

Revegetation of Lands Impacted by Northern Hard Rock Mining:

Case Studies

Prepared For:

West Kitikmeot Slave Society



Prepared By:

Aboriginal Engineering Ltd.



Acknowledgments

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Purpose

Introduction

Discovery Mine Silty Clay Borrow Pit



- **Top:** July 2002 AEL Borrow Pit Test Plot
- **Middle:** Borrow Pit prior to revegetation effort by AEL under DIAND CARD
- **Bottom:** Borrow Pit following revegetation efforts by AEL (Summer 2003)

Information Sources: Discovery Mine 2004 Remediation Plan Final Report, Supporting Document A4, Borrow Pit Vegetation Enhancement Summer 2004 and field work by AEL.

Funding Sources and/or Client: DIAND Contaminant and Remediate Directorate

Researchers:

Company/Institution: Aboriginal Engineering Ltd.

Personnel: Shaun Lamoureux and Alvaro Reyes

Year of Research: 2003, 2004 and 2005

Purpose: To reclaim the Silty Clay Borrow Pit at the Discovery Mine through natural and sustainable methods. INAC has adopted a tiered approach to reclaiming the Borrow Pit, of which revegetation of the exposed banks serves to provide a long term and sustainable solution to sediment loading. Roots will stabilize the banks and the insulating effects of a vegetation cover will help aid in preventing further permafrost degradation.

Amendments: Fertilizer and Cocomat secured using biodegradable stakes

Discussion and Results: In 1997, Public Works and Government Services Canada (PWGCS) placed a cover over the majority of the historical tailings present at the Discovery Mine. Construction of this cover required the borrowing of approximately 100,000 m³ of silty clay. The resulting depression or "Borrow Pit" filled with water within a two year period following excavation activities. Repeated wave action, runoff and sloughing caused by the retreat of permafrost imparts sediment loading into the Borrow Pit sufficient to cause the concentration of TSS within its waters to exceed applicable limits. Impacted waters in excess of the Borrow Pit capacity overflows via a small spillway into Giauque Lake. INAC has adopted a tiered approach to reclaiming the Borrow Pit, of which revegetation of the exposed banks serves to provide a long term and sustainable solution to sediment loading. Roots will stabilize the banks and the insulating effects of a vegetation cover will help aid in preventing further permafrost degradation.

In July 2002, Aboriginal Engineering Ltd. constructed a vegetation enhancement test plot along the western shore of the Borrow Pit. A seed mixture was selected that would yield an aggressive root matrix with little additional nutrients and did not include invasive species. The test plot was seeded with 20kg of seed and 25kg of fertilizer. The results of the test plot were encouraging. The grass seeds quickly took root and produced a solid mat of green vegetation with little to no care and

Discovery Mine Silty Clay Borrow Pit



- **Top:** Placement of Cocomat along the banks of the Borrow pit following seeding in 2003
- **Middle:** Looking from the access road at the Borrow Pit in the summer of 2005
- **Bottom:** Natural succession beginning to take place

Discussion and Results Cont.: Based on the test plot results, AEL began full scale revegetation of the Borrow Pit under the direction of INAC CARD. In 2003 and 2004 the same seed mix and fertilizer used during testing of revegetation was hand broadcast on the exposed banks of the Borrow Pit at approximately 75 kg/ha and 25 kg/ha N, respectively. Seeds were raked into the subsurface. Cocomat was initially placed over the seeded area in 2003 to fix surface moisture and prevent the loss of seeds. In addition the Cocomat imparted physical stability to the slumping banks. The cocomat was fixed in place through the use of biodegradable stakes. Following the 2003 season, the use of cocomat was no longer necessary as the establishment of organic matter from below and above ground plant tissue growth aided in retaining moisture and holding seeds in place following broadcast application. The degradation of the cocomat is estimated to take approximately 5 years and will provide a steady source of nutrients for plant growth.

In 2005, AEL hand broadcast an alternate seed mix along with the same nutrient addition rates. The revegetation of the Borrow Pit has been successful and revegetation efforts are planned to continue into the future. Fireweed, willows, black spruce and Labrador tea have all been noted as plant species beginning to naturally invade the revegetated areas. AEL is currently experimenting with the transplanting of willows and black spruce on steeply sloping banks; the deep tap rooting system of the willow and black spruce should further aid in stabilizing areas continuing to experiencing permafrost degradation and will also positively impact the Borrow Pit water balance through large rates of evapotranspiration. Results from test plants will be available in 2006.



- **Left** Willow cuttings were placed along the borrow pits bank in 2003. However, due to a dry season and variable water levels, establishment was poor. Note the formation of some buds. Willows were transplanted on steeply sloping banks in 2005. Results will be assessed in 2006, following wintering

Discovery Mine Post Demolition Plots



- *Top: Aerial view of revegetated demolition plots*
- *Middle: Revegetated area denoted by yellow box*
- *Bottom: Revegetated area denoted by orange box*

Information Sources: Based on field work conducted by AEL during the Discovery Mine Reclamation Project (Summer 2005)

Funding Sources and/or Client: DIAND Contaminant and Remediate Directorate

Researchers:

Company/Institution: Aboriginal Engineering Ltd.

Personnel: Shaun Lamoureux, Alvaro Reyes and Bob Johnson.

Purpose: to promote natural succession of vegetation within demolition plots and to prevent subsequent erosion of the post demolition plots.

Amendments: Fertilizer

Discussion and Results: A large effort was put into the removal of unsafe infrastructure during the Reclamation of the Discovery Mine in 2005. Following the demolition of site structures, AEL actively contoured and reseeded the remaining plots. The same seed mix and fertilizer used in the revegetation of the Borrow Pit in 2005 was hand broadcast onto the barren plots at the rates employed during the 2005 Borrow Pit revegetation efforts. Seeds were raked into the subsurface. Plots were initially watered using a fire pump and hose provided by INAC CARD; soils were initially kept moist to promote seed germination and prevent the air born loss of seeds from wind erosion. Vegetation grew densely and vigorously and propagated within all seeded plots.

Discovery Mine

Seed Mixes

Mix #1	Mix #2	Mix #3
Borrow Pit 2003 and 2004	Borrow Pit 2005	Demolition Plots
Annual/ Perennial Grass and Legume	-	-
Annual Rye Grass	Slender Wheat Grass	Slender Wheat Grass
Slender Wheatgrass	Foul Blue Grass	Foul Blue Grass
Canadian Wild Rye	Rocky Mountain Fescue	Rocky Mountain Fescue
Foul Blue Grass	Spike Trisetum	Spike Trisetum
Fringed Bromegrass	Awed Wheat Grass	Awed Wheat Grass
Rough Fescue		
June Grass		
Tuffed Harigrass		

Colomac Mine Spruce Lake Trials



- **Top:** Aerial view of revegetated area adjacent to Dyke 7 a year after revegetation trials
- **Middle:** Results of Riparian Revegetation
- **Bottom:** Vegetation growing adjacent to the Dyke 7 within the Spruce Lake Tailings

Information Sources: Based on revegetation field work within the Spruce Lake Tailings facility undertaken by AEL in the summer of 2004 and subsequent assessment by AEL and UBC in the summer of 2005.

Funding Sources and/or Client: West Kitikmeot Slave Study and DIAND CARD

Researchers:

Company/Institution: Aboriginal Engineering Ltd., Taiga Environmental Laboratory and the University of British Columbia Department of Biological and Chemical Engineering

Personnel: Shaun Lamoureux (AEL), Bob Johnson (AEL), Dr. Sue Baldwin (AEL) and Jaime Romano (Taiga)

Purpose: to investigate the potential of reclaiming northern gold mine tailings through revegetation (gold recovered through cyanidation)

Amendments: fertilizer, Cocomat erosion control matting secured with biodegradable stakes, , pulpmill Compost Mulch, natural peat/topsoil.

Discussion and Results: AEL mobilized to the Colomac mine in the first week of August, 2004. After assessing the hydrological and topographical features of the Spruce Lake tailings deposit it was decided that the following revegetation scenario would be undertaken:

- Three replicate revegetation blocks consisting of individual test plots to assess the effects of differing tailings amendments and their rates of addition. One block was located in a topographically high area exposed to the wind; another block was located adjacent to a sprinkler and would therefore receive a constant supply of water; and the third block was located between two bodies of water where it was expected that the water table would be sufficiently high to prevent excessively dry tailings during the growth period.
- One field scale test plot adjacent to the Dyke 7 which would test revegetation at a larger scale under amendment conditions expected to sufficiently mitigate plant growth limiting physical and chemical properties of the tailings;
- A test plot along Dyke 7 (2-3 ha) to test the potential to revegetate the coarse grained materials typical of tailings Dams and Dykes. Amendments were added at the same rates as the field scale test plot adjacent to Dyke 7; and
- A riparian test plot adjacent to a body of water within the Spruce Lake tailings facility.

The field scale and riparian trials both were covered with Cocoa matting which was secured using biodegradable pegs. All revegetation trials were seeded with the same native seed mixture with the exception of the riparian trial, which received an application of a Northern riparian seed mix.

Colomac Mine Spruce Lake Trials



- **Top:** Seeding and placing coca matting at the riparian testing plot
- **Middle:** Constructing the revegetation test plots located between two bodies of water with the Spruce Lake tailings deposit
- **Bottom:** One of the pieces of equipment constructed by AEL for roughening the tailings surface

Discussion and Results Cont.: Fertilizer and seeds were hand broadcast and amendments were incorporated into the surface 10 cm of tailings. Prior to broadcasting, the surface of the tailings was roughened using various apparatuses pulled behind a quad. The apparatuses were constructed in the field by AEL. Roughening of the surface broke up the salt hard pan that was present at the tailings surface and provided micro sites for seeding.

Within the three replicated revegetation blocks the following tailings amendments were tested: fertilizer; cocoa matting; pulpmill process solids, natural peat (provided by the care and maintenance contractor, Tli Cho Logistics) and seed rate. The following amendment rates were tested:

- Seeding rate 0, 25kg, 50kg and 75kg, pulpmill process solids



Colomac Mine Spruce Lake Trials



- *Top:* vegetation propagating on Dyke 7
- *Middle:*
- *Bottom:*

- *Top:* Preparing the Revegetation test plot adjacent to Dyke 7. The seed mix was broadcast at 75 kg/ha, fertilizer was broadcast at 50 kg N/ha
- *Bottom:*

Colomac Mine Spruce Lake Trials



- **Top:** Constructing the test plots adjacent to the sprinkler (August 2004)
- **Middle:** Constructing the test plots between the two bodies of water (August 2004)
- **Bottom:** Similar view as middle photo following one years irrigation and a wet season

- **Top:** Alex Wah-Shee and Gary Lafferty landscaping the Spruce Lake tailings (Summer 2004)
- **Bottom:** Area following revegetation (Summer 2005)

Colomac Mine Spruce Lake Trials



- **Top: Middle:** Constructing the test plots between the two bodies of water (August 2004)
- **Bottom:** Similar view as middle photo following one years irrigation and a wet season

- **Top:** Flooded area of test plots which were established between two bodies of water within the Spruce Lake tailings. Irrigation and a wet season raised the water table substantially.
- **Bottom:** Dr. Baldwin sampling vegetation within the test plots adjacent to the sprinkler. Due to erosion and flooding of test plots, only seeding rate was able to be assessed. However, many practical lessons with respect to operational revegetation were learned during the Colomac Mine revegetation trials.

Colomac Mine Spruce Lake Trials

“Areas amended with and storing the pulpmill (Top photo) compost mulch exhibited much growth of Hawkweed and Ragweed. The similar and dense growth of these two species in all areas amended with pulpmill compost mulch and the isolation of many of plots from indigenous seed sources suggest that these two species were present within the pulpmill compost mulch prior to shipment to the NWT.”



- **Top:** Pulp mill solids pile. Vegetation not seeded by AEL grew within all areas containing pulpmill solids, including residual amendment piles
- **Bottom:** Dr. Baldwin sampling vegetation within the test plots adjacent to the sprinkler. Due to erosion and flooding of test plots, only seeding rate was able to be assessed. However, many practical lessons with respect to operational revegetation were learned during the Colomac Mine revegetation trials.

