Some forbs (e.g. fireweed) naturally re-vegetate disturbed areas and was the only natural colonizer present on plots (other than native mosses) | - Community employment/ business opportunities for seed harvest & supply<br>- Confirm optimal species/mix<br>- |
| **Shrubs** | Native shrubs and seed harvested locally or purchased from supplier | Y | Salix and Betula species will naturally colonize disturbed sites in the long-term; similar species to mature native tundra communities; diversity | Collection time is species-specific across seasons; Little is known about ericaceous shrubs which are abundant in tundra. | Native tundra communities are dominated by ericaceous or non-ericaceous shrubs, with low species diversity; growth hormones to increase rooting of cuttings | - Community employment/ business opportunities for shrub collection & supply<br>- Confirm procedure and season(s) for obtaining & preserving or cultivating cuttings for future use |

| Material | Summary | Recommend (Y/N/U) | Benefits | Limitations | Supplemental Requirements | Outstanding Questions |
|---|---|---|---|---|---|---|
| **Soil Crust (Moss)** | Native plants harvested locally | Y | Stabilize soil surface, regulate surface temperature, increase diversity, ground cover, minimize erosion, increase surface water; medium size bryophyte fragments produced highest density, abundance and diversity on soils but large fragments were more resilient to wind and rain and yielded higher total and live cover during field trials; moss cover increased with use of erosion control materials | Source collection requires some disturbance to other areas; not propagated in greenhouse | Can be collected in summer and fall and stored in a freezer; erosion is an issue and burial of moss. | - Confirm fragment size |
| **Soil Crust (Lichen)** | Native organisms harvested locally | Y | Stabilize soil surface, regulate surface temperature, increase diversity, ground cover, minimize erosion, increase surface water; grows best tundra soil, rock edges and in dips | Erosion is an issue and burial of lichen. | Can be collected in summer and fall and stored in a freezer; jute netting prevents erosion. | - Suitable species? |

| Material | Summary | Recommend (Y/N/U) | Benefits | Limitations | Supplemental Requirements | Outstanding Questions |
|---|---|---|---|---|---|---|
| ***Methods*** | | | | | | |
| **Seeding** | Dispersal of embryonic plant species enclosed in a protective outer covering | Y | Spring or fall seeding successful with better weather conditions in spring (less wind); broadcast methods generally effective and affordable | Preservation or age of seed may impact success; seed pre-treatments may be required particularly for forbs and shrubs; seed erosion | Hand seeders or use of an ATV mounted seeder. Small areas could be done by hand and reduce compaction.<br>Cool, dry conditions for storage. Use seed as soon as possible to maximize germination. | - Harvesting & preservation techniques and timelines |
| **Cuttings** | Portions of a plant that are removed and rooted in a new area | Y | Preferred technique for successful shrub re-vegetation for some species, which are similar species to mature native tundra communities; allows larger plants to be added to re-vegetation areas; | Success rates lower than for seed, more labour intensive than seeding, preservation or age of cuttings may impact success; harvest times are species-specific | Cool, dry conditions required for storage. Ideal to use as soon as possible after collection. Growth hormones improve rooting of some species, in particular Salix. | - Harvesting, cultivation and/or preservation techniques and timelines |
| **Microsites** | A small part of an ecosystem that differs markedly from its immediate surroundings | Y, in particular low parts such as depressions, trenches, furrows | Can occur or be created in existing substrates; easy to develop; provides shelter; accumulates water/ snow; increased seed germination, seedling establishment and plant growth and survival during Diavik field trials | Accumulated materials may smother plants/ seeds | Backhoe and/or truck or trailer pulling something with tines to create | - Confirm preferred types/ relief/ locations for Diavik site<br>- Size of microsites for best results. |

| Material | Summary | Recommend (Y/N/U) | Benefits | Limitations | Supplemental Requirements | Outstanding Questions |
|---|---|---|---|---|---|---|
| **Amendment Application - Capping** | Application of amendments by placing as a layer on top of substrate | Y | Operationally easy to apply; may be more beneficial for plant propagules in salvaged soil. | Amendments are more readily eroded off sites | Front end loader to apply. | |
| **Amendment Application - Incorporation** | Application of amendments by mixing them into the substrate | Y | Elimination of a substrate-amendment interface, increases water infiltration, nutrient distribution, plant rooting; reduces loss of amendments. Mix of mineral and organic materials better for structure. | Operationally more work to implement. For salvaged soil, may be reduction in viable plant propagules. | Front end loader and backhoe to apply. | |
| Erosion Control Methods | | | | | | |
| **Blanket** | Natural fibre mats used to cover seed and soil and prevent wind and water erosion | Y | Increased seed germination, plant establishment and re-vegetation success; maximize benefits of amendments; increased soil water content; some species benefit from use (moss); use in exposed areas; biodegradable and began to decompose after 2 years in field | Solid erosion control blankets or mats may reduce seed germination for some species ; public perception (not native); purchased material; potential wildlife attractant | - Ensure proper anchoring and placement techniques, depending on area(s) of use | - Identify areas where required |

