

MINE RECLAMATION AT DIAVIK DIAMOND MINE, NWT
SUBSTRATES, SOIL AMENDMENTS AND NATIVE PLANT COMMUNITY DEVELOPMENT
2005 ANNUAL REPORT

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Submitted To
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December 31, 2005

1. BACKGROUND

Mining for diamonds in the Canadian North has been initiated in the past decade. Three companies currently have diamond mines in the Northwest Territories, although exploration indicates that other diamond deposits exist and there is potential for further development. As a pioneer in the diamond industry in Canada, Diavik Diamond Mine, Inc. (Diavik) has the challenge to successfully reclaim mining disturbances to conditions resembling the premine environment and the opportunity to develop innovative, cost effective and environmentally sustainable methods to achieve this goal. Successful reclamation at select sites involves building soil and re-establishing soil processes such as nutrient cycling and native plant communities including a diversity of shrub, grass, forb and bryophyte species. Sites include gravel roads, gravel pads, waste rock and till stockpiles and the processed kimberlite containment facility. The greatest obstacles to overcome are lack of soil moisture, soil water holding capacity, available organic matter following mining activities and information on propagation techniques for arctic plant species.

Little peer reviewed research has been conducted on revegetation of disturbed mine sites in the North American arctic. Establishment of native plant cover is often slow in arctic environments, particularly if adjacent native seed sources are not present. Bishop and Chapin III (1989) found poor plant establishment and cover was a result of limited seed dispersal, lack of soil moisture for germination and slow growth due to low nutrient levels. Revegetation of arctic wetland communities has been more successful, perhaps due to the reliance on vegetative propagation techniques compared to seeding (Forbes and Jefferies 1999). Tundra plant species are readily adapted to mesic environments, and disturbances often alter the hydrology of the landscape thus making it inhospitable for some species. Re-establishment of terrestrial and wetland plant communities in the arctic is required (Jorgenson and Joyce 1994).

A number of trials have been conducted by industry and consulting firms to identify substrates, amendments and plant species that may be appropriate for revegetation of northern mine sites. Organic materials such as topsoil have been most effective for establishing a vegetation cover on these sites (Bishop et al. 1999; Kidd and Max 2001). Reid and Naeth (2005a, 2005b) found sewage sludge the best amendment to increase nutrients and peat the best for improving water and nutrient holding capacities. The use of structural and nutrient improving soil amendments was necessary to enhance plant growth; together sewage sludge and peat produced the greatest plant cover compared to nine other treatments tested in the field. While fertilizer has

been a successful and commonly applied amendment to increase agronomic and native grass cover on gravel fill sites, Bishop et al. (2000) found that after six years, sewage sludge was a significantly better amendment for enhancing nutrients and plant cover.

Kimberlite tailings may have a negative effect on plant growth due to its physical and chemical properties. However, native grasses and forbs established on kimberlite alone after one growing season although the long term effects of this substrate on plant growth are unknown (Kidd and Max 2001). When amended with organic materials, plant growth was successful for more than two seasons (Reid and Naeth 2005a, 2005b). Lyle (2001) found kimberlite amendment of gold mine tailings had no effect on plant growth. Sewage lagoon soil alone or in combination with kimberlite were most effective for grass growth in the greenhouse, and in the field, fertilizer and kimberlite were most effective. However this was after only one growing season.

2. RESEARCH OBJECTIVES

The goal of this research is to identify the most effective and economical methods for establishing a self-sustaining native vegetation cover on disturbed sites at the Diavik Diamond Mine, NWT. Specific objectives follow.

- To determine which substrates are most effective for plant establishment and growth.
- To determine which soil amendments are most effective at enhancing substrate properties and plant establishment.
- To determine which groups and individual native plant species are able to establish and survive on a variety of substrates.

3. MATERIALS AND METHODS

3.1 Study Site

Research is being conducted at the Diavik Diamond Mine approximately 320 km north-east of Yellowknife. The mine is situated on a 20 km² island, known as East Island, within Lac de Gras. The approximate footprint of the mine site is 7 km². The study site was established in 2004 on a raised gravel pad, previously used for ammonium nitrate storage (Photos 1 and 2). The raised pad is constructed of a layer of boulders over tundra, followed by a layer of small to mid-sized rocks, topped with a 50 cm layer of gravel. Most disturbed areas that will require reclamation

following mine decommissioning are raised gravel beds of this nature. Ammonium nitrate bags were stored on impermeable tarps, which have been removed, so contamination is not an issue.