Colomac Mine Spruce Lake Trials



- **Top: Middle:** Constructing the test plots between the two bodies of water (August 2004)
- **Bottom:** Similar view as middle photo following one years irrigation and a wet season

- **Top:** Pulpmill solids pile. Vegetation not seeded by AEL grew within all areas containing pulpmill solids, including residual amendment piles
- **Bottom:** Dr. Baldwin sampling vegetation within the test plots adjacent to the sprinkler. Due to erosion and flooding of test plots, only seeding rate was able to be assessed. However, many practical lessons with respect to operational revegetation were learned during the Colomac Mine revegetation trials.

Colomac Mine

Spruce Lake Trials



Information Sources: Based on field work conducted by AEL during the Discovery Mine Reclamation Project (Summer 2005)

Funding Sources and/or Client: West Kitikmeot Slave Study and DIAND CARD

Researchers:
Aboriginal Engineering Ltd.

Purpose: to investigate the potential of reclaiming northern gold mine tailings from the cyanidation gold recovery process

Amendments:
Cocomat erosion control matting with biodegradable stakes
Pulp and Paper process solids
Natural peat

Discussion and Results: A large effort was put into the removal of unsafe infrastructure during the Reclamation of the Discovery Mine in 2005. Following the demolition of site structures, AEL actively contoured and reseeded the remaining plots. The same seed mix and fertilizer used in the revegetation of the Borrow Pit in 2005 was hand broadcast onto the barren plots at the rates employed during the 2005 Borrow Pit revegetation efforts. Seeds were raked into the subsurface. Plots were initially watered using a fire pump and hose provided by INAC CARD; soils were initially kept moist to promote seed germination and prevent the air born loss of seeds from wind erosion.

- *Top: Training Aboriginal staff in methods of transplanting willows*
- *Middle: Results of Riparian Revegetation*
- *Bottom: Revegetated are denoted by orange box*

Colomac Mine

Seed Mixes

[illegible]

Con Mine

Summary

There are six tailings deposits at the Con Mine: the Negus, Crank Lake, Neil Lake, Lower Pud, Middle Pud and Upper Pud. Revegetation activities have been undertaken within the abandoned Negus, Crank Lake, Neil Lake and Lower Pud tailings deposits. The Upper and Middle Pud tailings deposits were operational until 2004 and therefore have not receive revegetation trials.

Revegetation efforts at the Con Mine can be broadly classified into two categories based on the time at which they were undertaken:

(1) 1976 to 1988: trials undertaken by R.T. Gardner of the Cominco Reclamation Research Center, Trail B.C (Nerco Con Mine); and

(2) present: research and operational activities undertaken by the environmental department of Miramar Con Mine in relation to final abandonment and restoration activities.

Revegetation studies have generally focused on mitigating the effects of tailings salinity and poor nutrient/physical properties.

Tailings salinity mitigation trials focused on the effects of flood leaching and peat amendment in reducing tailings electrical conductivity. In addition the following revegetation scenarios have been tested:

- the establishment of native saline tolerant plant species;
- the establishment of nitrogen fixing legumes on: (1) tailings amended with organic matter; (2) tailings vegetated with native alkaligrass, foxtail barley and atriplex; (3) tailings amended with muskeg and vegetated with creeping red fescue, meadow foxtail, alkaligrass and foxtail barley; (4) tailings amended with muskeg; and (5) unamended and unvegetated tailings within periodically flooded depressions;
- the effects of maintenance fertilizer on sustainable plant growth;
- a comparison of the potential to revegetate the Upper and Lower South Pud tailings to that of the Lower North Pud Tailings, based on tailings chemistry;
- operational revegetation of the Negus tailings (1981); and
- the final abandonment and restoration of historical tailings by Miramar Con Mine.

The following sections summarize the above revegetation activities. It should be noted that the author does not take credit for any of the work or interpretations of data described within each of the following sections. In addition, no attempt to verify the stated results was undertaken. The results are based on interpretations made and facts collected

Con Mine

Methods for Reducing Tailings Salinity: Flood Leaching (Study C-3-77)

The success of leaching in reducing tailings salinity is directly related the amount of water which infiltrates through the tailings, picking up soluble salts, and subsequently draining from the tailings deposit.

Flood leaching consists of applying large amounts of water to saline soils within a short period of time. The water rapidly infiltrates into and percolates through the soil profile, picking up and removing soluble salts. However, flood leaching requires extensive and planned drainage and subsequent treatment of large quantities of impacted drainage prior to discharge.

Information Sources:

- Studies for Restoration and Reclamation of Abandoned Tailings at Nerco Con Mine, 1988 (Cominco Reclamation Research Center)

Funding Sources and/or Client: NERCO Con Mine Ltd, NERCO Minerals Canada Ltd.

Researchers:

Company/Institution: Cominco Reclamation Research Center, Trail B.C.

Personnel: R.T. Gardiner

Purpose: To investigate the ability of flood leaching to reduce tailings salinity of the Con Mine Tailings impoundments

Amendments: Fertilizer

Discussion and Results: Preliminary growth room studies on the effectiveness of flood leaching as a method of reducing tailings salinity were conducted in 1976. Application of 1cm of water per 1 cm depth of tailings reduced tailings ECe from 16 to 2 ms/cm (very strongly saline to very slightly saline). Five species with varying levels of salinity tolerance propagated satisfactorily within the leached tailings (species not explicitly stated).

Based on the success of the growth room studies, between July 25 and August 17, 1978, leaching water was applied to three 84m² plots within the Lower Pud North tailings disposal facility at a rate of 0.3, 0.6 and 1.2 ha.m (7, 10 & 16 million litres per hectare; 6800L/day; infiltration rate 9.4×10^{-5} cm/s). 20 hours was allowed between flooding events. A 1m deep lined ditch and a lined perimeter dyke were constructed around the test plots to allow for the containment of surface and ground water during leaching. On June 23, 1979 fertilizer was applied at 80 kg/ha N, 400 kg/ha P₂O₅ and 100 kg/ha K₂O (ammonium phosphate and muriate of potash). The test plots were then broadcast seeded at 60 kg/ha (mix #1) and annual maintenance fertilizer (13-16-10) was applied at 400 kg/ha until 1988. No leaching of the tailings was undertaken in addition to that in 1978.

By 1988, flood leaching reduced tailings ECe to an average of 3 ms/cm in comparison to unleached tailings, which had an average ECe of 23 ms/cm. Upon initial application of leach water, tailings ECe were immediately reduced to an average of 2 ms/cm in all test plots.

Initially, in 1979, a dense population of seedlings was present (38 seedling/0.1 m²). 78% of total seedlings were grass species and 22% were the nitrogen fixing legume, alfalfa. All plots displayed similar seedling population and composition, regardless of the applied rate of leaching.

Con Mine

Methods for Reducing Tailings Salinity: Flood Leaching (Study C-3-77)

In 1988, average vegetation and biomass coverage within the leached plots was 70% and 1628 kg/ha. Based on assessments of the test plots through to 1988, flood leaching had successfully reduced the tailings conductivity to levels tolerated by the grasses creeping red fescue (seeded), meadow foxtail (seeded), foxtail barely (natural succession) and alkaligrass (natural succession).

Discussion and Results Cont.: The effects of different leaching rates on species composition and growth only became apparent with time. Increased leaching rates lead to increases in vegetation coverage and biomass. The seeded species creeping red fescue and meadow foxtail provided 95% of the overall coverage for the 1.2 ha.m leaching rate plots (overall coverage and biomass at 87% and 2379 kg/ha, respectively). Within the 0.3 ha.m leaching rate plots the naturally succeeding species foxtail barely and alkaligrass accounted for 41% of the overall coverage and the seeded grasses covered the remaining 51% overall coverage (overall coverage =58% and biomass = 969 kg/ha).

With time, native species were more successful in invading test plots which received the lower leaching rates. No alfalfa or lemmon's alkali-grass were present in any of plots in 1988 and dead plant litter covered an average of 28% of the tailings surface. Roots were concentrated within the upper 13 to 18 cm.

Tissue arsenic concentrations of vegetation propagating with the plots receiving leaching were slightly elevated with respect to concentrations of similar species of grasses growing within Yellowknife soils. However tissue arsenic concentrations for grasses growing within the tailings were below the Maximum Tolerable Levels of Dietary Minerals for Domestic Animals established by the National Research Council. It should be noted that leaching had no significant effects on tailings pH.

Despite the encouraging results on the experimental level, operational flood leaching may prove to be difficult in practice. If flood leaching is to be successful on an operational level, then extensive drainage will have to be constructed to remove the impacted drainage water from the tailings areas receiving treatment. Gardiner estimated that receiving waters would have to be capable of accepting 3 to 12 million litres per hectare of impacted leachate within a short period of time (Con mine tailings). Following drainage and collection, the leachate would have to be treated to license discharge limits. The requirement for treatment of the drainage water would most likely make revegetation with the use of flood leaching an economically unfeasible tailings reclamation option.

Con Mine

Methods for Reducing Tailings
Salinity: Flood Leaching
(Study C-3-77)

- *Top: 0.3 ha.m leaching rate*
- *Middle: 0.6 ha.m leaching rate*
- *Bottom: 1.2 ha.m leaching rate*
- *(Photograph extracted from Studies for Restoration and Reclamation of Abandoned Tailings at Nerco Con Mine (R.T. Gardiner 1988))*



Con Mine

Methods for Reducing Tailings Salinity: Peat Amendment (Unnamed Study)

The success of leaching in reducing tailings salinity is directly related the amount of water which infiltrates through the tailings, picking up soluble salts, and subsequently draining from the tailings deposit.

Peat amendment increases tailings permeability, by affecting soil texture, which results in more natural rain water leaching through the tailings with time. Peat amendment also reducing tailings salinity immediately through the dilutional effects of mixing. Mitigation of tailings salinity with peat amendment takes successive seasons to become effective and results in local variations of soils salinity throughout the course of treatment.

Information Sources:

- Studies for Restoration and Reclamation of Abandoned Tailings at Nerco Con Mine, 1988 (Cominco Reclamation Research Center)

Funding Sources and/or Client: NERCO Con Mine Ltd, NERCO Minerals Canada Ltd.

Researchers:

Company/Institution: Cominco Reclamation Research Center, Trail B.C.

Personnel: R.T. Gardiner

Purpose: To investigate the ability of peat amendment to reduce salinity within the Con Mine Tailings impoundments.

Amendments: Fertilizer

Discussion and Results: In August of 1977 a layer of peat, between 7.5 and 15 cm thick was rotovated into the upper 15 cm of a strip of tailings 5m x 183 m (South side of Lower Pud North) (study name not clearly identified). On May 29, 1978, a grass species (mix #2 @ 100kg/ha) and fertilizer were applied (80 kg/ha N, 400 kg/ha P₂O₅ and 50 kg/ha K₂O). Annual maintenance fertilizer applications of 50 kg/ha N, 60 kg/ha P₂O₅ and 40 kg/ha K₂O were applied to the test plot.

Amendment of the peat to the tailings gradually lowered and then maintained tailings salinity at a level tolerated by the seeded grasses creeping red fescue, kentucky bluegrass and meadow foxtail and the naturally succeeding species foxtail barely, nuttall's alkaligrass and atriplex (peat amended mean ECe in 1988 was 3 ms/cm & unamended tailings mean ECe = 28 ms/cm).

In 1988 vegetation composition of plots was more variable than flood leaching, due to the variability of tailings salinity during the initial years of testing. Biomass and plant coverage ranged from 858 to 2328 kg/ha and 55% to 85%, respectively. Creeping red fescue, kentucky bluegrass and meadow foxtail dominated tailings with ECe < 4 ms/cm and foxtail barely, nuttall's alkaligrass and atriplex dominated tailings with ECe ranging between 5 – 8 ms/cm. Plant tissue arsenic concentrations were slightly elevated with respect to plant tissue concentrations from similar species growing in Yellowknife. According to NRC guidelines, none of the reported tissue metal concentrations posed a risk to grazing wildlife.

Con Mine

Methods for Reducing Tailings Salinity: Peat Amendment (C-3-78)

Information Sources:

- Studies for Restoration and Reclamation of Abandoned Tailings at Nerco Con Mine, 1988 (Cominco Reclamation Research Center)

Funding Sources and/or Client: NERCO Con Mine Ltd, NERCO Minerals Canada Ltd.

