APPENDIX III-E

Aquatic Life Management Plan

NWT Diamonds Project

Appendix III-E1

Appendix III-E1 - Habitat Improvement Structures for Panda Diversion Channel

This Appendix describes the habitat improvement structures which may be incorporated in the Panda diversion channel to offset the loss of natural habitat in the streams where flow will be cut off or impaired. It is a portion of the Panda Lake Diversion and Fish Habitat Enhancement Channel report submitted to the Department of Fisheries (June 1994).

Meanders

The diversion channel flows in a meandering fashion at Station 8, 9 and 10 Meandering sections of the diversion channel will be constructed as shown in Figure E-1. Wing deflectors will form an acute angle with the stream bank of not more than 10 degrees (Figure E-2). Large rocks approximately 300 mm in diameter will be placed on the inside edge of a deflector, parallel to the running water. Gravel with a diameter of 50 to 100 mm will be placed within the triangular portion of the wing deflector. This will lead to the formation of spawning habitat for adult grayling as well as refuge habitat for fish fry. Fry and juvenile fish use the space between rocks for cover, and occasionally move out to search for food in running water. Sand and silt will be deposited at the downstream end of wing deflectors. Bed load deposition will occur on the inside face of the bank. This will result in a shallower zone of the channel which fry and juvenile fish can use for resting and feeding.

Banks opposite the wing deflector must be protected to prevent erosion. Erosion can cause high turbidity and sedimentation which may be harmful to both fish and fish habitat (Kerr *et al.* 1980) For this purpose, riprap bank revetments will be constructed of large rocks at Stations 9 and 10 as an anti-erosive measure. No revetments are needed at Station 8 as the maximum discharge will not spill over the banks of the diversion channel at this location.

Stream Intersection Structures

Stream intersections occur at Stations 2, 3, 4, 5, 6 and 7 Stream beds at these stations will be gently sloped by careful excavation. Baffles and outlet pools will be constructed at Stations 3, 4, 5 and 6 and designed rock placement will be done at several locations

Baffles are flow interference structures, usually in the form of low weirs (Figure E -3). The baffle recommended here is called "Offset Baffle", developed and tested by McKinley and Webb (1956). Baffles interrupt the flow pattern and provide the fish with a series of resting areas. The offset baffle configuration consists of paired baffles attached to the sides and bottom of a channel and

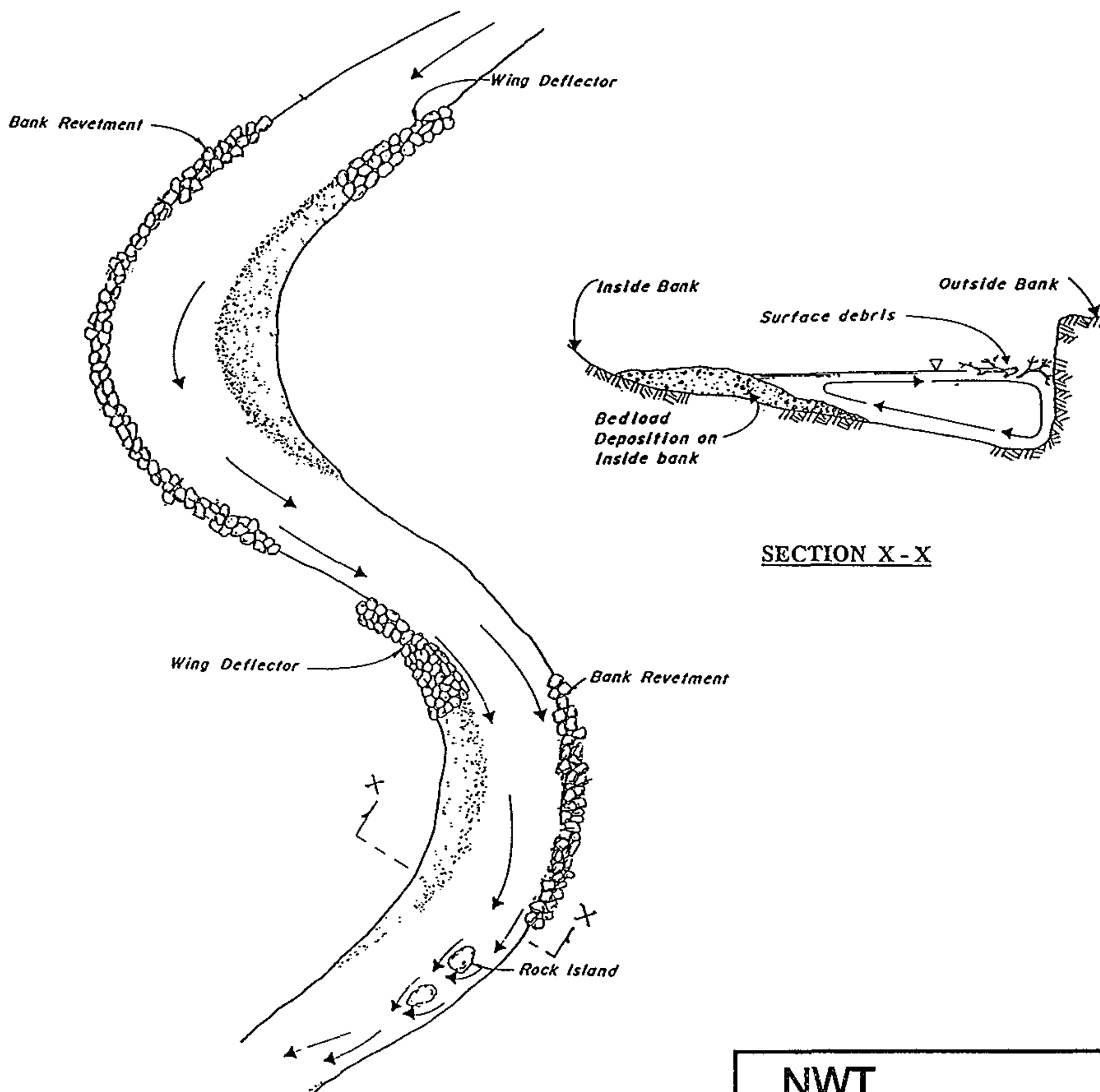

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Figure E-1
Fish Enhancement at Meandering Portions