Diavik Diamond Mine lies at the southern limit of the Southern Arctic Ecozone (Marshall and Schut 1999). This Ecozone is characterized by short summers with cool temperatures and long, cold winters. The mean monthly temperature at the mine site was -12.0 °C in 2004, -8.7 °C in 2003 and -9.7 °C in 2002 (Diavik data). Mean annual precipitation was 275.1 mm in 2004, 323 mm in 2003 and 352 mm in 2002. Mean monthly temperature during the 2004 growing season (June to August) was 9.1 °C and mean monthly precipitation was 24.2 mm. In the 2003 growing season, mean monthly temperature was 10.9 °C and mean monthly precipitation was 27.8 mm. An Environment Canada weather station is located just north at Ekati Diamond Mine, however, Diavik's weather is greatly modified by Lac de Gras compared to inland locations.

The Southern Arctic Ecozone provides a transition between the taiga forests and arctic tundra. Dwarf shrubs dominate the vegetation in upland areas and sedges and mosses in low lying wet tundra. Outcrops of Canadian Shield are common. Dominant species in heath tundra communities on the island include *Betula glandulosa*, *Salix glauca*, *Salix planifolia*, *Vaccinium vitis-idaea*, *Vaccinium uliginosum* and *Empetrum nigrum*. *Eriophorum angustifolium*, *Eriophorum vaginatum*, *Carex aquatilis* and *Calamagrostis inexplansa* dominate wet tundra communities. Both communities surround the research site (Photos 3 and 4).

3.2 Experimental Design and Treatments

A randomized incomplete block design was used. The site was divided into three blocks based on previous storage pads or areas (Figure 1). Five substrate treatments, four amendment treatments, two season of seeding treatments and six seed mix treatments were applied to each block. Blocks were irregular shapes and plots were established within them to make use of all available space. Each block was divided into five substrate plots of equal area; substrate plots in Blocks 1 and 3 were approximately 300 m² and in Block 2 were 150 m². Each substrate plot was further divided into four amendment plots of equal size. Each amendment plot was oriented north-south and divided in half for season of seeding. Each season of seeding plot was divided into 6 to 10 5 m² plots for individual seed mixes. All treatments were randomly assigned to plots.

The five substrates and four soil amendments were selected based on previous reclamation research at diamond mines in northern regions (ABR Inc. 2001; Reid and Naeth 2005a, 2005b) and Diavik's Reclamation Research Plan (2002). The substrates are glacial till (till), fine

processed kimberlite from the containment facility (PK), 50% PK and 50% till mix, 25% PK and 75% till mix and no substrate addition. Glacial till is the most readily available waste material at the mine site, however, little research has been conducted on its potential for use in revegetation of disturbed areas. Processed kimberlite has been investigated at the BHP mine site, and found adequate as a substrate to establish plants with soil amendments (Reid and Naeth 2005a, 2005b). Differences in PK properties may exist and will be quantified. Initial soil analyses indicated this fine PK is composed of greater than 95% sand, while till has less sand and greater silt. Consequently the 75% PK and 25% till treatment was eliminated from the experimental design as it would not be an appropriate substrate to support plant growth. Plots were marked and substrate was placed between July 27 and September 21, 2004. A 30 to 40 cm deep cover was applied by a front end loader.

Salvaged topsoil can be a good source of organic matter, nutrients, microbial populations and native plant propagules. Shallow topsoil in the natural environment means insufficient topsoil will be available for reclamation of disturbed sites. Revegetation methods will need to minimize the quantity required while maximizing its benefits. Therefore, topsoil was applied as a soil amendment to all substrates, September 9 to 21, 2004. Inorganic fertilizer is most commonly used in reclamation to provide nutrients to soils that are deficient and a standard reclamation formulation was applied. Rates of nitrogen were reduced from those commonly used when seeding agronomic species as higher rates may inhibit native species. Preliminary soil analyses showed soils were already high in potassium and sulfur and low in phosphorus therefore an 11-52-0 fertilizer was applied to both spring and fall seeded plots between August 9 and 16, 2005. Sewage sludge, a waste product at the mine, could be a source of nutrients, providing a greater suite of micro and macro nutrients over a longer time period than inorganic fertilizer. Use of on site waste products would reduce operational expenses required to dispose of the waste and to obtain off site materials to amend soils. Sufficient solid sewage for all treatments was not obtained in fall 2004, therefore this amendment was only added to the 50% PK / 50% till fall seeded treatments. Sufficient material was not available in spring 2005 for all substrates, therefore sewage was only applied to the 50% PK / 50% till and the till alone spring seeded treatments. Amendments were added and spread by a bobcat with a backhoe.