Researchers:

Company/Institution: Cominco Reclamation Research Center, Trail B.C.

Personnel: R.T. Gardiner

Purpose: To investigate the ability of peat amendment to reduce salinity within the Con Mine Tailings impoundments.

Amendments: Fertilizer

Discussion and Results: In 1977, peat was incorporated into strongly saline tailings at four replicated sites (herein referred to as sites #1, 2, 3 & 4) at 0, 88, 132 and 176 tonnes/ha (i.e., 0, 3.75, 7.5 and 15 cm depths). The study plots were located throughout the western portion of the Lower Pud tailings facility. Ammonium phosphate and muriate of potash were broadcast to supply 88 kg/ha N, 448 kg/ha P_2O_5 and 56 kg/ha K_2O . Seeds were broadcast at 100 kg/ha (mix #3). 13-16-0 maintenance fertilizer was applied at 300kg/ha (1977 – 1988).

In 2000 Harvey Martens and Associates Ltd. (HMA) evaluated the original test plots. The texture of the soil was found to be on average silt to silt-loam. Levels of organic matter were correlated to original peat amendment addition rates (i.e., the higher the original rate of peat addition the higher the current level of organic matter within the tailings). Organic matter was limited largely to the top 15 cm of tailings. Tailings salinity was gradually and effectively lowered by amendment with peat to non and very slightly saline (effect noted in 1988 [10 years]). It should be noted that all plots, even those not receiving peat amendments had low salinity levels in 2000 (23 years). This suggests that natural effects (i.e., repeated rainfall or long term leaching) reduce tailings salinity even without focused short term leaching or the addition of amendments such as peat.

Con Mine

Methods for Reducing Tailings Salinity: Peat Amendment (C-3-78)

The success of leaching in reducing tailings salinity is directly related the amount of water which infiltrates through the tailings, picking up soluble salts, and subsequently drains from the tailings deposit.

Natural leaching process are bound by the original properties of the unamended tailings. Saline tailings tend to form a thin surface crust as the salts precipitate from tailings pore water during surface evaporation. This crust tends to greatly reduce tailings permeability to meteoric water and greatly increases the time for effective salinity reduction



- *Above: A white salt precipitate crust covering the surface of a tailings deposit. This crust renders the tailings highly impermeable to precipitation.*

Discussion and Results Cont.: Finally, within control points, which did not receive any form of reclamation, natural processes had not established any form of vegetation in 23 years. Tailings E_{Ce} within the control points were reduced naturally from and E_{Ce} of 22 ms/cm in 1976 to an E_{Ce} of approximately 4 ms/cm in 2000 (top 7.5 cm of tailings). Salinity increased with depth (average of 10.15 ms/cm at 30-60 cm). Exchangeable Sodium Percentage (ESP) values were above limiting criteria at all depths within control point tailings. This suggests that without intervention through active revegetation, tailings with physical and chemical properties to the Con Mine tailings in a similar environment will not naturally revegetation in approximately a quarter of a century.

Water capacity and plant available nutrients were directly correlated to the level of original rate of peat amendment, both increasing with increasing peat addition rates. HMA concluded that the decomposition of organic matter was providing a source of nutrients sufficient to maintain long term plant growth within the tailings.

After the first two growing seasons following initial planting in 1977 plant coverage was 70% on strongly saline tailings (site 4) and 90% on moderately saline tailings (site 2). The cover consisted mainly of those species which had been seeded and was dominated by Arctared fescue and Tall wheatgrass. (Tall wheatgrass died out after 4 years). Thirteen years following the last addition of maintenance fertilizer plant cover ranged from 29% to 61% (2000). Foxtail barely and Alkali grass (native salt tolerant) were prominent in tailings receiving no peat (dominant after 10 years) and seeded species dominated the plots receiving peat addition (Nugget bluegrass and Arctared fescue co-dominated). Atriplex was the only native plant species to survive on very strongly saline tailings. HMA concluded that all sites sampled supported a stable plant community after 23 years. The time that it took to establish a stable community was indirectly correlated to original salinity concentrations and directly correlated to original levels of peat amendment rate.

Con Mine

Establishment of Native Saline Tolerant Plant Species (C-20-80)

Information Sources: Studies for Restoration and Reclamation of Abandoned Tailings at Nerco Con Mine, 1988 (Cominco Reclamation Research Center)

Funding Sources and/or Client: NERCO Con Mine Ltd, NERCO Minerals Canada Ltd.

Researchers:

Company/Institution: Cominco Reclamation Research Center, Trail B.C.

Personnel: R.T. Gardiner

Purpose: to investigate the ability of native saline tolerant plant species to propagate within saline tailings at the Con Mine

Amendments: Fertilizer

Discussion and Results: In 1978, the native saline tolerant grass Nuttall's alkaligrass was transplanted from a saline marsh near Ft. Smith into the Lower Pud North tailings. The native grass grew well on both fertilized and unfertilized tailings and produced large amounts of seeds, resulting in the establishment of the species throughout the testing area.

Following this initial success, in 1980 over 900 alkaligrass plugs were removed from saline soils and transplanted within the northern portion of the Lower Pud North tailings. Plugs were placed within a 0.18 ha area, spaced at 1m within rows and 2m between rows. 13-16-10 fertilizer was broadcast at 215 kg/ha, prior to transplanting. 13-16-10 maintenance fertilizer was applied at 400 kg/ha (up to and including the 1987 season). The 2m spaces between rows were rotovated to encourage the entrapment of seeds. In 1981, an additional 900 alkaligrass plugs were transplanted within the southern portion of the Lower Pud North tailings, using alkaligrass plugs from the 1980 northern Lower Pud North tailings. A slow release fertilizer was placed within each transplant hole, prior to placement of the plug. Spacing was identical to the 1980 study and spaces between rows were also rotovated. 13-16-10 maintenance fertilizer was applied at 400 kg/ha (up to and including the 1984 season). In 1988, only one half of the 1980 test plots received fertilizer, in order to assess the effects of discontinuing maintenance fertilizer.

High transplant mortality and poor seedling establishment was experienced within the 1981 plots due to the high level of salinity (35, 26 & 16 ms/cm in 1981, 82 & 84) within the northern portion of the Lower Pud North tailings. In 1984 cover was 1% and biomass was 4 kg/ha.

Con Mine

Establishment of Native Saline Tolerant Plant Species (C-20-80)

Discussion and Results Cont.: The 1980 transplant site had lower salinity levels (16, 11 & 9 ms/cm in 1981, 82 & 84). As a result, in 1984 alkaligrass occurred within 75 % of sampled quadrats, averaging 21% cover and 1177 kg/ha. Alkaligrass cover and biomass was strongly correlated to salinity within these test plots with 50% cover and 2224 kg/ha biomass within tailings averaging 4 ms/cm ECe. In contrast, tailings with an average ECe of 12 ms/cm had alkaligrass populations with 9% coverage and 262 kg/ha biomass. In 1985, alkaligrass coverage averaged 62% with noted Foxtail barley coverage of 14%. Overall, Gardiner concluded that the effectiveness of transplanting plugs of the native saline tolerant grass, Nuttall's alkaligrass was limited to the lower end of the strongly saline category.

In 1988, during the cessation of maintenance fertilizer on one half of the 1980 test plots, tailings salinity were slightly to moderately saline (mean ECe = 3ms/cm). Vegetation was composed of the native species Alkaligrass, Atriplex and Foxtail Barely with some noted occurrences of moss species. The discontinuation of maintenance fertilizer for one year resulted in a decrease in coverage and biomass from 53% to 27% and 1235 kg/ha to 240 kg/ha, respectively. Decreases were due primarily to decreases in Alkaligrass and Atriplex.

Con Mine

Establishment of Nitrogen Fixing Legumes on Tailings Amended with Organic Matter Study (C-1-87)

Information Sources:

Studies for Restoration and Reclamation of Abandoned Tailings at Nerco Con Mine, 1988 (Cominco Reclamation Research Center)

Funding Sources and/or Client: NERCO Con Mine Ltd, NERCO Minerals Canada Ltd.

Researchers:

Company/Institution: Cominco Reclamation Research Center, Trail B.C.

Personnel: R.T. Gardiner

Purpose: to investigate the ability of nitrogen fixing legumes to establish within the Con Mine Tailings impoundments.

Amendments: Fertilizer and peat

Discussion and Results: Studies regarding the survival of nitrogen fixing legumes were initiated to aid in lessening the impact of discontinuing maintenance fertilizer and promoting self sustaining plant communities within saline soils; nitrogen fixing legumes fix atmospheric N (strong triple bonded) into a form of nitrogen available to plants within the soil. When the legumes die, the nitrogen is released into the surrounding environment.

Northern varieties of the legumes alfalfa (rambler, rangeland, peace and anik), sainfoin, birdsfoot, trefoil, Cicer milkvetch and Sweet clover were tested. The following grass species were also seeded: Tall wheatgrass, Altai wildrye, Mammoth wildrye Slender wheatgrass, Creeping red fescue and Meadow foxtail (mix #4). In 1986, four test plots within the Lower Pud North were amended with 15 to 20 cm of muskeg obtained from an on-site bog. Amended muskeg was rotovated into the tailings. 55 kg/ha N, 275 kg/ha P_2O_5 and 50 kg/ha K_2O were broadcast and incorporated and 1000 seeds per m^2 were subsequently hand broadcast and raked into test plots in June of 1987.

Incorporation of muskeg did little to amend salinity; tailings salinity increased, which was in direct contrast to previous organic amendment studies. No reason was identified for the differing trend in salinity. Legumes established on only 10 % of the test plots. Test plots were reseeded and refertilized in 1988 as per the 1987 study. In 1998, mean ECe increased again in comparison to 1987 values (1988 test plot average = 27.75 ms/cm).

Con Mine

Establishment of Nitrogen Fixing Legumes on Tailings Amended with Organic Matter Study (C-1-87)

Discussion and Results Cont.: Gardiner reported that the most promising nitrogen-fixing legume species for revegetation of strongly saline tailings amended with organic matter were sainfoin, sweet clover, and Alfalfa var. Rambler. However, seedling establishment was not satisfactory with some seedling exhibiting signs of chlorosis. (height of seedlings = 1 – 5 cm). At the end of 1988, sweet clover ranged in height from 45 to 60 cm with a coverage of 50%.

Growth of alтай wildrye and tall wheatgrass were superior to other grass species and at the end of the first growing season ranged up to 45 and 75 cm, respectively, with coverage of 69 and 66%. Tall wheatgrass did not sustain growth for more than three growing seasons.

In 2000, HMA reassessed the Legume test plots. Salinity in the year 2000 had been reduced to 2.15 ms/cm within a 13 year period. Plant available nutrients were in sufficient concentrations to support growth within the tailings. Living cover in 2000 was 80% (alfalfa Rambler = 25%, Revenue slender wheatgrass = 25%, Arctared fescue = 15%, mammoth rye = 15% and litter = 100 %).

Con Mine

Survival of Nitrogen Fixing Shrubs And Other Woody Species: Overview

The following salt tolerant nitrogen fixing legumes and woody species were employed in vegetation trials within the Lower PUD tailings facility. Nitrogen fixing legumes promote natural cycling of nitrogen.

Salt tolerant nitrogen fixing shrubs: Hippophae rhamnoides, Siberian pea shrub (both indigenous to Siberia) and fourwing saltbrush (indigenous to southwestern USA)

Woody Species: Indigenous willow and rose species

The above listed salt tolerant nitrogen fixing shrubs and woody species were tested under the following four site conditions:

- (1) tailings Vegetated with native grasses alkaligrass, foxtail barely and atriplex;
- (2) tailings amended with muskeg and vegetated with creeping red fescue, meadow foxtail, alkaligrass and foxtail barely;
- (3) tailings amended with muskeg; and
- (4) unvegetated tailings, located with periodically flooding depressions.

(Note: above species referred to as Mix #10 in the seed mixes table)

Initial planting of the seedlings within the above listed scenarios occurred in September 1986, June 1987 and June 1988 (only willows and siberian pea shrub were planted in 1988). A chain saw auger prepared the planting holes, into which a 10 g slow release fertilizer pellet was placed. The test plots were assessed in 1988 (1988 seedlings had only grown for 43 days and had not over-wintered).