Source Rescan

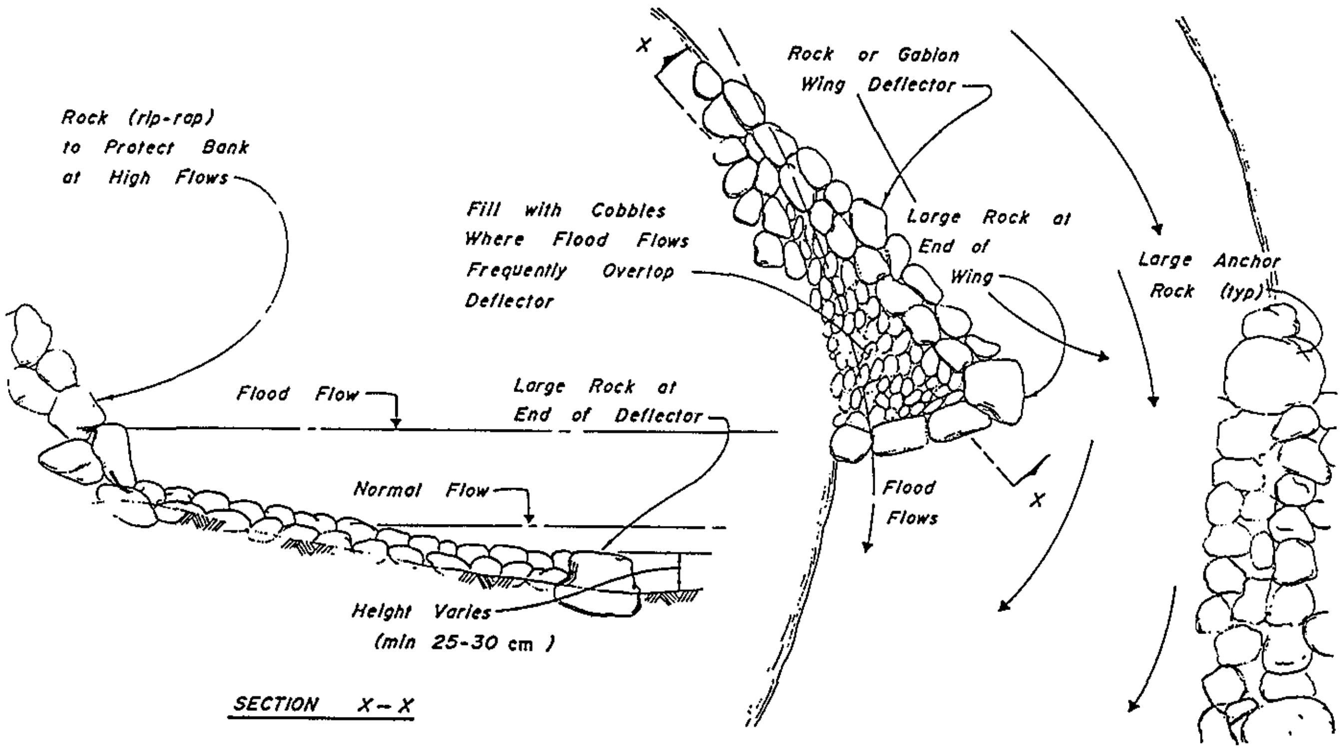

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Figure E-2
Typical Wing Deflector Constructed of Rock

Source: Rescan

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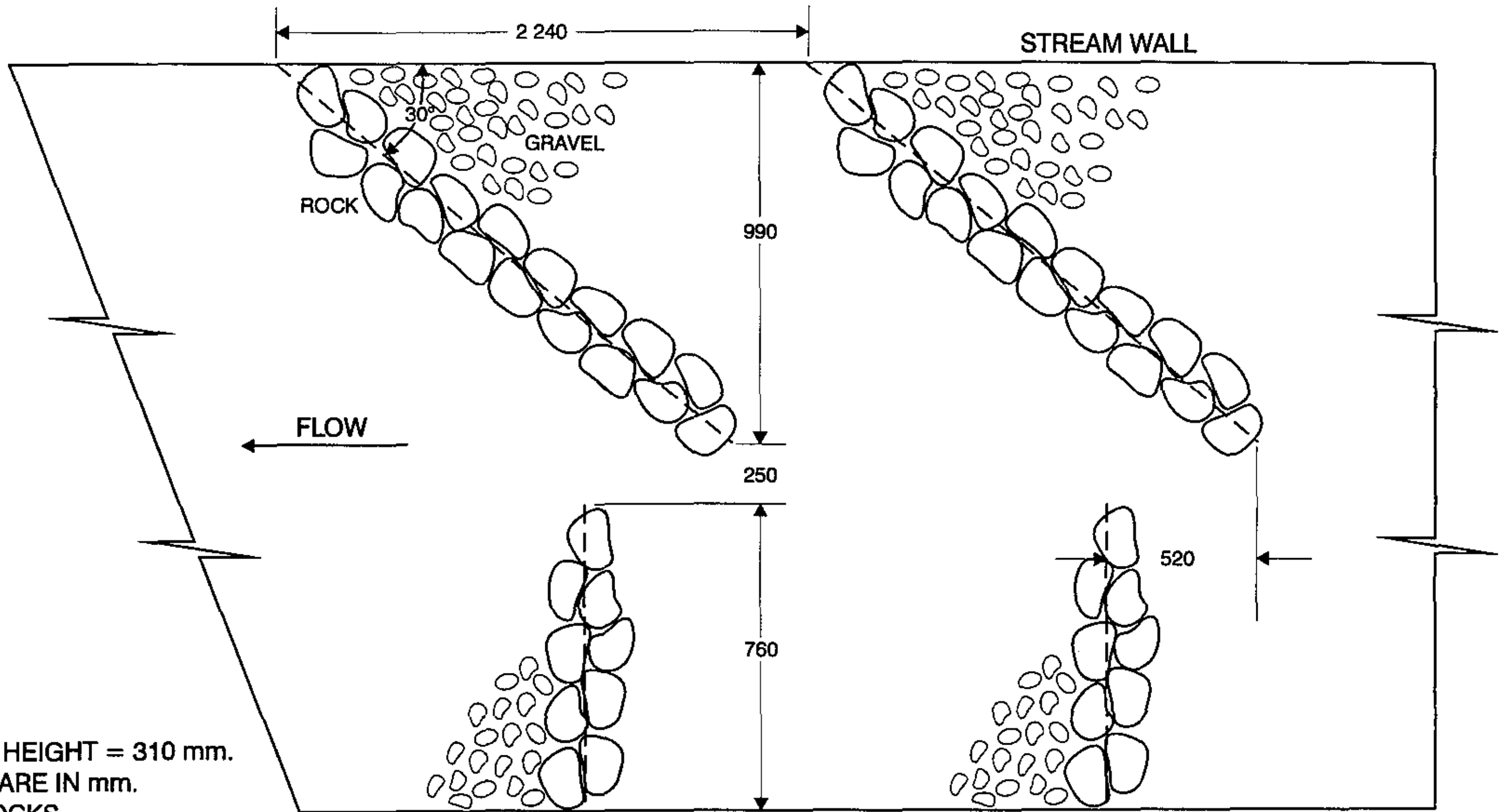

PLAN

NOTE:
1 MINIMUM BAFFLE HEIGHT = 310 mm.
2. ALL DIMENSIONS ARE IN mm.
3. TWO ROWS OF ROCKS, DIAMETER 300 - 500 mm.
4. GRAVEL 50 - 100 mm DIAMETER.
5. NUMBER OF PAIRED BAFFLES REQUIRED = 46.