| Material | Summary | Recommend (Y/N/U) | Benefits | Limitations | Supplemental Requirements | Outstanding Questions |
|---|---|---|---|---|---|---|
| **Net** | Natural fibre net used with seed and soil to help prevent wind and water erosion | Y | Increased seed germination, plant establishment and re-vegetation success; some species benefit from use (lichen); use in exposed areas; biodegradable and began to decompose after 2 years in field | Public perception (not native); purchased material; potential wildlife attractant | - Ensure proper anchoring and placement techniques, depending on area(s) of use | - Identify areas where required |
| **Soil Lynx** | Commercial powder stabilizer that binds with soil and fertilizer | U | Increased plant establishment and re-vegetation success; maximize benefits of amendments; creates a stable and porous surface; may bind with fertilizer, soil and seed to reduce loss from site | Public perception (not native); purchased material; potential wildlife attractant. | Required to be mixed with water for application. | Field data would confirm benefits of this method. |
| ***Other*** | | | | | | |
| **Environment Conditions** | Supporting conditions & processes for plant growth | Y | Abundant sunlight, acceptable adsorption ratios, high potassium, suitable soil and air temperatures, wildlife grazing levels unlikely detrimental, | Short growing season, strong winds, low precipitation, lower than suitable cation exchange, nitrogen & phosphorous limiting nutrients, low soil water content, slow plant litter development; shallow soil profile. | | |

| Material | Summary | Recommend (Y/N/U) | Benefits | Limitations | Supplemental Requirements | Outstanding Questions |
| --- | --- | --- | --- | --- | --- | --- |
| **Metal Uptake in Plants from Soils** | Community concerns that elevated metals in substrates/ amendments could result in plant uptake and therefore wildlife consumption | - | High substrate concentrations did not necessarily result in high plant uptake; PK has highest concentrations of some metals and is not likely to be used as a re-vegetation substrate; | Few guidelines exist for plant metal concentrations or wildlife consumption; zinc and nickel may cause plant toxicity, if present at elevated concentrations; till/lake sediment had elevated concentrations of some metals as well. | For metal to be taken up in plant tissue, it has to be mobile, transported and available through soil water uptake. In soils, most metals bind to other matter and are unavailable to plants; SSRBCC soil criteria?? | - Confirm longer-term accumulation with results from 2014 samples at Phase I plots |
| **Natural re-vegetation** | Native vegetation that colonizes an area without human assistance | Y, in conjunction with assisted soil reclamation and revegetation, use of patches. | Areas of natural re-vegetation have been observed at the mine site; native species; little to no cost; source of seed or propagules and enriched soils if these areas were disturbed for future for closure activities; | May impact site infrastructure and cause issues with dams or cover materials post-closure; unpredictable and may result in low vegetation cover and/or species diversity. | Epilobium angustifolium (fireweed) is a common early successional species that dominates following disturbance, with wind dispersed seeds, low nutrient needs, and the ability to facilitate the establishment of other plants once it dies. | - What species have successfully established and where?<br>- Can we harvest and re-use/re-plant some of these species elsewhere? |

| Material | Summary | Recommend (Y/N/U) | Benefits | Limitations | Supplemental Requirements | Outstanding Questions |
|---|---|---|---|---|---|---|
| **Re-vegetation Procedure** | A series of actions required to support plant growth | Y | Consistent and reliable methods for determining where and how to re-vegetate; can be reviewed and approved by stakeholders; reference document for species identification; based on proven research results | Once approved, significant changes are unlikely so important to get it right; knowledge base of northern ecosystems and reclamation methods are still in their infancy; | Calculate total surface area requiring re-vegetation/seeding and determine seed, scarification and substrate/ amendment requirements | - Reference template recommended for use in developing procedure? |
| **Short and Long-term Monitoring** | Observe and record progress and quality of re-vegetation over time | Y | Allows pro-active response to address seeding, planting and/or substrate/ amendment issues over first 5 years in response to monitoring results; data collection beneficial for future developments | Slow growth rates may mask issues with methods or plant health; few guidelines exist for comparison; expert knowledge of plants required to conduct species-level monitoring | Plan to conduct the following monitoring: plant assessments (overall health including: cover, density, species identification, species diversity, seed production, litter, evidence of wildlife grazing), area assessments for plant ingress/egress/invasive species identification, soil samples for structure and texture, pH and organic matter. | - Frequency of monitoring events for aspects identified at left<br>- How do we define success in relation to re-vegetation monitoring?<br>- What happens if re-vegetation is unsuccessful?<br>- Determine if metal uptake levels in plants require development of a monitoring plan, based on SSRBCC, or other applicable criteria. |