Con Mine

Survival of Nitrogen Fixing
Shrubs And Other Woody
Species: Tailings Vegetated with
Native Grasses Alkaligrass,
Foxtail Barely and Atriplex
(Study C-1-86)

Information Sources:

Studies for Restoration and Reclamation of Abandoned Tailings at Nerco Con Mine, 1988 (Cominco Reclamation Research Center)

Funding Sources and/or Client: NERCO Con Mine Ltd, NERCO Minerals Canada Ltd.

Researchers:

Company/Institution: Cominco Reclamation Research Center, Trail B.C.

Personnel: R.T. Gardiner

Purpose: To investigate the ability of nitrogen fixing shrubs and other woody species to establish within the Con Mine Lower Pud North tailings facility

Amendments: Fertilizer

Discussion and Results: Seedling were planted at ten sites containing the native grasses within the Lower Pud tailings facility. Vegetation within the ten sits was established by directly transplanting alkaligrass plugs and natural succession.

In 1988, tailings vegetated with alkaligrass, foxtail barely and atriplex had an average ECe of 3 ms/cm. Poor survival was noted for the species planted in 1986 and 1987, with the exception of the siberian peashrub (66% survival rate for 1987 seedlings). Willow had a 20% survival for 1987 seedlings and rose had a 30% survival for 1987 seedlings. Fourwing saltbrush was completely killed off during the initial winter season. All 1986 seedlings suffered high mortality rates (80—100%). The 1988 siberian peashrub and willow seedlings had an excellent survival rate (average of 92% and 72%, respectively). However, willows suffered high mortality on very strongly saline sites. It should be noted that two species planted in 1988 had only grown for 43 days and had not over-wintered.

Con Mine

Survival of Nitrogen Fixing
Shrubs and Other Woody
Species: Tailings Vegetated with
Native Grasses Alkaligrass,
Foxtail Barely and Atriplex
(Study C-4-78(87))

Information Sources:

Studies for Restoration and Reclamation of Abandoned Tailings at Nerco Con Mine, 1988 (Cominco Reclamation Research Center)

Funding Sources and/or Client: NERCO Con Mine Ltd, NERCO Minerals Canada Ltd.

Researchers:

Company/Institution: Cominco Reclamation Research Center, Trail B.C.

Personnel: R.T. Gardiner

Purpose: To investigate the ability of nitrogen fixing shrubs and other woody species to establish within the Con Mine Lower Pud North tailings facility

Amendments: Fertilizer

Discussion and Results: C-4-78 (87) was created in 1978 to assess the effectiveness of five native and five commercial salt and drought tolerant species. Native muskeg (0, 3.75, 7.5 and 15 cm) and fertilizer were applied as amendments. Maintenance fertilizer was supplied to the test plots up until 1984 (alkali and Foxtail barley established; seeded species died out). In 1987, salinity was identified as being reduced to a level acceptable for the establishment of a vegetative cover. In the same year, ten seedlings of rose (*Rosa woodsii*) and willow (*Salix plainifolia*) were planted within each of the plots.

In 2000 HMA assessed the long term growth of the willows and roses and reported that both species had successfully established themselves within the test plots. The number of roses had more than doubled in three of the four plots (10 to an average of 21). Height of the roses averaged 23.25 cm and their growth was not correlated to the original level of peat amendment. Unlike the roses, the growth of willows was correlated to the original level of peat amendment. The number and height of willows averaged 49 and 90.75 cm, with the most number of and tallest species occurring with the plots which received 7.5 cm of peat (77 and 110 cm, respectively). Propagating herbaceous species were noted by HMA as Arctared fescue, Revenue slender wheatgrass, wild rye and Foxtail barely. The 7.5 cm peat addition rate had the highest herbaceous coverage at 35%

Con Mine

Survival of Nitrogen Fixing
Shrubs and Other Woody
Species: Tailings Amended with
Muskeg and Vegetated With
Creeping Red Fescue, Meadow
Foxtail, Alkaligrass and Foxtail
Barely

Information Sources:

Studies for Restoration and Reclamation of Abandoned Tailings at Nerco Con Mine, 1988 (Cominco Reclamation Research Center)

Funding Sources and/or Client: NERCO Con Mine Ltd, NERCO Minerals Canada Ltd.

Researchers:

Company/Institution: Cominco Reclamation Research Center, Trail B.C.

Personnel: R.T. Gardiner

Purpose: To investigate the ability of nitrogen fixing shrubs and other woody species to establish within the Con Mine Lower Pud North tailings facility

Amendments: Fertilizer (muskeg historically applied to test sites)

Discussion and Results: Woody species were planted on sites that were amended with 7.5 cm of muskeg in 1977. Sites were rotovated prior to planting woody species to eliminate any competition from other vegetation species (foxtail barely, alkaligrass and atriplex had previously grown densely for nine seasons). In 1988, testing sites had an average of 5 ms/cm, while the 1987 mean was 11 ms/cm.

The 1987 planted siberian pea shrub, willow and rose had 78%, 22% and 33% survival rates respectively. All 1986 seedling suffered very high mortality and Fourwing saltbrush suffered 100% winterkill. The 1988 Siberian peashrub and willow seedlings had an excellent survival rate (88% and 68%, respectively, however they had not experienced winter growth. It should be noted that 1987 growing season survival for Siberian pea was 98%, which dropped to 78% following the winter season, while willows remained at 22% following winter.

Con Mine

Survival of Nitrogen Fixing Shrubs and Other Woody Species: Muskeg Amended

Information Sources:

Studies for Restoration and Reclamation of Abandoned Tailings at Nerco Con Mine, 1988 (Cominco Reclamation Research Center)

Funding Sources and/or Client: NERCO Con Mine Ltd, NERCO Minerals Canada Ltd.

Researchers:

Company/Institution: Cominco Reclamation Research Center, Trail B.C.

Personnel: R.T. Gardiner

Purpose: To investigate the ability of nitrogen fixing shrubs and other woody species to establish within the Con Mine Lower Pud North tailings facility

Amendments: Fertilizer (muskeg historically applied to test sites)

Discussion and Results: In July 1986, 10 to 15 cm of muskeg were incorporated into tailings at 20 sites within the Lower Pud North (10 within the south side and 10 within the north side). In 1988, ECe averaged 3 and 7 ms/cm in the northern and southern sites, respectively. Only the 1987 planted Siberian shrub was noted as growing satisfactorily (north coverage = 70% and south coverage = 68 %). *Hippophae rhamnoides* had an 18% survival rate and rose and willow averaged 3%. Fourwing saltbrush suffered 100% winterkill and all seedlings in 1986 suffered very high mortality rates. 1988 willow seedlings did not establish within tailings with ECe higher than 3 ms/cm.

- *Top: Training Aboriginal staff in methods of transplanting willows*
- *Middle: Results of Riparian Revegetation*
- *Bottom: Revegetated are denoted by orange box*

Con Mine

Survival of Nitrogen Fixing
Shrubs and Other Woody
Species: Unamended,
Unvegetated, Periodically
Flooded Depressions

Information Sources: Studies for Restoration and Reclamation of Abandoned Tailings at Nerco Con Mine, 1988 (Cominco Reclamation Research Center)

Funding Sources and/or Client: NERCO Con Mine Ltd, NERCO Minerals Canada Ltd.

Researchers:

Company/Institution: Cominco Reclamation Research Center, Trail B.C.

Personnel: R.T. Gardiner

Purpose: To investigate the ability of nitrogen fixing shrubs and other woody species to establish within the Con Mine Lower Pud North tailings facility

Amendments: None

Discussion and Results: Seedlings were transplanted into depressions which temporarily ponded water during heavy rain and/or spring freshet. In 1986 and 1987 tailings within the depressions averaged 13 ms/cm. 1987 seedling survival for Siberian Peashrub, willow, rose and *H. rhamnoides* averaged 67%, 9%, 18% and 16%, respectively (1988 values). All woody species planted in 1986 suffered a very high mortality rate (84% to 100 %)

Con Mine

Maintenance Fertilizer (Study C-3-74)

Information Sources: Studies for Restoration and Reclamation of Abandoned Tailings at Nerco Con Mine, 1988 (Cominco Reclamation Research Center)

Funding Sources and/or Client: NERCO Con Mine Ltd, NERCO Minerals Canada Ltd.

Researchers:

Company/Institution: Cominco Reclamation Research Center, Trail B.C.

Personnel: R.T. Gardiner

Purpose: To investigate the effects of discontinuing maintenance fertilizer on plant growth within the Negus tailings.

Amendments: Fertilizer

Discussion and Results: In 1975, four seed mixtures (#6 = 45kg/ha, #7 = 60 kg/ha, #8 = 75kg/ha and #9 = 60 kg/ha) were applied at two different application rates within the Negus tailings facility. One treatment plots received maintenance fertilizer for seven years (1974 to 1981) and the other received fertilizer for only two growing seasons (1975 and 1976). In 1978, seven of the ten original seeded species had died out within the no maintenance fertilizer plots. Remaining species included: Reed canary grass, crested wheatgrass, Boreal fescue and Nugget bluegrass. Overall coverage had declined from a max of 75% to ca. 25%. In 1988, the no maintenance fertilizer plots were dominated by Foxtail Barely, alkaligrass, Boreal fescue and moss. Plots receiving maintenance fertilizer were dominated by Boreal fescue and Meadow foxtail. In 2000, HMA reassessed the plots. No maintenance plots had an average coverage of 23%, which was comprised of Boreal fescue, Foxtail barely, fireweed, aster, willow (*Salix lanata*) and moss. Plots which had received maintenance fertilizer had a total coverage of 43%, comprised of Boreal fescue (27%), Foxtail barely (10%), fireweed (3%) and moss (5%).

Con Mine

Comparison of Vegetation Potential of Upper Pud Tailings and Lower South Pud Tailings to the Lower North Pud Tailings

Information Sources: Studies for Restoration and Reclamation of Abandoned Tailings at Nerco Con Mine, 1988 (Cominco Reclamation Research Center)

Funding Sources and/or Client: NERCO Con Mine Ltd, NERCO Minerals Canada Ltd.

Researchers:

Company/Institution: Cominco Reclamation Research Center, Trail B.C.

Personnel: R.T. Gardiner

Purpose: to compare the revegetation potential of tailings deposits not containing revegetation test plots to those tailings deposits which contained revegetation test plots based on tailings chemical and physical properties

Amendments: N/A

Discussion and Results: A comparison between the vegetation potential of the Upper Pud Tailings (UPT) and Lower South Pud Tailings (LSPT) to the Lower North Pud tailings (LNPT) was based on a comparison between the chemical and physical properties of respective tailings samples. If the UPT and LSPT tailings were similar in chemical and physical properties to that of LNPT then the experiences gained from revegetation trials within the LNPT could be employed with the UPT and LSPT. The following parameters were compared:

Water soluble cation and anion content, Sodium Adsorption Ratio (SAR), arsenic content and texture (60 surface and subsurface samples); plant available nutrient content, available water storage capacity and bulk density (12 surface samples); and sulfur content and CaCO_3 equivalent (47 surface and subsurface samples for acid generation potential).

Results indicated that physical and chemical properties of the three tailings deposits were similar. Tailings averaged 7.0 in pH with low sulphur content and excess carbonates, which indicates that acidic conditions will not develop within the tailings. Salinity was sufficient in concentrations to be limiting to vegetation establishment. Salinity was imparted to the tailings via large concentrations of sodium and chloride ions. Tailings were also devoid of organic matter and arsenic concentrations were similar (ca. 0.17%). Available water capacity was slightly higher than typical silt loam to silt textures sampled (all but 4% of soil water). Overall, plant establishment within the three tailings deposits were limited by high salinity and lack of essential plant nutrients.

Con Mine

Operational Revegetation of the Negus Tailings (1981)



- **Top: Vegetation propagating within the Negus Tailings two growing seasons following cessation of maintenance**

fertilizer (Photograph extracted from *Studies for Restoration and Reclamation of Abandoned Tailings at Nerco Con Mine* (R.T. Gardiner 1988))

Information Sources: Studies for Restoration and Reclamation of Abandoned Tailings at Nerco Con Mine, 1988 (Cominco Reclamation Research Center)

Funding Sources and/or Client: NERCO Con Mine Ltd, NERCO Minerals Canada Ltd.

Researchers:

Company/Institution: Cominco Reclamation Research Center, Trail B.C.