Sludge from the North Inlet Water Treatment Plant (NIWTP) was tested in 2005 as a possible amendment to enhance substrate properties and plant growth. Sludge produced by the NIWTP consists of particulate matter from ground rock, old lakebed sediment, till that has collected at the bottom of the open-pit and wastewater from seepage and runoff (de Rosemond and Liber

2005). The sludge is slightly higher than the Canadian Council of Ministers of the Environment (CCME) Agriculture Guidelines (1999) for arsenic, barium, chromium, copper and nickel. However, the concentrations are of little toxicological concern because they will be diluted when applied over the land surface. It is low in total organic carbon, but high in ammonium which may be beneficial to plants. The sludge is approximately 81% sand and 12% silt and has very high water content (~92%), therefore has poor consistency for land application. The sludge was applied by hand to a depth of 3 to 4 cm to the 25% PK / 75% till substrate treatments between June 28 and July 5, 2005.

A suite of plant species representing the main plant groups (grasses, forbs and shrubs) and sources (cultivars, wild collected seed and vegetative propagules) were selected (Table 1). A limited number of native cultivars are available for revegetation of arctic environments. Native cultivars are also mainly limited to grass and a few legumes. Seed was purchased from northern sources to prevent contamination of gene pools and to support northern economies. Seed was also wild collected on East Island. In spring 2002 and 2003, *Betula glandulosa* (bog birch) seed was collected by Diavik. In summer 2005, U of A staff collected seed of four species, *Empetrum nigrum* (crowberry), *Arctostaphylos rubra* (bearberry), *Ledum decumbens* (northern Labrador tea) and *Loiseleuria procumbens* (alpine azalea). Six main seed mixes were sown in all blocks, the remaining four mixes listed were only seeded in Blocks 1 and 3 due to space limitations.

The grass and forb only mixes were broadcast seeded by hand in mid September 2004, so seed could take advantage of the early spring moisture in 2005. Although seeding all ten mixes was planned, extremely windy weather did not allow for this. The remaining fall treatments and wild collected seed plots were seeded by hand between August 30 and September 2, 2005. All mixes were seeded in the spring treatments between June 21 and July 5, 2005. Seeding rates were based on establishment of 50 plants m⁻². This is sufficient to provide ground cover, prevent erosion and allow for natural invasion of species from adjacent undisturbed areas. Insufficient seed was wild collected to achieve this seedling density, thus wild collected seed was equally distributed among designated plots.

3.3 Soil and Vegetation Measurements

HOBO Micro Stations (Onset Computer Corp.) were installed in the centre of each amendment plot. Soil moisture and soil temperature Smart Sensors™ were placed above the gravel pad substrate interface (approximately 30 to 35 cm) and 10 cm below the surface in September

2004. The data loggers were set to retrieve data every hour. Stations were mounted above ground level to prevent flooding or snow burial. Below -40 °C temperatures prevented data collection from February 2005 onwards. In spring most stations were showing error messages therefore data were downloaded and the program was relaunched to collect data over the growing season. Batteries were replaced on some stations in the spring.

Three randomly located soil samples were collected from each amendment plot in September 2004. Plots established in spring 2005 were sampled at that time. At each location, samples were taken at two depths, 0 to 10 cm and 20 to 30 cm. Samples were kept cool until delivered to Enviro-Test Laboratories in Edmonton for analyses. Samples were analyzed for particle size (sand, silt, clay), pH, electrical conductivity, sodium absorption ratio, total organic carbon and inorganic carbon, cation exchange capacity, exchangeable cations and available nitrogen, phosphorus, potassium and sulfur. A third of the samples were analyzed for metals restricted in concentration by the Canadian Council of Ministers of the Environment including silver, arsenic, barium, beryllium, cadmium, cobalt, chromium, copper, mercury, molybdenum, nickel, lead, antimony, selenium, tin, thallium, uranium, vanadium and zinc. Samples taken in the sewage sludge plots were also analyzed for fecal coliform and *Salmonella*.

A vegetation assessment was conducted between August 9 and 16, 2005. Within each subplot seedling density by species was recorded. In future years, canopy cover by species and ground cover will be measured. Plant nomenclature follows Porsild and Cody (1980).