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Figure E-3
General Layout for Offset Baffle Arrangement

Source: Rescan

extends out into the main flow of water. The baffles produce a flow pattern compatible with fish migration while minimizing fish interference with debris or bed load movement Baffles have the following further advantages:

- baffles will be constructed from rock material which is abundant locally
- baffles are easier to construct than a pool and weir fishway system since reinforced concrete is not required and accurate excavation is not necessary for creating small sized pools along the stream bed
- while migrating upstream, fish fry may find it easier to travel through baffles than a pool and weir fishway system
- baffles constructed of rock can be rearranged or repaired after a flood event, if necessary

Outlet pools (Figure E-4) will be constructed at Stations 3, 4, 5 and 6. These pools will be equipped with tailwater control which perform the function of an adjustable weir at the outlet The general purpose of an outlet pool is to

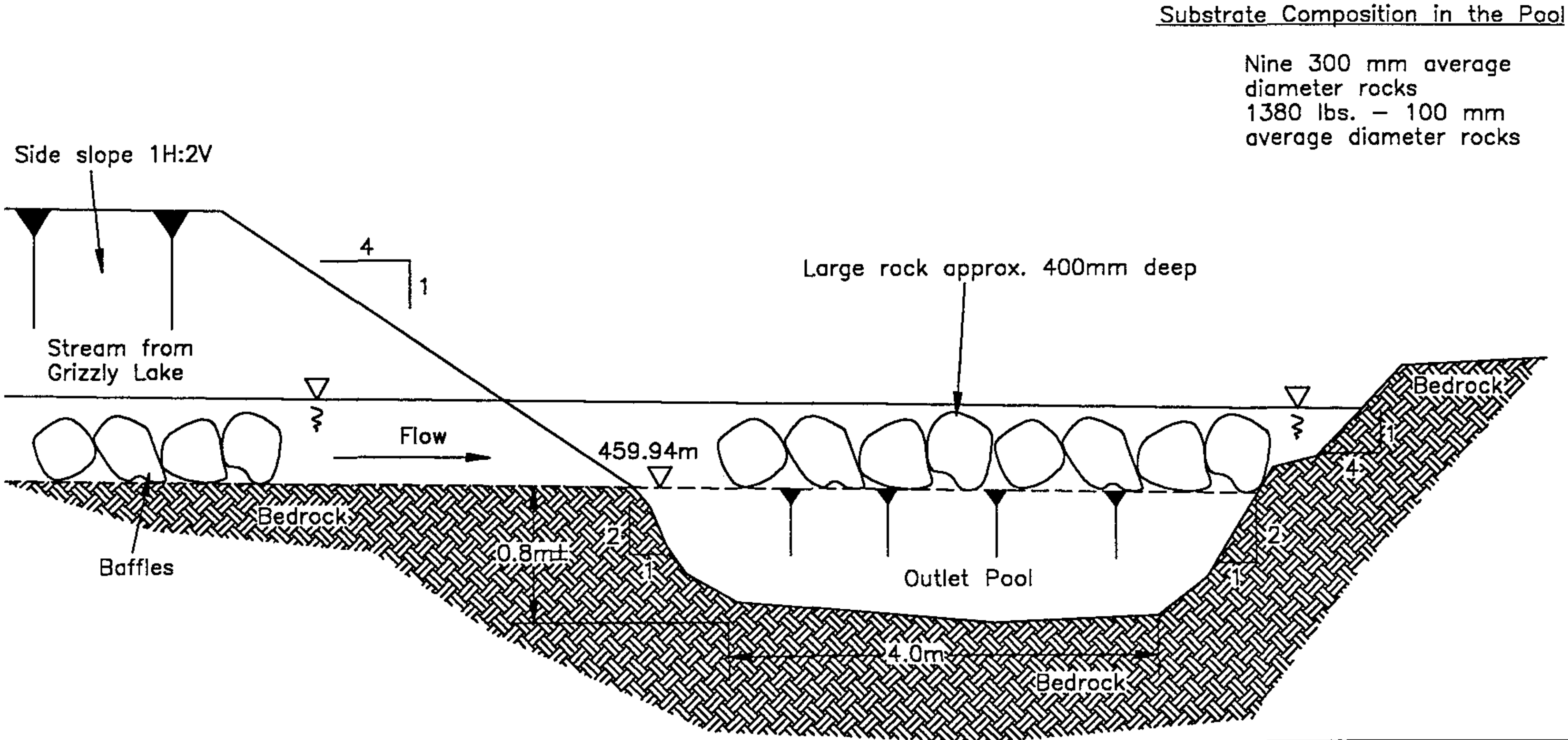
- provide a resting area for fish before they re-advance into the higher velocity zone of the intersecting stream or the diversion channel itself
- reduce velocity at the entrances to the intersecting streams
- dissipate much of the energy contained in the stream water in the pool
- provide a transition zone between the intersecting stream and the diversion channel

Rock and gravel will be placed in the outlet pool to create a heterogeneous substrate for fish habitat. This substrate composition will provide growth medium for periphyton (i.e., attached algae) and will supply nourishment to herbivorous forms of benthic invertebrates. The benthic invertebrates will colonize the stream bed and will in turn, provide food for fish

Main Channel Structures

Enhancement structures will be constructed at various points in the main channel. These structures will assist in fish movement along steeper gradients and provide cover for resident fish. Double Step Invert Control pools (DSIC pools, Figure E-5) and designed rock placement will be used to create habitat in the main channel.