Personnel: R.T. Gardiner

Purpose: to revegetate the Abandoned Negus Tailings Deposit

Amendments: Fertilizer

Discussion and Results: The Negus pond was prepared for large scale revegetation in June of 1981 through both contouring the tailings surface and removal of debris from the general area. A chain link fence was erected around the perimeter of the tailings in order to prevent access. In mid July of 1981 a local landscaping contractor applied seed mix #5 at 50 kg/ha with a turf shaper machine. 11-55-0 and 13-16-10 were broadcast on the tailings, prior to seeding, at 365 and 400 kg/ha, respectively and incorporated with a rotovator. In June of 1983, tailings were reseeded with 20 kg/ha Lemmon's alkaligrass. Reseeding was initiated due to variable establishment of the previously seeded mixture.

By 1984, grass had established within 93% of the Negus tailings. Coverage averaged 31%, however coverage ranged from 0 to 95 %. Biomass averaged 653 kg/ha and ranged from 0 to 1960 kg/ha. Alkaligrass was the dominant species (frequency in quadrats = 75% and cover average = 13%). Meadow foxtail and Creeping red fescue were identified within 43% and 45% of quadrats and had respective coverage of 7% and 8%. Foxtail barely was present in 43% of quadrats and averaged 3% coverage. Tissue arsenic concentrations were slightly elevated with respect to concentrations of similar species of grasses growing within Yellowknife soils. In 1986, 50% of the revegetated tailings were excavated and subsequently used in dam construction. Gardiner reported that the remaining vegetation propagated for an additional two years without any maintenance fertilizer.

Con Mine

Operational Revegetation of the Negus Tailings (1981)

Discussion and Results Cont.: In 1988, prominent species included: Foxtail barely, Nuttall's alkaligrass and Creeping red fescue. After two years with no fertilizer, biomass and coverage averaged 408 kg/ha and 38% coverage. Dominant vegetation species were Foxtail barely (13% cover) and alkaligrass (12% cover). Creeping red fescue and Meadow foxtail coverage averaged 8% and 1%, respectively. In June of 1988, fertilizer was reapplied after one season with no application. 13-16-10 fertilizer was applied at 400 kg/ha within two strips (4m wide by tailings width long). Vegetation cover and biomass increased to 56% and 1324 kg/ha. Alkaligrass, Creeping red fescue and Meadow foxtail coverage were increased to 16%, 13% and 9%. Moss species were noted as covering 7% of the tailings surface .

Con Mine

Final Abandonment and Restoration of Historical Tailings Deposits at the Con Mine (Miramar: 2005)

- HMA recommended that the Negus tailings will not require amendment as salinity levels had been reduced with time to a range tolerable by most plant species.
- The tailings deposits to date have not generated acidic drainage and are considered to not have the potential to generate acidic drainage in the future.

Information Sources:

- Section 6 of the Miramar Con Mine Draft Final Abandonment and Restoration Plan (Golder 2004);
- Reclamation of Abandoned Tailings, Miramar Con Mine, Ltd., Yellowknife, NT, An Assessment of Long-Term Studies (Harvey Martens and Associates Inc. May 2001)

Funding Sources and/or Client: Miramar Con Mine

Researchers:

Company/Institution: Miramar Con Mine, Harvey Martens and Associates Ltd.; and Golder

Personnel: Ron Connell (Miramar); Harvey Martens (HMA)

Purpose: to revegetate the Abandoned Negus Tailings Deposit

Amendments: Fertilizer

Discussion and Results: The general Con Mine tailings matrix is composed mainly of quartz, chlorite, ankerite, muscovite, calcite and sulphides minerals. A more thorough review of the chemistry of historical tailings deposits other than Middle and Upper Pud was provided previously within the tailings properties comparison section. Tailings deposits are generally lacking organic matter and nutrients. The tailings also contain high concentrations of salinity following initial abandonment, until natural or applied methods leach salts from the tailings profile. The tailings deposits to date have not generated acidic drainage and are considered to not have the potential to generate acidic drainage in the future.

In 2000, Miramar Con Mine Contracted HMA to review historical revegetation and to make recommendations for operational revegetation based on this review. HMA recommended that the Negus tailings will not require amendment as salinity levels had been reduced with time to a range tolerable by most plant species. HMA further recommended that the Negus tailings be contoured to avoid ponding of water and that the surface should be roughened to receive seeds. Seed mix #9 and granular fertilizer (10-30-10) should be broadcast at 60 kg/ha and 200 kg/ha, respectively. The entire seeded area should be harrowed to incorporate the seed and fertilizer into the surface to promote germination and establishment. Follow up seeding of Adanac slender wheatgrass and alkaligrass on saline patches of tailings and maintenance fertilizer application (16-20-0 @ 300 kg/ha in early June) was recommended.

Con Mine

Final Abandonment and Restoration of Historical Tailings Deposits at the Con Mine (Miramar: 2005)

Discussion and Results Cont.: The current Final Abandonment and Restoration Plan submitted to the MVLWB by Miramar Con Mine states the following primary objective for abandonment of tailings deposits *“to reclaim the tailings surface in such a manner as to prevent dust generation and minimize water, human, and animal contact with the tailing substrate, preferably with revegetation , and where this is not feasible, by physically capping the tailings surface with a geotechnically stable material such as mine waste, waste rock, or overburden”*.

The Upper and Middle Pud tailings deposits are highly saline as they have just recently been abandoned and have therefore not had sufficient time to leach salts. These tailings deposits may have to be covered with an engineered cap (40 to 50 mm minus waste rock or mine muck). Some revegetation of the surface of the engineered cap will occur to encourage revegetation. Several islands of local northern vegetation up to 1/2 ha. in size have been proposed. Vegetation is expected to propagate from these caps through natural succession. If additional successful and economical methods of revegetation can be identified then programs will be developed to execute methods operationally. The timing of full scale closure of these deposits will be dependent upon their physical stability of the deposit as it settles. Revegetation of the downstream slopes of dams has also been proposed.

Progressive reclamation of the Lower, Crank Lake, Neil Lake and Negus tailings deposits was initiated in 2002 and is expected to be mostly completed by 2007. In the fall of 2002, based on the recommendation of HMA, a 4.5 ha. revegetation test plot was constructed within the Neil Lake tailings facility. The surface of the test plot was amended with a small quantity of clay and subsequently fertilized and seeded. Based on this success of these trials, the Negus, Neil lake and Lowe Pud tailings facilities will be reclaimed via revegetation, based on HMA recommendations. Portions of the historical tailings deposits may require some form of clay amendment to mitigate residual concentrations of salinity and some additional future amendments may be required based on the initial success of the revegetation.

Con Mine

Seed Mixes

Mix #1	Mix #2	Mix #3	Mix #4	Mix #5	Mix #6	Mix #7	Mix #8	Mix #9
Flood Leaching Study C-3-77 (1978)	Peat Amendment	C-1-87 Legumes and Select Grasses	Negus Pond	Maint. Fertilizer #1	Maint. Fertilizer #2	Maint. Fertilizer #3	Maint. Fertilizer #4	Operational Revegetation Seed Mix Recommended by HMA
Grass and Legume mix	Grass	Grass and Legume mix	-	-	-	-	-	-
Creeping red fescue var. Boreal	Tall Wheatgrass var. Orbit	Tall Wheatgrass var. Orbit	Tall Wheatgrass var. Orbit	Timothy var. Climax	Orchardgrass var. Chinook	Rye	Barely	Creeping red fescue var. Arctared
Meadow Foxtail	Creeping red fescue var. Arctared	Altai wildrye	Creeping red fescue var. Arctared	Hard fescue var. Durar	Creeping red fescue var. Boreal	Meadow foxtail	Red top	Meadow Foxtail var. Common (Nutraccoat)
Alfalfa var. Rambler	Kentucky bluegrass var. nugget	Mammoth wildrye	Meadow Foxtail	Crested Wheat-grass var. Summit	Pubescent wheatgrass var. Greenleaf	Canada Bluegrass	Creeping red fescue var. Boreal	Kentucky bluegrass var. nugget
Alkaligrass var. Lemmon's	Meadow foxtail	Slender Wheatgrass		Alfalfa var. Rambler	Alfalfa var. Rhizoma	Hard fescue var. Durar	Kentucky bluegrass var. nugget	Altai Wildrye var. Common
		Creeping red fescue var. Boreal						Slender Wheatgrass var. Adanac
		Meadow Foxtail						Alkaligrass var. Nuttal's
		Alfalfa						Alfalfa var. Rambler (Noducoat)
		Sainfoin						
		Birdsfoot						
		Trefoil						
		Cicer milkvetch						
		Sweet Clover						

Con Mine

Seed Mixes

[illegible]

Giant Mine

North Pond: Revegetation Study of North Pond Tailings Beach at the Giant Mine

Information Sources:

Funding Sources and/or Client:

Researchers:

Purpose:

Amendments:

Discussion and Results: The scope of the report was to identify which tailings amendments maximized plant growth within the North Pond tailings facility at the Giant Mine, NWT. A laboratory experiment was conducted during the winter of 2000 on tailings samples removed from the North Pond. It should be noted that the report was written prior to completion of the experiment and therefore the results presented were representative of interim experimental conditions.

The following list of amendments were used during the experiment: (1) Compost (provided by a local Yellowknife resident, which consisted of vegetable and fruit trimmings, coffee grounds and garden cuttings); (2) processed kimberlite tailings (sand sized particles with traces of gravel and silt); (3) peat (retrieved from Kam Lake Road area, which contained roots, leaves, wood bits and gravel); (4) lagoon sludge (obtained from Fiddlers Sewage Lagoon, which contained aquatic and shoreline biomass). The above amendments were combined in the following manner to construct the experimental growth mediums: (1) tailings; (2) sewage sludge; (3) processed kimberlite; (4) processed kimberlite and sewage sludge; (5) tailings and sewage sludge; (6) tailings and peat; and (7) tailings and compost. Seeds from Adanac Slender Wheatgrass and Alpine Bluegrass species were used. The above listed combinations of amendments were placed in 30 cm high x 15 cm diameter free draining columns. 2 grams of Shultz Bloom Plus plant food fertilizer (N-P₂O₅-K₂O ratio of 1:6:1) was mixed with water and applied to the columns. For the first three weeks the columns were maintained at 60% field capacity. After this time watering was decreased in rate as amendments were draining from the column and the top of the amendment had sunk into the soil surface. Florescent grow tubes were used for lighting and room temperature was maintained. Each experimental combination was produced in triplicate. The following experimental variables were observed: (1) number of days between seeding and germination; (2) mean shoot height after five weeks of growth; and (3) overall vigor. Physical and chemical properties of the various amendment and tailings combinations were also obtained.

Giant Mine

North Pond: Revegetation Study of North Pond Tailings Beach at the Giant Mine

Discussion and Results Cont.: Based on comparisons of the above mentioned experimental variables within each of the amendment combinations Gardois had the following observations: the (1) Adanac Slender Wheatgrass/lagoon sludge/tailings; (2) Adanac Slender Wheatgrass/kimberlite/lagoon sludge/tailings; (3) Alpine Bluegrass/lagoon sludge/tailings; and (4) Alpine Bluegrass/kimberlite/lagoon sludge/tailings combinations performed the best. However, the Adanac Slender Wheatgrass produced more biomass than the Alpine Bluegrass.

- *Top: Training Aboriginal staff in methods of transplanting willows*
- *Middle: Results of Riparian Revegetation*
- *Bottom: Revegetated are denoted by orange box*

Giant Mine

North Pond: Preliminary In-Situ Tailings Study



Information Sources:

Funding Sources and/or Client:

Researchers:

Purpose: To investigate the potential of revegetation of the Giant Mine Tailings (Gold recovery through cyanidation)

Amendments:

Discussion and Results: Based on the experimental results presented in Section 4.1.1 a field study was undertaken within the North Pond tailings facility of the Giant Mine, NWT. Pulp waste sludge was added as an additional tailings amendment.