3.4 Statistical Analyses

Data will be tested for normality and homogeneity of variance prior to analysis. Appropriate tests such as analysis of variance (ANOVA) will be conducted to determine if differences in measured parameters exist between substrate, soil amendment and seeding treatments. Within treatments, performance of plant species will be compared.

4. PRELIMINARY RESULTS

Preliminary soil analyses show that for all treatments, phosphorus is the most limiting nutrient, cation exchange capacity is relatively low, pH is neutral and total organic carbon is low. Heavy metal concentrations of potential concern include arsenic, chromium, cobalt and nickel.

Plant growth was limited at the time of the assessment and seedlings were not more than 5 cm in height. Fall seeded fertilizer plots had the greatest plant establishment although densities were not more than 25 seedlings per plot. Grasses established more readily than forbs, which were uncommon. In the topsoil treatments, *Betula* sp. and *Vaccinium* sp. established from remnant vegetation islands. There was evidence of the importance of microsites (safe sites) in all plots; seed appeared to germinate and establish more readily if there was some protection provided (rocks, soil clumps etc.) by the substrate.

5. 2006 RESEARCH PLAN

Field work will commence after snow melt in spring 2006. Data will be downloaded from the HOBO Micro Stations and any adjustments required will be conducted. The same fertilizer amendment (11-52-0) will be applied at the same time as in 2005 (early to mid August) once vegetation in spring and fall seeded plots is actively growing. This will ensure fertilizer is available to plants at the time they require it. Seed germination will be assessed by determining seedling emergence in late June or early July and seedling establishment will be assessed in August. If there is enough growth to permit, species health will be assessed on a 0 to 4 grade system (0 = dead, 4 = healthy), ground cover by species, and plant height will be assessed.

Year one data will be compiled and analyzed in early 2006 and year two data will be compiled and analyzed in fall 2006. A progress report will be submitted to Diavik by December 31, 2006.

6. REFERENCES

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Table 1. Seed mixes designed for disturbed sites revegetation study, Diavik Diamond Mine.

Mix Number	Mix Name	Mix Description
Seeded In All Blocks		
Mix 1	Grasses	<i>Arctagrostis latifolia</i> , <i>Agrostis scabra</i> , <i>Agropyron violaceum</i> , <i>Agropyron pauciflorum</i> , <i>Calamagrostis canadensis</i> , <i>Deschampsia caespitosa</i> , <i>Festuca rubra</i> , <i>Festuca saximontana</i> , <i>Poa alpina</i> , <i>Poa glauca</i> , <i>Puccinellia nuttalliana</i> (11 grasses)
Mix 2	Forbs	<i>Hedysarum mackenzii</i> , <i>Hedysarum alpinum</i> , <i>Oxytropis splendens</i> , <i>Oxytropis deflexa</i> , <i>Epilobium latifolium</i> (5 forbs)
Mix 3	Grasses Without Aggressive Species	All grasses except <i>Festuca rubra</i> , <i>Calamagrostis canadensis</i> , <i>Agropyron pauciflorum</i> (8 species)
Mix 4	Adaptable	<i>Arctagrostis latifolia</i> , <i>Deschampsia caespitosa</i> , <i>Poa glauca</i> , <i>Festuca saximontana</i> , <i>Festuca rubra</i> , <i>Hedysarum mackenzii</i> (6 species)
Mix 5	Esker	<i>Poa glauca</i> , <i>Festuca saximontana</i> , <i>Agropyron violaceum</i> , <i>Epilobium latifolium</i> , <i>Poa alpina</i> (5 species)
Mix 6	No Seed	No seed added
Seeded Only in Blocks 1 and 2		
Mix 7	Wet Tundra	<i>Deschampsia caespitosa</i> , <i>Agrostis scabra</i> , <i>Puccinellia nuttalliana</i> , <i>Calamagrostis canadensis</i> , <i>Arctagrostis latifolia</i> , <i>Agropyron pauciflorum</i> (6 species)
Mix 8	Heath	<i>Arctagrostis latifolia</i> , <i>Calamagrostis canadensis</i> , <i>Poa alpina</i> , <i>Agropyron violaceum</i> , <i>Oxytropis splendens</i> (5 species)
Mix 9	Wild Collected (fall seeded only)	<i>Empetrum nigrum</i> , <i>Arctostaphylos rubra</i> , <i>Ledum decumbens</i> and <i>Loiseleuria procumbens</i>
Mix 10	Birch (wild collected)	<i>Betula glandulosa</i>