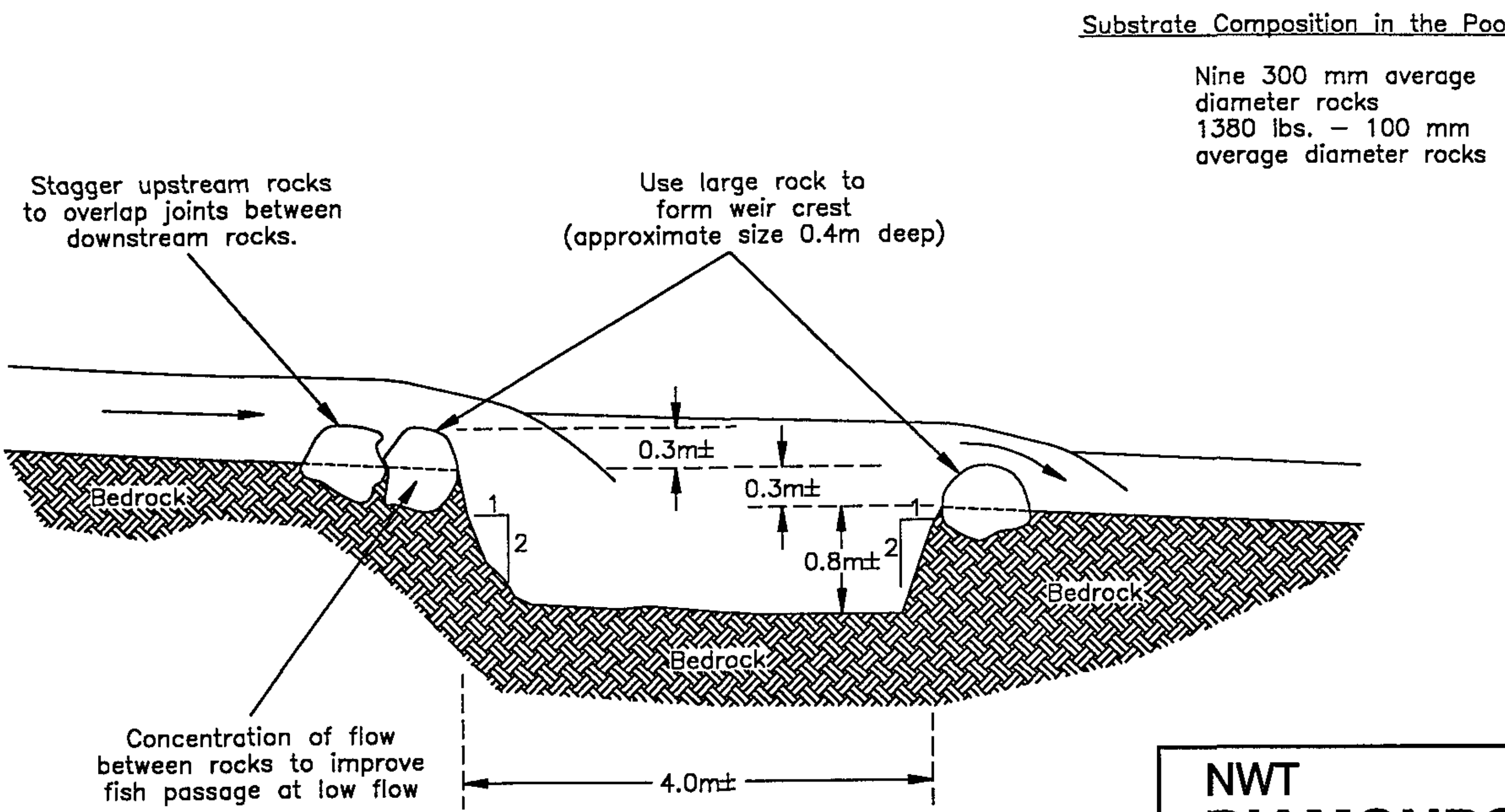
Five DSIC pools will be constructed at uniform intervals between Stations 7 and 8. The bed slope is greatest between Stations 7 and 8 (2.3 percent) and could hinder fish movement along the diversion channel DSIC pools have been



NWT **DIAMONDS** PROJECT

Figure E-4
Cross-section of Outlet Pool at Stations 3,4,5 and 6

Source: Rescan



NWT DIAMONDS PROJECT

Figure E-5
Profile of Double Step Invert Control Pool

Source: Rescan

recommended as a stream channel improvement measure (Kerr *et al* 1980). The general purpose of this structure is to provide resting places for fish within sections of swifter moving water. DSIC pool dimensions and substrate

composition will be the same as those of the outlet pools previously mentioned The use of riprap at both the upstream and downstream ends of the DSIC pools has a number of advantages:

- the material is readily available and easy to place on site
- the structure is adjustable at any time by adding or subtracting rock, and can be readily shaped to provide specific features
- rock is compatible with the natural stream substrate and will blend physically and aesthetically with the natural surroundings
- the structure provides a higher flow depth at low discharge conditions

According to DFO's Land Development Guidelines (1992), segments of the diversion channel and intersecting stream beds will be laid in a staggered fashion with sized/secured riprap or rocks of diameters varying from 300 to 500 mm (average diameter of 400 mm). The rock surfaces will create a feeding habitat for fish and will provide suitable resting areas to assist fish in migrating upstream or downstream

Specific design criteria that will be incorporated into stream crossing designs are outlined in the Land Development Guidelines for the Protection of Aquatic Habitat (DFO and B.C. MOE, Lands and Parks, 1992):

- diameter of culvert should not be <0.45 m
- average water velocity in the culvert should not exceed 1 2 m/s for culverts <24.4 m in length and 0.9 m/s for culverts >24 4 m
- the depth of water should not be <0.23 m at any point in the culvert
- all culverts should accommodate a 100 year flood
- the culvert should not be completely submerged at the upstream end
- the slope of the culvert should not exceed 0 5% for a culvert greater than 24 m in length and should not exceed 1 0% for culverts <24 m in length
- the culvert should be installed so that the bottom is at least 0 31 m below the grade line of the natural bed of the stream

Maintenance of stream crossing structures largely involves removing obstruction in the culvert Although large woody debris is absent in the project area, smaller shrub debris can accumulate. Of more importance in terms of maintenance is to prevent ice build-up in the culverts. Culvert lids can be installed prior to freeze-up and frozen culverts can be thawed by high pressure steam units prior to freshet.

APPENDIX III-F

Reclamation, Decommissioning, Closure

Appendix III-F1

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LITERATURE REVIEW OF MINE RECLAMATION RESEARCH IN THE ARCTIC

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22 May 1995

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INTRODUCTION

The exploration and extraction of minerals in the Arctic has resulted in the creation of a variety of terrain disturbances that usually require some level of post-mining rehabilitation. The types of disturbances include gravel roads, pads, mine pits, waste-rock stockpiles, and tundra damage from off-road vehicle traffic (Walker et al. 1987, Lawson 1986, Johnson 1981, Mackay 1970). Concerns over the loss of wildlife habitat and biological diversity, degradation of pristine areas, and reduction in subsistence opportunities has prompted government agencies and private citizens to demand that areas affected by mineral extraction be rehabilitated to restore these resource functions and values.