In late summer of 2000, three revegetation test plots were constructed under the guidance of Ryan R. Lyle (University of Waterloo Geological Engineering. Plot #1 (3.5 m²) was amended with pulp waste sludge and fertilizer; Plot #2 (10 m²) was amended only with fertilizer; and Plot #3 (10m²) was amended with kimberlite tailings and fertilizer. Fertilizer 2-14-0 and 15-30-15 were applied to the plots at 30 g/m² and 10 g/m². Adanac Slender Wheatgrass was applied to all three plots at a rate of 30 kg/ha. Tailings were scarified prior to placement of seeds and amendments. Plot #1 and #2 were seeded on August 15, 2000 and Plot #3 was seeded on August 18, 2000 (well after freshet).

Grass began to grow in Plot #1 between the 22nd and 50th day of planting and was noted as growing in patches within the plot. Growth in Plot #2 was present on September 5, 2000, 21 days following planting. Grass was noted throughout the entire plot and was described by Lyle as being the tallest growth within the three plots. Plot #3 had growth on the 5th of September throughout the entire plot in equal proportions to that of Plot #2. In 2000, Lyle reported Plot #2 and #3 as performing the best based on the distribution of plant growth within the test plots (i.e., Plot #1 was patchy). It was also suggested that kimberlite tailings were not necessary as an amendment as both plots #2 and #3 performed equally well. This makes sense as kimberlite tailings have been noted as being coarse grained and nutrient poor and would therefore would most likely not provide any additional cation exchange, water holding capacity or nutrient addition.

- *Top: Training Aboriginal staff in methods of transplanting willows*
- *Middle: Results of Riparian Revegetation*
- *Bottom: Revegetated are denoted by orange box*

Giant Mine

North Pond: Preliminary In-Situ Tailings Study

Discussion and Results Cont: In the summer of 2005, AEL and the University of British Columbia Department of Biological and Chemical Engineering visited the Giant Mine and photographed the three test plots. No physical or chemical analysis of the tailings or vegetation was undertaken. Based on visual observation, Plot #1 (amended with pulp mill sludge) had preformed the best after five years of growth. Growth remained patchy, however the Adanac Slender Wheatgrass ranged up to a foot in plant height, which is approximately the same as the maximum height reached under the kimberlite/lagoon sludge experimental conditions (best performer in experiment for plant height; refer to section 4.2.1). Little to no growth was observed in Plot #2 and Plot #3. It is the authors opinions that the pulp waste sludge amendment in Plot #1 would have increased, in the long term, water holding capacity, nutrient exchange capacity relative to tailings and nutrient content, providing more suitable conditions for sustained growth. The patchiness could be attributed to seed distribution during planting, uneven incorporation of the pulp waste sludge or uneven establishment of seedlings. Plot #2, which received only one application of fertilizer as an amendment would have problems sustaining growth since after the nutrients had either leached or been used up by the plants the growth conditions would be similar to tailings only. Plot #3 received fertilizer and kimberlite; little difference, with the exception of an initial reduction in salinity due to mixing with the kimberlite tailings, would be experienced between Plot #2 and Plot #3. Kimberlite would not increase the water holding capacity of the tailings as it is composed mainly of sand sized particles. In addition, Kimberlite amendment would not increase nutrient levels or cation exchange capacity.

- *Top: Training Aboriginal staff in methods of transplanting willows*
- *Middle: Results of Riparian Revegetation*
- *Bottom: Revegetated are denoted by orange box*

Giant Mine

Central Pond



- **Top:** Aerial view of the area within the Central Tailings Pond which was revegetated in the 1980's
- **Middle:** Root zone of grasses growing with revegetated area
- **Bottom:** Select propagating grasses

Information Sources:

Funding Sources and/or Client:

Researchers:

Purpose:

Amendments:

Discussion and Results:

Giant Mine

Central Pond



- ***Top:** Portion of Central Pond revegetation where transect was taken from. Note that the central portion of the revegetation was removed during reprocessing of tailings*

Giant Mine

Central Pond: Identified Species



Fireweed (*Epilobium angustifolium*) and Goldenrods (*Solidago* spp.) difficult to ID further as there are no flower structures. (Herbs)



Caption describing picture or graphic.



Foxtail Barley - *Hordeum jubatum* (grass) Wild Black Current (*Ribes americana*) (shrub)



Wheatgrass *Agropyron trachycaulumm* also called *Elymus trachycaulumm* and maybe some small amount of Polargrass (*Arctagrostis latifolia*)



Foxtail Barley - *Hordeum jubatum* (grass)



wheatgrass *Agropyron trachycaulumm* also called *Elymus trachycaulumm* (grasses) + Foxtail Barley - *Hordeum jubatum* (grass)

Giant Mine

Central Pond: Identified Species



Hawkweed - *Hieracium umbellatum* (herb)



Wheatgrass - *Agropyron trachycaulum*



Western Dock - *Rumex occidentalis* (Herb)



Foxtail Barley - *Hordeum jubatum* (grass)



Foxtail Barley - *Hordeum jubatum* (grass) + Hawkweed - *Hieracium umbellatum* (herb)



Wheatgrass - *Agropyron trachycaulum*

Giant Mine

Bank Below Roaster Stack

Information Sources:

Funding Sources and/or Client:

Contracted Companies:

Purpose:

Amendments:

Discussion and Results:

- *Top: Training Aboriginal staff in methods of transplanting willows*
- *Middle: Results of Riparian Revegetation*
- *Bottom: Revegetated are denoted by orange box*

Giant Mine

Natural Succession



Information Sources:

Funding Sources and/or Client:

Researchers:

Purpose:

Amendments:

Discussion and Results:

- *Top: Training Aboriginal staff in methods of transplanting willows*
- *Middle: Results of Riparian Revegetation*
- *Bottom: Revegetated are denoted by orange box*

Port Radium
Natural Succession

Information Sources:

Funding Sources and/or Client:

Researchers:

Purpose:

Amendments:

Discussion and Results:

Port Radium

Identified Species



Saxifrage – *Saxifraga* + Stonecrop *Sedum* (Directly adjacent to capped tailings)



Foxtail Barley - *Hordeum jubatum*



Wheatgrass *Agropyron trachycaulum*



Sedge



Raspberry



Western Dock - *Rumex occidentalis* (Herb) + Foxtail Barley - *Hordeum jubatum* (grass)

Port Radium

Identified Species



Grass *Agropyron* spp.



White Arctic Mountain Heather *Cassiope tetragona* (Shrub) + *Saxifraga* + Mossy Stonecrop *Sedum* spp.



Sedge (tailings cap)



Three leaved cinquefoil *Potentilla tridentate* herb (directly adjacent to tailings cap)



White Arctic Mountain Heather *Cassiope tetragona* (Shrub) (directly adjacent to tailings cap)



Pincushion orange *Xanthoria polycarpa* + grey lichen (unkown) (directly adjacent to covered tailings)

Port Radium

Identified Species



Western Dock - *Rumex occidentalis* (Herb) + Foxtail Barley - *Hordeum jubatum* (grass) + Grass *Agropyron* spp. (exposed tailings and rock cover area)



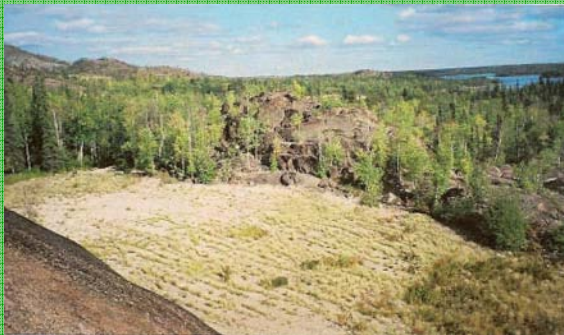
Stonecrop *Sedum* spp. (exposed tailings/rock cover interface)



Stiff Club Moss *Lycopodium annotinum* (exposed tailings)

Rayrock Mine

Tailings Soil Cover



- **Top:** North Tailings Pond Following Revegetation
- **Middle:** Dump Area
- **Bottom:** Example of Vegetation Propagating Within the Tailings Covers in 2002, Six Growing Seasons Following Seeding

(Photo taken from 2002 Rayrock Long-Term Monitoring Program (Rescan 2003))

Information Sources:

- 2002 Rayrock Long-Term Monitoring Program (Rescan February 2003)

Funding Sources and/or Client: DIAND Contaminant and Remediate Directorate

Researchers:

Purpose:

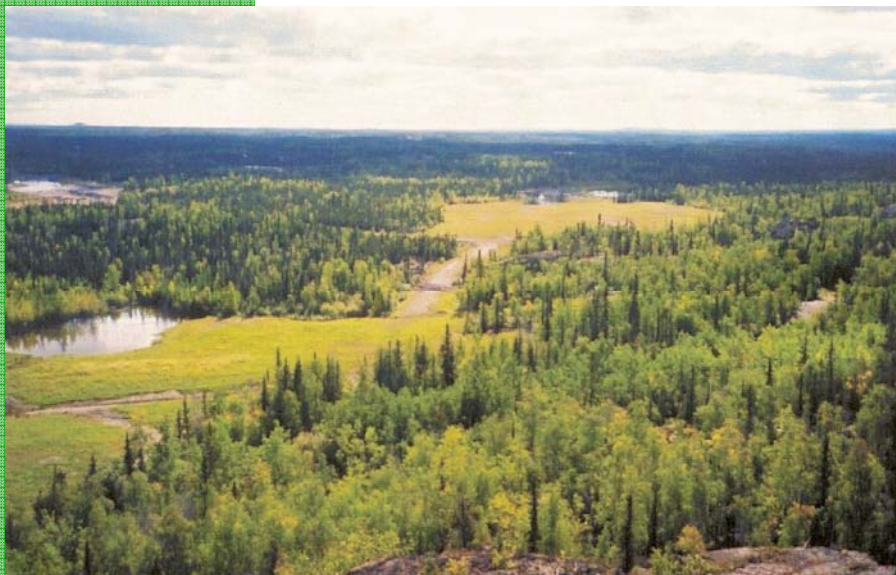
Amendments:

Discussion and Results:

In 2002, Rescan visited the Rayrock Mine and noted that the cover vegetation of the North Tailings Pond silty/clay soil cover was generally in good shape and comprised dense, self-seeding grasses and clover. Only a few upland areas were noted as having sparse vegetation coverage. Minor desiccation cracking was noted in areas containing sparse vegetation.

Rayrock Mine

Tailings SoilCover



- **Top:** *North and South Tailings Facilities Prior to Revegetation*
(Photo taken from EBA)
- **Bottom:** *North and South Tailings Facilities Following Revegetation (2002)* (Photo taken from 2002 Rayrock Long-Term Monitoring Program (Rescan 2003))

Rayrock Mine

Seed Mixes

Mix #1

North and South Tailings
Cover

Dawson Seed Co. Ltd. Big
Horn Interior Reclamation
Mixture No. 7303

Northern Orchard Grass
Blend (ARCTIC, DS7 and
Mobile)

Smooth Bromegrass

Climax Timothy

Perennial Ryegrass

Creeping Red Fescue

Kentucky Bluegrass

Red Top

Meadow Fox Tail

White Clover

Alsike Clover

BHP Ekati™ Diamond Mine

Long Lake Tailings Facility Revegetation Studies

2000 Greenhouse Trials

**Neil Burton Reid Masters of
Science Thesis**

“Kidd noted that the sewage sludge was a sustainable physical tailings amendment in comparison to peat as the peat would require destruction of additional wetlands”

Information Sources:

- Ekati™ Diamond Mine Processed Kimberlite Tailings Reclamation, Annual Report for BHP Diamonds Inc., Department of Renewable Resources University of Alberta (January 19, 2001)
- Establishment of a Vegetation Cover on Kimberlite Mine Tailings, Neil Burton Reid Master of Science Thesis, 2002
- Processed Kimberlite Tailings Reclamation at the Ekati™ Diamond Mine, Technical Workshops February 2003

Funding Sources and/or Client: BHP Diamonds Inc., Faculty of Graduate Studies and Research, University of British Columbia and Department of Renewable Resources, University of Alberta

Researchers:

Company: Department of Renewable Resources University of Alberta, Ekati™ Diamond Mine and Harvey Martens and Associates

Personnel: Neil Burton Reid (UofA), Dr. M. Anne Naeth (UofA), Dr. Robert Grant (UofA), Dr. David Chanasyk (UofA), Dr. Peter Kershaw (UofA), Emmanuel Mapfumo (UofA), Helen Butler (BHP) and Harvey Martens (HMA)

Purpose: To characterize the kimberlite tailings from the study area; to test potential kimberlite tailings revegetation amendments; and to assess the potential of select plant species for use in revegetation of kimberlite tailings at the Ekati™ Diamond Mine LLCF.