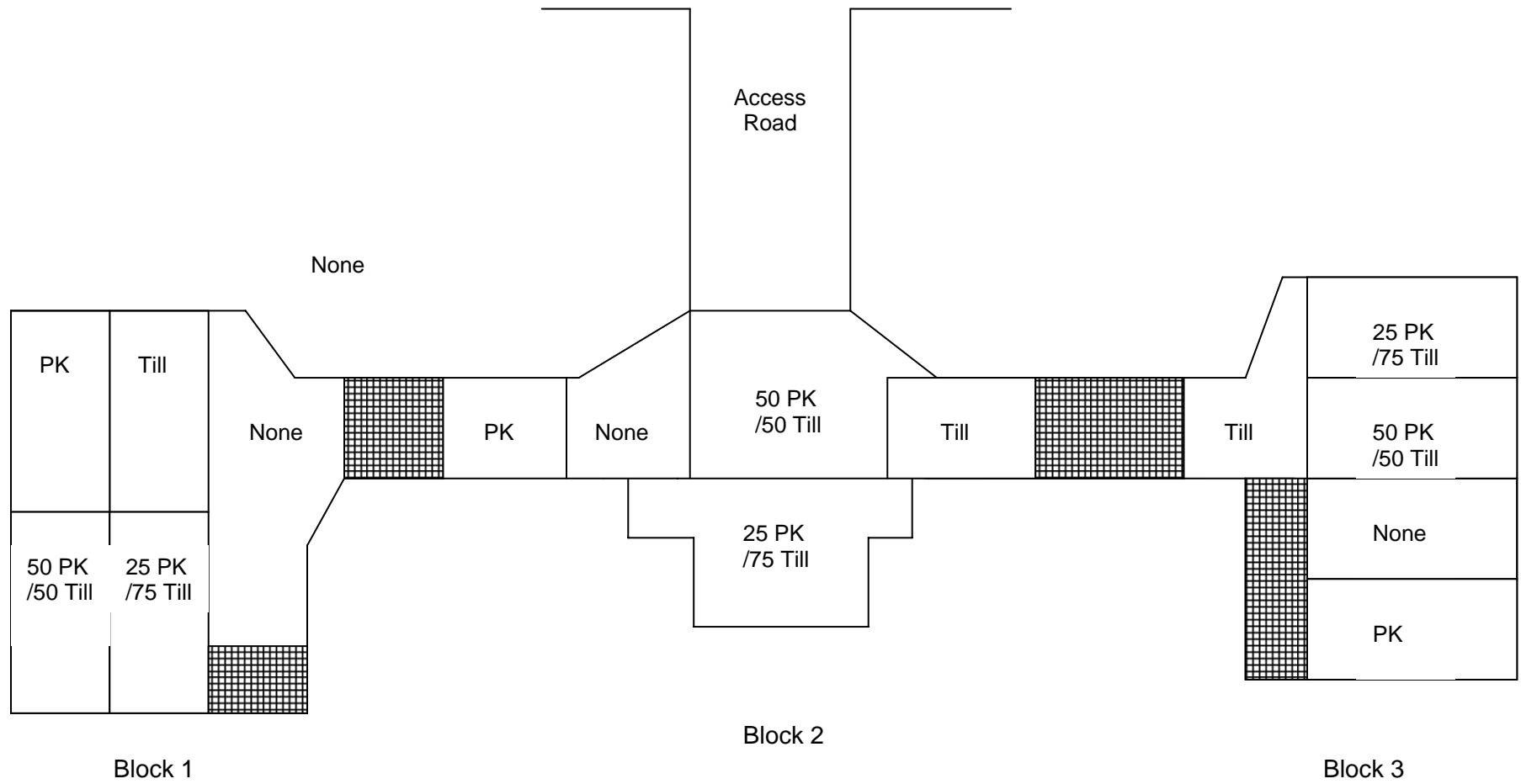


Figure 1. Experimental layout of revegetation research site, Diavik Diamond Mine, NWT.



Photo 1. Overview of revegetation research site (in foreground), Diavik Diamond Mine.



Photo 2. Revegetation research study site, Diavik Diamond Mine.



Photo 3. Wet tundra community to south of revegetation research site, Diavik Diamond Mine.



Photo 4. Heath tundra community similar to that adjacent to revegetation research site, Diavik Diamond Mine.