Traditionally, the primary concern with respect to mitigating impacts associated with mining was to control soil erosion (maintaining water quality) resulting from removal of natural vegetation during mine activities (Bolstad 1971, McKendrick et al. 1984). In permafrost areas, reestablishing vegetation also was promoted to minimize the thermal erosion (thermokarst) associated with disturbing ice-rich soils (Mackay 1970, Bureau of Land Management 1973, Dabbs et al. 1974, Hernandez 1973a, Haag and Bliss 1973). More recently, however, the objectives of revegetation have expanded to include the establishment of plant communities that are productive, self-regulating ecosystems integrated with the landscape in which they occur. Aesthetics, biological diversity, and wildlife habitat are all factors that are presently considered in the development and implementation of many revegetation research plans (Jorgenson and Joyce 1994, Helm 1992, Densmore et al. 1987, Walker et al. 1987).

Successful rehabilitation of disturbed lands in the Arctic must overcome many limitations posed by the severe environment. The growing season is very short, warm days are infrequent, and frosts can occur at anytime during the summer. Low temperatures decrease rates of organic matter decomposition and nutrient cycling, reduce seed production, and retard rates of plant colonization of disturbed areas (Billings 1987, Haag 1974). In areas where hard-rock mining occurs, the soil frequently is poorly developed and contains little organic matter, making it a poor source of topsoil for amending disturbed soils. In addition, because the disturbed land surface associated with mining typically is waste rock, it has few physical and chemical characteristics conducive to promoting plant establishment and growth. The low precipitation greatly affects raised surfaces such as gravel pads and roads, where the soils are very dry and salt crusts may develop

Since the early 1970s, numerous studies have been conducted to develop techniques for revegetating disturbed areas to facilitate long-term ecosystem recovery This report reviews many of these studies in an attempt to synthesize the status of reclamation research in the Arctic and to provide background and justification for the proposed reclamation plan of the BHP Diamond Mine The first section describes the plant cultivation, soil conditioning, fertilization, and surface manipulation and preparation treatments that have been evaluated, and the prospects and limitations associated with each treatment The second section summarizes the results of several vegetation rehabilitation case studies that have been conducted in Arctic Alaska, northern Yukon, and the Northwest Territories The third and final section outlines recommendations for future research with emphasis on a successional approach to ecosystem recovery

PLANT CULTIVATION

Research into developing a suite of plant materials for revegetating disturbed lands in the Arctic has been ongoing since the early 1970s (Johnson and Van Cleve 1976, Johnson 1981, Hernandez 1973a, Mitchell and McKendrick 1974a, 1974b), and has undergone considerable evolution over the years since (Gill 1974, Vaartnou 1974, Mitchell and McKendrick 1974b, Jorgenson and Joyce 1994, Jorgenson et al 1990, Wright 1990, Wright et al 1993, Jorgenson and Carter 1991, Kidd and Jorgenson 1994, Jacobs et al. 1994, Helm 1991)

NATURAL COLONIZATION

Colonization of disturbed sites by species from adjacent undisturbed plant communities has been monitored at a number of locations (Hernandez 1973a, Kershaw and Kershaw 1987, Taylor and Gill 1974, Chapin and Chapin 1980, Jorgenson et al 1990, Chapin and Shaver 1981, Abele et al 1984, Everett et al 1985, Gartner et al 1986, Cargill and Chapin 1987, Ebersole 1987, McKendrick 1987, Felix and Reynolds 1989), the success of which is dependent on factors such as the nature and type of disturbance, soil characteristics, and the species composition of potential source plant communities When only the organic tundra mat is disturbed, natural colonization is fairly successful, and can include a variety of herbs, graminoids, and shrubs. On thin (<25 cm thick) gravel fill, natural colonization occurs at a slower rate than on disturbed tundra, but still can comprise a variety of species, primarily herbs (e.g., *Draba* and *Braya* sp.) and graminoids (e.g., *Carex aquatilis* and *Eriophorum* sp.) (Jorgenson et al. 1990). On gravel-fill depths greater than 80 cm, natural revegetation is negligible. If the disturbance is only minor, natural colonization may be preferable over plant cultivation for revegetating disturbed sites where soil properties are favorable, because the colonizing species come from adjacent areas and thus should be better adapted to arctic conditions than are cultivated species.

AGRONOMIC CULTIVARS

Many of the first attempts to actively revegetate disturbed areas used commercially available cultivated grasses and legumes as the primary plant material source (Johnson and Van Cleve 1976, Johnson 1981, Hernandez 1973a, Mitchell and McKendrick 1974a, 1974b). A study in the Prudhoe Bay Oilfield evaluated over 100 varieties based on positive laboratory tests (Mitchell and McKendrick 1974b) to determine what species may be applicable. Although many of the species germinated and showed rapid growth, most did not persist beyond the first season. This die-off was primarily due to winter kill. Several grass species, however, did persist up to three years or more and were used through the 1980s (Johnson 1981, Wishart 1988, Evans and Kershaw 1989). These species included *Poa pratensis* (Kentucky Bluegrass), *Festuca ovina* (Sheep Fescue), *Agropyron trachycaulum* (Revenue Slender Wheatgrass) and *Phleum pratense* (Climax Timothy). The principal attraction of these species was their ability to establish a rapid cover, their tolerance to low moisture conditions, and their adaptability to short summers and cold winters.

Despite some success, several limitations are associated with using agronomic cultivars for revegetating disturbed lands in the Arctic. First, because agronomic cultivars are not part of the native flora (usually cultivated in more southern latitudes), they tend to be less adapted to the harsh environmental conditions of the Arctic. Second, they generally are dependent on a fairly high level of nutrients and tend to require repeated fertilizations, particularly if they are on gravelly soils with little organic matter (Johnson 1976, Klebesadel 1966, Jorgenson and Joyce 1994). If repeated fertilization does not occur, the grasses tend to die back, leaving a large amount of above-ground biomass remaining that does not readily decompose. Finally, because they can establish a rapid cover and are very effective at sequestering nutrients, agronomic cultivars tend to competitively exclude natural colonizers (Native Plants 1980, Densmore et al. 1987, Younkin and Martens 1987, Densmore 1992, McKendrick et al 1993) In situations where the disturbance involves thick gravel fill, however, few native species are able to colonize these areas and competition with cultivars may not be a concern (Jorgenson and Joyce 1994)

NATIVE-GRASS CULTIVARS

The concern over introducing exotic species into the Arctic, and the variable success associated with using agronomic cultivars, has prompted researchers to investigate the use of native-grass cultivars for vegetation rehabilitation (Gill 1974, Vaartnou 1974, Mitchell and McKendrick 1974b, Jorgenson and Joyce 1994) Mixtures of native grasses have been used for several experimental (Klebesadel 1966, Mitchell 1972) and full-scale applications in Alaska oilfields and mine sites (Jorgenson et al 1990, Wright 1990, Helm 1991, Jorgenson and Cater 1991, Wright et al 1993, Kidd and Jorgenson 1994, Jacobs et al 1994), and at mine sites in the northern Yukon and Northwest Territories (Wilson 1987, Hutchinson and Kuja 1988, Dabbs et al 1989, Maslen and Kershaw 1989) (Table ?) Preliminary results have shown a productive cover can develop fairly rapidly Results have been best on thick gravel fill where organic topsoil has been applied (Jorgenson and Cater 1991), and on overburden stockpiles where the soil has a high percentage of fines and where permafrost under the thin active layer prevents leaching of nutrients (Jorgenson et al 1990, Jacobs et al 1994) Growth of grasses on thick gravel fill without any manipulation of the site or topsoil application has been slower, even after fertilizer was applied the first and third years (Jorgenson and Cater 1992)

Although native-grass cultivars are more adapted to arctic conditions than their agronomic cousins, the problem of declining productivity over time and the inhibitory effect on natural colonizers are still problems yet to be resolved However, native-grass cultivars still are a useful tool for establishing rapid cover on disturbed soils, and they help improve soil properties by increasing soil biological activity, soil moisture, and capturing wind-dispersed plant propagules. To minimize competition with native colonizers, seeding rates at some sites have

Table ? Plant species that have been planted by various methods for rehabilitating disturbed lands in the Arctic (modified from Jorgenson et al 1994)

Species	Natural Colonization	Native-Grass Cultivars	Indigenous Seeds	Stem Cuttings	Sprigging	Sod Transplanting
GRAMINOIDS						
Alopecurus alpinus	-		-			
Arctagrostis latifolia	*	*	*			
Arctophila fulva	*				*	
Beckmannia syzigachne		-				
Carex aquatilis	*		*			*
Calamagrostis canadensis		-				
Deschampsia caespitosa	*	?	-			
D beringensis		*				
Dupontia fisheri	-		*			-
Eriophorum angustifolium	*		*			*
E scheuchzeri	*		*			*
Festuca baffinensis	*					
F rubra	*	*				
Poa alpigena	*					
Poa arctica	-					
P glauca	-	*				
Puccinellia langeana	*	?	-			-
Trisetum spicatum	-					
FORBS						
Artemisia arctica	*	?	*			
Astragalus alpinus	-	?	*			
Braya purpurascens	*					
Cerastium beeringianum	-					
Cochlearia officinalis	*					
Descurainia sophioides	-					
Draba sp	*					
Epilobium latifolium	-	?	-			
Hedysarum alpinum	*	?	*			
H mackenzii	*	?	*			
Oxytropis borealis	*	?	*			
O campestris	-	?	-			
O deflexa	*	?	*			
O nigrescens	-		-			
O viscida	*	?	*			
Sagina intermedia	-					
SHRUBS						
Dryas integrifolia	-					-
Salix arctica	-			-		-
S glauca	-			-		-
S ovalifolia	-			-		-
S phlebophylla	-			-		-
S. planifolia	-			-		-

* Commonly found or used, - uncommon, ? under evaluation

been reduced to establish a more open cover, thereby encouraging species from adjacent undisturbed areas to colonize

INDIGENOUS SPECIES

In an effort to more closely restore the plant communities that have been disturbed as a result of mining activities, effort has been put into collecting indigenous plants for use in revegetation experiments (Wein and MacLean 1973, Maslen and Kershaw 1989, Jorgenson and Kidd 1991, Jorgenson et al 1992, Jorgenson et al 1994) With the exception of some grasses, no native plants are available at a commercial scale and, thus, collections tend to be small, localized, and site-specific The types of plant materials collected include seed, containerized seedlings, cuttings, sprigs, and plugs of the vegetation mat, which generally comprise more than one species (Table ?)

Seed

Seed collection efforts have focused primarily on hydrophylic grasses and sedges (Wein and MacLean 1973, Jorgenson and Kidd 1991, Jorgenson et al 1992), xerophylic legumes and Wormwood (*Artemisia* sp) (Moore 1993, Kidd and Jorgenson 1994), and willow (*Salix*) species (Cooper and Beschta 1993, Cooper and Haveren 1994) Preliminary observations of seed germination of these plant groups indicate that the technique is feasible, although germination rates are low, growth rates of seedlings are slow, and availability of seed is dependent on how successful seed production is during any one year Data have not been collected yet, however, to assess adequately the results of those applications, and much needs to be learned about this technique, including· seed handling and storage requirements for optimizing germination, potential germination rates, annual variability in seed production for harvesting, effect of site conditions on germination and growth, and interspecific variation among species

Two plant groups that are of particular interest to revegetation specialists are legumes and *Artemisia* species (Moore 1993, Kidd and Jorgenson 1994) Legumes are appealing for their association with nitrogen-fixing bacteria and potential contribution to long-term productivity. They also appear to be well adapted to gravelly soils with low soil moisture and little organic matter. *Artemisia* also tolerates xeric soils and is an attractive food source for caribou and arctic ground squirrels (Janet Kidd, per comm.) The feasibility of cultivating these species at a commercial scale, however, is yet to be determined

Containerized Seedlings

Germinating seeds and growing seedlings in a greenhouse before planting has not generally been used as a revegetation technique because of the expense in maintaining a greenhouse and the logistical constraints associated with most sites requiring rehabilitation in arctic Alaska and Canada A study conducted in Denali National Park evaluated ten species (grasses, forbs, and shrubs) for use in revegetating areas in the Park disturbed by construction activities (Densmore and Holmes 1987) Survival after one year was high for all species planted, but their long-term survival is yet to be determined For small-scale disturbances or critical habitat areas, containerized seedlings may be warranted, but because little research has been done on their potential as compared to other methods, they probably would not be practical for large areas

Cuttings and Sprigs

Revegetation with cuttings only has been done for woody shrubs and a few tree species (Epps 1973, Densmore et al 1987, Jorgenson and Cater 1991, Kidd and Jorgenson 1994, Helm 1994) Their potential for use in revegetation studies has not been fully evaluated but initial results are encouraging Some of the factors affecting establishment and long-term survival of cuttings are season of collection, plant competitors, planting media, and climatic conditions Survival appears to be greater when cuttings are obtained as early in the spring as possible, which allows them enough time to develop overwintering buds (Densmore et al 1987). A moderate-to-high cover of cultivated grasses affects survival, as the grasses are more effective at capturing soil nutrients than the cuttings (Densmore et al 1987, Helm 1994) A gravel substrate in a low precipitation area also may affect cutting survival, especially during initial establishment Finally, if cuttings are planted in windy areas that lack snow cover in winter, mortality may occur from wind desiccation (Kidd and Jorgenson 1994).

For sprigs, *Arctophila fulva* (Arctic Pendant Grass) has been used for experiments in establishing wetland vegetation (Moore 1991, Moore 1993, Jorgenson et al 1992, Jorgenson et al 1993), and has proven to be highly amenable to transplanting, even into fairly nutrient-poor, gravelly substrate (Jorgenson et al 1993) At most study sites where *Arctophila* has been planted, additional tillers are present usually within the same growing season The main limiting factor is the intense grazing some of the young plants experience, which includes both removal of biomass and uprooting (Jacobs et al. 1993) Although more expensive than seeding, this technique has proven to be reasonably cost-effective because of the colonizing ability of this species Further research with other wetland species may identify additional candidates for sprig transplants

Plugs and Tundra Mats

Revegetation using plugs and tundra mats of undisturbed vegetation has been tested at several sites and has appeal because usually more than one species is contained in a single plug Thus, the potential for colonization of a disturbed area by a variety of species is much greater Several studies using tundra plugs have conducted in the Prudhoe and Kuparuk oilfields of Alaska as part of wetland restoration and land rehabilitation efforts (Kidd and Jorgenson 1992, Jorgenson et al 1992, Jorgenson et al 1993) The species present in plugs come primarily from moist and wet tundra and include *Carex aquatilis* (Water Sedge), *C bigelowii* (Bigelow Sedge), *Eriophorum* sp (Cottongrass), and *Salix* sp (Willows). The plugs usually were planted in an organic substrate, although shallow depths of gravel were present at the surface At one location, plugs were planted in a thick gravel substrate (Jorgenson et al. 1992) Survival of the plugs has been quite high, but lateral expansion has been limited

Transplant of tundra mats has been tested only at three locations in the Kuparuk Oilfield in Alaska, Tuktoyuktuk in Northwest Territories, and Rae Point, Melville Island, Canada The first experiment was a complete failure as the tundra was in a frozen state and was very difficult to excavate The attempt was aborted after the excavating equipment was severely damaged (Torre Jorgenson, pers comm) The experiment at Tuktoyuktuk was more successful, with vegetation recovery accelerated in those areas where the tundra mat was placed as compared to those areas where the mineral substrate was left to be colonized naturally (Younkin and Martins 1985) However, composition of the soil in the disturbed area was such that natural recovery was still possible, albeit at a slower rate. Tundra replacement at Rae Point was largely unsuccessful because the mat was placed in a very wet area and much of it was underwater In addition, the area where the tundra was removed had subsided and vegetation was composed primarily of mosses. Because of expensive logistical costs and limited areas available for excavating tundra mats, it is unlikely this method will become more commonplace. Like containerized seedlings, however, it may be recommended when specific habitats are targeted for restoration

FERTILIZATION

Many of the disturbed areas targeted for vegetation rehabilitation do not have sufficient levels of nutrients for promoting plant establishment and growth (Walker et al 1987) In addition, some undisturbed tundra communities have depressed levels of soil nutrients, particularly nitrogen, because decomposition in slow and much of the soil nitrogen is tied up in undecomposed plant material (Dadykin 1958, Haag 1974) To compensate for the lack of nutrients, fertilizer usually is added to increase soil nutrient status and facilitate more rapid establishment of cover on disturbed soils The rate of fertilizer to be applied is dependent on the composition of the soil substrate and on the types of plant species targeted for revegetation Graminoids and forbs prefer fairly high rates of fertilizer (McKendrick et al 1978, Chapin and Shaver 1985), whereas some shrubs respond more positively to lower levels of nutrients (Russel 1973, Henry et al 1994)

The question of multiple versus single applications of fertilizer has not been completely resolved In cases where the plant species used are grasses and they attempting to establish on thick gravel, multiple fertilizations usually are necessary to maintain plant productivity (Kidd and Jorgenson 1993) If the soil is more loamy in origin and has some organic material, a single application of fertilizer may be all that is necessary. A single fertilization also may be warranted if trying to encourage colonization of native shrubs is a priority

SOIL CONDITIONING

Depending on the origin and composition of the disturbed soil substrate, the addition of soil conditioners may be necessary to ameliorate acidic or alkaline conditions, sodium toxicity, improve the soil microbial flora, or increase the soil-water storage capacity Most of these amendments are site specific and require an assessment of site conditions to determine the rate and amount of conditioner to apply

LIMING

Although the application of lime usually is not necessary because the pH of tundra soil and gravel fill normally are neutral or slightly alkaline, lime has been applied in association with a tundra oil spill because increased microbial activity reduced the soil pH from near neutral (7) to less than 6 (Jorgenson and Cater 1992a) Elemental sulfur and sulfuric acid have been added to small plots on an overburden stockpile in the Kuparuk Oilfield of Alaska to reduce alkalinity of the soil (Jorgenson et al 1990) These rates appeared to have little effect on soil alkalinity or plant growth, however

GYPSUM

Gypsum has been applied to reduce the sodium hazards in tundra that was damaged by fire-extinguishing agents (primarily sodium bicarbonate) used during fire-fighting training at the SWPT Pad in the Kuparuk Oilfield of Alaska (Cater and Jorgenson 1994b) After one month, the sodium adsorption ratio decreased from 3 1 to 2 5, and germination tests indicated that sodium levels (mean = 290 mg/L) were no longer toxic to plants

MICROORGANISMS

Soil microorganisms have been applied in a soil-water slurry on small germination test plots to inoculate the roots of legumes with nitrogen-fixing *Rhizobium* bacteria (Cater and Jorgenson 1994a) No results are yet available on the effectiveness of this technique, but if nitrogen-fixing bacterial populations can establish in disturbed soils, the need for frequent fertilization could be moderated to some degree The use of soil transfer for introducing mycorrhizal bacteria also has been tested at a coal mine site in south-central Alaska (Helm and Carling 1992) That study found that *Populus balsamifera* (Balsam Poplar) cuttings grew taller in plots treated with soil transfer in combination with a phosphorus fertilizer than cuttings in plots treated with fertilizer alone Mycorrhizae have been shown to be important to plant productivity because they increase soil nutrient availability and moisture by increasing the surface area of plant roots (Linderman 1994) Some evidence also indicates that mycorrhizae help guard against plant pathogens (Duchesne 1994)

WATER ABSORBANTS

Inadequate soil moisture is one of the primary factors limiting establishment of vegetation on mine soil. Mine soil frequently is made up of predominantly coarse gravels, which have little capacity to hold water and promote high rates of evaporation. To increase the water storage capacity of coarse gravel soils, soil amendments such as starch-based polymer absorbents or sandy overburden (which would increase soil moisture by retaining additional water during snowmelt) have been tested on plots in the Kuparuk Oilfield in Alaska (Cater and Jorgenson 1994a) Initial results indicate mean values for soil moisture in the absorbent treatment and overburden were similar to those in an unamended control, but over time these treatments may result in increased benefit

TOPSOIL ADDITION

To increase the water-storage capacity, nutrient status, and biological activity of disturbed soils, topsoil (a mixture of organic and mineral horizons from tundra soil) has been applied as a soil amendment in several studies (Jorgenson and Cater 1991, Jorgenson and Cater 1992, Cater and Jorgenson 1994a) Topsoil significantly increased vegetation cover and plant productivity over controls in all of these studies Unfortunately, topsoil is very limited at most mine sites in the Arctic

SEWAGE SLUDGE ADDITION

Domestic sewage sludge from mine camp facilities has the potential to improve soil properties on thick gravel fill Like topsoil, it is composed primarily of organic matter and, thus, has many of the same beneficial properties In experimental plots, sewage sludge was applied to a thick gravel pad at three different tonnage rates in the Kuparuk Oilfield (Cater and Jorgenson 1994a). Although differences in total organic carbon, and nitrogen and phosphorus were pronounced immediately after application when compared to the control, soil properties did not appear to be improved substantially on a long-term basis The lack of improvement appeared to be due to application rates that were too low Factors limiting the application rates of sludge include the low cation-exchange capacity of gravel and concerns over applying excessive amounts of nitrate that can leach into adjacent wetlands Although groundwater below the plots had concentrations of fecal coliform bacteria and heavy metals that were similar to background levels, nitrate concentrations were three times higher under the sludge-amended plot. Given the lack of topsoil available, sludge could provide an alternative source of organic matter. However, potential adverse impacts of pathogens, heavy metals, and nitrates associated with application of sludge on gravel fill needs to be further evaluated.

SURFACE MANIPULATION

BERM AND BASIN CONSTRUCTION

Thick gravel fill, which is one of the most extensive types of disturbance at mine sites, presents a severe environment for plant growth. One of the factors limiting plant growth is soil moisture. Berms can be constructed perpendicular to prevailing winds to capture drifting snow during winter and increase water input during snowmelt, thus compensating for low precipitation in summer and low soil moisture on thick gravel fill (Jorgenson et al. 1990, Jorgenson and Cater 1991). In areas with fine-grained soils, such as overburden stockpiles, meltwater can be impounded permanently to create wetlands (Jorgenson et al. 1993). Moderately sized berms (~1 m high) and shallow basins (≤0.5 m) constructed on thick gravel fill at a drill site in the Prudhoe Bay Oilfield (Jorgenson and Cater 1991) resulted in substantial snow capture and, after three years (1994), soil was moist within the basins through the end of summer (J. Kidd, pers. comm.)

Large (~4 m) berms were constructed to capture snow and smaller berms (~2 m) were constructed to impound the meltwater (Jorgenson et al. 1992a) within an overburden stockpile in the Kuparuk Oilfield (Jorgenson and Cater 1992). Because of the presence of fine-grained soil and permafrost beneath the shallow active layer (seasonally thawed ground), water levels increased in the basin from 1990 to 1993 (Jacobs et al. 1994). Transplanted sprigs of *Arctophila fulva* and the presence of aquatic invertebrates in the impounded basin have made this site attractive to numerous waterbirds.

FILL REMOVAL

Removal of gravel fill to facilitate the development of pedologic and hydrologic conditions similar to those found in adjacent undisturbed tundra has been investigated at several sites in the Prudhoe Bay Oilfield (Jorgenson and Kidd 1991, Jorgenson et al 1993) Without the removal of gravel and the associated increase in the availability of water and nutrients, the growth of plants on thick gravel fill is poor Jorgenson (1988) found plant growth to be negligible on gravel thicker than 1 m and attributed the response to the low rate of capillary rise of groundwater as a result of the thickness of the fill

How much gravel to remove from roads and pads remains problematic Because tundra soils typically are underlain by ice-rich permafrost, the removal of gravel can initiate thaw settlement as permafrost adjusts to the new thermal regime Some gravel can be left in place to compensate for thaw settlement, but tundra soil will remain buried If gravel is removed completely to expose the buried tundra soil, excessive thaw settlement may cause the site to become flooded permanently, and water movement in the adjacent tundra may be altered, which occurred at one of the study sites in the Prudhoe Bay Oilfield (Jorgenson and Kidd 1991) The impounded water provides an opportunity to create aquatic habitats, but it also restricts the types of plant materials that can be used

FLOODING OF MINE SITES

Abandoned gravel mine sites can be flooded with water and connected to nearby drainages to support overwintering fishes (Hemming 1989, Hemming 1990, Hemming 1991) Natural colonization by fishes has been rapid in mine sites that have been flooded and connected to adjacent streams with access channels. Eleven species of fishes have been found at these sites arctic cisco (*Coregonus autumnalis*), broad whitefish (*C nasus*), least cisco (*C sardinella*), round whitefish (*Prosopium cylindraceum*), burbot (*Lota lota*), ninespine stickleback (*Pungitius pungitius*), rainbow smelt (*Osmerus mordax*), Dolly Varden char (*Salvelinus malma*), arctic grayling (*Thymallus arcticus*), slimy sculpin (*Cottus cognatus*), and fourhorn sculpin (*Myoxocephalus quadricornis*)

SURFACE PREPARATION

Surface preparation techniques include compaction, scarifying, raking or dragging, and mulching These techniques have not been evaluated as rigorously as other techniques and, thus, they will be discussed only briefly Compaction was done on an abandoned spur road in the

Kuparuk Oilfield with a large, rubber-balloon-tired vehicle (Rolligon) to improve contact between the applied sod and the underlying thin layer of gravel (Cater and Jorgenson 1993) Scarifying has been done at many sites by using a grader equipped with chisel teeth or by pulling a pipe equipped with tines (Jorgenson et al 1990, Jorgenson and Cater 1991, 1992b), and raking or dragging has been conducted to improve soil-seed contact (Jorgenson and Cater 1992b) Plants at scarified sites typically are most abundant in the bottom of furrows, suggesting that scarification increases seed germination by providing favorable microsites. Finally, mulch has been applied to thick gravel fill to reduce the rate of evaporation of soil moisture. Although seed germination was improved in the mulched areas, soil temperatures and moisture were lower than in the unmulched plots because the mulch intercepted solar radiation and precipitation (Jorgenson and Cater 1992a)

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