Amendments: Peat moss, sewage sludge (obtained from Ekati™ Diamond Mine, lake sediment (Koala Lake), Agri-Boost (commercial soil conditioner), pulpmill solids, fertilizer, calcium carbonate, gypsum and rock phosphate.

Discussion and Results: Combinations of amendments that were not feasible to test in under field conditions (i.e., to many resources required to test the range of amendment combinations under a complete factorial design) were examined through laboratory scale revegetation trials. Calcium carbonate, gypsum and rock phosphate were used to amend the serpentine conditions of the kimberlite tailings (Serpentine Ca/Mg = 0.58; normal Ca/Mg = 2).

Kidd classified the amendments based on their effect on either the physical (texture, water holding capacity etc.) or nutrient status (nitrogen, phosphorus, cation exchange capacity etc.) of the kimberlite tailings, with respect to conditions suitable for plant growth. Peat, pulpmill sludge, lake sediment and Agri-Boost were considered as physical tailings amendments and fertilizer (10-34-10-4), gypsum, calcium carbonate and rock phosphate were considered to be nutrient tailings amendments. Sewage sludge was listed as both a physical and nutrient tailings amendment.

BHP Ekati™ Diamond Mine

Long Lake Tailings Facility Revegetation Studies

2000 Greenhouse Trials

Neil Burton Reid Masters of Science Thesis

Discussion and Results Cont.: The greenhouse study ran from October 2000 to 2001 and was subdivided into three four month experimental runs. The first four month experimental period was designed to test combinations similar to those proposed for the field scale trials to allow for a bench mark of comparison. The second experimental run focused on the rates of physical tailings amendment addition. The third experimental trial assessed the rate of chemical tailings amendment addition. Both the second and third experimental trials focused on amendment combinations outside the range of the proposed field scale revegetation trials.

In addition, all three experimental trials were randomized complete block design. All variable combination are too long to review within this document. The reader is therefore referred to the information sources for a complete listing.

Polyfill bedding cloth lined 12.5 cm in diameter by 15 cm deep pots with four drainage holes were used to house the tailings, amendments and plants. Field capacity was maintained within the soils and the greenhouse ambient conditions (light and temperature) were maintained to reflect those of the expected field conditions of the Ekati™ Diamond Mine.

Plant response to the tested combinations of amendments were evaluated based on: ground cover, shoot biomass, root biomass, plant height. Change in tailings properties in response to amendment application were assessed based on: available macronutrients, cation exchange capacity, percent organic carbon and calcium/magnesium balance.

Based on the results of the greenhouse trials Kidd concluded that a combination of physical and nutrient tailings amendment provided the best plant growth. The single most effective amendment was sewage sludge, while paper mill sludge and peat moss preformed well. Sewage sludge was also identified as the most economical amendment, however its application on tailings provides an pathway for pathogenic exposure to harmful microorganisms if not managed properly. Lake sediment application resulted in a negative plant growth response. However, Kidd suggested that the lake sediment application rate employed during the greenhouse trials were too high. Furthermore, Kidd recommended that testing with lake sediment addition rates of <5 cm in combination with optimum rates of sewage sludge and peat moss should be undertaken. Addition of calcium amendments did not mitigate the serpentine conditions of the kimberlite tailings. Finally Kidd noted that a rate increase in amendments was not strongly correlated to an increase in plant growth.

BHP Ekati™ Diamond Mine

Long Lake Tailings Facility Revegetation Studies

2000 Reclamation Research

Soil Amendment Trials

Information Sources:

- Ekati™ Diamond Mine Processed Kimberlite Tailings Reclamation Research Program, 2000 (HMA 2000)
- Ekati™ Diamond Mine Processed Kimberlite Tailings Reclamation Research Program, 2002 (HMA 2002)
- Ekati™ Diamond Mine Revegetation Research Projects 2004 (HMA 2004)
- Processed Kimberlite Tailings Reclamation at the Ekati™ Diamond Mine, Technical Workshops February 2003
- Establishment of a Vegetation Cover on Kimberlite Mine Tailings, Neil Burton Reid Master of Science Thesis, 2002

Funding Sources and/or Client: BHP Ekati™ Diamond Mine

Researchers:

Company/Institution: Department of Renewable Resources
University of Alberta, Ekati™ Diamond Mine and Harvey Martens and Associates

Personnel: Harvey Martens (HMA); Neil Burton Reid (UofA); and Helen Butler (BHP)

Purpose: to test the efficiency of various soil amendments for use in revegetation of the LLCF

Amendments: *Nutrients:* fertilizer, rock phosphate, calcium carbonate, gypsum; *Structural:* peat and lake sediment; *Nutrient & Structural:* sewage sludge.

Discussion and Results: Soil amendment trials were undertaken based on the results of greenhouse studies conducted by Reid and the University of Alberta and the expertise of Harvey Martens and Associates. Trials were designed to: (1) address the serpentine conditions of the LLCF (i.e., high nickel concentrations and calcium and magnesium ions present in a ratio of less than 0.8); and (2) assess the relationship between vegetation establishment and improvements to the processed kimberlite tailings substrate physical and nutrient status.

Three calcium amendments were compared: (1) rock phosphate; (2) gypsum; and (3) lime (calcium carbonate). Calcium amendment rates were selected based on the normal Ca:Mg ratio of tundra soils (Ca:Mg ratio ~ 2.0) and analytical analysis of the LLCF tailings. Analytical testing indicated that the kimberlite tailings within Cell B of the Long Lake tailings facility have a calcium to magnesium ratio of ~ 0.62.

BHP Ekati™ Diamond Mine

Long Lake Tailings Facility Revegetation Studies

2000 Reclamation Research

Soil Amendment Trials

“Tailings structural amendments were incorporated to improve the texture, water holding capacity and cation exchange capacity of the tailings (structural amendments such as peat may also possibly bind metals, acting as a sink and making them less biologically available)”

Discussion and Results Cont.: Two soil structural amendments were tested (1) peat; and (2) lake sediment. Both were applied by volume (peat = 8 cm & lake sediment = 10 cm).

Test plots were constructed during the period between June 26 and July 6, 2000. The following variable combinations (incomplete block design) were tested in triplicate within 2m x 2m plots: (1) rock phosphate (2080 kg/ha); (2) calcium carbonate (1667 kg/ha); (3) gypsum (2173 kg/ha); (4) peat (8 cm) & gypsum (2173 kg/ha) & calcium carbonate (1667 kg/ha); (5) peat (8 cm) & gypsum (2173 kg/ha); (6) lake sediment (10 cm); (7) lake sediment (10 cm) & gypsum (2173 kg/ha) & rock phosphate (2080kg/ha); and (8) peat (8 cm) & sewage sludge (10 cm) & rock phosphate (2080 kg/ha) & gypsum (2173 kg/ha).

Test plots were rotovated prior to the broadcasting of seed (mix #36 @ 40 kg/ha) and fertilizer (mixture of 10-34-10-5 @ 280 kg/ha & 33-0-0 @ 75 kg/ha). Information regarding the geographic origin and development are provided in HMA 2000. Plots were covered with a Curlex erosion control blanket, which was secured using metal staples. Curlex erosion control blanket prevents both the wind borne loss of seed and soil moisture. A fence was erected around a 57 x 40 m area containing the test plots in order to prevent trampling and grazing of the vegetation by caribou and arctic hare (indigenous herbivores).

Results from the soil amendment trials were assessed by Martens and Reid. The response variables selected for assessing plant growth were: general plant health, tillering, flowering, vegetation cover, plant height and shoot biomass. .

The best performing plots were those in which the both soil structural and nutrient enhancing amendments were incorporated into the processed kimberlite tailings. The single best performing tailings amendment was sewage sludge. Nutrient only amended tailings (i.e., fertilizer only) did not perform as well with respect to plant growth and allowed nutrients to leach into deeper tailings profiles, thus increasing the risk of off site impact from nutrient loading.

Lake sediment & gypsum amended kimberlite tailings had the highest first year plant cover at 38%, but failed to produce favorable growth during subsequent seasons. Neil suggested that lake sediment trials using less than 5cm of lake sediment should be undertaken and that the lake sediment should also be combined with a suitable organic substrate and a nutrient source.

Calcium amendment failed to significantly affect the calcium to magnesium ratio of the kimberlite tailings and their addition as an amendment did not affect plant growth.

BHP Ekati™ Diamond Mine

Long Lake Tailings Facility Revegetation Studies

2000 Reclamation Research

Soil Amendment Trials

“Results of the soil amendment trials suggest that a vegetative cover on the LLCF is a feasible long term solution for stabilizing the tailings deposit.”

Discussion and Results Cont.: Plant species did not appear to be affected by the moderate levels soil salinity present within the processed kimberlite tailings (4.0 to 6.8 us/cm).

As stated previously, amendment combination #8 had the best plant response with 57% coverage (2004). Coverage for other planted species ranged between 21 to 33% (2004). Norton and norcoast bering hairgrass (mean coverage = 19% in 2002), and arctared fescue (mean coverage = 9% in 2002). Alpine and tundra bluegrass provided little cover, while polar grass did not experience any visible growth.

In 2004, a layer of wind blown kimberlite tailings was noted as covering the majority of the soil amendment test plots (up to >30 cm in depth). Arctared fescue and norton and norcoast bering hairgrass continued to propagate, despite the tailing deposition.

Results of the soil amendment trials suggest that a vegetative cover on the LLCF is a feasible long term solution for stabilizing the tailings deposit. Sewage sludge amendment proved to be very promising in promoting long term establishment of vegetation within the LLCF and its use would provide an environmentally positive application for a current on-site waste product. However, if sewage sludge is to be employed as a tailings amendment, then proper managerial controls will have to be established to avoid exposure of receptors to disease vectors and prevent the overloading of the tailings with nutrients and metals. The reader is referred to various guidance documents published by the USEPA under the Part 503 rule for management of biosolids application. These documents can be accessed at the National Environmental Publication Information System for the USEPA at <http://www.epa.gov/nepis>.

BHP Ekati™ Diamond Mine

Long Lake Tailings Facility Revegetation Studies

2000 Reclamation Research Revegetation Trials

“Two phase seeding consists of initially planting an annual plant species which then subsequently dies, providing an organic substrate which acts to improve soil conditions with respect to plant growth. Native perennial plant species are then subsequently planted within the area of die back. Perennial species can be planted as early as fall.”

Information Sources:

- Ekati™ Diamond Mine Processed Kimberlite Tailings Reclamation Research Program, 2000 (HMA 2000)
- Ekati™ Diamond Mine Processed Kimberlite Tailings Reclamation Research Program, 2002 (HMA 2002)
- Ekati™ Diamond Mine Revegetation Research Projects 2004 (HMA 2004)
- Processed Kimberlite Tailings Reclamation at the Ekati™ Diamond Mine, Technical Workshops February 2003

Funding Sources and/or Client: BHP Ekati™ Diamond Mine

Researchers:

Company/Institution: Harvey Martens and Associates and BHP Ekati™ Diamond Mine

Personnel: Harvey Martens (HMA); and Helen Butler (BHP)

Purpose: To test the effectiveness of various revegetation techniques with and without the addition of peat in establishing and maintaining a primary plant cover within the LLCF.

Amendments: *Nutrients:* fertilizer; *Physical:* peat

Discussion and Results: The revegetation study test plots were constructed in 2000, within the same 57 x 40 m area as the soil amendment study revegetation test plots, using a split plot randomized block design with 4 x 8m test plots. Peat was added to select test plots to test the effectiveness of a physical amendment in combination with differing revegetation techniques. Peat also mitigated the most limiting characteristics of the tailings with respect to plant growth, allowing a better assessment of revegetation technique on plant response.

Two seeding methods were tested: (1) row seeding with perennial species only; and (2) two phase seeding. Two phase seeding consists of initially planting an annual plant species which then subsequently dies, providing an organic substrate which acts to improve soil conditions with respect to plant growth. Native perennial plant species are then subsequently planted within the area of die back. Perennial species can be planted as early as fall.

Two seed mixtures were employed; (1) perennial; and (2) annual. One half of the plots received an annual species (mix #37) and the remaining half received a perennial species (mix #38). The perennial seed mix was row seeded at 20 kg/ha to a depth between ½ and 1 cm using an Earthway Precision Seeder. The annual seed mixture was row seeded at 130 kg/ha to approximately 4cm. Plots received an inorganic fertilizer application (mixture of 10-30-10-5: 100 kg/ha & 33-0-0: 25 kg/ha).

BHP Ekati™ Diamond Mine

Long Lake Tailings Facility Revegetation Studies

2000 Reclamation Research

Revegetation Trials

Discussion and Results Cont.: The following revegetation trial combinations were tested within the LLCF: (1) perennial; (2) annual; (3) low peat (4cm mixed with tailings) & perennial; (4) low peat (4cm mixed with tailings) & annual; (5) high peat (8cm mixed with tailings) & perennial; (6) high peat (8cm mixed with tailings) & annual; and (7) control. Half of the first six combinations were amended with calcium (gypsum @ 2173 kg/ha & rock phosphate @ 2080 kg/ha). Plots were created in triplicate.

The annual plots were subsequently reseeded in September 2000 (i.e., two phased seeding) and July 2001 with indigenous seeds collected and packaged by BHP and ABR Inc. Environmental (*Oxytropis deflexa* & *Epilobium angustifolium* plus *E. latifolium*) (mix #39) *O. deflexa* was drill seeded between every second row of Regreen and Fall rye (½ cm depth @ ca. 770 seeds/m²). *E. angustifolium* and *E. latifolium* were hand broadcast over the annual seed plots (1 packet/25m²) (seed packet details provided in HMA 2000).

In 2002 fertilizer (18-24-10) was reapplied with a drop seeder the south one half of each of the annual plots at a rate of 150 kg/ha.

By 2002, all of the originally seeded plants were dead within the annual plots. The only growth within annual plots was attributed to wind born deposition of hair grass and alkali grass. Martens concluded that this form of seeding indigenous species into annual plots was unsuccessful.

The growth of the perennial species in the kimberlite, low peat and high peat plots was doubled by the reapplication of fertilizer in the spring of 2000 (post maintenance fertilizer coverage = 47 – 67%). The calcium treatments had no apparent affect on plant growth within the perennial plots. Hairgrass and Arctared fescue accounted for approximately 2/3 and 1/3 of living cover.

BHP Ekati™ Diamond Mine

Long Lake Tailings Facility Revegetation Studies

2000 Reclamation Research

Species Trials

Information Sources:

- Ekati™ Diamond Mine Processed Kimberlite Tailings Reclamation Research Program, 2000 (HMA 2000)
- Ekati™ Diamond Mine Processed Kimberlite Tailings Reclamation Research Program, 2002 (HMA 2002)

Funding Sources and/or Client: BHP Ekati™ Diamond Mine

Researchers:

Company/Institution: Harvey Martens and Associates and BHP Ekati™ Diamond Mine

Personnel: Harvey Martens (HMA); and Helen Butler (BHP)

Purpose: to assess the revegetation potential of each of the seven grass species employed in the revegetation and soil amendment trials (i.e., mix #36).

Amendments: *Nutrient:* Gypsum, Rock Phosphate, fertilizer; *Physical:* peat

Discussion and Results: In 2000, the seven grass species (mix #36) were seeded separately in 8 m rows, 20 cm apart, with the following amendment combinations: (1) kimberlite & 4cm peat; (2) kimberlite & 4cm peat & gypsum (2173 kg/ha) & rock phosphate (2080 kg/ha); (3) kimberlite & gypsum (2173 kg/ha) & rock phosphate (2080 kg/ha); and (4) kimberlite. All rows were rotovated prior to seeding and following calcium amendment. Seeds were hand seeded into 1-2 cm furrows and fertilizer was hand broadcast (mixture of 10-34-10-5: 280 kg/ha & 33-0-0: 75 kg/ha).

Bering and Norton hairgrass and Arctared fescue were the best performers with row coverage ranging between 30% to 90%. Portions of the short growing Alpine bluegrass and Sourdough reedgrass were buried by wind blown tailings. Alyeska Polar grass did not germinate. HMA 2002 provides a tabular summary of the mean cover and plant height for the seven perennial species employed during the species trials.

BHP Ekati™ Diamond Mine

Long Lake Tailings Facility Revegetation Studies

2000 Reclamation Research

Assessment of Processed Kimberlite at Con Mine

Information Sources:

- Ekati™ Diamond Mine Processed Kimberlite Tailings Reclamation Research Program, 2000 (HMA 2000)

Funding Sources and/or Client: BHP Ekati™ Diamond Mine

Researchers:

Company/Institution: Ekati™ Diamond Mine and Harvey Martens and Associates

Personnel: Harvey Martens (HMA) and Helen Butler (BHP)

Purpose: To gather information which may aid in revegetation of processed kimberlite at the Ekati™ Diamond Mine.

Amendments:

Discussion and Results: In August of 1997, processed kimberlite was transferred from the Diavik mine to the Con Mine for disposal. Natural succession over 3-4 years has lead to an estimated plant coverage of 25%. The predominant species noted by Harvey Martens was tufted alkali grass (*Puccinellia nutalliana*), with some occurrence of foxtail barely. ECe ranged between 12 to 17.2 ms/cm.

BHP Ekati™ Diamond Mine

Long Lake Tailings Facility Revegetation Studies

2000 Reclamation Research

Characterization of Plant Communities on Kimberlite

Information Sources:

- Ekati™ Diamond Mine Processed Kimberlite Tailings Reclamation Research Program, 2000 (HMA 2000)

Funding Sources and/or Client: BHP Ekati™ Diamond Mine

Researchers:

Company/Institution: Ekati™ Diamond Mine and Harvey Martens and Associates

Personnel: Harvey Martens (HMA) and Helen Butler (BHP)

Purpose: To examine local sites for natural plant colonization of kimberlite parent material.

Amendments: N/A

Discussion and Results: In July of 2000 Harvey Martens examined two local sites, the Mark and Arnie outcrops. The Mark site has exposed kimberlite resulting from exploration and the Arnie site has exposed kimberlite due to alluvial erosion (situated mid slope along a water course valley).

The pioneer plants species of mix #40 were noted as naturally colonizing the Mark site. However, chemical analysis of the substrate at the Mark site indicated that the soil was in fact primarily till. The naturally invading species therefore are representative of natural succession of disturbed till.

The soils at the toe of the slope of the Arnie site were borderline serpentine (Ca:Mg ~ 0.8). White Dryad (*Dryas integrifolia*) (shrub) was noted by Martens as being the predominate species colonizing the lower slope position.

BHP Ekati™ Diamond Mine

Long Lake Tailings Facility Revegetation Studies

2001 and 2002 Reclamation Studies

Lake Sediment Trials

Information Sources:

Funding Sources and/or Client:

Researchers:

Purpose:

Amendments:

Discussion and Results: Lake sediment studies in 2001 were employed more thoroughly test the revegetation potential of lake sediments and were based on encouraging reports from both 2000 field studies (Harvey Martins 2000) and greenhouse studies by the University of Alberta (Reid and Naeth 2001). In July of 2001 the following combinations were tested in 4m x 4m plots: (1) rotovated kimberlite tailings; (2) kimberlite tailings & 5 cm lake sediment (both rotovated); (3) kimberlite tailings & 5 cm lake sediment & 4 cm peat moss (all rotovated); (4) non rotovated kimberlite tailings; (5) a control of rotovated tailings which did not receive fertilizer or seed applications; and (5) kimberlite tailings & 4 cm pulp and paper waste (both rotovated; 2.2 m x 2.2 m plots). Three replicated blocks of test plots were constructed and within each block, amendment combinations 1 through 3 were created in triplicate (9 test plots total for each amendment combination). An individual test plot for amendment combinations 4 through 6 were constructed within each block.

The paper waste test plots were row seeded with seed mix #2 (2002). Amendment combination 4 and two of the three test plots of amendment combinations 1 through 3 were row seeded with annul rye grass (100kg/ha) and seed mix #1 (20 kg/ha) in alternating rows. All rows were spaced 20 cm apart and seeds were applied using an Earthway Precision Garden Seeder. The third test plots for amendment combinations 1 through 3 received transplanted native species. The native species were planted in late June/early July of both 2001 and 2002 to test the effects of differing climatic conditions on both growth and establishment. Willow cuttings (21 cuttings), one willow bundle and transplanted shrubby tundra species (dwarf birch, blueberry, crowberry and bearberry) were used for experimentation. Inorganic fertilizer (10-34-10-5 @ 100 kg/ha & 33-0-0 @ 25 kg/ha) was applied. On September 30, 2001 one of the replicate test plots within each block for amendment combinations 1 through 3 received a maintenance application of sewage sludge (applied @ ½ cm or 5 litres/m²).

- *Top: Training Aboriginal staff in methods of transplanting willows*
- *Middle: Results of Riparian Revegetation*
- *Bottom: Revegetated are denoted by orange box*

BHP Ekati™ Diamond Mine

Long Lake Tailings Facility Revegetation Studies

2001 and 2002 Reclamation Studies

Lake Sediment Trials

Discussion and Results Cont.: Harvey Martins assessed the plots in 2002 (two seasons of growth). Soil pH and ECe ranged between 7.9 to 8.1 pH units and 5 to 7 ms/cm. Plots with a two year vegetative cover had higher ECe values at the 15 to 30 cm depth due to the interception of soil water from a developed root system. Unvegetated and pulp waste sludge one year growth plots had highest ECe values at the surface 0 -15 cm soil depth. Nutrient levels were common among treatment plots due to plant uptake. Highest nutrient levels were noted in the control and kimberlite non rotovated test plots. Only perennial plants provided live cover in the 2000 assessment. Plant coverage ranged from 17% to 23% in all plots with the exception of the non rotovated plot which had a coverage of 7%. Year one plant coverage in the pulp waste test plots averaged 55%. Wind blown kimberlite tailings adversely affected plant growth. The tall and rapidly establishing hairgrass species and Arctared fescue were the only species to survive burial in kimberlite tailings. First year willow cutting growth (number of sprouting cuttings) was greater in 2001 than in 2002 (63% versus 43% showed signs of growth). In 2002 only 5% of the 2001 willow cuttings had survived and showed signs of growth. Willow bundles showed similar trends of signs of growth (first year growth: 2001 = 34 sprouts, 2002 = 17 sprouts & second year growth: 2001 = 2 sprouts). The poor success of willows in 2002 was attributed to a dry period following their planting. Willows in the lower slope position had the greatest rate of survival. Dwarf birch and blueberry were most successful for first year growth in both 2001 and 2002 (Dwarf birch = 8 of 9 healthy & blueberry 5 healthy), while bear berry and crowberry performed poorly (both had 3 healthy survivors). Like the willows, survival for the shrubby tundra species was poor in for second year growth (average survival across species = 2 of 9 transplants). Birch and blueberry were the best performers in both first and second year results.

BHP Ekati™ Diamond Mine

Long Lake Tailings Facility
Revegetation Studies

*2001 and 2002 Reclamation
Studies*

**Effects of Herbivores on
Establishment of Plant Cover**

Information Sources:

Funding Sources and/or Client:

Researchers:

Purpose:

Amendments:

Discussion and Results:

BHP Ekati™ Diamond Mine

Long Lake Tailings Facility Revegetation Studies

2002 Reclamation Studies

Rock Pile Shelter Study

Information Sources:

- Ekati™ Diamond Mine Revegetation Research Projects 2004 (HMA 2004)
- Ekati™ Diamond Mine Processed Kimberlite Tailings Reclamation Research Program, 2002 (HMA 2002)

Funding Sources and/or Client: BHP Ekati™ Diamond Mine

Researchers:

Company/Institution: Harvey Martens and Associates and BHP Ekati™ Diamond Mine

Personnel: Harvey Martens (HMA); and Helen Butler (BHP)

Purpose: To assess the effects of wind shelter from piles of waste rock placed within the LLCF on plant growth.

Amendments:

Discussion and Results:

BHP Ekati™
Diamond Mine

Long Lake Tailings Facility
Revegetation Studies

2002 Reclamation Studies

Species Trials

Information Sources:

Funding Sources and/or Client:

Researchers:

Purpose:

Amendments:

Discussion and Results: