PROJECT #1009-002-16 GIS # HB-22-004b March 01 2011

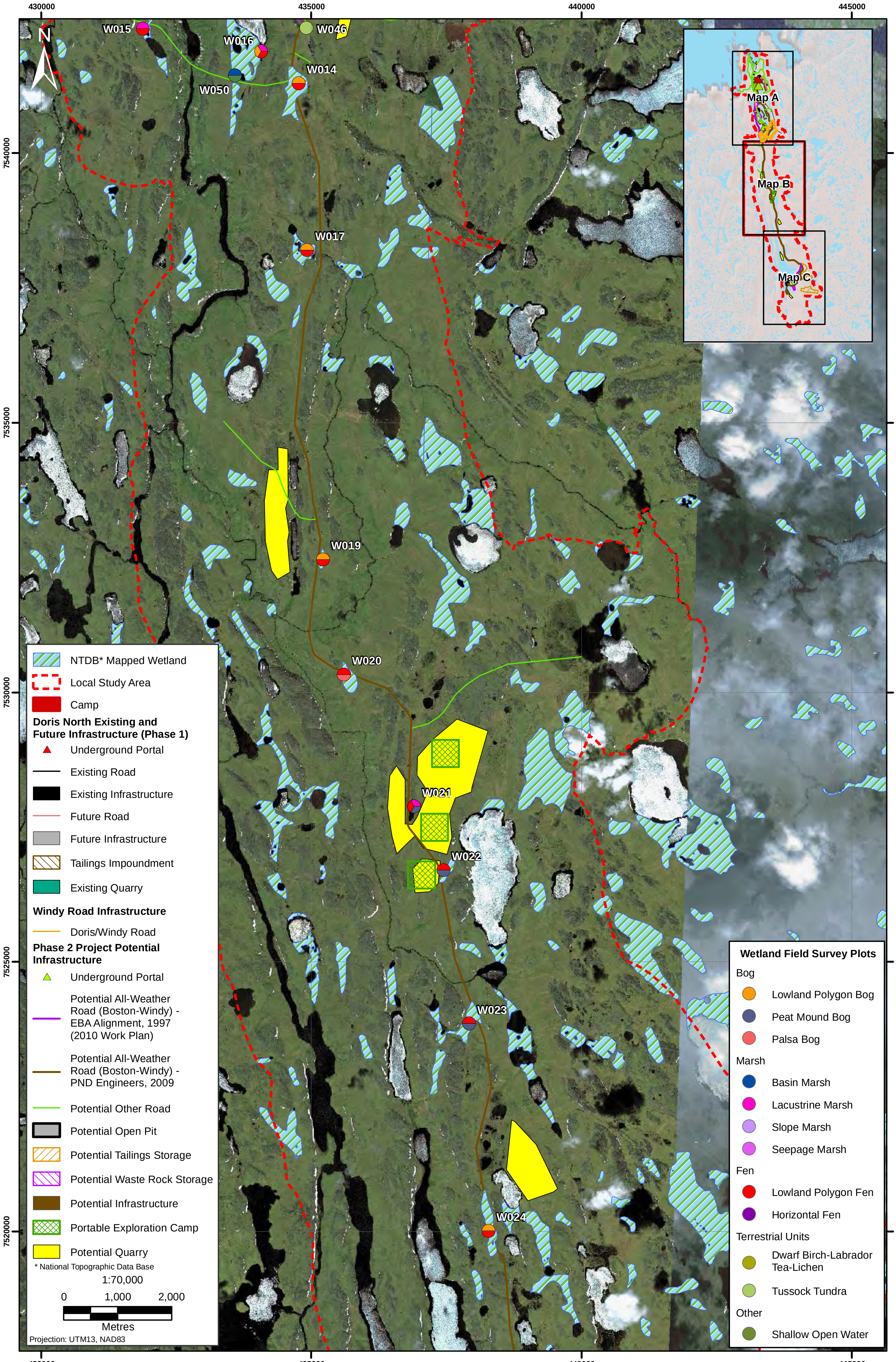


Figure 3.2-2b

NEWMONT NORTH AMERICA

Wetland Field Survey Plots and Wetland Classification; Mid Belt

Figure 3.2-2b

Rescan Engineers & Scientists

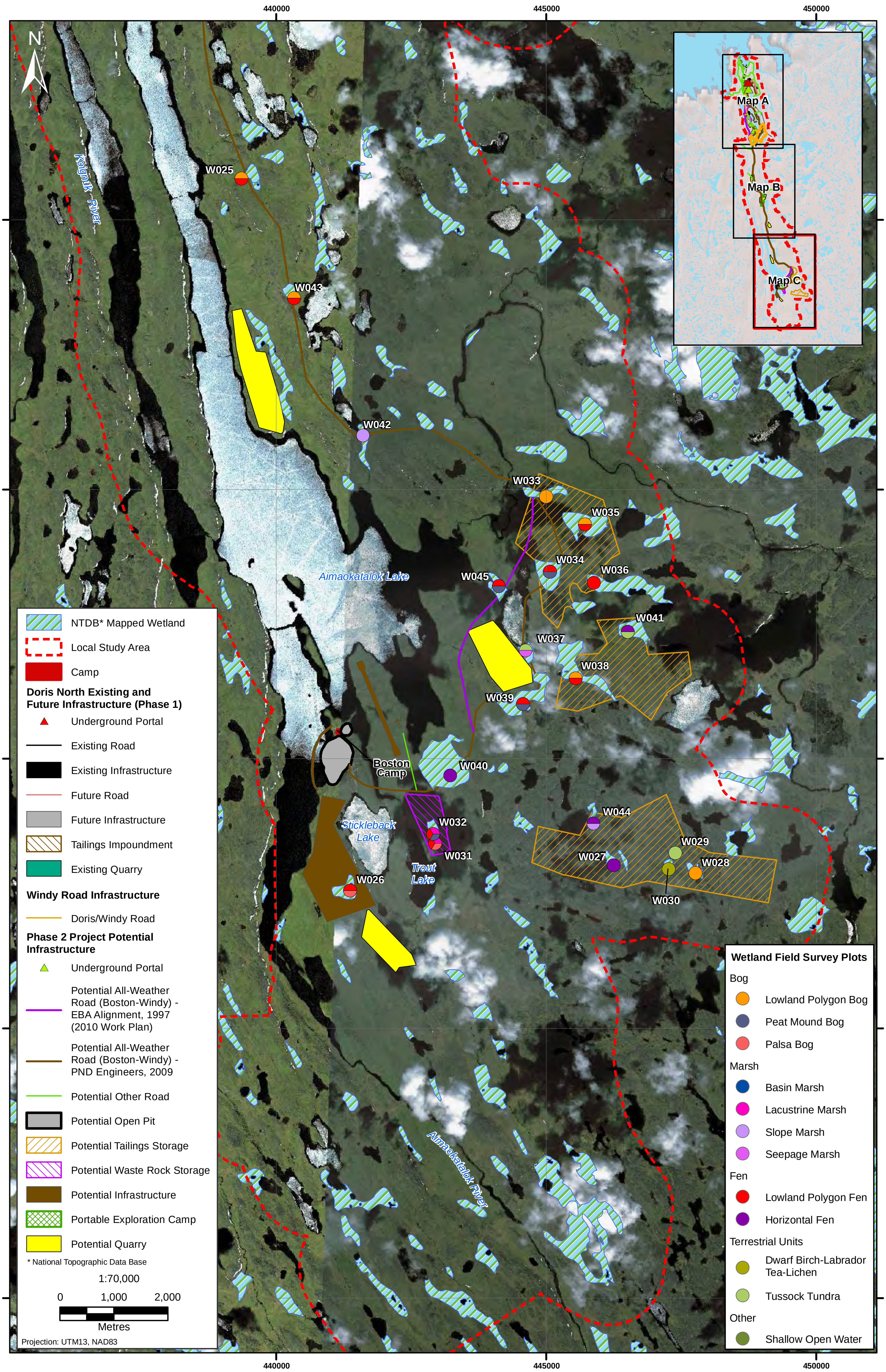


Figure 3.2-2c

NEWMONT NORTH AMERICA

Wetland Field Survey Plots and Wetland Classification; South End of Belt

Rescan Engineers & Scientists

Figure 3.2-2c

Table 3.2-3. Characteristics of Fen Wetlands Observed during 2010 Field Surveys

Survey Parameter	Range
Soil Moisture Regime	very wet (VW) to wet (W)
Soil Nutrient Regime	poor (B) to medium (C)
Hydrodynamic Index	stagnant (ST) to mobile (Mo)
Von Post (scale of decomposition)	3 to 7
depth to permafrost (cm)	10 to 42
pH (pH units)	5 to 7
Conductivity (μS/cm)	63 to 406

3.2.3.1 Horizontal Fen

Three plant communities occur as horizontal fens within the study area and include the following: water sedge (*Carex aquatilis*), cotton grass (*Eriophorum angustifolium*) and chordroot sedge (*Carex chordorrhiza)*. The water sedge community occupies wet depressions subject to extended flooding and is most common near the margins of ponds and lakes (Rescan 1997). The tall cottongrass community occurs on sloping sites and is often associated with the water sedge community (Plate 3.2-1). The chordroot sedge community occupies level areas with poor drainage near the margins of marshes or shallow open water (Plate 3.2-2). Other common species include water sedge (*Carex aquatilis),* fragile sedge *(Carex membranacea),* short-leaved sedge *Carex fulginosa* spp. *misandra,* sheathed sedge *Carex vaginata,* round sedge *(Carex rotundata) and* looseflower alpine sedge *Carex rariflora*. Lousewort (*Pedicularis spp.*) is also often present in trace amounts.

Plate 3.2-1. A mixed water sedge and tall cottongrass fen located at plot W024.

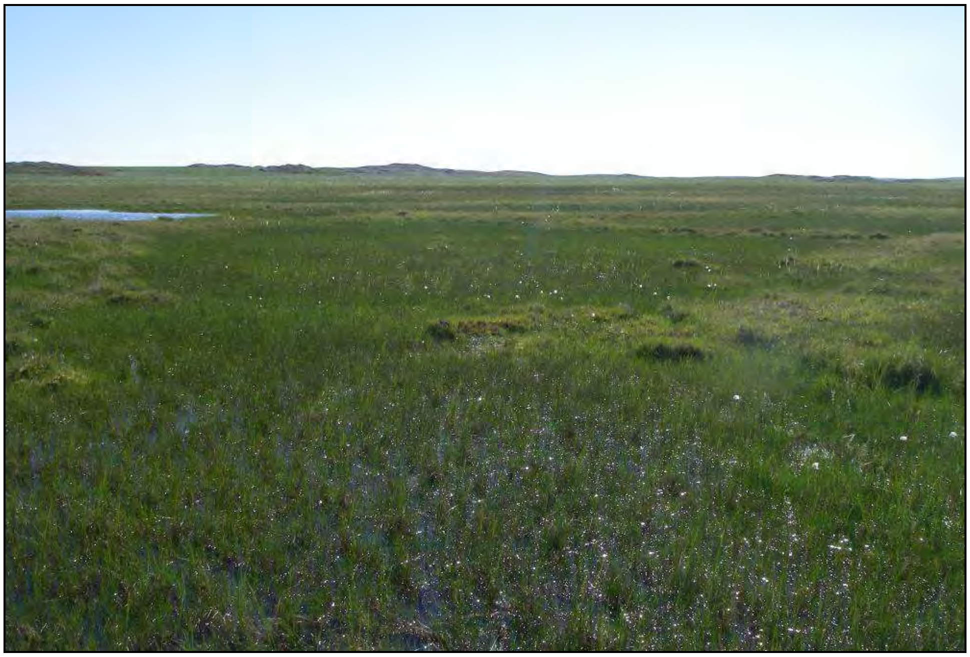


Plate 3.2-2. A cordroot sedge community near the margin of an open water feature (W017).

3.2.3.2 Lowland Polygon Fen

Lowland polygon fens form when the active layer within the soil directly influences surface landscape morphology. They are characterised by repeating variations of wet depressions (flarks) and dry linear hillocks (ribs) resulting from the displacement of soil due to freeze thaw cycles and permafrost dynamics (Plate 3.2-3). The wet soil conditions within the depressions support predominantly *Carex* species, including *C. aquatilis* (Plate 3.2-4), *C. membranacea, C. rotundata and C. atrofusca,* as well as *Eriophorum Angustifolium (*Plate 3.2-5). The drier hillocks support plant species assemblages characteristic of Arctic bog ecosystems, such as bog blueberry (*Vaccinium uliginosum*), lingonberry (*Vaccinium vitis idaea)* and to a lesser extent bearberry (*Arctostaphylos* spp).

3.2.4 Bogs

Bogs are nutrient-poor, *Sphagnum* or brown moss-dominated peatland ecosystems in which the rooting zone is isolated from mineral-enriched groundwater. Precipitation, fog, snowmelt, and seasonal melt of permafrost are the primary water sources. Precipitation does not usually contain dissolved minerals and is mildly acidic, therefore bog waters are low in dissolved minerals and acidic in nature. Bog water acidity is enhanced because of organic acids formed during the decomposition of peat (Warner and Rubec 1997). Due to the acidity, few minerotrophic plant species occur (MacKenzie and Moran 2004).

Bogs are numerous in occurrence but limited in extent throughout the LSA. Three types of bog forms were identified: lowland polygon bogs, peat mound bogs, and palsa bogs, all of which occurred in association with fen forms. Table 3.2-4 presents a summary of the typical site characteristics observed at bog sites during the field surveys.

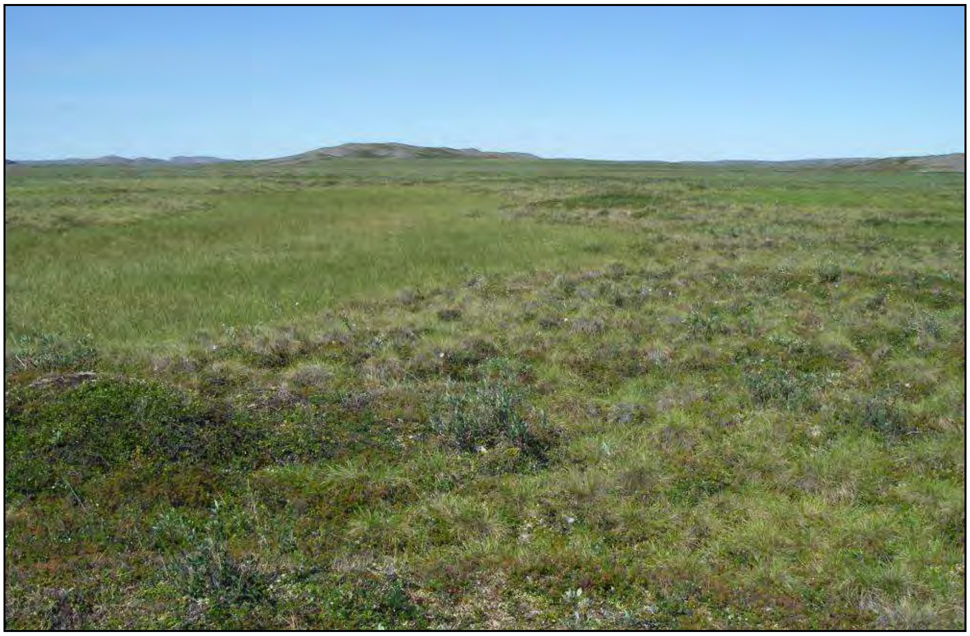


Plate 3.2-3. A lowland polygon fen and bog complex resulting from freeze thaw cycles.

*Plate 3.2-4. Macroview of the inflorescence of water sedge (*Carex aquatilis*), a common fen and marsh sedge.*

*Plate 3.2-5. Macroview of the inflorescence of tall cottongrass (*Eriophorum angustifolium*), a dominant sedge in fens throughout the Local Study Area.*

Table 3.2-4. Characteristics of Bog Wetlands Observed during 2010 Field Surveys

Survey Parameter	Range
Soil Moisture Regime	mesic (M) to wet (W)
Soil Nutrient Regime	poor (B) to medium (C)
Hydrodynamic Index	n/a[1]
Von Post (scale of decomposition)	2 to 5
depth to permafrost (cm)	20 to 29
pH (pH units)	4 to 5.5
Conductivity (μS/cm)	n/a[2]

[1] The Hydrodynamic Index was not recorded because of the presence of permafrost at approximately 30 cm below the soil surface and a lack of surface water. These features combined to eliminate HDI indicators such as channels, rivulets, ponding, and seepage.
[2] The measurements not taken because there was no surface water available to sample in the bog.

3.2.4.1 Lowland Polygon Bog

Lowland polygonal bogs are perennially frozen peatlands characterized by linear ridges underlain by ice-wedges (Plate 3.2-6). This ecosystem occurs in conjunction with the lowland polygon fen and represents the raised drier portions of the wetland complex. Lowland polygon bogs occur most commonly near estuaries, along river floodplains, and in depressions (Routledge 2004).

Plate 3.2-6. Typical linear ridges of lowland polygon bogs within the Local Study Area (W017).

3.2.4.2 Peat Mound Bog

Peat mound bogs are characterized by small hummocks (>3 m in diameter) of peat which have been raised by frost action (Plate 3.2-7). They occur most commonly adjacent to or surrounded by fen wetlands.

Plate 3.2-7. Raised hummocks within a peat mound bog at W021.

3.2.4.3 Palsa Bog

Palsa bogs are convex, uneven mounds of perennially frozen peat and mineral soil usually raised up to one metre above the adjacent ground due to ice wedge activity and frost heave (Warner and Rubec 1997; Plate 3.2-8). They typically occur in complexes with lowland polygon, basin, and horizontal fens. They support species more common in the terrestrial units BL and BM such as dwarf birch, Labrador tea and bog blueberry. Within the study area, palsas most commonly have relatively thin veneers of peat overlying frozen mineral soil horizons.

3.2.5 Marshes

Marshes are permanently to seasonally flooded non-tidal mineral wetlands dominated by emergent graminoid vegetation (W.H. MacKenzie and J.R. Moran 2004). Marshes are strongly influenced by groundwater or surface water and have relatively high hydrodynamic indices. The water table is above the soil surface for the entire growing season, which limits species richness to those few plants that can tolerate prolonged anoxic conditions. The soil nutrient regime is relatively rich compared to other wetland types as a result of nutrient inputs associated with high plant productivity and relatively rapid organic decomposition (Rescan 1997). Soils are typically mineral but can also have a well decomposed organic surface tier (B.G. Warner and C.D.A. Rubec 1997; W.H. MacKenzie and J.R. Moran 2004).

Three wetland marsh form types (lacustrine marsh, slope marsh, and basin marsh) were identified during field surveys. Table 3.2-5 presents a summary of the site characteristics at marsh sites within the LSA.

3.2.5.1 Lacustrine Marsh

Lacustrine marshes occur along lake margins or, less commonly, along unconfined low-gradient streams in microsites protected from erosional flows and ice and wave scour (Rescan 1997; Plate 3.2-9). Water sources are a combination of inputs from adjacent lakes, rivers and streams flowing into the lake, as well as surface runoff from adjacent catchment areas.

Plate 3.2-8. Typical palsa bog mound feature in association with a lowland polygon fen at W20.

Table 3.2-5. Characteristics of Marsh Wetlands Observed during 2010 Field Surveys

Survey Parameter	Range
Soil Moisture Regime	very wet (VW)
Soil Nutrient Regime	medium (C) to rich (D)
Hydrodynamic Index	sluggish (SL) to stagnant (ST)
Von Post (scale of decomposition)	3 to 5
depth to permafrost (cm)	10 to 34
pH (pH units)	5 to 7.5
Conductivity (μS/cm)	73 to 242

3.2.5.2 Slope Marsh

Slope marshes occupy the lower portions of seepage slopes in areas of groundwater discharge and are characterized by hummocky terrain (Warner and Rubec 1997; Plate 3.2-10).

3.2.5.3 Basin Marsh

Basin marshes occupy the well defined depressions in inland areas that are not influenced by salt water (Plate 3.2-11 and 3.2-12).

Plate 3.2-9. A lacustrine marsh located at W016.

Plate 3.2-10. A typical slope marsh (far left) surrounding an open water feature. Hummocky terrain in the foreground is a characteristic feature of slope marsh sites.

*Plate 3.2-11. A basin marsh dominated by marsh cinquefoil (*Caltha palustris*) and sedges (*Carex *spp.) surrounds the open water feature at Plot W050.*

Plate 3.2-12. Aerial view of a basin marsh (centre of the photo) located south of the open water feature at Plot W050.

3.2.6 Open Water

3.2.6.1 Shallow Open Water

Shallow open water wetland ecosystems are permanently flooded by still or slow-moving water and dominated by submerged and floating-leaved aquatic plants. Shallow open water wetlands can represent the transitional unit from permanent deep water bodies (i.e., sluggish streams and lakes) to fens and marshes (B.G. Warner and C.D.A. Rubec 1997; W. H. MacKenzie and J. R. Moran 2004). They are among the most important habitat for wildlife and fish for providing cover and high prey densities (W. H. MacKenzie and J. R. Moran 2004). Sedimentation and nutrient loading are the biggest concern for these wetlands because changes in turbidity block light penetration that influences where submerged rooted aquatic vegetation can grow (W. H. MacKenzie and J. R. Moran 2004). A variety of shallow open water features were observed throughout the study area, most commonly in association with emergent marshes or larger water bodies (Plate 3.2-13 to Plate 3.2-15).

Plate 3.2-13. Shallow open water surrounded by Carex aquatilis *at W012.*

3.3 ECOSYSTEMS AND PLANTS OF INTEREST

3.3.1 Sensitive or At Risk Vegetation Communities

Arctic ecosystems are well known for their sensitivity to anthropogenic disturbance. Even small, low intensity disturbances, such as vehicle use on Arctic tundra, often create immediate and persistent effects on vegetation and soils (Forbes, Ebersole, and Strandberg 2001). In particular, disturbances to wetter areas may affect soil thaw characteristics that define many ecosystems. Although many Arctic species are adapted to rapid re-colonization of disturbed sites, the altered vegetation communities may no longer provide pre-disturbance ecosystem functions or habitat values (Forbes et al. 2001).

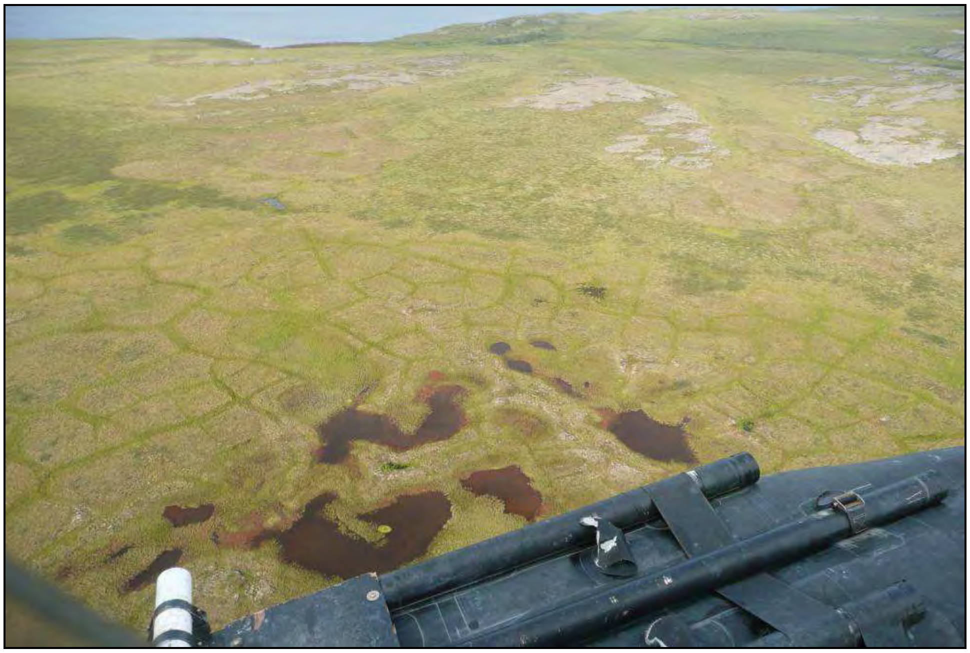


Plate 3.2-14. A shallow open water and marsh wetland complex surrounded by lowland polygon bogs and fens, near plot W025.

Plate 3.2-15. A shallow open water and peat mound bog wetland complex at W034.

Lowland ecosystem units with high water tables and relatively shallow active layers are sensitive to disturbances that result in soil compression, partly because disturbance can cause ground thawing and changes to hydrology (Jorgenson, Ver Hoef, and Jogenson 2010). However, if the disturbance is not too severe, the vegetation in these areas (primarily graminoids) may recover relatively quickly following disturbance. Upland ecosystems are generally dryer and water shedding, so physical disturbances may have a limited affect on water movement relative to lowland ecosystems. However, the vegetation species growing in dryer areas are often slower to recover following disturbance (Kemper and Macdonald 2009; Jorgenson, Ver Hoef, and Jogenson 2010). The marine ecosystem units are generally sparsely vegetated and characterized by unstable substrates that are constantly or erratically disturbed by tides, ice scouring and wave action. Vegetation that occurs in these ecosystem units should have a greater ability to re-colonize after disturbance, but literature reviews of Arctic marine foreshores indicate that knowledge in this area is limited.

3.3.2 At Risk Plant Species

There are documented occurrences of five at risk plant species within Nunavut, which include hairy rockcress (*Braya pilosa*), Drummond bluebell (*Mertensia drummondii*), Banks Island alkali grass (*Puccinellia banksiensis*), Raup's willow (*Salix raupii*), and Nahanni aster (*Symphyotrichum nahanniense*) (R. Gau, pers. comm. 2010). The National General Status Working Group (NGSWG) also tracks 121 plant species that may be at risk in the NWT and may also occur in Nunavut (Appendix 4).

Field plots surveyed in 2010 identified 102 plants by genus and species, and 24 by genus alone (Appendix 8). Of these plants, none are considered at risk.

Golder (2009) identified three bryophyte species that were considered to be at risk globally. *Sphagnum orientale* is ranked by NatureServe as G2G4, indicating that it is globally imperilled to apparently secure. *Cinclidium latifoliumi* is ranked as G3G5, indicating it is globally vulnerable to secure, while *Frullania tamarisci* is ranked G5T4 (globally secure, but subspecies apparently secure). All three species rankings are provided as ranges, which indicate that data deficiencies limit more accurate assessments of their global status (NatureServe 2010). The status of these three species in the NWT and Nunavut has not been assessed. None of these species were identified during the 2010 field surveys.

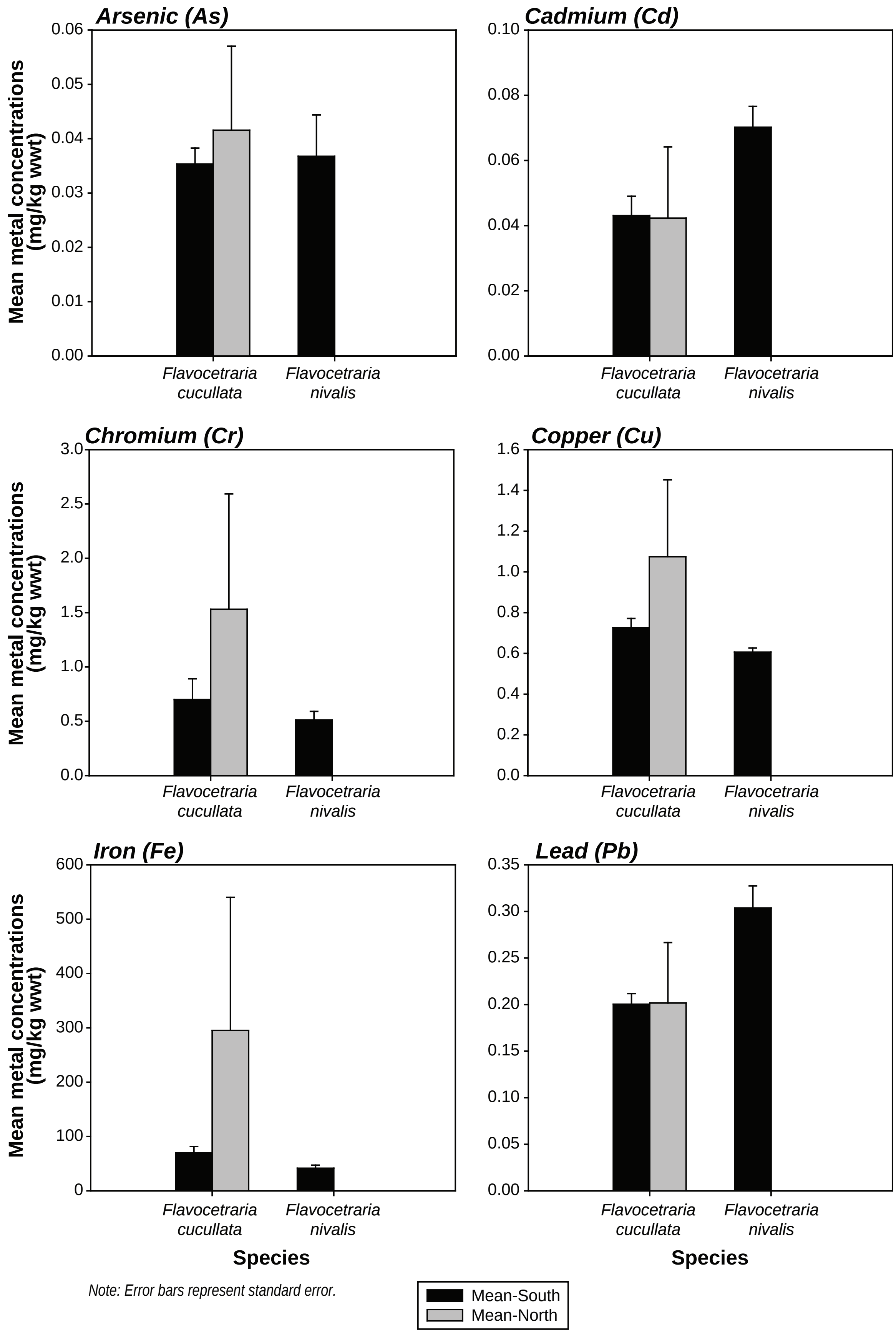
3.3.3 Invasive Plant Species

There is limited information available for invasive plant species in Nunavut. Information regarding invasive plants was compiled from the NWT Department of Environment and Natural Resources 2010, the Invasive Species Specialist Group (ISSG) Global Invasive Species Database, and the Evergreen Native Plant Database and compared with field data collected in 2010 (Appendix 5). Field surveys found one potentially invasive plant, common dandelion (*Taraxacum officiniale*) at plot 006. There are two subspecies of common dandelion (*Taraxacum officinale*), one of which is native (formerly known as *Taraxacum lacerum)* and the other is invasive (*T. officinale* ssp. *officinale*). Plant species were generally not identified to the subspecies level and thus field personnel were unable to determine the status of the plant in question.

3.4 METAL CONCENTRATIONS IN PLANT TISSUES

Twelve metals of interest were summarized and are discussed in this section. These do not include metals for which over 50% of the tissue samples had concentrations that were below detection limits. The raw analytical results for metal concentrations in the lichen tissue samples (both wet and dry weights) are presented in Appendix 10. There are no territorial or federal guidelines for metal limits in vegetation.

Metal concentrations for *Flavoceraria cucullata* samples are summarized by location, based on their occurrence within the North or South end of the belt (Table 3.4-1; Figure 3.4-1).



Note: Error bars represent standard error.

2010 Mean Metal Concentrations in Sampled Lichen Tissue

Figure 3.4-1a

NEWMONT NORTH AMERICA

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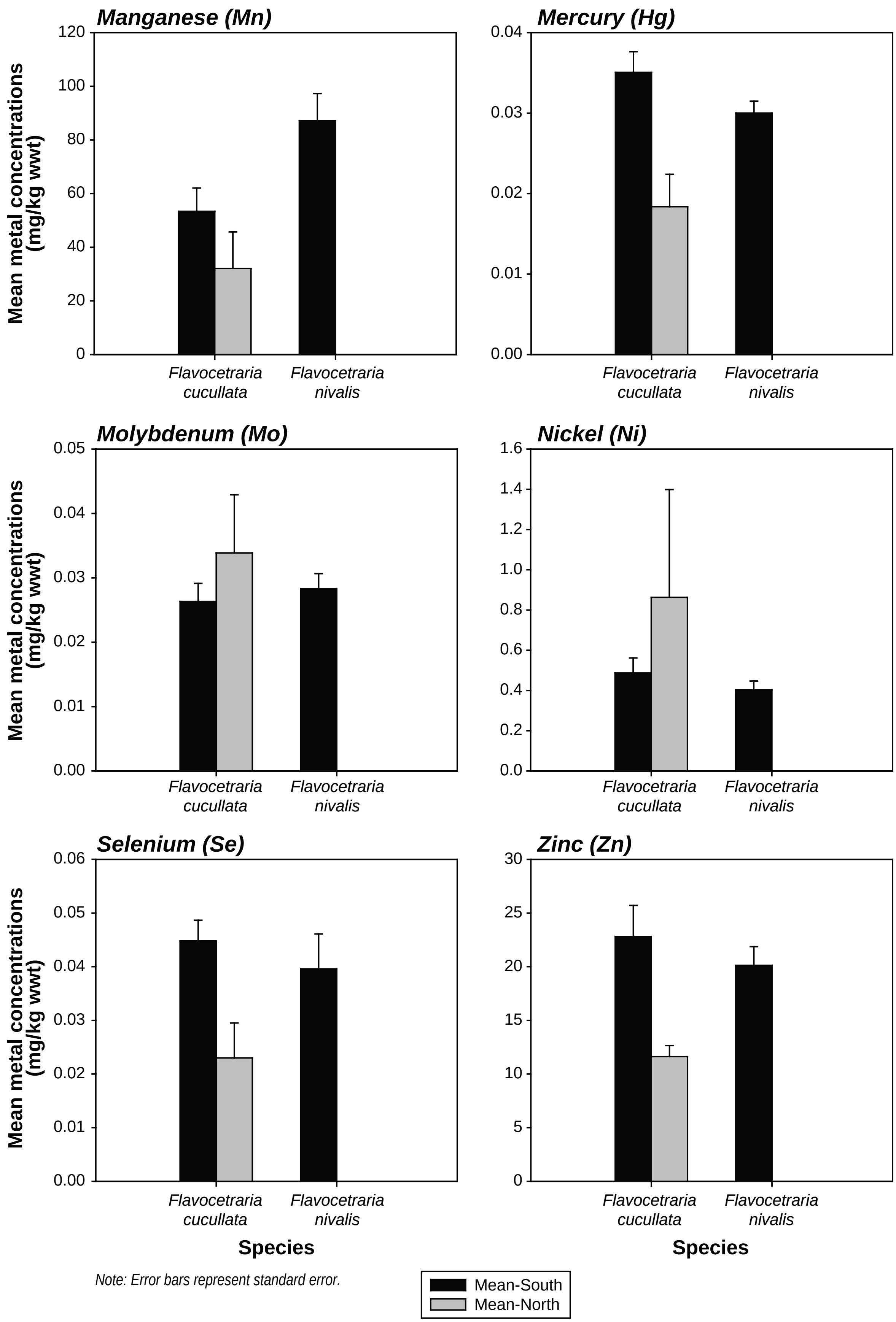

Note: Error bars represent standard error.

NEWMONT NORTH AMERICA

2010 Mean Metal Concentrations in Sampled Lichen Tissue

Figure 3.4-1b

Rescan Engineers & Scientists

Table 3.4-1. Summary Metal Concentration Results for Collected Samples of *Flavocetraria cucullata*

		F. cucullata South Summary n=5				*F. cucullata* North Summary n=3			
	Units	Mean	Standard Error	Minimum	Maximum	Mean	Standard Error	Minimum	Maximum
Physical Tests									
% Moisture	%	18	5.0	8.1	36	48	8.7	31	61
Metals									
Arsenic (As)	mg/kg wwt	0.04	0.003	0.02	0.04	0.04	0.02	0.02	0.07
Cadmium (Cd)	mg/kg wwt	0.04	0.006	0.03	0.07	0.04	0.02	0.02	0.09
Chromium (Cr)	mg/kg wwt	0.70	0.19	0.36	1.4	1.5	1.1	0.36	3.6
Copper (Cu)	mg/kg wwt	0.7	0.04	0.6	0.8	1.1	0.4	0.4	1.6
Iron (Fe)	mg/kg wwt	70.0	11.4	39.9	110	295	245	40.6	785
Lead (Pb)	mg/kg wwt	0.20	0.011	0.17	0.24	0.2	0.06	0.07	0.3
Manganese (Mn)	mg/kg wwt	53	8.7	34	84	32	14	6.1	52
Mercury (Hg)	mg/kg wwt	0.04	0.003	0.03	0.04	0.02	0.004	0.01	0.02
Molybdenum (Mo)	mg/kg wwt	0.03	0.003	0.02	0.04	0.03	0.01	0.02	0.05
Nickel (Ni)	mg/kg wwt	0.5	0.08	0.4	0.8	0.86	0.54	0.25	1.9
Selenium (Se)	mg/kg wwt	0.05	0.004	0.04	0.06	0.02	0.01	0.01	0.03
Zinc (Zn)	mg/kg wwt	23	2.9	14	29	12	1.0	9.8	13

Metal concentrations for *Flavoceraria nivalis* samples are summarized for the South end of the belt as no *F. nivalis* samples were collected in the North end of the belt (Table 3.4-2; Figure 3.4-1).

Table 3.4-2. Summary Metal Concentration Results for Collected Samples of *Flavocetraria nivalis*.

		F. nivalis South Summary n=10			
	Units	Mean	Standard Error	Minimum	Maximum
Physical Tests					
% Moisture	%	19	3.1	9.5	36
Metals					
Arsenic (As)	mg/kg wwt	0.04	0.008	0.02	0.1
Cadmium (Cd)	mg/kg wwt	0.07	0.006	0.05	0.1
Chromium (Cr)	mg/kg wwt	0.5	0.08	0.2	1.1
Copper (Cu)	mg/kg wwt	0.6	0.02	0.5	0.7
Iron (Fe)	mg/kg wwt	42	5.7	27	88
Lead (Pb)	mg/kg wwt	0.3	0.02	0.2	0.4
Manganese (Mn)	mg/kg wwt	87	10	42	145
Mercury (Hg)	mg/kg wwt	0.03	0.001	0.02	0.04
Molybdenum (Mo)	mg/kg wwt	0.03	0.002	0.02	0.05
Nickel (Ni)	mg/kg wwt	0.4	0.04	0.2	0.6
Selenium (Se)	mg/kg wwt	0.04	0.006	0.01	0.08
Zinc (Zn)	mg/kg wwt	20	1.7	14	31

Mercury, selenium and zinc had higher mean values in plant tissues from the South end of the belt than in the North end of the belt. No further conclusions about differences between species or metals can be made due to limited sample sizes and high variability among the samples.

3.5 OVERVIEW OF ECOSYSTEM FUNCTIONS

This section provides a brief overview of the overall function of terrestrial ecosystems in the Project LSA.

3.5.1 Terrestrial Ecosystem Functions

For this discussion, terrestrial ecosystems include local ecosystem units grouped in the upland category. These include ecosystem units that are generally water shedding, situated in mid, upper, and crest landscape positions, and generally located on morainal, colluvial, or weathered bedrock parent materials, often overlaying bedrock outcrops. Upland ecosystems comprise 28.5% of the LSA and 40.4% of the RSA.

With the exception of the BL unit, upland ecosystems generally have lower primary productivity. They are typically dominated by slower growing vegetation and are generally nutrient poor. These ecosystems function much differently than the more common lowlands. They include a significant cover of dwarf shrubs (mainly prostrate *Betula nana*, *Salix* spp., and *Vaccinium* spp.) in comparison to lowland areas that are largely dominated by a mix of similar shrub species and extensive cover of herbaceous species, namely *Carex* spp. and *Eriophorum* spp. Higher shrub cover results in important wildlife habitat opportunities, and also increases the depth and duration of snow cover relative to lowland areas (Liston et al. 2002). With the exception of dry, wind-blown crests, the ability of upland ecosystems to retain deeper snow cover for a longer duration provides meltwater later in to the growing season. This extended meltwater production may beneficially affect downslope communities that are dependent on continuous water flows, and by providing nutrients (Liston et al. 2002; Callaghan et al. 2004). Increased snow cover also increases winter soil temperature, improving soil biochemical cycling and Nitrogen uptake during snowmelt (Callaghan et al. 2004; Bilbrough et al. 2000). The timing of snowmelt, combined with air temperature, is also known to affect carbon cycling (Groendahl, Friborg, and Soegaard 2007).

Upland ecosystems, particularly dry rocky crests, provide a multitude of early season wildlife habitat values (further described in Section 4.3.4). These areas have low snow cover due to wind exposure and albedo, providing wildlife such as muskox and caribou opportunities to forage on important lichen communities (Joly, Jandt and Klein 2009).

Terrestrial ecosystems in the Project LSA also provide numerous habitat functions. In particular, dry crests of bedrock outcrops and eskers provide important habitat for much of the region’s ungulate species (Rescan 2011). These areas are wind swept during the winter resulting in limited snow cover and easy access to lichens and other browse. During the spring, as lowland areas are still frozen and snow covered, ridges melt early and expose important food, such as the previous years’ overwintered berries. They also serve as movement corridors for many species as the ground remains relatively solid year round relative to lowlands that are largely wet and dominated by tussocks, making travel more difficult. Eskers in particular are valuable denning sites for grizzly bears, wolves, foxes, and wolverines. Eskers often have deeper active layers and deeper mineral soils that provide good digging substrate. Other upland ecosystems provide a wide variety of food and shelter opportunities.

3.5.2 Wetland Functions

This section provides a brief overview of the overall function of the wetland ecosystems in the Project LSA.

3.5.2.1 Wetland Ecosystem Functions

Wetland function is defined as a process or series of processes that occur within a wetland (United States Geological Survey Water 1997). Wetlands perform a wide variety of functions due to their physical, chemical, and biological attributes. Wetland function is separated into four primary categories: hydrological, biochemical, ecological, and habitat (Environment Canada 2003). Wetland ecosystems comprise 58 % of the LSA and 32% of the RSA.

3.5.2.2 Hydrological Functions

The hydrological function of a wetland is defined as the wetland's ability to regulate water contributions to and from surface and groundwater reserves. Hydrological function in Arctic wetlands depends greatly on spring snowmelt and the summer thaw period (NSF-ARCSS 2000; Woe and Thomas 1993). The freezing and thawing of frozen soil dictates the presence or absence of wetlands and drives the timing of plant growth, as well as evaporation, infiltration, and runoff (NSF-ARCSS 2000). Most wetland runoff occurs during snowmelt in the spring and may cease entirely in late summer, even if wetland soils remain near saturation (Roulet and Woo 1986). As spring transitions to summer, peat thaws and is able to retain more water, limiting the discharge of wetland drainages (Ryden 1977). Changes in wetland hydrology due to warming temperatures also have implications for biochemical functions.

3.5.2.3 Biochemical Functions

Biochemical function is defined as the wetland's influence on the quality of surface water and groundwater. This function is particularly difficult to quantify given the number of specific interactions within and between the different soil, water, and vegetation systems in a wetland.

The pH and conductivity of wetlands were measured to aid in wetland classification (MacKenzie and Moran 2004) and provide baseline data on these aspects of biochemical function. The status of peat decomposition and permafrost depth were assessed in order to characterize rate of decomposition within the wetland (an important consideration for carbon dynamics).

An important function of high latitude wetland ecosystems is their role in the carbon cycle. This role has recently received more attention from the scientific community due to the potential release of large amounts of methane (CH_4) and smaller amounts of carbon dioxide (CO_2) from Arctic wetlands in response to warming temperatures (Bubier et al 1995; Juutinen et al 2010).

The functional and structural responses of carbon storage by wetland ecosystems at high latitudes have important implications for the amount and rate of CO_2 accumulation in the atmosphere (Smith and Shugart 1993; McGuire and Hobbie 1997). Globally, while high latitude wetlands cover only 4 to 5% of the terrestrial surface, they may contain up to 450 Gt C[1]. This is approximately 20% of the carbon in the terrestrial biosphere (Gorham 1991, Maltby and Immirzi 1993), and 40% of the world's soil carbon inventory (McGuire and Hobbie 1997).

Under current conditions, high latitude wetlands are a small, persistent sink for CO_2 (Gorham 1995) and a large source of CH_4 (Fung et al 1991). Functional and structural changes, caused by Arctic temperature increases, have the potential to influence the current balance between terrestrial and atmospheric carbon (Smith and Shugart, 1993; McGuire and Hobbie 1997). In many areas of the Arctic, peat accumulation has been extensive due to production exceeding decomposition. As warming occurs, however, it is predicted that large reservoirs of soil carbon may become available for decomposition.

[1] 1Gt C is a gigatonne of carbon or one petagram, Pg, or 1015 g C

This is particularly the case with frozen peat, as decomposition occurs rapidly once the thaw cycle has been initiated (Bubier et al 1995).

The methane storage function of Arctic wetlands is of particular importance because methane is a potent greenhouse gas (Christensen et al 2004). Permafrost has stored methane since the end of the last ice age. During the last glacial advance, organic and mineral Arctic soils became saturated and frozen. Under these conditions, decomposition of organic compounds occurs anaerobically, resulting in a build-up and storage of CH_4.

There is mounting evidence from a variety of sources that permafrost is degrading (Adams et al 2001; Burn 1992; Camill and Clark 2000; French and Egorov 1998; Halsey et al 1995; Kershaw 2003; Osterkamp 2003; Vitt et al 1994). As permafrost melts, the release of CH_4 is accelerated due to the release of stored methane as well as increased anaerobic respiration via methanogenesis (Christensen et al 2004). The rate of release is related to the type of vegetation cover. Christensen et al (2004) reported that the release of CH_4 in discontinuous environments was positively correlated with sedge meadows and treed areas in the northern boreal forest. Vegetation communities dominated by shrubs were found to release methane at much lower rates.

3.5.2.4 Habitat Functions

Wetlands provide key habitats for both terrestrial and avian wildlife (Environment Canada 2003; UNESCO 2009). In Arctic environments, wetlands have been identified as one of the top rated habitats for all mammalian and avian valued ecosystem components (Rescan 2007). Functional wetland habitats host a high diversity of avian and small mammal species, which in turn provide prey for raptors, wolves, foxes, and other predators. In addition, wetlands provide forage habitat for caribou, muskox (Thorpe et al. 2001), and waterfowl, which are important game species for Inuit in the Project area. Many wildlife species that require wetlands for foraging and/or nesting habitat are afforded special protection through the Migratory Bird Convention Act, the Wildlife Act, and the Species at Risk Act. Two species assessed by COSEWIC, the peregrine falcon (*Falco perigrinus tundrius*) and short-eared owl (*Asio flammeus*), choose nest sites adjacent to or in close proximity to wetlands and riparian areas where a reliable source of prey can be found (Sinclair et al. 2003; COSEWIC 2007, 2008). Various other species nesting in wetland habitats have been ranked as sensitive by NWT ranking categories, including American golden plover (*Pluvialis dominica*), red-necked phalarope (*Phalaropus lobatus*), northern pintail (*Anas acuta*), and long-tailed jaeger (*Stercorarius longicaudus*) (DOENR 2010). The presence of waterfowl and shorebirds is used as an indicator of the availability of functional wetland habitat in an area.

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Appendix 1

Preliminary Local Ecosystem Classification System for the Project Area (Rescan 1997)

Rescan™
Engineers and Scientists

EXECUTIVE SUMMARY

Mapping of bioterrain and terrestrial ecosystem units within the Hope Bay Belt study area (N.W.T., Canada) was completed in accordance with protocol developed in British Columbia. Thirteen typic ecosystem units were identified through analysis of vegetation and environmental data collected at 412 sampling sites. Three broad ecosystem-bioterrain associations occur within the study area. The moist-to-wet ‘Lacustrine, Fluvial and Fine Marine Substrates Association’ comprises approximately 65% of the terrestrial landbase and supports the most prevalent ecosystem unit, Eriophorum Tussock Meadow, on fine marine deposits. On drier upland sites, the ‘Rock-Outcrop and Coarse, Dry Substrates Association’ supports the common Dryas Herb Mat ecosystem unit; however, wide and gradual slopes extending into the wetter lowlands commonly support transitional occurrences of this ecosystem unit as well. The ‘Ocean Shoreline Association comprises a very small portion of the study area and is located only along the coastal margin in Roberts Bay. Here the Marine Intertidal and Backshore ecosystem units occur in linear arrangement in close association with unvegetated beach sands.

This report is accompanied by four map sets (1:20,000 scale) which identify, by way of detailed labels and generalized colour theming, the surficial materials and ecosystem units in the Hope Bay Belt study area.

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1.0 OBJECTIVES

Terrestrial Ecosystem Mapping (TEM) is a protocol for stratifying the landscape into polygons that delineate ecosystem units. Within the context of the multi-disciplinary study of the Hope Bay Belt, the overall objective of employing TEM is to provide baseline maps and a database of ecosystem and terrain data for use in:

- guiding resource management decisions,
- monitoring changes to ecosystems over time,
- interpreting wildlife values at landscape and site-specific levels,
- developing mitigation or compensation strategies for proposed developments, and
- aiding in the identification of sensitive and/or rare ecosystems.

Specific objectives of this TEM project are:

- to identify and describe terrain types and ecosystem units,
- to identify any broad vegetation and terrain differences within the study area,
- to produce maps and supporting databases for terrain and ecosystem units, and
- to produce an accompanying report to the maps and databases

2.0 STUDY AREA

2.1 Location

The Hope Bay Volcanic Belt (the Belt) is situated approximately 65-km to the east of Bathurst Inlet on the northern mainland coast of the Northwest Territories, Canada (Figure 1). It measures 90-km in length and approximately 15 to 20 km in width. The study area, which lies entirely within the Belt at its north end, is 17,624 ha and stretches south from Roberts Bay to Spyder Lake, a distance of 65.2-km. The boundaries of the study area were delineated to produce a 2-km wide corridor centered on the proposed winter road alignment, and to connect three principle sites of interest - a) the proposed barge landing facility in Roberts Bay (550 ha), b) the Doris Lake Property at the north tip of Doris Lake (1,650 ha), and c) the Boston Property on Spyder Lake (1,970 ha). As changes to the proposed road alignment were made during the course of the study, the mapped width of the road corridor exceeds 2-km in some areas.

2.2 Ecological Land Classification

The Northwest Territories (N.W.T.) have been classified within a national classification system that provides a framework for describing ecological patterns across the country. At its broadest level, this hierarchical system recognizes fifteen terrestrial Ecozones, nine of which occur in the Northwest Territories (Ecological Stratification Working Group 1996). The Belt is situated within the Southern Arctic Ecozone (SAE), a broad zone characterized by a vegetative transition from southern taiga forest to northern treeless arctic tundra (Ecological

Stratification Working Group, 1996). Being situated along the northern boundary of the SAE, the Belt supports vegetation more characteristic of treeless arctic tundra.

Ecozones are divided into Ecoregions, which represent characteristic landforms, climates, vegetation, soils, water and human activity. Seventeen ecoregions comprise the SAE; the study area straddles two of these - Queen Maud Gulf Lowlands (QMGL) and Bathurst Hills (BH). The following excerpt describing vegetation characteristics for the QMGL Ecoregion is taken from a report of the National Land Use Information Series (Wiken *et al.*, 1987):

> Species diversity and biomass production and accumulation are due to the cold climate, short growing season, edaphic conditions and consequent low soil temperatures. Soil conditions are generally sufficient to support continuous (>60%) cover of sedge tussocks along with herbs, mosses, and trailing shrubs. Typical lowland flats and concavities are characterized by poorly drained peaty soil materials containing medium to high ice content and permafrost.
>
> The dominant sedge is *Carex aquatilis* and occasionally (*C. rupestris, C. nardina, C. misandra*, *C. scirpoidea*, *C. chordorrhiza and C. membranacea*). Dominant graminoids include cotton grass (*Eriophorum angustifolium* spp. *triste*, *E. vaginatum* spp. *spissum*) and grasses (*Poa arctica*, *P. alpigena*, *Arctagrostis latifolia*). [Cotton grasses (*Eriophorum* spp.) actually belong to the sedge (Cyperacaea) family not the graminoid family.] Among the forbs and herbs *Saxifraga* spp. (saxifrage varieties), *Pedicularis* spp. (lousewort varieties) and *Dryas* spp. (aven varieties) are common. Mosses cover up to 50% of the surface. In the shallow pools of low-center polygons (a common feature in poorly drained lowlands) *Drepanocladus* spp., *Scorpidium* spp. and *Aulacomnium* spp. mosses are common among the sedges. *Salix arctica* and *S. glauca* are usually present on better drained polygon shoulders or small mounds and occasionally *S. alaxensis* and *S. alba* (forms of arctic willow). Other shrubs may include *Vaccinium Vitis-idaea* var. *minus*, *Ledum decumbens*, *Arctostaphylos rubra*, and herb *Dryas integrifolia*. *Sphagnum* spp. moss may occur on some polygon shoulders and lichens are generally absent.

Ecoregions are further subdivided into ecodistricts representing areas of "distinctive assemblages of landform, relief, surficial geological material, soil, water bodies, vegetation and land uses" (Ecological Stratification Working Group 1996). The study area straddles two ecodistricts – '157' within the BH Ecoregion and '159' within the QMGL Ecoregion. Most of the Belt lies within Ecodistrict 159; only the most northern portion of the area, the coastal margin, lies within Ecodistrict 157 (see accompanying map set). Due to the small scale (1:2,000,000) at which this boundary has been mapped by the federal government, its actual position on the accompanying map set (1:20,000) is somewhat arbitrary. Its position was based on topographical features which serve to separate contiguous coastal lands from those protected and partially isolated by rock outcrops. Descriptions of Ecodistricts are stored in a federal database currently being developed for general release (Marshall, pers. comm.). Differences in vegetation and soils, at least within the study area boundaries, relate to the saltwater influence on plant communities, active marine washing of soils, and possibly the influence of a maritime climate regime. Attributes that serve to distinguish the two ecodistricts, as identified within the federal database, may or may not be apparent from the results of this study due to the minimal size of the Belt relative to the total areas of the two ecodistricts.

The national classification system provides for three more levels of classification (ecosection, ecosite and ecoelement), however public mapping at these successively finer scales has not been conducted.

2.3 General Landscape Features

Over the past 10,000 years, three large-scale geological processes have shaped the Belt's landscape to its modern condition - glaciation, marine transgression (invasion of the land by the sea), and marine washing of surface deposits. Combined, they have created a relatively subdued landscape. Recent deposits and periglacial processes continue to modify the landscape on a smaller scale. All are discussed in section 4.0.

The topography of the Belt is best described as gently rolling valleys with a roughly parallel drainage pattern resulting from parallel rock outcroppings and valleys. The Koignuk River is the major watercourse in the region; it flows into the study area from the south where it feeds Spyder Lake. North of the lake, the Koignuk River flows north-by-northwest and empties into Hope Bay. It has downcut sharply through partially consolidated marine and till deposits and is characterized in many places by relatively steep cutbanks. Three sets of falls and rapids within the study area occur in association with constrictions at rock outcroppings. As well as the Koignuk River, there are numerous unnamed streams that flow through the study area. Thaw lakes are numerous.

Generally, the Belt is characterized by gentle, north-by-northwest tending valleys filled with silty-clay marine deposits. The valleys are typically separated by discontinuous, gently sloping, oblong or linear rock outcrops, predominantly of Archean-aged mafic volcanic and intrusive origin. Occasionally, particularly in the north, younger Franklin diabase sills and Mackenzie diabase dykes rise sharply and steeply. Over most of the landscape the mafic outcrops which are most easily weathered rise to elevations of no more than 50-m while the more resistant sills and dykes protrude as high as 160-m. The Belt is bordered by the regionally dominant felsic rocks (predominantly granodiorites, granites and gneisses) that form the Canadian Shield (Gebert, 1995).

At the extreme southern end of the study area, the landscape is a gently rolling plain overlain by complexes of washed till and fine marine deposits. North of Doris Lake to the coast, bedrock outcrops are characterized by marine and till mantles of variable thickness. High boulder exposure and coarse sandy textures characterize portions of rock outcrops that have undergone energetic washing. The differences in topography and surficial materials between the north and south portions of the study area appear to correspond closely with differences described by Bird (1961) between the two local physiographic regions - 'Buchan Upland' and the 'Elu Rock Plain'. The 'Buchan Upland' in the south is described as consisting of convex-sided rock-knob hills, which are generally drift-free, and valleys filled with washed glacial till. In contrast, the 'Elu Rock Plain' region is described as a region dominated by silt plains of marine origin interrupted by a high proportion of rock ridges.

3.0 METHODOLOGY

For the purposes of this study, the term "ecosystem" is defined as "a segment of land relatively uniform in its biotic and abiotic components, structure, and function" (Sukachev and Dylis 1964) - a restrictive but practical definition suited to management-oriented land classification.

Abiotic and biotic components of ecosystems are numerous and variable, making data collection a potentially complicated and exhaustive process. Ecosystem classification therefore generally concentrates on identifying and characterizing those components which integrate other components, reflect ecosystem function best, and which are most conveniently studied (Meidinger and Pojar 1991) - components such as plant species, soils and terrain conditions on which the plants persist.

Ecosystems of the N.W.T. have only been described over limited areas and usually in association with specific development projects (for example Oikos Ecological Services Ltd., 1995) or for academic research (for example Bliss, 1977). Sub-regional descriptions have not been attempted, nor has a protocol for mapping them been developed. Consequently, we developed sampling and analysis strategies based on a protocol developed and widely used in British Columbia (Resources Inventory Committee, 1995, 1996a). This protocol allowed us to formally describe the ecosystems of the Belt and produce ecosystem and terrain maps.

3.1 Modifications to Standard TEM Methodology

3.1.1 Ecosystem Description

Lands of the Northwest Territories have only been classified to a broad ecological level called the Ecodistrict using a national system of classification (Ecological Stratification Working Group 1996). In contrast, much of B.C. has been classified to the ecosystem unit level (termed site series and site series modifiers) using two provincial systems – the Ecoregional Classification System (Demarchi 1988 and Demarchi *et al.* 1990) and the Biogeoclimatic Ecosystem Classification (BEC) system (Meidinger and Pojar, 1991).

The broadest level of classification utilized in B.C.'s terrestrial ecosystem mapping is the Ecosection, which represents areas of minor physiographic and macroclimatic variations (Demarchi 1988 and Demarchi *et al.* 1990) and is roughly equivalent to the national Ecodistrict level (Ecological Stratification Working Group 1996). The BEC site series units are appropriate to develop site-specific prescriptions and are roughly equivalent to the ecosystem unit used in this study.

Table 1 compares ecological land classification hierarchies associated with each major classification system described here Mapping the study area incorporates two-levels of classification hierarchy, the *Ecoregion Units* and *Ecosystem Units*. The national classification system provides the broad level classification in *Ecoregion Units* (Ecozone, Ecoregions and Ecodistricts – see table below), while the present study, through sampling, analysis and description, provides the detailed classification in *Ecosystem Units* (Ecosystem Units and Ecosystem Modifiers). Modifiers are attached to ecosystems to account for variation in the proportions of plant species associated with variation in edaphic and terrain characteristics between sites. The modifiers used have been largely developed from those used in B.C (Resources Inventory Committee 1996a).

TABLE 1: COMPARISON OF ECOLOGICAL LAND CLASSIFICATION HIERARCHIES BY JURISDICTION/AREA

BRITISH COLUMBIA	CANADA AND N.W.T.	HOPE BAY AREA
ECOREGION UNIT ECOREGION--------------- ECOSECTION-------------	*ECOREGION UNIT* ---ECOREGION------------------ ---ECODISTRICT---------------- ECOSECTION ECOSITE	*ECOREGION UNIT* ----ECOREGION ----ECODISTRICT
BIOGEOCLIMATIC UNIT SUBZONE	*-no equivalent*	*-no equivalent*
ECOSYSTEM UNIT SITE SERIES----------- SITE MODIFIER-------	*ECOSYSTEM UNIT* ----ECOELEMENT------------ ------------------------------------	*ECOSYSTEM UNIT* ----ECOSYSTEM UNIT ----ECOSYSTEM MODIFIER

3.1.2 Aerial Photography

Large-scale aerial photos were not available until after the 1996 field season. Small-scale (1:60,000) photos do not provide adequate resolution of terrain and vegetation necessary for mapping ecosystems but were used during the first field season for navigation, to identify gross terrain features, and to permanently record sample plot locations.

3.2 Phototyping

Ecosystem mapping normally begins with the delineation of terrain map units (or polygons) on large-scale aerial photos, a process known as phototyping. Terrain polygons represent areas that are relatively uniform in landform and surficial materials. TEM takes a bioterrain approach to phototyping in that terrain polygons are further subdivided according to biologically significant attributes that control the expression of distinct ecosystems. In this way, a terrain unit of bedrock uniformly overlain by a veneer of glacial till may be subdivided to reflect that the crest is drier than the side slopes. Similarly, if slopes are significant enough, opposite aspects of the unit may be separated to reflect that different ecosystems will be found on opposing aspects due to differences in insolation and/or duration and depth of snow cover.

Bioterrain polygons were delineated on 1:15,000 aerial photos following the first field season when the photos became available. Sample data already collected was used to strengthen initial phototyping while data from the second season served to confirm and/or refine designations.

Apart from the necessary departures from standard methodology (as discussed in Sections 3.1.1 and 3.1.2) phototyping closely followed the protocol outlined by the Resources Inventory Committee (1995, 1996a). According to this protocol, polygons may contain up to three bioterrain and ecosystem unit components, which are identified in polygon labels along with their proportional decile occurrences. Terrain phototyping adopted the symbology of Howes and Kenk (1988, 1997) except for minor differences, including the substitution of ‘T’ for ‘M’ to represent glacial till, and ‘M’ for ‘W’ to represent marine deposits. This was done so symbols correspond more closely with those used by federal (Geological Survey of Canada) and territorial agencies.

3.3 Field Sampling

At regional levels, climate determines the general type of vegetation in an area (i.e. tundra vs. forest). Distinct plant species assemblages however, are determined by factors such as topography, surficial geology, and soil properties through their influence on soil moisture and nutrients. These factors together with the plant community are used to describe ecosystem units. Sample plots were located systematically across the study area, on all terrain types and at different slope positions, according to an initial plan refined following reconnaissance of the study area.

Sample plots (10-m x 10-m) were established in areas uniform in vegetation, terrain and soils. Transitional areas were sampled in the second field season in order to improve the accuracy of phototyping and refine community descriptions. Plot locations were permanently recorded onto 1:60,000 photos and subsequently transferred to large-scale photos once they came available.

TEM recognizes two types of sampling plots: detailed and visual plots. Detailed plots are the most comprehensive and are the type required for statistical analysis to identify and describe ecosystems units. Visual plots are less detailed and are used to confirm terrain phototyping and ecosystem assignment. Sampling in 1996 concentrated on the establishment of detailed plots. Six or more plots per ecosystem unit are preferred in order to strengthen the reliability of ecosystem descriptions; however, uncommon units may be described using fewer plots. Field crews attempted to obtain at least six samples for each ecosystem unit encountered. Visual plots established in 1997 included the collection of complete plant lists so that a greater number of plots could be used in the analysis.

Sampling was consistent with the methods of Luttmerding *et al.* (1990), the Resources Inventory Committee (1995, 1996a) and Mitchell *et al.* (1989). Standard ecosystem field forms were filled out at each sampling location. Site-specific information recorded onto field cards included slope, aspect, mesoslope position, surface shape, moisture and nutrient regimes, terrain type and surface substrate composition. Soils were classified according to the Canadian system of soil classification (Agriculture Canada Expert Committee on Soil Survey 1987). Soils data included soil profile descriptions, numerous genetic horizon characteristics, drainage class, rooting depth, presence or absence of seepage water, depth to (and type of) root restricting layer, and humus form type.

Plant species were identified and given a unique seven-letter code. Percent cover and physiognomic form (herb, shrub, moss or lichen) were also recorded. Voucher specimens of all plant species were collected. Species that could not be positively identified on site were identified later with the aid of taxonomic keys (Hulten 1968, Porsild and Cody 1980, Vitt *et al.* 1988). A collection of mosses encountered was sent to a specialist for identification (LaFarge-England 1996). Representative photographs of the soil pit and vegetation community were taken at each sampling location. Common plant names, if available, were taken from Hulten (1969), Porsild and Cody (1981), Trelawny (1988), Vitt *et al.* (1988), Schofield (1992).

3.4 Analysis

3.4.1 Overview

The objective of ecosystem analysis is to reveal the relationship of sample plots by grouping them into ecosystem units on the basis of their floristic composition and environmental attributes (i.e. soils, terrain, soils moisture and nutrients). When the effective range of environmental attributes is initially uncertain, a common approach to classifying ecosystems is to analyze vegetation data independently of environmental data (Kent and Coker 1996); this is known as indirect analysis.

SYN-TAX 5.0 (Podani 1994) is a package of multivariate statistical procedures chosen for its powerful analysis capabilities and its flexibility in meeting specific study requirements. This flexibility is reflected in its capacity to perform numerous indirect classification procedures useful in mathematically and graphically demonstrating the relationships between sample plots. Four indirect procedures were used to group plots into tentative ecosystem units based on the vegetation data. The four procedures used were; hierarchical classification, non-hierarchical classification, fuzzy clustering, and ordination; they are outlined below. Once this was done, the relationship between environmental variables and vegetation was examined.

3.4.2 Analytical Procedures

The grouping or separation of plots is based on mathematical distances between them as represented by statistically determined similarity or dissimilarity coefficients. All analysis is based on the calculation of these distances, which are commonly referred to as distance scores (Podani 1994). Syntax 5.0 provides no less than fourteen distance score coefficients, however Kent and Coker (1996) indicate that the **Euclidean distance coefficient** is commonly and reliably used in analyzing quantitative vegetation data. This coefficient was used in all procedures.

<u>Hierarchical Classification</u>

Hierarchical classification is probably the most widely used procedure for showing similarities (or dissimilarities) among plots at successive levels of grouping. Hierarchical classification begins by segregating one large group containing all plots into successively smaller groups at successive levels of analysis. This continues until all plots are shown as separate groups. It is up to the discretion of the analyst to determine the most practical level at which groupings should be halted. Two methods of hierarchical clustering were explored: minimization of sums of squares in new clusters and global optimization. In the first approach, successive segregations occur if the sum of squares of distance scores of the newly obtained groups is the minimum for a given level in the hierarchy. In the second approach, segregations are made if the ratio of distance scores within clusters and between clusters is minimized for a given hierarchy.

Non-Hierarchical Classification

The second procedure, non-hierarchical clustering (by global optimization), requires that the user specify the number of groups in advance. Plots are then assigned to groups based on an optimal solution which minimizes the ratio of average within cluster distances and the average between-cluster distances (the G-Ratio). Several trials are run, each time specifying a different number of groups.

Fuzzy Clustering

A third procedure, known as fuzzy clustering, calculates the affinity of each plot to one of the prespecified number of clusters (groups). The optimal solution is obtained through the minimization of the so called fuzzy sum of squares of clusters calculation.

Ordination

The fourth procedure, ordination, is a graphical technique that depicts the relationships of plots to each other in a two or three-dimensional space as a scattergram. Non-metric multidimensional scaling ordination arranges the plots along two or three axes using distance scores converted to rank order. This reduces clumping of plots and helps remove distortion when distance scores are far apart. The rank distances between any two plots or groups of plots reflects their degree of similarity in floristic composition - the further apart they are the more dissimilar they are. This procedure, as well as fuzzy clustering helped assign specific plots to the most appropriate units where hierarchical and non-hierarchical procedures were unable to do so definitively.

SYNTAX 5.0 is limited in the size of the dataset that certain procedures can handle. Hierarchical and non-hierarchical procedures were able to analyze our full dataset and provided an unbiased and appropriate guide for separating the plots into two or three subgroups which then became the input datasets for size restricted procedures (fuzzy clustering and ordination). Reference to these subgroups [A, (A1, A2) and B] is made in Section 4.3.

An initial analysis was conducted after the first field season prior to final identification of all species, namely bryophyte and willow (*Salix)* spp. The ecosystem units developed from that analysis were used as a guide during the 1997 sampling season to collect visual plot data having full species lists and with the intention of reanalyzing the data. The final analysis was conducted late 1997.

3.5 Digital Mapping and Database

Maps-3D Digital Mapping Solutions™[1] is a suite of software tools used to digitally capture data for further use by a GIS software package. The software utilizes Microstation PC ®[2] as the graphics engine to achieve the data capture. Raw linework (polygon lines delineating ecosystem units) was digitized directly from large-scale aerial photos using the Mono Restitution module (MONO-3D) within the Maps-3D package. This module utilizes ground control points, a Triangulated Irregular Network (TIN) surface and a mathematical model

[1] Maps-3D Digital Mapping Solutions™ is a suite of software tools produced by Pacific International Mapping Corp. (Victoria B.C., Canada.)

[2] Microstation PC is a product of Bentley Systems Inc. (Exton Pennsylvania, U.S.A)

that allows the user to transfer photo coordinates into X, Y and Z ground coordinates. Ground control points within the study area were provided by Land Data Technologies Inc. (Edmonton Alberta, Canada). The TIN surface was created from a Digital Elevation Model (DEM) of the study area, also provided by Land Data Technologies. Once captured, the digitized linework was vector cleaned using various modules within the Maps-3D software. This resulted in a topologically correct digital model of the ecosystem polygons within the study area.

Data entry as well as format and content validation programs were designed to transcribe ecosystem and bioterrain labels into a Microsoft Access Database. Standards for data entry as established by the Resources Inventory Committee (1996b,c) were followed. Map labels for each polygon were created using an in-house label generator. These labels were then imported into the Geographics database and annotated to the maps using Microstation Geographics ® [3]

It should be noted that a small section (480 ha) of the study area to the southeast of Spyder Lake was not digitized because aerial photo coverage and a digital elevation model were lacking. This is the reason for a number of sampling plots being located outside the mapped area.

4.0 RESULTS AND DISCUSSION:

4.1 Surficial Geology and Major Landforms

The late Wisconsinan Glaciation was responsible for the transportation and deposition of till into the area. This till chiefly comprises a sandy matrix with a low coarse fragment content (0-25%). During the period of glacier recession (approximately 8800 to 3500 ± 1000 years ago - see Ryder and Associates, 1992) the region became entirely submerged (marine transgression) and marine sediments were deposited over most, if not all, of the landscape (Bird and Bird, 1961). The marine sediments within the study area are predominantly composed of silts and clays and form the dominant surficial deposit.

Since the end of the Wisconsinan Glaciation the land formerly inundated has emerged from the sea through isostatic rebound. As it emerges, surface sediments are exposed to washing regimes that vary as a consequence of local differences in topography, exposure and nearshore currents.

Erratic boulders found scattered across the landscape identify where finer fractions of till and glaciofluvial materials have mostly been washed away or moved downslope by solifluction[4]. Although washed till occurs throughout the study area, it is most prevalent in the south, at times complexed with marine sediments. Near Spyder Lake, washed till predominantly occurs as wide, gently undulating plains, as typified by three drumlinoids located just south of Boston Camp. North of Spyder Lake, along the Koignuk River corridor, till overlies bedrock and forms smaller and discrete complexes of till, rock and marine sediments.

[3] Microstation Geographics ® CAD software is a product of Bentley Systems Inc. (Exton Pennsylvania, U.S.A)

[4] Solifluction is the *slow* gravitational downslope movement of saturated soils overlying permafrost.

The distribution of surficial sediments resulting from glacial and marine processes is characterized by relatively thick marine deposits in valleys, and thinner marine, till, and glaciofluvial deposits at higher elevations. Areas exposed to high energy washing have either had the fine marine sediments washed away completely exposing the underlying till and/or bedrock, or have had larger, coarse marine sediments (predominantly sands and gravels) deposited and preserved as strandlines (isolated beaches), predominantly in the northern portion of the study area.

4.2 Recent Deposits and Periglacial Processes

Numerous erosional, depositional, and periglacial[5] processes have been modifying the Hope Bay landscape since its emergence from the ocean. Photo-typing and soils data collected during the study were used to identify and characterize the landforms and surficial deposits resulting from these processes.

4.2.1 Erosional and Depositional Processes

Fluvial deposits result from suspended sediments settling out of flowing water. Within the study area they are relatively common but limited in area. Along rivers and streams they occur as level or slightly sloped terraces, benches or plains overlying marine and till deposits. In landscape positions remote from present watercourses, their association with lacustrine deposits suggests they have been deposited during rapid drainage stages of thaw lakes (see Section 4.2.2).

Solifluction is prevalent in the study area on all sloped terrain. It occurs in any saturated soil types but is most common in fine-textured soils. On shallow slopes (3-5%) evidence of solifluction is difficult to detect because slope materials move very slowly and in a sheet-like manner, leaving little surface disturbance. On steeper slopes it occurs more quickly, often creating surface deformities in the shape of lobes. Such lobes were observed in a few instances while phototyping and field sampling.

Saturated soils can also undergo *rapid* downslope movement where slopes and high moisture content combine to weaken soil structure. Upon thawing, the slope fails and the eroded sediments are deposited downslope as colluvium. Within the study area, these thaw flow slides (also known as earth- or mudflows) are most common in marine sediments along the steep banks of the Koignuk River (Figure 2). They also occur on the steep banks of smaller streams and within shallower seepage tracks. The trigger for slope failure in seepage tracks is high soil moisture, which weakens soil strength. Adjacent to rivers, the trigger is fluvial erosion of the lower bank. When an initial failure takes place, ice-rich, subsurface soils are exposed. These subsequently thaw and become susceptible to failure. An initial failure typically begins a cycle of successive slope failures producing a semicircular backwall that continues eroding further back into the slope until the gradient is decreased by collapsing sidewalls. The deposition of collapsed materials buries underlying substrates and thawing ceases.

Colluvial deposits also originate in non-saturated coarse-textured materials (where slopes are steep enough) as well as in rock that fractures when interstitial water freezes - a process

[5] The term 'periglacial processes' refers to those processes that occur in association with permafrost and freeze-thaw cycles in cold climates (Howes and Kenk 1997).

known as frost-wedging (Washburn, 1980). Aprons of rubble (large angular rock fragments) are found throughout the study area at the base of rock outcrops, particularly diabase outcrops (PLATE 6)

Figure not Available

FIGURE 2: Thaw flow slides along the cutbanks of the Koignuk River

4.2.2 Periglacial Processes

Periglacial processes produce several recognizable features across the landscape including thaw lakes, patterned ground (ice-wedge polygons), beaded streams, and frost mounds.

Thaw lake cycles are variable and depend highly on local terrain features and soil texture. They are most common in fine-textured substrates. When the active layer[6] and near-surface permafrost thaw at the lake margins, shorelines erode, and sediments are sorted and transported within the water column. Over time, shorelines advance outward and adjacent lakes may coalesce. When outlet drainage channels develop, lake levels fall exposing lacustrine and fluvial sediments along valley-bottom positions (Bird, 1967; Britton, 1967).

Thaw lakes are numerous in the study area and are often associated with polygonal (or patterned) ground. Britton (1967) explains this association as a direct result of the thaw lake cycle. As a thaw lake enlarges, it melts ice-wedges and erodes patterns. Britton hypothesizes that after a lake drains and patterned ground begins to form again, it does so by differential thawing along existing pattern lines preserved beneath the lacustrine and fluvial deposits. Thaw lake margins lacking patterned ground may have deposits too thick to allow the expression of buried patterns. Surface soils in the drained basins are also generally composed of some organic materials. Productive wet meadows form a major component of the plant communities in these basins. The annual dieback of above-ground biomass tends to

[6] 'Active layer' refers to the upper portion of the soil column that undergoes seasonal freezing and thawing and which is underlain by permafrost. The depth of the active layer varies from year to year and is highly dependent on soil texture. It is deepest in well-drained coarse-textured soils and remains very shallow (0-40 cm) when the surface is blanketed by wet organic soils.

accumulate while the rate of accumulation and thickness of the resulting organic layers depend on factors such as degree of seasonal flushing and time since the thaw lake cycle was last completed

Within the study area, two types of patterned ground are recognized: high-centered polygons and low-centered polygons[7]. Low-centered polygons are dominated by flat, wet-to-moist basins, separated by raised, linear ice-wedges. Description of these formations as ‘polygons’ reflects the distinct angles at which the ice-wedges intersect. In contrast, high-centre polygons are dominated by palsas (mounds domed-up by a growing lens of ice). Each mound is typically encircled by wet meadow where runoff and seepage are concentrated. Patterned ground is found most commonly on level, poorly drained valley bottoms overlain by fine marine or sandy lacustrine and fluvial sediments. In such situations, patterned ground occurs in elongated low-lying areas between thaw-lakes. Patterned ground occasionally occurs in depressional areas along streams, rivers, and at upper elevations remote from any water bodies. In all situations however, the patterns occur on poorly drained, level to slightly sloped (approximately 0-1.5%) fine substrates.

Beaded streams are another permafrost-related phenomenon found within the study area. The beads (or pools) are believed to form in the stream channel at ice-wedge intersection points (Tedrow 1977). As stream-water flows over these wedges, they melt to depths greater than the channel bed and result in the formation of deep, round or oval pools. Beaded streams typically occur on gently sloped terrain overlain by fine marine deposits.

Frost mounds, also known as non-sorted circles (Washburn, 1973), earth hummocks (Tarnocai and Zoltai, 1978), mud circles (Bird, 1967) and frost boils occur throughout the arctic (Tedrow, 1977) and are common within the Hope Bay Belt area. According to the polygenetic classification scheme of Washburn (1970) frost mounds are one of many forms of patterned ground; however we restrict the usage of patterned ground to low-centre and high-centre polygons which are easily distinguishable on air photos. Consistent with Zoltai and Tarnocai (1974), the term “frost mound” is used here to describe features with the general shape of a low dome, or mound, where frost is the driving force behind its formation. In the Hope Bay Belt area, mounds most commonly form in fine-textured soils in gently sloped terrain, and infrequently on coarse-textured soils. Strong cryoturbation within frost mounds is evidenced by distinct organic intrusions, buried organic layers, and discontinuous soil horizons, which indicate that cryogenic (freeze-thaw) processes above the permafrost table are responsible for mound formation. The proportion of unvegetated mineral soils is often an indication of the degree of cryogenic activity within the mounds. In the study area, active mounds are typically 0.5 to 1.5 metres in diameter and 0.3 to 0.5 m in height. Vegetated inter-mound distances vary highly depending on the degree of activity. Active mounds are typically only partially vegetated, while inactive mounds are often completely vegetated and sustain shrubs.

The occurrence and distribution of major plant community types is strongly influenced by major landforms, surficial sediments and permafrost-related processes, which are featured in the description of ecosystem units throughout Section 4.4. Bioterrain theme maps have been developed to present, in a more generalized and visually effective manner, the detailed

[7] Usage of the word polygon in this context should not be confused with its usage as a mapping unit that delineates an area similar in ecosystems or bioterrain, as the case may be.

information contained in the bioterrain maps. Colour theming is based on the dominant surficial material with a map polygon. In this way, a polygon with a complex of surficial materials such as 70% glacial till and 30% marine sands is coloured as a glacial till polygon.

4.3 Analysis

A total of 412 sample plots were established over the course of two field seasons: 127 detailed plots and 49 visual plots in 1996 (July 28 - August 16) and 236 visual plots (with full vegetation species lists) in 1997 (July 5 - July 23). The locations of all plots are identified on the accompanying mapset. Ecosystem analysis was based on the data from 113 of the 127 detailed plots and 121 of the 236 visual plots established in 1997.

One hundred and seventy eight (178) plots were not included in the analysis for the following reasons:

- A preliminary analysis of all detailed plots established in 1996 determined that six plots were outliers and eight plots represented transitional situations. These fourteen plots were thus not included in the final analysis.
- The 49 visual plots established in 1996 incorporated only dominant vegetation species, terrain descriptions, and abbreviated soil descriptions. As such they were not intended for use in the analysis but rather as sources for confirming and refining terrain and ecosystem designations.
- Visual plots established in 1997 initially represented typic (unmodified) ecosystems (121 plots) and atypic (transitional and/or modified) ecosystems (115 plots). Only those representing typic units were intended for inclusion in the analysis.

The results of the analysis are presented in Appendices B-1 to B-8 and are summarized below.

4.3.1 Hierarchical Classification

Two dendrograms (Appendices B-1 and B-2) depict the results of hierarchical classification (by minimization of sums of squares in new clusters and by global optimization). Comparison of the figures shows that the two techniques produce similar results in that plots tend to be grouped into the same clusters. Notable differences do exist. The technique that produced results most similar to preliminary field groupings was global optimization. At this stage of analysis the number of distinct groups remained undefined.

4.3.2 Non-hierarchical Classification

Non-hierarchical classification by global optimization requires prior specification of the number of groupings to run the analyses. Several runs were processed with number of groups specified at 12, 13, 14, 15 and 16. The best results are defined by a combination of minimizing the global optimization ratio, or G-ratio, maximizing the frequency of a particular G-ratio, as well as subjectively assessing the appropriateness of plots in each group. The best results were obtained when fifteen groups were prespecified. The results are presented in Appendix B-3. Examination of the results showed that differences between G-ratios for each of the twenty runs is minimal. This means that placement of some plots into different groups produces minimal differences. This is why utilizing other techniques, such as fuzzy clustering and ordination, is important to strengthen groupings.

4.3.3 Fuzzy Clustering

The third technique, fuzzy clustering, is limited by the number of groups (maximum 10) that can be pre-specified. The sample plots were therefore separated into two subgroups based on the hierarchical classification already conducted. In this way it was assured that placement of plots into each subgroup did not bias or confound results. Fuzzy clustering results are presented in Appendices B-4 and B-5 for subgroups A and B respectively. The output of fuzzy clustering is a list of all plots and respective membership weights (or affinities) that each plot has for each of the pre-specified number of groups. Using an arbitrary value of 0.65 as a lower limit to define membership to one of the groups, those plots with no membership weights exceeding this limit (all plots in bold) were subjectively assigned to a group or treated as outliers.

4.3.4 Ordination

The fourth technique, non-metric multi-dimensional scaling ordination, required that the data be grouped into three subgroups (A1, A2, and B). The same criteria for grouping plots into subgroups were used as those employed for the purposes of fuzzy clustering. The results of the outputs are presented in Appendices B-6, B-7 and B-8.

4.3.5 Examination of Environmental Data

In the final stage of analysis, environmental (abiotic) variables were examined for each community developed through indirect analysis. The effect of this procedure was the definition of final ecosystem units that include the typical ranges of environmental variables as well as the typical plant species assemblages. Each ecosystem unit identified is described below in Section 4.4.

4.4 Ecosystem Unit Descriptions

In summary, the analysis produced the following notable results:

1. Thirteen unique terrestrial ecosystem units were identified within the Hope Bay Belt study area:

Dry Carex-Lichen (12)	*Riparian Willow (19)*
Dryas-Herb Mat (20)	*Wet Meadow (28)*
Betula-Ledum-Lichen (33)	*Emergent Marsh (1)*
Dwarf Shrub-Heath (19)	*Low Bench Floodplain (4)*
Betula-Moss (15)	*Marine Intertidal (4)*
Eriophorum Tussock Meadow (68)	*Marine Backshore (4)*
Dry Willow (7)	

Note: Numbers in brackets indicate the number of sample plots established in each ecosystem unit identified as typic prior to analysis

2. Each of these units is defined by a distinct (typic) plant species assemblage and a finite range of environmental conditions (edaphic, topographic and terrain). Often, transitional communities occur where site conditions are intermediate between those which define

typic ecosystem units. In such cases, plant species assemblages exhibit characteristics of two or more of these units. Where site conditions change gradually along shallow slopes, transitional communities can be extensive.

3. Where typic plant species assemblages occur but individual species proportions and site conditions vary from those defining the typic unit, modifiers (topographic and edaphic) are applied to account for the variation (i.e. x – drier, m – mounded, s – steeper). Several recurrent modified ecosystem units were found to occur, the most prevalent are identified and described in further sections. The analysis identified two specific modified types that were initially identified in the field as distinct groups (potential ecosystem units). As discussed below in Sections 4.4.1 and 4.4.2, they are the nutrient-poor Tussock Meadow type (TMp) and the bouldery Betula Ledum type (BLb):

4. The Eriophorum Tussock Meadow (TM) ecosystem unit is the most widespread and dominant unit within the study area. Although three types of TM communities were initially identified in the field, the analysis distinguished only one typic community (TM and one modified unit (TMp, as mentioned above).

5. Although two wet meadow plant assemblages are represented in the field data, one dominated by water sedge (*Carex aquatilis* var. *stans*) and the other by tall cotton-grass (*Eriophorum angustifolium*), the environmental conditions are not reliably distinct between the two. As both communities are largely ecological equivalents and are not reliably distinguishable by phototyping, they collectively represent the Wet Meadow ecosystem unit.

6. The preliminary segregation of willow-dominated riparian communities into lake-margins, seepage zones, and medium and high bench floodplains was not supported by the field data, largely due to significant overlap in floristic composition. Consequently they were grouped to form one ecosystem unit called Riparian Willow.

7. Three broad Ecosystem-Bioterrain associations occur within the study area (Figure 3):

    i. The ‘Rock Outcrop and Coarse, Dry Substrates Association’ includes four ecosystem units, which occur under the dry to mesic conditions of coarse glacial till overlying bedrock, or well-drained coarse glaciofluvial and marine deposits.

    ii. The ‘Lacustrine, Fluvial and Fine Marine Substrates Association’ includes seven typic ecosystem units. These units occur under mesic to wet conditions attributable to fine soil textures, shallow active layers, or seepage receiving landscape position.

    iii. The ‘Ocean Shoreline Association’ contains the Marine Intertidal and Marine Backshore ecosystem units.

Figure not Available

FIGURE 3: Northwest view of Roberts Bay coastline; i) 'Rock Outcrop and Coarse, Dry Substrates Association' supporting bare rock and a bouldery Betula-Ledum-Lichen community (foreground), ii) 'Lacustrine, Fluvial and Fine Marine Substrate Association' supporting a hummocky wet meadow community (centre-left), and iii) 'Ocean Shoreline Association' supporting unvegetated beach sands and marine intertidal and backshore communities (centre-right).

Sections 4.4.1, 4.4.2 and 4.4.3 detail the environmental conditions and floristic composition of each ecosystem unit identified. Environmental conditions discussed include relative soil moisture and nutrient regimes, topography, percent slope, soil classification, texture, terrain classification and presence or absence of a water table. These are then summarized in an environmental characteristics table. Discussion of floristic composition includes typical plant species assemblages and the environmental conditions which support them. Common modified and/or transitional units are also discussed in relation to the topographic and edaphic conditions producing them. Definitions of relative soil moisture and nutrient regimes are presented as Appendix A. All plants identified from the study area are listed in Appendix C along with a citation for the source of the botanical names and the species descriptions. A key to the identification of ecosystem units within the Hope Bay study area has been included as Appendix D.

4.4.1 Ecosystem Units Associated with Rock Outcrops and Coarse, Dry Substrates

Dry Carex - Lichen (CL)
(PLATE 1)

Environmental Conditions

The CL unit is the driest and most nutrient-limited unit in the study area. It occurs on crests and upper slopes underlain by coarse washed till, glaciofluvial materials, or sandy marine deposits. Sands comprise the typical soil matrix, although loamy sands (LS) and coarser skeletal materials are occasionally dominant. A deep permafrost boundary, (usually deeper than 100 cm of the surface), coarse soil textures, and convex slope shape are all contributing factors to the moisture and nutrient-deficient conditions typical of this unit. Slopes typically range from zero to seven percent. Soil development is minimal, typically being Regosolic, occasionally Brunisolic and rarely Cryosolic.

Environmental Characteristics – Typic Dry Carex-Lichen (CL)	
SMR:	1 - 2 - (3)
SNR:	B - A (- C)
Percent Slope:	0 – 7
Soil Classif.:	typically Regosol (R), occasionally Brunisol (B), rarely Static Cryosol (GL.SC, BR.SC)
Soil Texture:	typically sand (S), occasionally loamy sand (LS)
Terrain Classification:	washed till, glaciofluvial outwash and sandy marine deposits
Water Table:	may be present immediately after rain events and at beginning of growing season at interface with frozen soil
Common Modifiers:	x, c, z

Vegetation Characteristics

Harsh environmental conditions limit the number and type of plant species that occur here. Drought conditions and wind abrasion almost preclude the occurrence of shrubs, although Arctic willow (*Salix arctica*) is favoured due to its prostrate growth-form and drought-resistance, and may be up to 10% of the ground cover. Curly sedge (*Carex rupestris*), a pronounced calciphile and drought-resistant dwarf sedge, forms the loose matrix of this community. Arctic avens (*Dryas integrifolia*), another calciphile, is typically present but its abundance is limited by shallow rooting depth, low nutrients and drought conditions. Other common plant species scattered at low abundance include alpine sweetgrass or holy grass (*Hierochloe alpina*), moss campion (*Silene acaulis* var. *exscapa*), prickly saxifrage (*Saxifraga tricuspidata*), purple saxifrage (*S. oppositifolia*) and arctic oxytrope (*Oxytropis arctica*). Crustose lichens occur on exposed rock and dead moss throughout. Unvegetated mineral soil (usually fine gravels and coarse sand) is typically present and reflects the harsh conditions for most plants. The diagnostic plant species assemblage that characterizes the CL unit is recurrent throughout the Arctic on sites where comparable environmental conditions exist.

Vegetation Characteristics – Typic Dry Carex-Lichen (CL)	
Layer (%)	**Species (%)**
Shrubs (<10)	no dominant species
Herbs (45-80)	*Carex rupestris* (35-60) *Dryas integrifolia* (<30)
Moss (0-10)	no dominant species
Lichen (15-40)	crustose lichens

Typical modifiers applied to the CL ecosystem unit include x (dry), c (coarse), and z (steep). These modifiers are related in that they infer faster drainage and drier soils. Lower total plant cover and fewer plant species characterize these modified communities.

Communities with characteristics intermediate between the CL and DH ecosystems are common but the transition between the two is typically rapid.

Dryas Herb Mat (DH)
(PLATE 2)

Environmental Conditions
The DH unit occurs on moderately well to well-drained substrates at landscape positions that receive minor or no seepage inputs. This includes sandy/gravelly marine deposits and more typically, mantles of washed till in complex with rock outcroppings. On rare occasions the soil matrix develops from weathered bedrock. Soil textures are moderate (SiL) to coarse (S and gravelly S). Relative soil nutrient regime is moderate (C) to poor (B) and relative moisture is most commonly subxeric (2), occasionally submesic (3), and rarely xeric (1) or mesic (4). Soil development is variable (Brunisolic Cryosols, both Static and Turbic, Regosols, and Brunisols) reflecting degree of soil churning and the variable depths of active layers.

Environmental Characteristics – Typic Dryas Herb Mat (DH)	
SMR:	(1 -) 2 – 3 (-4)
SNR:	C – B
Percent Slope:	0 – 7
Soil Classification:	Brunisolic Static and Turbic Cryosols (BR.SC, BR.TC), Regosol (R), and Brunisol (B)
Soil Texture:	Variable – moderate to very coarse (LS)
Terrain Classification:	washed till and sandy/gravelly marine deposits occasionally weathered bedrock
Water Table:	may be present immediately after rain events and at beginning of growing season at interface with frozen soil
Common Modifiers:	x, y, f, m, s

Vegetation Characteristics
This ecosystem unit is distinguished by high cover of Arctic avens, a ubiquitous pioneer species that flourishes in dry, gravelly calcareous soils where it roots very deeply. Dwarf shrubs, primarily alpine bilberry (*Vaccinium uliginosum* var. *alpinum*), Arctic willow and net-veined willow (*Salix reticulata*), are usually present at low cover. Curly sedge is nearly always present and often relatively abundant. This community contains a diverse assemblage of herbaceous species, each typically present at low cover. The high diversity is attributable to the moderate availability of nutrients, lack of competition from shrubs (limited by low moisture and wind abrasion), and microsite variation associated with variable conditions on rock outcrops, where the DH unit is most often found. Liquorice-root (*Hedysarum alpinum*), Maydell's oxytrope (*Oxytropis maydelliana*), arctic heather (*Cassiope tetragona*) and Lapland rosebay (*Rhododendron lapponicum*) are typically present in amounts of < 5%. Less frequently occurring species include arctic oxytrope (*Oxytropis arctica*), woolly and capitate louseworts (*Pedicularis lanata*, *P. capitata*), and single-spike sedge (*Carex scirpodea*). Mosses usually occur in trace amounts within frost cracks. Crustose and foliose (*Cetraria* sp.) lichens are typically present and often relatively abundant.

Vegetation Characteristics – Typic Dryas Herb Mat (DH)	
Layer (%)	**Species (%)**
Shrubs (2-20)	*Vaccinium uliginosum* var. *alpinum* (0-15) *Salix arctica*, *S. arctophila* and *S. reticulata*
Herbs (60-90)	*Dryas integrifolia* (45-70) *Carex rupestris* (<30) Hedysarum alpinum
Moss (0-5)	Dicranum elongatum
Lichens (5-25)	crustose and foliose lichens

The DH unit is widespread and several recurrent modifiers have been applied in association with atypic conditions; the more common ones include (x-drier, y-wetter), finer soil textures (f-fine), steeper slopes (z-steep) and mounding (m-mounded). Drier (x) and steeper (z) types typically sustain lower cover of arctic avens and higher cover of curly sedge. Wetter types (y) also have lower arctic avens cover and typically have increasing amounts of mosses, *Carex* sedges, and other generally uncommon herbaceous species such as the northern bog orchid (*Habenaria obtusata*), which was found only near the coast. Plant species characteristic of DH communities also occur on fine-textured soils (f) where crumbly, granular surface layers on raised mounds (m) provide suitable rooting conditions for arctic avens and other species generally associated with coarse-textured soils.

Plant species characteristic of the DH ecosystem commonly persist downslope and result in significant transitional occurrences. Communities with characteristics intermediate between DH and Dwarf Shrub–Heath (SH) ecosystems are common on rock outcrops but typically small in area.

Betula-Ledum-Lichen (BL)
(PLATE 3)

Environmental Conditions

This unit occurs almost exclusively on level-to-gentle hillslopes overlain by washed till of variable thickness. It rarely occurs on glaciofluvial outwash and sandy marine sediments. It is most prevalent in the southern half of the study area where washed till is most common. In the vicinity of Spyder Lake, where till terrain occurs as gentle undulating plains, this unit is quite uniform and expansive. Along the Koignuk River corridor, just North of Spyder Lake, till overlies rock and forms discreet complexes of till, bedrock and marine sediments. In these situations the BL unit is generally less expansive, is complexed with DH, CL, and the Dwarf Shrub-Heath (SH) units and occasionally occurs on slopes up to eighteen percent. Soil textures are sands and loamy sands. Coarse fragments range from 0 to 65 percent and are predominantly gravels and cobbles. Relative soil moisture regime is subxeric (2) to submesic (3), occasionally mesic (4) and rarely xeric (1). Relative soil nutrient regime is poor (B) to very poor (A). Soils are Brunisols (B), Regosols (R) and Brunisolic Static Cryosols (BR.SC) depending on the depth to permafrost and degree of soil development. Occasionally, the unit occurs on Regosolic Static Cryosols (R.SC).

Environmental Characteristics – Typic Betula-Ledum-Lichen (BL)	
SMR:	(1-) 2 - 3 (- 4)
SNR:	B - A
Percent Slope:	0 to 7 (- 18)
Soil Classif.:	Brunisol (B), Regosol (R), Brunisolic Static Cryosol BR.SC; rarely Regosolic Static Cryosol (R.SC)
Soil Texture:	S and LS
Terrain Classification:	almost exclusively glacial till; rarely glaciofluvial or marine deposits
Water Table:	may or may not be present; present at active layer interface; may be present for two or three days following precipitation; may be present at the beginning of growing season
Common Modifiers:	b

Vegetation Characteristics

Coarse, well-drained and nutrient-deficient soils limit the diversity and abundance of herbs and mosses, which results in low total ground cover (range: 90-100% including shrubs, herbs, mosses and lichens), relative to more productive ecosystems. Shallow frost wedges, exposed rock (<5%) and mineral soil (<2%) are typically present and provide low to moderate variation in microtopography. Dwarf birch and northern Labrador tea (*Ledum decumbens*) are typically the dominant shrubs. Alpine bilberry and lingonberry (*Vaccinium Vitis-idaea* var. *minus*) are typically present and occasionally abundant. Alpine bearberry (*Arctostaphylos alpina*) and crowberry (*Empetrum nigrum*) are usually present at low cover. Arctic heather, Maydell's oxytrope and alpine sweet-grass are typically present in trace amounts.

Vegetation Characteristics – Typic Betula-Ledum-Lichen (BL)	
Layer (%)	**Species (%)**
Shrubs (50-75)	*Betula glandulosa* (10-30) *Ledum decumbens* (10-30) *Vaccinium uliginosum* var. *alpinum* (2-25) *Vaccinium Vitis-idaea* var. *minus* (2-10) *Empetrum nigrum* *Arctostaphylos alpina*
Herbs (1-10)	*Cassiope tetragona* *Oxytropis maydelliana* *Hierochloe alpina*
Mosses (0-20)	*Dicranum elongatum* *Dicranum groenlandicum* *Aulacomnium turgidum*
Lichens (10-40)	crustose, foliose and fructicose lichens

Occurrences of the Betula-Ledum-Lichen (BL) ecosystem unit that are modified by high boulder cover (BLb) are frequent in the north and south ends of the study area. Based on initial field data this bouldery condition was believed to represent a distinct unit; however the analysis did not support such a distinction, as vegetation and environmental conditions overlap significantly with the typic BL unit. High boulder cover is generally found where an energetic marine environment has washed away the finer soil matrix leaving behind coarse fragments. This condition is typically found on slopes and crests of rock outcrops and occasionally on glaciofluvial deposits (i.e. eskers and outwash). The unit is characterized by less northern Labrador tea (0-15%) and, generally higher cover of lichens, crowberry and alpine bearberry than the typic BL unit. The distinction between BL and BLb units by aerial phototyping is unreliable, as species assemblages are very similar. Known occurrences (from plot data) of the BLb and BL units are labeled as such on the ecosystem maps; however all BL units not tied to plots represent the potential range of plant species assemblages encompassed by both the typic (BL) and modified (BLb) units.

The transition to downslope communities is often gradual and results in significant transitional communities. Transitions to the Betula-Moss (BM) unit occur at lower slope positions in relation to decreasing coarse fragment content and increasing sand fraction. The greater occurrence of dwarf birch and mosses distinguishes the BM from the BL community.

Dwarf Shrub-Heath (SH)
(PLATE 4)

Environmental Conditions

The Dwarf Shrub Heath unit occurs on moderate to moderately steep slopes of rock outcrop terrain overlain by glacial till as well as on gentle to moderate slopes at the base of rock outcrops. On slopes greater than approximately ten-percent solifluction is evident, as are strongly cryoturbated soils. Where permafrost lies within two meters of the surface soils are typically Brunisolic Turbic Cryosols (BR.TC), otherwise Regosols predominate. Soil textures range from moderately fine to coarse (silty loam to sand). Coarse fragment content is variable depending on the origin of material and may include colluvial fragments from exposed outcrops above. Relative soil nutrient regime is moderate to poor and relative moisture regime is mesic (4) to submesic (3).

Environmental Characteristics – Typic Dwarf Shrub-Heath (SH)	
SMR:	4 – 3
SNR:	C – B
Percent Slope:	commonly 10 to 40 (rarely < 10 and 40 - 60)
Soil Classif.:	commonly Brunisolic Turbic Cryosol (BR.TC); occasionally Brunisolic Static Cryosol (BR.SC), Regosol (R) and Brunisol (B);
Soil Texture:	variable SiL – S; most commonly SL
Terrain Classification:	predominantly glacial till; rarely marine deposits
Water Table:	may or may not be present
Common Modifiers	m

Vegetation Characteristics

This typic community is characterized by the prevalence of arctic heather and moderate to high variation in microtopography as a result of the influence of rock outcrops and boulders. A relatively diverse assemblage of herbs, mosses and lichens results from the microsite variation associated with the uneven distribution of coarse substrates, "stepped" or uneven slopes, soil mixing, presence of rock crevices and variation in moisture availability. Predictable differences in plant species assemblages occur in relation to aspect. West-facing slopes are typically drier and sustain higher cover of alpine bilberry and arctic avens. East-facing aspects are often late snow-lie areas, which sustain high cover of arctic heather and mosses. Some of the more rarely observed species within the project area were found in this community, including: northern anemone (*Anemone parviflora*), heart-leaved saxifrage (*Saxifraga punctata* ssp. *Porsiliana*), alpine saxifrage (*S. nivalis*) and fir clubmoss (*Lycopodium selago*).

Vegetation Characteristics – Typic Dwarf Shrub-Heath (SH)	
Layer (%)	**Species (%)**
Shrubs (10-60)	*Betula glandulosa* *Vaccinium uliginosum* var. *alpinum* *Salix species* *Ledum decumbens* *Arctostaphylos rubra*
Herbs (60-90)	*Cassiope tetragona* (20-50) *Dryas integrifolia* (0-25)
Moss (7-30)	*Dicranum groenlandicum* *Aulacomnium turgidum*
Lichen (1-10)	crustose, foliose and fruticose lichens

The occurrence of frost mounds (m-mounding) is common in the transitional zones to downslope ecosystem units where soil textures are at the finer end of the range considered typical for this unit. Herb and grass species associated with drier conditions are common on the raised mounds.

The boundaries with upslope and adjacent ecosystem units (i.e. DH) are generally distinct, while the transition to downslope units (i.e. Tussock Meadow) is often broad due to gradually changing soil properties.

4.4.2 Ecosystem Units Associated with Lacustrine, Fluvial and Fine Marine Substrates

Betula-Moss (BM)
(PLATES 5 & 6)

Environmental Conditions
The Betula-Moss unit occurs on level to slightly sloped (1-4%) sandy lacustrine and fluvial sediments. Typically these deposits have been laid down at different stages of thaw lake cycles but they also occur as stream and river terraces. Numerous typical examples are found adjacent to thaw lakes, the Koignuk River and its tributaries. Although soil textures are moderate to coarse (SL to S), relative soil moisture regime is typically mesic due to a) the level topography, b) level-plain or toe-of-slope landscape position and c) presence of a relatively shallow permafrost boundary (typically 25 to 60 cm from the surface). Soils are typically Brunisolic Static Cryosols (rarely Gleysolic) and occasionally Brunisolic Turbic Cryosols.

Environmental Characteristics – Typic Betula-Moss (BM)	
SMR:	(3 -) 4 (- 5)
SNR:	C – B
Percent Slope:	0 – 4
Soil Classif.:	Brunisolic Static Cryosols (BR.SC), occasionally Brunisolic Turbic Cryosols (BR.TC), rarely Gleysolic Static Cryosols (GL.SC)
Soil Texture:	moderate to coarse (SL, LS, S)
Terrain Classification:	fluvial and lacustrine
Water Table:	Usually present (depth dependent on depth to permafrost)
Common Modifiers	m, y

Vegetation Characteristics
High cover of dwarf birch and mosses are the main distinguishing features of the Betula-Moss ecosystem unit. In general, and relative to other communities, plant species diversity is low in the BM community. Dwarf birch thrives in the moist, sandy and somewhat nutrient-deficient soils that are typical of this ecosystem unit. Willows, particularly *S. pulchra*, are commonly present in minor amounts, generally along frost cracks where the moisture regime is wetter due to the accumulation of organic materials. Moss cover increases and dwarf birch cover decreases with increasing size and influence of frost cracks. Herbs are typically present in minor quantities.

Vegetation Characteristics – Typic Betula-Moss (BM)	
Layer (%)	**Species (%)**
Shrubs (50-85)	*Betula glandulosa* (40-70) *Salix lanata* ssp. *Richardsonii* and *S. pulchra* *Vaccinium uliginosum* var. *alpinum* and *V. Vitis-idaea* var. *minus*
Herbs (<10)	*Arctagrostis latifolia*
Moss (20-90)	*Aulacomnium turgidum* (5-50) *Dicranum groenlandicum* (0-30)
Lichen (1-20)	crustose, foliose and fruticose lichens

The transition to adjacent ecosystem units (e.g. Tussock Meadow) is typically abrupt, although strong mounding will allow the BM community to persist. The BM ecosystem is maintained, but becomes stagnant through the development of strongly mounded palsas.

<u>Eriophorum Tussock Meadow (TM)</u>
(PLATE 7)

Environmental Conditions:
The TM ecosystem unit is the most widespread unit within the study area. It occurs on marine silts and clays in a variety of landscape positions where seepage or active-layer meltwater inputs are nearly balanced by outputs through lateral drainage. Relative soil moisture regime, therefore, is typically subygric (5) to mesic (4). Relative soil nutrient regime is; typically moderate (C), commonly poor to moderate (B-C) where birch and Labrador tea are the dominant shrubs, and slightly richer (C-D) where prostrate willow spp. are the dominant shrubs. Slopes are generally less than five percent but occasionally reach ten percent. Soils are of the Cryosolic order; most commonly Gleysolic Static Cryosol (GL.SC) but others include Brunisolic and Regosolic Static Cryosols (BR.SC and R.SC respectively), as well as Gleysolic, Brunisolic and Regosilic Turbic Cryosols (GL.TC, BR.TC and R.TC). The Turbic Cryosol great group is predominantly found within ecosystem units modified by mounding.

Environmental Characteristics – Typic Eriophorum Tussock Meadow (TM)	
SMR:	4 - 5 (- 6)
SNR:	(B) C - D
Percent Slope:	0 to 5 (- 10)
Soil Classif.:	Gleysolic Static Cryosol (GL.SC); less commonly Brunisolic and Regosolic Static Cryosols (BR.SC, R.SC), and Gleysolic Brunisolic and Regosolic Turbic Cryosols (GL.TC, BR.TC, R.TC)
Soil Texture:	fine (predominantly SiCL; occasionally SiL) occasionally medium to coarse (CL, fSL, L, and SC)
Terrain Classification:	almost exclusively marine occasionally fluvial, lacustrine or organic veneers overlying marine
Water Table:	May or may not be present; present at the beginning of growing season while snow is melting and permafrost interface is nearest the surface, and for short periods of time following precipitation.
Common Modifiers:	z, x, y, m, p, s

Vegetation Characteristics

High cover of the tussock-forming sheathed cotton-grass (*Eriophorum vaginatum*) distinguishes this community from all others. It has been reported (Mark et al. 1985) that minimum ages of mature *E. vaginatum* tussocks ranged from 122 to 187 years across several sites in Alaska. Where the average heights and diameters of mature tussocks in the Alaskan study are comparable to those in this study area, it is likely that these are mature communities. The tussock-forming habit of *E. vaginatum* provides elevated microsites suitable for some plant species that are characteristically found in dry communities (i.e. arctic avens and alpine bilberry). In addition to tussocks, low to moderate degrees of mounding are typically present; mound size ranges between 0.5-1.2 m in diameter and 0.15-0.3 m in height. Mosses (several species) comprise the dominant cover in the mesic inter-tussock troughs, and tall cotton-grass (*Eriophorum angustifolium*) is often dominant over mosses in the deeper, wetter troughs. The accumulation of organics in the troughs, and the dense blocky soils comprising the mounds create microsite variation that promotes diversity in plant species. Woolly willow (*Salix lanata* ssp. *richardsonii*) and *Salix pulchra* are characteristically present and typically relatively tall (~0.75 m).

Vegetation Characteristics – Typic Eriophorum Tussock Meadow (TM)	
Layer (%)	**Species (%)**
Shrubs (25-50)	*Salix lanata* ssp. *Richardsonii* and *S. pulchr*a (10-30) *Betula glandulosa* (<30) *Ledum decumbens* (<10) *Vaccinium uliginosum* var. *alpinum* and *V. Vitis-idaea* var. *minus* (2-8)
Herbs (40-75)	*Eriophorum vaginatum* (35-65) *Eriophorum angustifolium* (0-10)
Moss (5-25)	*Dicranum groenlandicum* *Aulacomnium palustre and A. turgidum* *Tomenthypnum nitens* *Hylocomium splendens*
Lichen (trace)	foliose and fruticose lichens

Three preliminary field groups dominated by *Eriophorum vaginatum* were recognized in the field. Two have been amalgamated to form the typic Tussock Meadow Ecosystem Unit while the third group has been classified as a modified type (TMp) on the basis of its poorer nutrient regime. Distinguishing between the typic and modified types by aerial photo interpretation was not possible and consequently all have been labeled as typic TM. Relative to the typic unit, nutrient poor (SNR: B) sites sustain low willow cover (<10%), high northern Labrador tea cover (10-25%), and higher dwarf birch and *Sphagnum* moss (up to 25%). The occurrences of TMp in relation to landscape position is uncertain; however it seemed to be encountered most often (but not predictably) adjacent to diabase dykes and on rock outcrop saddles overlain by marine silts and clays.

Plant species indicative of wet conditions such as giant water moss (*Calliergon giganticum*), sweet coltsfoot (*Petasites frigidus*) and marsh marigold (*Caltha palustris*) are sustained in trace quantities where shallow standing water is maintained throughout most of the growing season in the deepest troughs in wetter sites (‘y’ for wetter). Occasionally, wetter tussock meadow communities (TMy) are characterized by high cover of sheathed cotton-grass and tall cottongrass or *Carex* sedges with very low shrub and moss cover.

A common modifier applied to the TM unit describes strong mounding (m). Although very common in fine-textured marine soils, mounds also occur in coarse soils and consequently the edaphic conditions that promote frost mounding are not clearly understood. Within the study area, it appears that frost mounds are most common on crests and gentle valley slopes near rock outcrops. In the latter situation it may be that differential heaving of the soil column is promoted by locally variable moisture conditions, which arise from different seepage and runoff regimes from the outcrops. Mounded communities typically sustain greater proportions of species indicative of drier communities such as alpine bilberry, Arctic avens and Maydell's oxytrope.

Other common modifiers applied to the TM community include 'x' for drier soil moisture regime, 'z' for steeper slopes, and 's' for shallow soils. These types commonly occur along with strong mounding but are also related to slope concavity, crest landscape positions and thin marine mantles over till or bedrock.

Upslope transitions are usually gradual and are marked by a sharp decrease in the proportion of sheathed cotton-grass. Typical upslope transitions include DH or SH units. Downslope transitions, typically to WM ecosystems, are generally more abrupt and are marked by a sharp decrease in shrub cover.

Dry Willow (DW)
(PLATE 8)

Environmental Conditions
The DW unit occurs on gentle to steeply-sloped river banks and lakeshores that have been affected by significant post-marine washing. The unit is most common within the study area along the mid-portion of the Koignuk River and its major tributary. Along these watercourses it typically occurs where the rivers have downcut and made the soils prone to thaw flow-slides. Although uncommon (at least within the study area) the unit also occurs along some lakeshores where historical lake levels wave-washed the shorelines and induced sheet erosion. It occurs on fine (SiL to SiCL) marine sediments from upper slope breaks to mid-slope positions. This unit grades at lower slope positions into the Riparian Willow unit. Relative soil moisture regime is predominantly mesic (4), occasionally submesic (3) at upper slope positions and occasionally subhygric (5)at mid slope positions. Permafrost depth ranges from 35 to 55 cm. Relative soil nutrient regime is moderate (C) to poor (B). Soils are generally Brunisolic Turbic or Static Cryosols.

Environmental Characteristics – Typic Dry Willow (DW)	
SMR:	4 (range: 3 - 5)
SNR:	C - B
Percent Slope:	variable (5 – 55)
Soil Classification:	Brunisolic Static and Turbic Cryosols (BR.SC, BR.TC)
Soil Texture:	fine (typically SiL to SiCL)
Terrain Classification:	marine
Water Table:	amy or may not be present
Common Modifiers:	j, m, y

Vegetation Characteristics

The high cover of gray-leaved willow (*Salix glauca*) distinguishes this community from all others. The microtopography is usually slightly mounded as a result of freeze-thaw processes. As mounds form, subsurface horizons are compacted and roots are only able to penetrate surface horizons. The result is a thick, crumbly layer (a poorly developed B horizon) on the surface of the mounds, which provides a suitable microsite for dwarf birch, which typically thrives on sandy coarse-textured soils. Large-flowered wintergreen (*Pyrola grandiflora*) is typically present where leaf litter accumulates beneath the canopy of gray-leaved willow. Trace amounts of alpine arnica (*Arnica alpina* ssp. *angustifolia*), alpine milk-vetch (*Astragalus alpinus*) and Maydell's oxytrope are also common.

Vegetation Characteristics – Typic Dry Willow (DW)	
Layer (%)	**Species (%)**
Shrubs (80-95)	*Salix glauca* (50-80) *Betula glandulosa* (0-15) *Salix lanata* ssp. *Richardsonii* and *S. pulchra*
Herbs (3-15)	*Pyrola grandiflora* *Arnica alpina* ssp. *angustifolia*
Moss (0-5)	*Hypnum plicatulum* *Dicranum groenlandicum* *Aulacomnium turgidum*
Lichen (0-2)	crustose, foliose and fructicose lichens

A commonly occurring modified DW community occurs on strongly mounded (m), shallowly-sloped (j-shallow slope) sites. Distinctive features of DWjm communities include: 1) higher cover (up to 45%) of dwarf birch, 2) greater proportion of exposed mineral soils, and 3) wider range of moisture conditions.

Riparian Willow (RW)
(PLATES 8, 9 &10)

Environmental Conditions

The RW unit occurs in landscape positions that are strongly influenced by a seasonally fluctuating water table such as active floodplains along rivers and streams, and within the eulittoral zone of lakes and ponds. It also occurs where significant seepage inputs occur (seepage tracks and toe-of-slope positions). Along streams, rivers, lakes and ponds, soils typically have sandy and/or silty textures (reflecting their fluvial or lacustrine origin) while in seepage tracks, soils may have any genesis. Relative soil moisture regime is typically subhygric (5) to hygric (6) and occasionally wetter in low-gradient seepage tracks. Relative soil nutrient regime is predominantly rich (D) due to the influx of nutrients by flowing water but can be moderate (C) where inputs are minimal.

Environmental Characteristics – Typic Riparian Willow (RW)	
SMR:	5 - 6 (-7)
SNR:	C – D
Percent Slope:	0 - 7 (occasionally higher to 20)
Soil Classification:	Gleysolic Static Cryosol (GL.SC); occasionally Brunisolic Static Cryosol (BR.SC), Gleysolic Turbic Cryosol (GL.TC), or Organic Cryosol (OC)
Soil Texture:	variable; fine to coarse (SiCL to S); occasionally fibric or humic
Terrain Classification:	generally fluvial veneer overlying marine; occasionally organic veneer overlying fluvial or marine occasionally organic plain
Water Table:	may or may not be present; always present in seepage tracks.
Common Modifiers	b,

Vegetation Characteristics

High willow (*Salix lanata* and *S. pulchra*) cover distinguishes this unit from all others. Variation in soil texture and nutrient availability associated with the mode of soil deposition (fluvial vs lacustrine) and seepage effects result in variation in understorey plant species assemblages. Although both willow species can be dominant and are often intermixed, *Salix pulchra* tends to be more abundant in fluvial communities. Seepage tracks tend to sustain an abundance of water sedge (*Carex aquatilis* var. *stans*) and tall cotton-grass and have high overall plant cover. Soils along larger streams and rivers support lower cover of water sedge and low to moderate cover of tall cotton-grass. The understorey along lakeshores is typically characterized by higher moss cover, low to moderate sedge (*Carex* and *Eriophorum*) cover, and coltsfoot (*Petasites frigidus*).

Vegetation Characteristics – Typic Riparian Willow (RW)	
Layer (%)	**Species (%)**
Shrubs (50-90)	*Salix lanata* and *S. pulchra* (50-90) *Betula glandulosa* (0-15)
Herbs (20-90)	*Carex* species (0-50) *Eriophorum angustifolium* (0-40)
Mosses (5-40)	*Aulacomnium turgidum* (0-15) *Sphagnum* species
Lichens (0)	

The combined action of ice, wind, waves and boulders along various lake shorelines and portions of the Koignuk River produces a modified RW community characterized by the prevalence of boulders. The plant community typically has lower shrub and herb covers and lower species diversity where channels are kept unvegetated or sparsely-vegetated by scouring. This modified unit has been designated as RWb on accompanying maps.

Low Bench Floodplain (FP)
(PLATES 9 & 10)

Environmental Conditions
The FP unit is found on the active floodplains of rivers and streams as well as at outlets of lakes under hydrologic conditions that favor significant flushing of decaying plant matter during spring floods. It is most prevalent on the Koignuk River, particularly in reaches upstream of main channel constrictions, where slower flows deposit a significant bedload of fluvial sediments and produce shallowly-sloped shorelines. Soils are typically composed of layered organic and mineral deposits or pure layered mineral deposits reflecting annual inundation regimes. Soil textures range from silt loam (SiL) to pure sand (S) depending on the prevailing hydrologic regime. Relative soil nutrient regime is moderate (C) to rich (D) depending on the amount of organic input from decaying plant matter and waterfowl inputs. Relative moisture regime is subhydric (7) to hygric (6). Soil development (typically Gleysolic Static Cryosols) reflects the duration of seasonal inundation and /or the presence of a near surface fluctuating water table..

Environmental Characteristics – Typic Low Bench Floodplain	
SMR:	7 (- 6)
SNR:	C – D
Percent Slope:	0 to 2
Soil Classification:	Gleysolic Static Cryosol (GL.SC)
Soil Texture:	bedded sands and silts (occasionally clays) overlying clay loams
Terrain Classification:	active fluvial veneer overlying marine
Water Table:	present at or near the surface; annual or periodic inundation
Common Modifiers:	b

Vegetation Characteristics
Prolonged flooding and seasonal deposition of fine sediments precludes the occurrence of many plant species and limits annual production within this community, which typically sustains diminutive plant species with low overall plant cover (~80%). High cover of goose-grass (*Dupontia Fischeri* ssp. *psilosantha*) and a lack of shrubs and lichens distinguish the Low Bench Floodplain (FP) community from all others. Mare's tail typically occurs in nearshore and shoreline areas where it usually occurs in association with yellow water crowfoot (*Ranunculus gmelini*) and trace quantities of marsh marigold, particularly in the transition to *goose-grass*, which is typically the dominant species in the upslope portion of the FP community. The contribution of nutrients from goose droppings is significant in FP communities along the Koignuk River as a result of extensive grazing of goose-grass by Canada geese.

Vegetation Characteristics – Typic Low Bench Floodplain (FP)	
Layer (%)	**Species (%)**
Shrubs (0)	
Herbs (50-85)	*Dupontia fischeri* ssp. *Psilosantha* (5-50) *Hippurus vulgaris* (5-30) *Ranunculus gmelini*
Mosses (15-50)	no dominant species
Lichens (0)	

Portions of the Spyder Lake and lower Koignuk River shorelines are characterized by fine-to-medium textured soils with significant boulder cover. These areas are typically sparsely-vegetated or possess highly variable or patchy herb mat and/or moss cover due to the combined scouring action of ice, boulders and waves. This scouring disturbance regime maintains such sites at disclimax states of succession. They are labeled on the ecosystem maps as Low Bench Floodplain ecosystem units modified by boulder cover with a structural stage of 1 (FPb 1 label on ecosystem maps).

Wet Meadow (WM)
(PLATES 11 & 12)

Two types of wet meadow communities are represented in the field data with respect to vegetation; one dominated by water sedge (*Carex aquatilis* var. *stans*) and the other by tall cotton-grass (*Eriophorum angustifolium*). Analysis did not support such a distinction since landscape position and environmental (edaphic) conditions often overlap. In addition, intermediate communities are common. As both communities are largely ecological equivalents, they were grouped to collectively represent the Wet Meadow ecosystem unit.

Environmental Conditions

The WM unit occurs on wet, level-to-gently sloped terrain with slopes typically below seven percent. Relative moisture regime is generally hygric to subhydric (6-7) however hydric (8) sites are not uncommon. Soils are predominantly Gleysolic Static Cryosols (GL.SC) but occasionally are Turbic (TC) or Organic (OC). Wet meadows occur on fine to coarse-textured deposits of variable origin (marine, lacustrine, fluvial or organic). Invariably however, a water table is present at or near the surface and where slopes exceed two percent, there is constant runoff from upslope. Typically, wet meadows are found in three types of landscape positions: toe-of-slope, level plain, and valley slopes. They occur at toe-of-slope and level plain positions where seepage and active layer-meltwater collect. On valley slope positions they occur where seepage inputs are significant (such as in depressional seepage tracks) or downslope of perched lakes and ponds. In general, the *Carex* phase is the slightly wetter of the two phases and is found where surface and sub-surface run-off is impeded to a greater degree than in situations where the *Eriophorum* phase is found. Relative nutrient regime is characteristically moderate (C) to rich (D) due to the influx of nutrients by seepage and meltwater. Generally, wet meadows occur on level to only slightly-sloped terrain (0 - 1.5%) but on occasion also occur on slopes up to seven percent

Environmental Characteristics – Typic Wet Meadow (WM)	
SMR:	6-7 (8)
SNR:	C-D (- E)
Percent Slope:	0 to 1.5 (<7)
Soil Classification:	Gleysolic Static Cryosol (GL.SC); occasionally Organic Cryosol (OC), Brunisolic Static Cryosol (BR.SC), or Turbic Cryosol
Soil Texture:	organic (fibric to humic), or fine to moderate (SiCL to SCL)
Terrain Classification:	marine deposits or organic veneer overlying variable (marine, lacustrine, or fluvial) deposits,
Water Table:	present throughout the growing season at or near the surface
Common Modifiers:	i, r, x

Vegetation Characteristics

The high cover of hydrophilic sedges and general lack of shrubs and lichens distinguishes this unit from all others. The prevalence of water sedge or less frequently yellow bog sedge (*Carex gynocrates*) characterize wet depressions in areas subject to prolonged flooding (i.e. margins of ponds and lakes). The latter species is typically associated with persistent shallow standing water and a contiguous algae mat. Tall cotton-grass becomes more prevalent with increasing slope angle, although it is also common in wet depressions in association with water sedge. A mixed *Carex* and *Eriophorum* association is prevalent in upper slope positions and slightly drier transitional areas. Extensive WM occurrences are often a mosaic of *Carex* and/or *Eriophorum*-dominated communities. A total of 15 species of *Carex* sedges were found within the WM sites sampled. Some of the more frequently occurring species include: *Carex membranacea*, *C. atrofusca*, *C. misandra*, *C. vaginata*, *C. capillaris*, *C. rariflora*. Occasional species include *C. physocarpa* and *C. bigelowii*. Uncommon occurrences include *C. microglochin*, *C. amblyorhyncha* and *C. holostoma*, the last species is a range extension. Sudetan lousewort (*Pedicularis sudetica*), an indicator of saturated organic soils, is typically present, although in trace amounts.

Vegetation Characteristics – Typic Wet Meadow	
Layer (%)	**Species (%)**
Shrubs (<5)	no dominant species
Herbs (80-99)	*Eriophorum angustifolium* (5-95) *Carex* species (5-90) *Carex aquatilis* var. *stans* (1-65) *Pedicularis sudetica*
Mosses (0-25)	*Drepanocladus revolvens* *Hypnum pratense*
Lichens (0-t)	no dominant species

Modified WM communities are frequently associated with drier (x-drier) soil conditions (SMR: 5-6) and are typically characterized by higher species richness and evenness of *Carex* sedges than the typic community. WM communities are also modified by the presence of ice wedges (i-ice wedges) or low, transverse ridges (r-ridges) of organic or mineral materials; however the typic species assemblage is little affected by either.

Transitional communities are often extensive and may extend into or occur on upper slope positions in association with DH or BL communities, particularly where runoff and seepage from upslope is concentrated or localized. Transitional communities in upslope areas are typically dominated by *Carex* spp. indicative of mesic conditions such as C. misandra, C. bigelowii. Transitional communities between WM and TM ecosystems are also common but small in area and feature species assemblages that are intermediate between them.

Polygonal Ground
(PLATES 16, 17 & 18)

Polygonal ground is typically characterized by disjunct communities that are a product of the spacially rapid and repeating variation in microtopography. The two common types of polygonal ground within the study area are the high-centre type in which a matrix of palsas are encircled by wet meadow depressions, and the low-centre type, in which a matrix of flat wet basins are delineated by linear ridges underlain by ice-wedges. The relatively dry soil conditions on palsas and along the crests of the ridges typically support plant species assemblages characteristic of BL or BM units (see PLATES 16, 17, and 18). As the ice lens in a palsa grows, relative soil moisture drops and plant productivity stagnates. This change is accompanied by a transition in vegetation from a wet meadow community through a BM communityunit to a BL community. Patterned ground in which palsa formations are distinct are labeled on the accompanying ecosystem maps as B*q. This label reflects the invariable presence of dwarf birch (B__), the variable assemblages of other species typically found in BM and/or BL units (_*_), and the presence of an underlying ice lens (__q) which modifies the palsa community from that of a typic BM or BL unit. Within the study area, palsas most commonly have relatively thin veneers of peat overlying frozen mineral soil horizons, indicating that the wet meadow basins within which they typically develop also have relatively thin organic accumulations.

Emergent Marsh (EM)
(PLATE 13)

Environmental Conditions
The EM unit is the wettest unit mapped. It occurs on level organic plains along lake margins or less commonly along unconfined low-gradient streams in microsites protected from erosional flows and ice and wave scour. The water table is above the surface the entire growing season (SMR 8) and relative soil nutrient regime is rich (D) to very rich (E) as a result of nutrient inputs associated with high plant productivity and relatively rapid organic decomposition in the warmer shallow waters.

Environmental Characteristics – Typic Emergent Marsh (EM)	
SMR:	8
SNR:	D – E
Percent Slope:	0
Soil Classif.:	Organic Cryosol (OC)
Soil Texture:	organic
Terrain Classification:	organic plain
Water Table:	present throughout the growing season at or above the soil surface
Common Modifiers:	none

Vegetation Characteristics

Occurrences of this ecosystem unit are rare within the study area and are generally too small to map. This is largely due to the limited occurrence of suitable conditions; primarily stable water table (5–30 cm. above the ground surface) throughout the growing season and organic sediments for rooting. In most areas the development of EM communities is prevented due to the combined scouring of rocks, ice and waves. The Emergent Marsh (EM) community typically occurs along or within Wet Meadow communities in low lying areas immediately adjacent to large ponds or lakes, or less frequently along flooded areas bordering low-gradient streams. The prevalence of aquatic and semi-aquatic plant species including marsh cinquefoil (*Potentilla palustris*), mare's tail (*Hippurus vulgaris*), marsh marigold (*Caltha palustris* var. *arctica*), Pallas's buttercup (*Ranunculus pallasii*), and giant water moss (*Calliergon giganticum*) distinguish the EM community from all others.

Vegetation Characteristics – Typic Emergent Marsh (EM)	
Layer (%)	**Species (%)**
Shrubs (0)	
Herbs (50-95)	*Carex aquatilis* var. *stans* (5-50) *Hippurus vulgaris* (0-25) *Caltha palustris* *Potentilla palustris*
Mosses (10-25)	*Calliergon giganticum* *Drepanocladus revolvens* *Hypnum pratense*
Lichens (0)	

4.4.3 Ecosystem Units Associated with the Ocean Shoreline

The Marine Intertidal and Backshore Units are generally found in association with unvegetated beach sands (BE label on maps). Due to the linear nature of all three units they are often too small to map separately and, even when combined, they frequently occur as inclusions within map polygons dominated by more expansive neighbouring upland units.

Marine Intertidal (MI)
(PLATE 14)

Environmental Conditions

Occurrences of this ecosytem unit are strictly limited to intertidal flats and shallowly sloped (0-2%) shorelines, which are uncommon in Roberts Bay. This unit occurs on veneers of marine sands overlying gleyed, structureless or weakly-structured marine clays. Frequent inundation with saltwater precludes the occurrence of most plant species. Buried organic materials (primarily marine algae and seaweed) are strongly oxidized and appear as black planes in the soil profile. Soils are typically gleysolic or regosolic reflecting the fluctuating water table and constant disruptive forces, which preclude even minor soil development.

Environmental Characteristics – Typic Marine Intertidal (MI)	
SMR:	7 (8)
SNR:	C (D)
Percent Slope:	0 to 2
Soil Classif.:	Gleysol or Regosol (generally lacking soil structure)
Soil Texture:	Structureless silty clay over massive marine clays and heavy clays
Terrain Classification:	marine (intertidal) blanket
Water Table:	frequently inundated and persistently saturated, at low tide the water table may occur at depths between of 20-30 cm.
Common Modifiers:	none

Vegetation Characteristics

Frequent inundation with saltwater precludes the occurrence of most plant species. This simple community is characterized by the prevalence of only two plant species, creeping alkaligrass (*Puccinelia phryganodes*) is dominant in the lower, most frequently inundated portion and Hoppner sedge (*Carex subspathacea*) extends to the strand line where Pacific silverweed (*Potentilla egedii*), scurvy-grass (*Cochlearia officinalis*) and *Carex amblyorhyncha* are typically found. Another salt-tolerant species, low chickweed (*Stellaria humifusa*) occurs in greatest abundance in association with Hoppner sedge but often extends into the alkaligrass-dominated portion.

Vegetation Characteristics – Typic Marine Intertidal (MI)	
Layer (%)	**Species (%)**
Shrubs (0)	
Herbs (50-90)	*Carex subspatheca* (15-70) *Puccinelia phyrganodes* (10-30)
Moss (0)	
Lichen (0)	

<u>Marine Backshore (MB)</u>
(PLATE 15)

Environmental Conditions

The Marine Backshore ecosytem unit occurs immediately upslope of the intertidal community on thick deposits of washed marine sands and is essentially equivalent to a sand dune. Where rocky headlands comprise much of the coastline, occurrences of the MB community are limited to protected or partially protected bays and inlets with shallowly-sloped shorelines. The unit is very dry and nutrient poor as a result of the coarse soil texture, lack of soil development and organic input, and limited vegetation cover.

Environmental Characteristics – Typic Marine Intertidal (MB)	
SMR:	1 (2)
SNR:	A
Percent Slope:	0-10 (variable where this community often resembles a sand dune)
Soil Classif.:	Regosol, Brunisol (weak)
Soil Texture:	S with weak structure
Terrain Classification:	Marine beach ridge
Water Table:	>1 m
Common Modifiers:	none

Vegetation Characteristics

The occurrence of seashore plant species such as lyme-grass (*Elymus arenarius* ssp. *mollis*), seabeach sandwort (*Honckenya peploides*) and seaside plantain (*Plantago juncoides* var. *glauca*) distinguish the MB community from all others. Up to 50% of the ground is typically unvegetated and plant cover is typically sparse, except around arctic ground squirrel burrows, which are common in this community. Low moisture and nutrients as well as the wind-blown sands preclude the establishment of most plant species. Northern sweet-vetch (*Hedysarum mackenzii*) is typically present in MB communities but was rarely observed inland. Scattered grasses and clumps of prickly saxifrage and arctic oxytrope are characteristically present.

Vegetation Characteristics – Typic Marine Backshore (MB)	
Layer (%)	**Species (%)**
Shrubs (t)	*Salix arctica*
Herbs (40-60)	*Elymus arenarius* ssp. *mollis (10-30)* *Oxytropis arctica (1-15)* *Hedysarum Mackenzii (1-10)* *Saxifraga tricuspidata*
Mosses (0-4)	
Lichens (0-10)	

5.0 CONCLUSIONS

The application of Terrestrial Ecosystem Mapping (TEM) protocols developed in British Columbia to the tundra landscape of the Hope Bay Belt proved to be effective in identifying and describing the ecosystem units and terrain of the study area.

Thirteen unique ecosystem units were identified. Eriophorum Tussock Meadow (TM), the dominant unit, along with six others (Betula-Moss, Riparian Willow, Dry-Willow, Low Bench Floodplain, Wet Meadow, and Emergent Marsh) are all ecosystems associated with moist to wet substrates overlying level to gently sloped terrain. Four ecosystem units (Dry Carex Lichen, Dryas Herb Mat, Betula-Ledum-Lichen, and Dwarf-Shrub Heath) found typically on drier soils, occur in close association with outcrops and coarse-to-medium textured substrates. The Dryas Herb Mat unit is the most common of these although this is largely due to the prevalence of calcium-rich soils. A third association, although very limited in extent is the ‘Ocean Shoreline Association which supports the Marine Intertidal and Marine Backshore ecosystem units, which usually occur in close association with unvegetated beach sands.

The application of ecosystem modifiers and the recognition of transitional community occurrences, further refine ecosystem classification and description to a level appropriate for developing prescriptions and identifying ecological values or environmental sensitivities.

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Appendix 2

2010 Ecosystem Mapping Field Survey Plot Card

Date:			**Plot #:**		**Project:**		
Surveyors:					**Photos:**		
UTM zone:		**Northing:**			**Easting:**		
SITE INFO:							
Slope:		**Aspect:**		**Elevation:**			
Slope Position:							
crest	upper	mid-slope	toe	level	depression		
Surficial Material:							
Terrain:				**Microtopography:**			
beach		alluv fan		hummocky		frost fiss.	
terrace		floodplain		frost boils		flat	
plateau		ridge crest		solifluct		br. outcrop	
valley bottom		cliff		circles		boulders	
slope		stream		bould strm		bould field	
delta		esker		polygon		shattered br.	
Mineral soil texture:				**Organic soil texture:**			
Sandy				Fibric			
Loamy				Mesic			
Silty				Humic			
Clayey							
Surface substrate (%) :							
bedrock (consolidated):				rock (> 0.75 cm):			
boulder (> 25 cm):				water:			
Permafrost? (Y/N)			**Permafrost depth:**				
Coarse Fragment Content							
<20%	20-35%	35-70%	>70%				
Soil Moisture Regime (0 = very xeric, 4 = mesic, 8 =hydric):							
Soil Nutrient Regime (A = very poor, C = medium, E = very rich):							
Notes / Site Diagram:							

VEGETATION							
% Cover by layer:							
Shrub:		**Herb:**			**Moss/Lichen:**		
Shrubs:	**%**	**Forbs**	%	**Forbs**	%	**Grasses**	%
ANDRPOL		ACHILLE		SAXICER		ARCTLAT	
ARCTALP		ANEMPAR		SAXIFOL		CALAMAG	
ARCTRUB		ANEMRIC		SAXIHIR		Dupontia	
BETUNAN		Antennaria		SAXINEL		Festuca	
CASSTET		Arabis sp.		SAXINIV		HIERALP	
DRYAINT		armemari		SAXIOPP		Poa	
EMPENIG		ARNIANG		SAXIRIV		Trisetum	
LEDUPAL		Artemisia		SAXITRI		CINNLAT	
RHODLAP		Aster		SILEACA			
SALIARC		Astragalus		TARAOFF			
SALIGLA		CERAALP		TEPHATR			
SALIPLA		CHRYTET		TOFICOC			
SALIRET		COCHGRO		TOFIPUS			
SALIRIC		COMAPAU				**Lichens:**	**%**
VACCULI		DRABALP				ALECTORIA	
VACCVIT		DRABGLA				ALECNIG	
		EPILANG				ALECOCH	
		Erigeron				CETRNIV	
		ERYSPAL		**Sedges:**	%	CETRCUC	
		HIPPVUL		CAREAQU		CLADINA	
		LUPIARC		CAREATR		CLADONIA	
		MERTMAR		CAREBIG		OPHILAP	
Fern/horsetail/clubmoss:	%	MINURUB		CARECAP		THAMVER	
		ORTHSEC		CAREMEM		XANTELE	
CYSTFRA		OXYRDIG		CARENAR		map	
DRYOFRA		OXYTARC		CARERUP		rock tripe	
EQUIARV		OXYTMAY		CARESCI		blk crustose	
HUPESEL		PAPARAD		ERIOANG			
LYCOANN		PEDIARC		ERIOSCH			
		PEDICAP		ERIOVAG			
		PEDILAB					
		PEDILAN					
		PEDILAP				**Mosses**	**%**
		PEDISUD				AULAPAL	
		PETAFRI				DICRELO	
		PETASAG		**Rushes**	%	HYLOSPL	
		POLYVIV		Juncus		RACOLAN	
		POTENIV		LUZUCON		SPHAGNU	
		PYROGRA		LUZUWAH		TOMENIT	
		RANUGME					
		RANUNIV					
		RANUPAL					
		RUBUCHA					

Appendix 3

2010 Wetland Habitat Information Form

Rescan™
Engineers and Scientists

WETLANDS:

Rescan Wetlands Ecosystem Survey Methodology

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1. Introduction

Wetlands are dynamic, low-lying or slightly sloping areas on the landscape that are saturated with water for a significant period of time during the growing season. Wetlands can range from sites that contain small, shallow areas of water that are present for only a few weeks after snow melt, to sites that comprise large, permanent open water zones (Stewart and Kantrud 1971) and peatland ecosystems. Wetland ecosystems fulfill a wide range of ecological, hydrological, biochemical and habitat functions (Environment Canada 2003; Environment Canada 2008). They maintain water quality, regulate water flow on the landscape and provide erosion control. They also provide habitat for a wide variety of wildlife, including many economically important game species (Natural Resources Canada 2009).

Wetlands are included in environmental baseline studies for a variety of large infrastructure and resource projects because guidance documents for environmental assessments in Canada and a number of provinces have identified wetlands as an ecosystem of special importance. Wetlands, in Canada, are managed and conserved through the Federal Policy of Wetland Conservation which states that there shall be "no net loss of wetland functions on all federal lands and waters". The Policy also states that the functions and values derived from wetlands will be maintained and wetlands will be enhanced and rehabilitated in areas of continuing loss and degradation (Environment Canada 1991). Generally wetland studies are planned to meet the requirements of the federal policy, however, exceptions are often made as this is a policy that is largely not applicable to non-federal projects.

Wetland studies are developed in consultation with hydrologists, aquatic biologists, and ecosystem mapping/wildlife scientists with the goal of identifying and, where possible quantifying wetland function. Wetland function is defined as the process or series of processes a wetland carries out such as its ability to regulate the local climate, filter surface water, recharge groundwater reserves, increase an areas ecosystem integrity, and provide wildlife habitat. Environment Canada (2003) has identified four primary functions which are typically the focus of wetland studies and consideration of wetland function is integral to wetland inventory methodology (Cox and Cullington 2009). Table 1 describes the primary functions and identifies which aspect of the wetland study data is collected to address a given function.

The following text presents the methodology for completing the ecosystem survey component of wetland studies. This is the largest aspect of wetland studies and provides valuable information for use in identifying, describing, and quantifying wetland function. This information also supports identification of wetland classes and associations, levels of permanence, and forms/subforms. It can be tailored to specific regions to meet specific delineation requirements or regional classification frameworks. The methodology presented below represents a general over and provides a solid base for incorporating regional specific data. This document describes the wetland classes of Canada (Warner and Rubec 1997), pre-fieldwork planning and equipment, vegetation/soil/water wetland data collection requirements, general study methodologies, and the wetland habitat information form (WHIF)

Table 1 Wetland Functions and Supporting Data

Wetland Function	Description	Supporting Data
Hydrological	Contribution of the wetland to the quantity of surface water and groundwater	Hydrology survey – Static and continuous data Ecosystem survey – Hydrodynamic indicators
Biogeochemical	Contribution of the wetland to the quality of surface water and groundwater	Ecosystem survey – Wetland classification, Aquatic biology survey – sediment and water chemistry Vegetation sampling – Tissue metal concentrations
Habitat	Relative abundance of terrestrial and aquatic habitat and connectivity to surrounding ecosystem	Ecosystem survey – Wetland classification Ecosystem survey – Wildlife observations
Ecological	Role of the wetland in the surrounding ecosystem	Ecosystem survey – Wetland classification Wetland classification – Red and blue listed ecosystems Wetland classification – Wetland complexes

2. Wetlands in Canada

Wetlands in Canada are classified according to the Canadian System of Wetland Classification (CSWC). All wetland baseline studies, environmental assessments, and surveys done on projects in Canada use the "Class" Description of wetlands presented in the CSWC. There are 5 classes (bog, fen, marsh, swamp, shallow open water). A description of each class, basic classification tools, and a representative site photo are provided below.

2.1 BOG CLASS

Description A bog is a nutrient-poor, *Sphagnum*-dominated peatland ecosystem in which the rooting zone is isolated from mineral-enriched groundwater, soils are acidic, and few minerotrophic plant species occur (MacKenzie and Moran, 2004).

Key Features Most bogs are treed; however, some can look similar to fens (open meadow like). The soil is less decomposed then fens and the pH is quite low (bogs have the lowest pH of any wetland). Trees are always conifers and there is always sphagnum moss.

pH < 5.5, Water movement is stagnant to sluggish, soil colour is often reddish brown and the soil is usually pretty spongy with visible bits of poorly decomposed sphagnum moss.

Photo

Plate 2.1-1 Treeless Bog – Northwest British Columbia

Plate 2.1-2 Treed Bog/Shallow Open Water Complex Northwest Territories

2.2 FEN CLASS

Description

A fen is a nutrient-medium peatland ecosystem dominated by sedges and brown mosses, where mineral-bearing groundwater is within the rooting zone and minerotrophic plant species are common (MacKenzie and Moran, 2004).

Key Features

Generally these are open "meadow like" ecosystem. There are not usually treed but occasionally trees can be present usually covering < 10% of an area (20 m by 20 m); at higher elevations dwarf tree species may be present in small clusters and are < 5 m tall. The dominant plants are sedges, mosses, and cotton grasses.

pH ~ 5.5 – 7.5, Water movement is stagnant to sluggish, soil colour is often reddish brown with visible bits of poorly decomposed moss and sedge.

Photo

Plate 2.2-1 Fen Complex Northwest British Columbia

Plate 2.2-2 Patterned Fen Northwest British Columbia

2.3 MARSH CLASS

Description: A marsh is a permanent or seasonally flooded non-tidal mineral wetland, dominated by emergent grass-like vegetation. Marshes may experience drawdown, which will result in portions drying up. They can typically recover from mechanical disturbance, provided their hydrology is maintained (MacKenzie and Moran, 2004).

Key Features Marshes are sedge dominated (though cattail and bulrush wetlands are also marshes) sites associated with open water. The ground is almost always covered by standing water. Soils are usually mineral and mucky; they have lots of nutrients so soils are dark. These sites never have trees and only occasionally have dwarf shrubs < 5% in a 20 m by 20 m area.

pH ~ > 7.0, Water movement is mobile to very dynamic,

Photo

Plate 2.3-1 Bulrush marsh/Shallow Open Water Complex Southern Interior British Columbia

Plate 2.3-2 Sedge Marsh Northwest British Columbia

2.4 SWAMP CLASS

Description

A swamp is a nutrient-rich wetland where significant groundwater inflow, periodic surface aeration, and elevated microsites support the growth of trees and tall shrubs (MacKenzie and Moran, 2004). Generally there is more than 30% tree cover and soils are often of the gleyed mineral group and can have a surface layer of anaerobically decomposed woody peat. There are three general physically different swamp communities (shrub-thicket, coniferous forest, and hardwood (deciduous) swamps) (Warner and Rubec, 1997).

Key Features

Swamps are mineral wetlands with lots of tree or tall shrub cover. Mineral wetland means their soil is black or very dark brown and feels slimy; they can also be gleyed which can look bluish-green sometimes with orange flecks. Shrubs are usually alder or willow and trees can be spruce, fir, or cedar. Tree/shrub cover is almost always > 5 m tall. Swamps can have a rolling micro-topography with trees growing on mounds and water filling the hollows.

pH ~ 5.5 – 7.5, Water movement is mobile to very dynamic, and soil is usually dark woody peat

Photo

Plate 2.4-1 Spruce/Horsetail Swamp Northwest British Columbia

2.5 SHALLOW OPEN WATER CLASS

Description

Shallow open-water wetlands are ecosystems permanently flooded by still or slow-moving water and dominated by rooted and floating leaved aquatic plants. Shallow open water wetlands are often the transition from bogs, fens, marshes, and swamps to permanent deep waterbodies (*i.e.*, sluggish streams and lakes) (Warner and Rubec, 1997; MacKenzie and Moran, 2004).

Key Features

These are basically ponds, or other areas of open water with emergent and submergeent vegetation < 2 m deep. They usually form a complex with other wetlands such as marshes but can also appear in fens and bogs where they have steep sides, very little vegetation and overhanging mats of peat. They usually have pond lily or pond weed.

Photo

Plate 2.5-1 Yellow Pond Lily Shallow Open Water Northwest British Columbia

Plate 2.5-2 Cattail Marsh Shallow Open Water Complex in Saskatchewan

3. Pre-fieldwork Planning and Equipment

As with any scientific study there are a number of considerations prior to field data collection that must be considered. The following is a condensed list of pre-field considerations.

- Check the work plan and budget to know specific studies being conducted and estimated field times.
- Review the kinds of wetlands that are expected from local, regional, and national wetland classification documents, Ducks Unlimited Canada, Natural Resources Canada, and/or RAMSAR
- Don't go into the field without large scale maps of the study area (1:5000 to 1:15000)
    - The wetland study area is usually the local development area which is often the TEM area.
- Organize your field equipment (see Table 2)
- Spend some time doing a pre-field reconnaissance to identify wetland/water features from the air. If you can see any wetlands focus on other aquatic features particularly in areas where development is expected.

Table 2 Suggested Wetland Field Equipment List

50 m eslon tape	Batteries	Flagging tape
Compass	Vegetation field guide(s)	Gumboots
Clinometer	Latex gloves	Waders
GPS	Ziploc bags	Rescan field safety manual
Range finder	pH Meter	VHF Radio
Field maps	Conductivity Meter	Sat-phone
Field notebook and data forms	Hand trowel	First aid kit
Pens, pencils, and sharpies	Soil auger	Bear bangers and spray
Digital Camera	Construction Tape Measure	

4. General Wetland Study Methodology

Once on site conduct an aerial or ground based reconnaissance level survey. This will help identify wetlands within the study area that need to be surveyed. At each survey site complete a wetland habitat information form (WHIF); some sites that are surveyed my not be wetlands but flood associations or shrub-carrs, or unclassified aquatic systems. Data on all of these ecosystems is important but wetlands are the focus of the survey. The following text describes information collected on the WHIF.

Before field surveys, equipment and field clothing should be cleaned using a 1% Virkon solution to prevent the spread of *Batrachochytrium dendrobatidis* between wetland sites. *B. dendrobatidis* is a pathogen for amphibians.

Establish a wetland plot center. Plots are 20 m×20 m and established in large uniform wetlands or at the centre of wetlands smaller than 400 m^2. The edges of wetlands smaller than 400 m^2 were used as the survey plot boundary. The wetland plot may include different associations or classes of wetlands.

Record the project ID, names of survey personnel, map sheet information, plot number, and survey date. This information should be collected as soon as a wetland survey plot is established. At the centre of the plot a GPS coordinate must be taken and photographs of the wetland, in each cardinal direction (starting at North) of the soil surface and of other significant features such as landforms, unique vegetation, and wildlife must also be collected. Record the GPS coordinates, elevation, and digital photo file number on the WHIF. Use a compass and clinometer to determine the average aspect and slope of the site. An aspect of 0 and slope of -1 indicates level ground.

Record the meso-slope position; which is the position of the plot relative to the local catchment area (Table 4.1).

Table 4.1 Meso-slope position descriptions

Meso-slope position	**Definition**
Crest	Upper most portion of a hill, convex in all directions, no distinct aspect.
Upper Slope	Generally the convex upper portion of the slope immediately below the crest of a hill; has a specific aspect.
Mid Slope	Area between the upper and lower slope has a straight or somewhat sigmoid surface profile with a specific aspect.
Lower Slope	The area toward the base of a slope; generally has a concave surface profile with a specific aspect.
Toe	The area demarcated from the lower slope by an abrupt decrease in slope gradient; seepage is typically present.
Depression	Any area concave in all directions; may be at the base of a meso-scale slope or in a generally level area
Level	Any level meso-scale area

Adapted from MOF 1998

Record the hydrogeomorphic; which describes the topographic position and hydrology of a site (Table 4.2).

Table 4.2 Hydrogeomorphic position descriptions

Hydrogeomorphic position	Definition
Estuarine	Sites at the confluence of fluvial and marine environments
Fluvial	Sites associated with flowing water, subject to flooding, erosion, and sedimentation
Lacustrine	Sites at lakeside
Basins and Hollows	Sites in depressions or topographic low points, receive water from groundwater or precipitation
Ponds and Potholes	Sites associated with Small water-bodies
Seepage slopes	Sloping sites with near surface groundwater seepage

Adapted from MacKenzie and Moran 2004

Identify vegetation within the survey plot; separately recording the tree/shrub species, forbs, and bryophytes. Estimate the percent cover of the species within each layer and estimate the percent ground cover by each layer. Each layer can add up to 100% but the sum of all layers can exceed 100%. Indicate if the vegetation list was complete or partial.

Establish a series of soil cores around the wetland; these can exceed the plot boundary but not the wetland boundary, though they may exceed the wetland boundary if confirmation of a wetland is needed. Look at all the soil cores within the wetland and describe soil properties on the WHIF using a representative core.

Determine the soil moisture regime (SMR) (Table 4.3).

Table 4.3 SMR descriptions

Soil Moisture Regime	Code	Definition
Moist	M	No water deficit (demand doesn't exceed supply), temporary groundwater table may be present. Generally supports forest.
Very Moist	VM	Rooting zone groundwater present during growing season. Groundwater table > 30 cm below ground surface. Unless otherwise limited supports forest
Wet	W	Sites at lakeside
Very Wet	VW	Sites in depressions or topographic low points, receive water from groundwater or precipitation

Adapted from MacKenzie and Moran 2004

Determine the Hydrodynamic Index (HDI) (Table 4.4).

Table 4.4 HDI descriptions

Hydrodynamic Index	Code	Definition/Indicators
Stagnant	St	Stagnant to very slow moving soil water, vertical fluctuations minimal, no evidence of flooding; lots of organic matter and high bryophyte cover
Sluggish	Sl	Gradual groundwater movement; patterned fens; brief periods of surface aeration
Mobile	Mo	Distinct flooding; open water tracks such as rivulets/ponds/potholes; well decomposed peat; patchy bryophyte cover.
Dynamic	Dy	Significant lateral flow and/or strong vertical fluctuations; pothole wetlands in arid climates; riparian/oxbow sites; little organic accumulation
Very Dynamic	VD	Highly dynamic surface water; exposed tidal sites; shallow potholes that dry completely; no organic matter accumulation or bryophytes.

Adapted from MacKenzie and Moran 2004

Determine the soil nutrient regime (SNR) (Table 4.5).

Table 4.5 SNR descriptions

Soil Nutrient Regime	Code	Indicators
Very Poor	A	HDI St, von post 1-3, tea coloured or yellowish water, pH < 5
Poor	B	HDI St-Sl, von post 3-6, tea coloured or yellowish water, possibly green-brown or clear, pH 4.5 - 6
Medium	C	HDI St-Mo, von post 4-7, tea coloured, yellowish, green-brown, or clear water, pH 5-6.5
Rich	D	HDI Sl-Dy, von post 7-10, green-brown and turbid water, pH 6-7.4
Very Rich	E	HDI Mo-Dy, von post 8-10, green-brown and turbid water, pH 6.5-8
Hyper	F	Excess salt accumulation, pH > 8, high conductivity

Adapted from MacKenzie and Moran 2004

Determine if mineral soils are present (silt, sand, or clay) and identify drainage (Table 4.6).

Table 4.6 Drainage Class for Mineral Soils

Drainage Class	Description
Very Rapid	Water is removed from the soil very rapidly in relation to supply. Water source is precipitation and available water storage capacity following precipitation is essentially nil. Soils are typically fragmental or skeletal, shallow, or both.
Rapid	Water is removed from the soil rapidly in relation to supply. Excess water flows downward if underlying material is pervious. Subsurface flow may occur on steep gradients during heavy rainfall. Water source is precipitation. Soils are generally coarse textured.
Well	Water is removed from the soil readily, but not rapidly. Excess water flows downward readily into underlying pervious material or laterally as subsurface flow. Water source is precipitation. On slopes, subsurface flow may occur for short durations, but additions are equaled by losses. Soils are generally intermediate in texture and lack restricting layers.
Mod. Well	Water is removed from the soil somewhat slowly in relation to supply because of imperviousness or lack of gradient. Precipitation is the dominant water source in medium- to fine-textured soils; precipitation and significant additions by subsurface flow are necessary in coarse-textured soils.
Imperfectly	Water is removed from the soil sufficiently slowly in relation to supply to keep the soil wet for a significant part of the growing season. Excess water moves slowly downward if precipitation is the major source. If subsurface water or groundwater (or both) is the main source, the flow rate may vary but the soil remains wet for a significant part of the growing season. Precipitation is the main source if available water storage capacity is high; contribution by subsurface or groundwater flow (or both) increases as available water storage capacity decreases. Soils generally have a wide range of texture, and some mottling is common.
Poorly	Water is removed so slowly in relation to supply that the soil remains wet for much of the time that it is not frozen. Excess water is evident in the soil for a large part of the time. Subsurface or groundwater flow (or both), in addition to precipitation, are the main water sources. A perched water table may be present. Soils are generally mottled and/or gleyed.
Level	Water is removed from the soil so slowly that the water table remains at or near the surface for most of the time the soil is not frozen. Groundwater flow and subsurface flow are the major water sources. Precipitation is less important, except where there is a perched water table with precipitation exceeding evapotranspiration. Typically associated with wetlands. For organic wetlands, also evaluate the soil moisture subclass, and when entering on the form, separate from drainage by a slash. For example, v/ac.

Adapted from MOF 1998

Determine if mineral soils are present (silt, sand, or clay) and mineral soil texture (Figure 4.1).

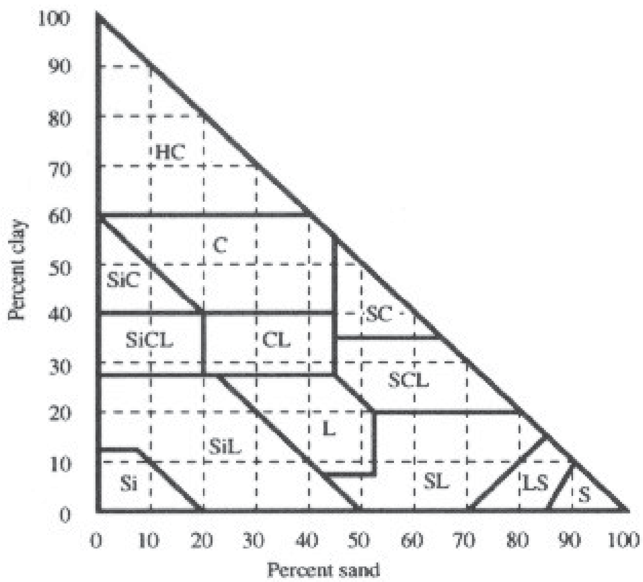

Figure 4.1 Soil Texture Triangle (MOF 1998)

Determine if Organic soils are present and identify moisture subclass (Table 4.7).

Table 4.7 Moisture Sub-class of Organic Soils

Moisture Sub-class	Description	Saturation period (mo.)
Aqueous	Free surface water	11.5-12
Peraquic	Soils saturated for very long periods	>10
Aquic	Soils saturated for moderately long periods	4-10
Subaquic	Soils saturated for short periods	<4
Perhumid	No significant water deficits in growing season	<2
Humid	Very slight deficit in growing season water availability	<0.5

Adapted from MOF 1998

Determine if Organic soils are present and identify the von post (Table 4.8).

Table 4.8 Von Posts

Von Post	Description
1	Completely undecomposed peat which, when squeezed, releases almost clear water. Plant remains easily identifiable. No amorphous material present.
2	Almost entirely undecomposed peat which, when squeezed, releases clear or yellowish water. Plant remains still easily identifiable. No amorphous material present.
3	Very slightly decomposed peat which, when squeezed, releases muddy brown water, but from which no peat passes between the fingers. Plant remains still identifiable, and no amorphous material present.
4	Slightly decomposed peat which, when squeezed, releases very muddy dark water. No peat is passed between the fingers but the plant remains are slightly pasty and have lost some of their identifiable features.
5	Moderately decomposed peat which, when squeezed, releases very “muddy” water with a very small amount of amorphous granular peat escaping between the fingers. The structure of the plant remains is quite indistinct although it is still possible to recognize certain features. The residue is very pasty.
6	Moderately highly decomposed peat with a very indistict plant structure. When squeezed, about one-third of the peat escapes between the fingers. The residue is very pasty but shows the plant structure more distinctly than before squeezing.
7	Highly decomposed peat. Contains a lot of amorphous material with very faintly recognizable plant structure. When squeezed, about one-half of the peat escapes between the fingers. The water, if any is released, is very dark and almost pasty.
8	Very highly decomposed peat with a large quantity of amorphous material and very indistinct plant structure. When squeezed, about two-thirds of the peat escapes between the fingers. A small quantity of pasty water may be released. The plant material remaining in the hand consists of residues such as roots and fibres that resist decomposition.
9	Practically fully decomposed peat in which there is hardly any recognizable plant structure. When squeezed it is a fairly uniform paste.
10	Completely decomposed peat with no discernible plant structure. When squeezed, all the wet peat escapes between the fingers.

Adapted from Ekono 1981

Determine if Organic soils are present and identify texture (Table 4.9).

Table 4.9 Organic Soil Texture

Texture	Description	Corresponding von post
Fibric	Visible and identifiable plant part, soil water clear	1-3
Mesic	Some visible plant parts, soil water slightly coloured	4-7
Humic	Muck!	8-10

Complete the soil and water descriptions by estimating the percentage of coarse fragments, measuring the depth of soil horizons (depth of organic layer, depth of mineral layer, depth to water, rooting depth, anything that looks interesting). Draw the soil profile, indicate the depth to all features, record the pH, conductivity, and estimate the percentage of open water. The pH and conductivity should be measured within the soil matrix and in open water features within the wetland as well. The colour of main open water feature should also be identified.

Identify vegetation species and record in the appropriate section of the field form. Ensure that shrubs (woody plants) are recorded in the appropriate area. Estimate the percent cover of each individual species, estimate the percent cover of species guilds, and indicate if the vegetation identification was complete or partial.

Complete the remainder of the WHIF by recording all wildlife observations, drawing the wetland, attempting wetland classification, and identifying wetland communities within a continuous ecosystem unit.

5. Wetland Habitat Information Form (WHIF)

The following form is the Wetland Habitat Information Form (WHIF). It was developed in 2010 and builds heavily off the Ground Inspection Form (GIF). Filed methods were developed for completing the Ground Inspection Form in wetland ecosystems (MacKenzie 1999); however, there were a number of data requirements not included in the GIF that have been added to the WHIF, such as a space for the hydrodynamic index, hydrogeomorphic position, and von post. Please provide any comments or suggestions to Wade Brunham regarding the layout and content of the WHIF.

Rescan Engineers & Scientists — WETLAND HABITAT INFORMATION FORM

W ☐ T ☐	PHOTO	X:	Y:	DATE

PROJECT ID	SURV.
MAPSHEET	PLOT #

UTM ZONE	NORTH	EAST

ASPECT	ELEVATION

SLOPE %	SMR	HDI	SNR

MESO SLOPE POSITION	☐ Crest ☐ Upper slope	☐ Mid slope ☐ Lower slope ☐ Toe	☐ Depression ☐ Level
HYDROGEO-MORPHIC POSITION	☐ Estuarine ☐ Fluvial	☐ Lacustrine ☐ Ponds & Potholes	☐ Basins & Hollows ☐ Seepage Slopes
DRAINAGE - MINERAL SOILS	☐ Very rapidly ☐ Rapidly	☐ Well ☐ Mod. well ☐ Imperfectly	☐ Poorly ☐ Very poorly
MINERAL SOIL TEXTURE	☐ Sandy (LS,S) ☐ Loamy (SL,L,SCL,FSL)	☐ Silty (SiL,Si) ☐ Clayey (SiCL,CL,SC,SiC,C)	
MOISTURE SUBCLASSES ORGANIC SOIL	☐ Aqueous ☐ Peraquic	☐ Aquic ☐ Subaquic	☐ Perhumid ☐ Humid

ORGANIC SOIL TEXTURE			SURF. ORGANIC HORIZON THICKNESS
☐ Fibric	☐ Mesic	☐ Humic	___________ cm
HUMUS FORM			ROOTING DEPTH
☐ Mor	☐ Moder	☐ Mull	Depth ______ cm Type ___________

VON POST

1	2	3	4	5	6	7	8	9	10

COARSE FRAGMENT CONTENT

☐ < 20% ☐ 20-35% ☐ 35-70% ☐ > 70%

ECOSYSTEM COMPONENT: ☐ WL1 ☐ WL2 ☐ WL3

BGC UNIT	WETLAND CLASS
SITE SERIES	ASSOCIATION
STRUCTURAL STAGE	MODIFIER

WETLAND POLYGON SUMMARY

	%	CLASS	ASSOCIATION
WL1			
WL2			
WL3			

WB-RES10-01 100510

WETLAND MAP

Features to include: North arrow, wildlife features, open water, slope, vegetation communities, wetland boundary, direction of water flow, soil core locations.

NOTES

DOMINANT / INDICATOR PLANT SPECIES

TOTAL %	TALL TREE	TREE / SHRUB	FORB	BRYOP.

TREE / SHRUB	%	FORB	%	FORB cont'd	%
				BRYOP.	%

☐ COMPLETE ☐ PARTIAL

WATER COLOUR

- ☐ Tea Coloured
- ☐ Yellow-Deep Brown Turbid
- ☐ Green-Brown Clear
- ☐ Green-Brown Turbid
- ☐ Blue-Green Clear

pH	CONDUCTIVITY	% OPEN WATER	DEPTH TO WATER

SOIL PROFILE	WILDLIFE OBSERVATIONS	
	SPECIES	FEATURE

Adapted from Ground Inspection Form: FS FS212-2(1) HRE 98/5-7610000694

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Appendix 4

Potentially Occurring At Risk or Sensitive Plant Species

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Appendix 4. Potentially Occurring At Risk or Sensitive Plant Species

Common Name	Scientific Name	Group	Family	NWT GSRank	COSEWIC Status	Ecozones
Yukon Fleabane	*Erigeron yukonensis*	Plant	Asteraceae	May Be At Risk	-	Southen Arctic, Taiga Plains, Boreal Cordillera
Pygmy Wood Aster	*Eurybia pygmaea (Lindl.) Nesom. (Aster pygmaeus Lindl. ; Aster sibiricus var. pygmaeus (Lindl.) Cody)*	Plant	Asteraceae	May Be At Risk	-	Northern Arctic, Southen Arctic
Saltwater Cress	*Arabidopsis salsuginea (Thellungiella salsuginea)*	Plant	Brassicaceae	May Be At Risk	-	Southen Arctic, Boreal Plains
Hairy Rockcress (Pilose Braya)	*Braya pilosa*	Plant	Brassicaceae	May Be At Risk	-	Southen Arctic
Yellowstone Whitlow-grass	*Draba incerta*	Plant	Brassicaceae	May Be At Risk	-	Southen Arctic, Taiga Cordillera, Taiga Plains
Persistent-sepal Yellowcress	*Rorippa calycina*	Plant	Brassicaceae	May Be At Risk	-	Southen Arctic
Gmelin's Orache	*Atriplex gmelinii*	Plant	Chenopodiaceae	May Be At Risk	-	Southen Arctic
Mackenzie Sedge	*Carex mackenziei (Carex norvegica Willdenow ex Schkuhr, Besch. Riedgrä)*	Plant	Cyperaceae	May Be At Risk	-	Taiga Plains, Southen Arctic
Moss Heather	*Harrimanella hypnoides (Cassiope hypnoides)*	Plant	Ericaceae	May Be At Risk	-	Arctic Cordillera, Northern Arctic, Southen Arctic
Beach Pea	*Lathyrus japonicus*	Plant	Fabaceae	May Be At Risk	-	Southen Arctic, Taiga Plains
Slender Rock-brake	*Cryptogramma stelleri*	Plant	Pteridaceae	May Be At Risk	-	Southen Arctic, Taiga Cordillera, Taiga Plains
Dane's Gentian	*Gentianella tenella*	Plant	Gentianaceae	May Be At Risk	-	Northern Arctic, Southen Arctic
Alternate-flower Water Milfoil	*Myriophyllum alterniflorum*	Plant	Haloragaceae	May Be At Risk	-	Southen Arctic, Taiga Plains
Drummond Bluebell	*Mertensia drummondii*	Plant	Boraginaceae	May Be At Risk	-	Northern Arctic, Southen Arctic
Mingan Moonwort	*Botrychium minganense*	Plant	Ophioglossaceae	May Be At Risk	-	Southen Arctic, Taiga Cordillera, Taiga Plains
Seaside Plantain	*Plantago maritima (Plantago juncoides)*	Plant	Plantaginaceae	May Be At Risk	-	Northern Arctic, Southen Arctic, Taiga Plains
Arctic Seashore Willow	*Salix ovalifolia (S. ovalifolia var. arctolitoralis)*	Plant	Salicaceae	May Be At Risk	-	Southen Arctic, Taiga Plains
Wedgeleaf Willow	*Salix sphenophylla*	Plant	Salicaceae	May Be At Risk	-	Southen Arctic
Northern Mudwort	*Limosella aquatica*	Plant	Scrophulariaceae	May Be At Risk	-	Southen Arctic, Taiga Plains, Taiga Shield
Muskeg Lousewort	*Pedicularis macrodonta (syn Pedicularis parviflora var. macrodonta (Richards.)*	Plant	Scrophulariaceae	May Be At Risk	-	Southen Arctic, Taiga Plains
Pale False Dandelion	*Agoseris glauca*	Plant	Asteraceae	Sensitive	-	Southen Arctic, Taiga Plains, Taiga Shield
Three-fork Sagebrush	*Artemisia furcata (Artemisia hyperborea)*	Plant	Asteraceae	Sensitive	-	Southen Arctic, Taiga Plains
Arctic Daisy	*Dendranthema arcticum (Chrysanthemum arcticum)*	Plant	Asteraceae	Sensitive	-	Southen Arctic, Taiga Plains
Four-leaved Marestail	*Hippuris tetraphylla*	Plant	Hippuridaceae	Sensitive	-	Southen Arctic, Taiga Plains
Arctic Rockcress	*Arabis arenicola*	Plant	Brassicaceae	Sensitive	-	Northern Arctic, Southen Arctic, Taiga Shield
Boreal Whitlow-grass	*Draba borealis*	Plant	Brassicaceae	Sensitive	-	Southen Arctic, Taiga Plains
Snowbed Whitlow-grass	*Draba crassifolia*	Plant	Brassicaceae	Sensitive	-	Southen Arctic
Yukon Stitchwort	*Minuartia yukonensis (Arenaria laricifolia)*	Plant	Caryophyllaceae	Sensitive	-	Taiga Plains, Southen Arctic
Creeping Campion	*Silene repens*	Plant	Caryophyllaceae	Sensitive	-	Southen Arctic, Taiga Plains
Sorensen's Campion	*Silene sorensenis*	Plant	Caryophyllaceae	Sensitive	-	Northern Arctic, Southen Arctic
Rocky Mountain Goosefoot	*Chenopodium salinum (Chenopodim gaucum var. salinum)*	Plant	Chenopodiaceae	Sensitive	-	Southen Arctic, Taiga Plains
Horned Sea-blite	*Suaeda calceoliformis*	Plant	Chenopodiaceae	Sensitive	-	Southen Arctic, Taiga Plains, Boreal Plains
White Sea-blite	*Suaeda maritima*	Plant	Chenopodiaceae	Sensitive	-	Southen Arctic
Water Blinks	*Montia fontana (syn Montia lamprosperma, Claytonia fontana)*	Plant	Portulacaceae	Sensitive	-	Southen Arctic, Taiga Cordillera, Taiga Plains
Circumpolar Sedge	*Carex adelostoma (Carex morrisseyi)*	Plant	Cyperaceae	Sensitive	-	Southen Arctic, Taiga Shield
Gravel Sedge	*Carex glareosa (Carex glareosa Wahlenberg subsp. glareosa ;Carex amphigena (Fernald) Mackenzie; C. cryptantha T. Holm; C. glareosa var. amphigena Fernald))*	Plant	Cyperaceae	Sensitive	-	Northern Arctic, Southen Arctic

Appendix 4. Potentially Occurring At Risk or Sensitive Plant Species

Common Name	Scientific Name	Group	Family	NWT GSRank	COSEWIC Status	Ecozones
Circumpolar Reed Grass	*Calamagrostis deschampsioides*	Plant	Poaceae	Sensitive	-	Southen Arctic
Anderson's Alkali Grass	*Puccinellia andersonii*	Plant	Poaceae	Sensitive	-	Northern Arctic, Southen Arctic
Prince Patrick Alkali Grass (Goose Grass)	*Puccinellia bruggemannii*	Plant	Poaceae	Sensitive	-	Northern Arctic, Southen Arctic
Polar Nuttall's Alkali Grass	*Puccinellia nuttalliana (Puccinellia deschampsioides, Puccinillia borealis?, and incl Puccinellia interior)*	Plant	Poaceae	Sensitive	-	Southen Arctic, Taiga Plains, Taiga Shield
Arctic Tussock Alkali Grass	*Puccinellia vaginata*	Plant	Poaceae	Sensitive	-	Southen Arctic
Purple Mountain Heather	*Phyllodoce caerulea*	Plant	Ericaceae	Sensitive	-	Northern Arctic, Southen Arctic, Taiga Shield
Alpine Cliff-fern (Northern Woodsia)	*Woodsia alpina*	Plant	Dryopteridaceae	Sensitive	-	Arctic Cordillera, Northern Arctic, Southen Arctic, Taiga Cordillera, Taiga Plains
Northern Beech Fern	*Phegopteris connectilis (Dryopteris phegopteris, Thelypteris phegopteris)*	Plant	Thelypteridaceae	Sensitive	-	Taiga Cordillera, Southen Arctic, Taiga Shield
Sea Bluebell	*Mertensia martitima*	Plant	Boraginaceae	Sensitive	-	Northern Arctic, Southen Arctic, Taiga Plains
Arctic Willowherb	*Epilobium arcticum*	Plant	Onagraceae	Sensitive	-	Arctic Cordillera, Northern Arctic, Southen Arctic, Taiga Plains
Dauria Willowherb	*Epilobium davuricum*	Plant	Onagraceae	Sensitive	-	Southen Arctic, Taiga Plains, Taiga Shield
Blunt-leaf Pondweed	*Potamogeton obtusifolius*	Plant	Potamogetonaceae	Sensitive	-	Southen Arctic, Taiga Shield
Yenisei River Pondweed	*Potamogeton subsibiricus (Potamogeton porsildiorum)*	Plant	Potamogetonaceae	Sensitive	-	Southen Arctic, Taiga Plains
Iceland Purslane	*Koenigia islandica*	Plant	Polygonaceae	Sensitive	-	Northern Arctic, Southen Arctic, Boreal Cordillera
Alaska Knotweed	*Polygonum humifusum ssp caurianum (Polygonum caurianum)*	Plant	Polygonaceae	Sensitive	-	Southen Arctic, Taiga Plains
Slender Primrose	*Primula borealis*	Plant	Primulaceae	Sensitive	-	Southen Arctic, Taiga Plains
Floating Marsh Marigold	*Caltha natans*	Plant	Ranunculaceae	Sensitive	-	Southen Arctic, Taiga Plains, Taiga Shield
Pallas' Buttercup	*Ranunculus pallasii*	Plant	Ranunculaceae	Sensitive	-	Southen Arctic, Taiga Plains
Sardinain Buttercup	*Ranunculus sabinei (Ranunculus pygmaeus ssp.sabinei)*	Plant	Ranunculaceae	Sensitive	-	Northern Arctic, Southen Arctic
Egede Cinquefoil	*Argentina egedii (Potentilla egedii)*	Plant	Rosaceae	Sensitive	-	Southen Arctic, Taiga Plains
Arizona Cinquefoil	*Sibbaldia procumbens*	Plant	Rosaceae	Sensitive	-	Southen Arctic, Taiga Cordillera, Taiga Plains, Taiga Shield, Boreal Cordillera
Halberd Willow	*Salix hastata (syn Salix farriae var. walpolei)*	Plant	Salicaceae	Sensitive	-	Southen Arctic, Taiga Plains
Northern Indian Paintbrush	*Castilleja hyperborea*	Plant	Scrophulariaceae	Sensitive	-	Southen Arctic, Taiga Cordillera, Taiga Plains
Red-tip Lousewort	*Pedicularis flammea*	Plant	Scrophulariaceae	Sensitive	-	Northern Arctic, Southen Arctic, Taiga Plains, Taiga Shield
Richarson's Phlox	*Phlox richardsonii (incl. spp alaskensis, syn P. alaskensis (P. richardsonii ssp alaskensis), P. sibirica ssp alaskensis)*	Plant	Polemoniaceae	Sensitive	-	Northern Arctic, Southen Arctic, Taiga Plains
Showy Jacob's Ladder	*Polemonium pulcherrimum*	Plant	Polemoniaceae	Sensitive	-	Southen Arctic, Taiga Cordillera, Taiga Plains
Smooth White Violet	*Viola macloskeyi (Viola pallens)*	Plant	Violaceae	Sensitive	-	Southen Arctic, Taiga Plains, Taiga Shield
Alpine Marsh Violet	*Viola palustris*	Plant	Violaceae	Sensitive	-	Southen Arctic, Taiga Shield

Source:Northwest Territories Environment and Natural Resources. 2010.NWT Species Monitoring Infobase http://www.enr.gov.nt.ca/_live/pages/wpPages/Infobase.aspx (accessed December 2010).
Gau, R. 2010. Wildlife Biologist (Species at Risk), Wildlife Division, Department of Environment & Natural Resources, Government of the Northwest Territories, Yellowknife; June 28, 2010.

Appendix 5

Invasive Plant Species Known to Occur in Nunavut or the Northwest Territories

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Engineers and Scientists

Appendix 5. Invasive Plant Species Known to Occur in Nunavut or the Northwest Territories

Scientific Name	Common Name	Predicted Invasiveness
Bromus inermis	awnless brome	moderate/low
Caragana arborescens	caragana	low
Cirsium arvense	creeping thistle	moderate/low
Medicago sativa	alfalfa	low
Phalaris arundinacea	reed canary grass	moderate/low
Poa compressa	flat-stem blue grass	minor
Agropyron cristatum spp pectinatum	crested wheat grass	low/potential
Poa pratensis	Kentucky blue grass	minor
Tanacetum vulgare	common tansy	potential
Atriplex patula	spear saltbush	not rated
Berteoa incana	hoary false-alyssum	low
Leucanthemum vulgare	oxeye daisy	not rated
Matricaria discoidea	pineapple chamomile	not rated
Melilotus alba	sweet white clover	moderate
Melilotus officinalis	yellow sweet clover	moderate
Puccinellia distans	spreading alkaligrass	not rated
Ranunculus acris var. acris	tall buttercup	not rated
Taraxacum officinale officinale	common dandelion	not rated
Tripleurospermum maritima	scentless chamomile	not rated
Vicia cracca	tufted vetch	not rated

Additional invasive species have been documented to occur in the Northwest Territories (See Oldham, M., 2006, 2006 Survey of Exotic Plants along Northwest Territories Highways, Report to the GNWT).

The invasive plant list was compiled from the following resources:

Northwest Territories Environment and Natural Resources. 2010.NWT Species Monitoring Infobase http://www.enr.gov.nt.ca/_live/pages/wpPages/Infobase.aspx (accessed December 2010).

The Invasive Species Specialist Group (ISSG) Global Invasive Species Database. http://www.issg.org/database/species/search.asp?sts=sss&st=sss&fr=1&sn=&rn=Nunavut&hci=-1&ei=-1&lang=EN (accessed December 2010)

Evergreen Native Plant Database. http://nativeplants.evergreen.ca/search/search-results.php?mode=guided&province=NU&type=invasive (accessed December 2010)

Appendix 6

Detection Limits for Metals Analysis

Appendix 6. Detection Limits for Metals Analysis

Sample ID	Measurement Units	D73 FLAVOCETRARIA CUCULLATA	D82 FLAVOCETRARIA CUCULLATA	D114 FLAVOCETRARIA CUCULLATA	023 FLAVOCETRARIA CUCULLATA	021 FLAVOCETRARIA CUCULLATA	010 FLAVOCETRARIA CUCULLATA	011 FLAVOCETRARIA CUCULLATA	024 FLAVOCETRARIA CUCULLATA	D63 FLAVOCETRARIA NIVALIS
Physical Tests										
% Moisture	%	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10
Metals										
Aluminum (Al)	mg/kg	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0
Aluminum (Al)	mg/kg wwt	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.40
Antimony (Sb)	mg/kg	0.010	0.010	0.010	0.010	0.010	0.010	0.010	0.010	0.010
Antimony (Sb)	mg/kg wwt	0.0020	0.0020	0.0020	0.0020	0.0020	0.0020	0.0020	0.0020	0.0020
Arsenic (As)	mg/kg	0.020	0.020	0.020	0.020	0.020	0.020	0.020	0.020	0.020
Arsenic (As)	mg/kg wwt	0.0040	0.0040	0.0040	0.0040	0.0040	0.0040	0.0040	0.0040	0.0040
Barium (Ba)	mg/kg	0.050	0.050	0.050	0.050	0.050	0.050	0.050	0.050	0.050
Barium (Ba)	mg/kg wwt	0.010	0.010	0.010	0.010	0.010	0.010	0.010	0.010	0.010
Beryllium (Be)	mg/kg	0.010	0.010	0.010	0.010	0.010	0.010	0.010	0.010	0.010
Beryllium (Be)	mg/kg wwt	0.0020	0.0020	0.0020	0.0020	0.0020	0.0020	0.0020	0.0020	0.0020
Bismuth (Bi)	mg/kg	0.010	0.010	0.010	0.010	0.010	0.010	0.010	0.010	0.010
Bismuth (Bi)	mg/kg wwt	0.0020	0.0020	0.0020	0.0020	0.0020	0.0020	0.0020	0.0020	0.0020
Boron (B)	mg/kg	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
Boron (B)	mg/kg wwt	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20
Cadmium (Cd)	mg/kg	0.010	0.010	0.010	0.010	0.010	0.010	0.010	0.010	0.010
Cadmium (Cd)	mg/kg wwt	0.0020	0.0020	0.0020	0.0020	0.0020	0.0020	0.0020	0.0020	0.0020
Calcium (Ca)	mg/kg	30	30	30	30	30	30	30	30	30
Calcium (Ca)	mg/kg wwt	23	18	15	10	13	18	20	18	18
Cesium (Cs)	mg/kg	0.0050	0.0050	0.0050	0.0050	0.0050	0.0050	0.0050	0.0050	0.0050
Cesium (Cs)	mg/kg wwt	0.0010	0.0010	0.0010	0.0010	0.0010	0.0010	0.0010	0.0010	0.0010
Chromium (Cr)	mg/kg	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20
Chromium (Cr)	mg/kg wwt	0.040	0.040	0.040	0.040	0.040	0.040	0.040	0.040	0.040
Cobalt (Co)	mg/kg	0.020	0.020	0.020	0.020	0.020	0.020	0.020	0.020	0.020
Cobalt (Co)	mg/kg wwt	0.0040	0.0040	0.0040	0.0040	0.0040	0.0040	0.0040	0.0040	0.0040
Copper (Cu)	mg/kg	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10
Copper (Cu)	mg/kg wwt	0.020	0.020	0.020	0.020	0.020	0.020	0.020	0.020	0.020
Gallium (Ga)	mg/kg	0.020	0.020	0.020	0.020	0.020	0.020	0.020	0.020	0.020
Gallium (Ga)	mg/kg wwt	0.0040	0.0040	0.0040	0.0040	0.0040	0.0040	0.0040	0.0040	0.0040
Iron (Fe)	mg/kg	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
Iron (Fe)	mg/kg wwt	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20
Lead (Pb)	mg/kg	0.020	0.020	0.020	0.020	0.020	0.020	0.020	0.020	0.020
Lead (Pb)	mg/kg wwt	0.0040	0.0040	0.0040	0.0040	0.0040	0.0040	0.0040	0.0040	0.0040
Lithium (Li)	mg/kg	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10
Lithium (Li)	mg/kg wwt	0.020	0.020	0.020	0.020	0.020	0.020	0.020	0.020	0.020
Magnesium (Mg)	mg/kg	50	50	50	50	50	50	50	50	50
Magnesium (Mg)	mg/kg wwt	45	35	30	20	25	35	40	35	35
Manganese (Mn)	mg/kg	0.020	0.020	0.020	0.020	0.020	0.020	0.020	0.020	0.020
Manganese (Mn)	mg/kg wwt	0.0040	0.0040	0.0040	0.0040	0.0040	0.0040	0.0040	0.0040	0.0040
Mercury (Hg)	mg/kg	0.0050	0.0050	0.0050	0.0050	0.0050	0.0050	0.0050	0.0050	0.0050
Mercury (Hg)	mg/kg wwt	0.0010	0.0010	0.0010	0.0010	0.0010	0.0010	0.0010	0.0010	0.0010
Molybdenum (Mo)	mg/kg	0.020	0.020	0.020	0.020	0.020	0.020	0.020	0.020	0.020
Molybdenum (Mo)	mg/kg wwt	0.0040	0.0040	0.0040	0.0040	0.0040	0.0040	0.0040	0.0040	0.0040
Nickel (Ni)	mg/kg	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10
Nickel (Ni)	mg/kg wwt	0.020	0.020	0.020	0.020	0.020	0.020	0.020	0.020	0.020
Phosphorus (P)	mg/kg	200	200	200	200	200	200	200	200	200
Phosphorus (P)	mg/kg wwt	225	175	150	100	125	175	200	175	175
Potassium (K)	mg/kg	1000	1000	1000	1000	1000	1000	1000	1000	1000
Potassium (K)	mg/kg wwt	900	700	600	400	500	700	800	700	700
Rhenium (Re)	mg/kg	0.010	0.010	0.010	0.010	0.010	0.010	0.010	0.010	0.010
Rhenium (Re)	mg/kg wwt	0.0020	0.0020	0.0020	0.0020	0.0020	0.0020	0.0020	0.0020	0.0020
Rubidium (Rb)	mg/kg	0.050	0.050	0.050	0.050	0.050	0.050	0.050	0.050	0.050
Rubidium (Rb)	mg/kg wwt	0.010	0.010	0.010	0.010	0.010	0.010	0.010	0.010	0.010
Selenium (Se)	mg/kg	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10
Selenium (Se)	mg/kg wwt	0.020	0.020	0.020	0.020	0.020	0.020	0.020	0.020	0.020
Silver (Ag)	mg/kg	0.0050	0.0050	0.0050	0.0050	0.0050	0.0050	0.0050	0.0050	0.0050
Silver (Ag)	mg/kg wwt	0.0010	0.0010	0.0010	0.0010	0.0010	0.0010	0.0010	0.0010	0.0010
Sodium (Na)	mg/kg	1000	1000	1000	1000	1000	1000	1000	1000	1000
Sodium (Na)	mg/kg wwt	900	700	600	400	500	700	800	700	700
Strontium (Sr)	mg/kg	0.050	0.050	0.050	0.050	0.050	0.050	0.050	0.050	0.050
Strontium (Sr)	mg/kg wwt	0.010	0.010	0.010	0.010	0.010	0.010	0.010	0.010	0.010
Tellurium (Te)	mg/kg	0.020	0.020	0.020	0.020	0.020	0.020	0.020	0.020	0.020
Tellurium (Te)	mg/kg wwt	0.0040	0.0040	0.0040	0.0040	0.0040	0.0040	0.0040	0.0040	0.0040
Thallium (Tl)	mg/kg	0.0020	0.0020	0.0020	0.0020	0.0020	0.0020	0.0020	0.0020	0.0020
Thallium (Tl)	mg/kg wwt	0.00040	0.00040	0.00040	0.00040	0.00040	0.00040	0.00040	0.00040	0.00040
Thorium (Th)	mg/kg	0.010	0.010	0.010	0.010	0.010	0.010	0.010	0.010	0.010
Thorium (Th)	mg/kg wwt	0.0020	0.0020	0.0020	0.0020	0.0020	0.0020	0.0020	0.0020	0.0020
Tin (Sn)	mg/kg	0.020	0.020	0.020	0.020	0.020	0.020	0.020	0.020	0.020
Tin (Sn)	mg/kg wwt	0.0040	0.0040	0.0040	0.0040	0.0040	0.0040	0.0040	0.0040	0.0040
Titanium (Ti)	mg/kg	0.050	0.050	0.050	0.050	0.050	0.050	0.050	0.050	0.050
Titanium (Ti)	mg/kg wwt	0.010	0.010	0.010	0.010	0.010	0.010	0.010	0.010	0.010
Uranium (U)	mg/kg	0.0020	0.0020	0.0020	0.0020	0.0020	0.0020	0.0020	0.0020	0.0020
Uranium (U)	mg/kg wwt	0.00040	0.00040	0.00040	0.00040	0.00040	0.00040	0.00040	0.00040	0.00040
Vanadium (V)	mg/kg	0.020	0.020	0.020	0.020	0.020	0.020	0.020	0.020	0.020
Vanadium (V)	mg/kg wwt	0.0040	0.0040	0.0040	0.0040	0.0040	0.0040	0.0040	0.0040	0.0040
Yttrium (Y)	mg/kg	0.010	0.010	0.010	0.010	0.010	0.010	0.010	0.010	0.010
Yttrium (Y)	mg/kg wwt	0.0020	0.0020	0.0020	0.0020	0.0020	0.0020	0.0020	0.0020	0.0020
Zinc (Zn)	mg/kg	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50
Zinc (Zn)	mg/kg wwt	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10
Zirconium (Zr)	mg/kg	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20
Zirconium (Zr)	mg/kg wwt	0.040	0.040	0.040	0.040	0.040	0.040	0.040	0.040	0.040

Appendix 6. Detection Limits for Metals Analysis

Sample ID	Measurement Units	D65 FLAVOCETRARIA NIVALIS	D62 FLAVOCETRARIA NIVALIS	D89 FLAVOCETRARIA NIVALIS	D97 FLAVOCETRARIA NIVALIS	D93 FLAVOCETRARIA NIVALIS	D116 FLAVOCETRARIA NIVALIS	D86 FLAVOCETRARIA NIVALIS	D114 FLAVOCETRARIA NIVALIS	D125 FLAVOCETRARIA NIVALIS
Physical Tests										
% Moisture	%	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10
Metals										
Aluminum (Al)	mg/kg	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0
Aluminum (Al)	mg/kg wwt	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.40
Antimony (Sb)	mg/kg	0.010	0.010	0.010	0.010	0.010	0.010	0.010	0.010	0.010
Antimony (Sb)	mg/kg wwt	0.0020	0.0020	0.0020	0.0020	0.0020	0.0020	0.0020	0.0020	0.0020
Arsenic (As)	mg/kg	0.020	0.020	0.020	0.020	0.020	0.020	0.020	0.020	0.020
Arsenic (As)	mg/kg wwt	0.0040	0.0040	0.0040	0.0040	0.0040	0.0040	0.0040	0.0040	0.0040
Barium (Ba)	mg/kg	0.050	0.050	0.050	0.050	0.050	0.050	0.050	0.050	0.050
Barium (Ba)	mg/kg wwt	0.010	0.010	0.010	0.010	0.010	0.010	0.010	0.010	0.010
Beryllium (Be)	mg/kg	0.010	0.010	0.010	0.010	0.010	0.010	0.010	0.010	0.010
Beryllium (Be)	mg/kg wwt	0.0020	0.0020	0.0020	0.0020	0.0020	0.0020	0.0020	0.0020	0.0020
Bismuth (Bi)	mg/kg	0.010	0.010	0.010	0.010	0.010	0.010	0.010	0.010	0.010
Bismuth (Bi)	mg/kg wwt	0.0020	0.0020	0.0020	0.0020	0.0020	0.0020	0.0020	0.0020	0.0020
Boron (B)	mg/kg	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
Boron (B)	mg/kg wwt	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20
Cadmium (Cd)	mg/kg	0.010	0.010	0.010	0.010	0.010	0.010	0.010	0.010	0.010
Cadmium (Cd)	mg/kg wwt	0.0020	0.0020	0.0020	0.0020	0.0020	0.0020	0.0020	0.0020	0.0020
Calcium (Ca)	mg/kg	30	30	30	30	30	30	30	30	30
Calcium (Ca)	mg/kg wwt	23	15	18	23	20	20	20	18	20
Cesium (Cs)	mg/kg	0.0050	0.0050	0.0050	0.0050	0.0050	0.0050	0.0050	0.0050	0.0050
Cesium (Cs)	mg/kg wwt	0.0010	0.0010	0.0010	0.0010	0.0010	0.0010	0.0010	0.0010	0.0010
Chromium (Cr)	mg/kg	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20
Chromium (Cr)	mg/kg wwt	0.040	0.040	0.040	0.040	0.040	0.040	0.040	0.040	0.040
Cobalt (Co)	mg/kg	0.020	0.020	0.020	0.020	0.020	0.020	0.020	0.020	0.020
Cobalt (Co)	mg/kg wwt	0.0040	0.0040	0.0040	0.0040	0.0040	0.0040	0.0040	0.0040	0.0040
Copper (Cu)	mg/kg	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10
Copper (Cu)	mg/kg wwt	0.020	0.020	0.020	0.020	0.020	0.020	0.020	0.020	0.020
Gallium (Ga)	mg/kg	0.020	0.020	0.020	0.020	0.020	0.020	0.020	0.020	0.020
Gallium (Ga)	mg/kg wwt	0.0040	0.0040	0.0040	0.0040	0.0040	0.0040	0.0040	0.0040	0.0040
Iron (Fe)	mg/kg	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
Iron (Fe)	mg/kg wwt	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20
Lead (Pb)	mg/kg	0.020	0.020	0.020	0.020	0.020	0.020	0.020	0.020	0.020
Lead (Pb)	mg/kg wwt	0.0040	0.0040	0.0040	0.0040	0.0040	0.0040	0.0040	0.0040	0.0040
Lithium (Li)	mg/kg	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10
Lithium (Li)	mg/kg wwt	0.020	0.020	0.020	0.020	0.020	0.020	0.020	0.020	0.020
Magnesium (Mg)	mg/kg	50	50	50	50	50	50	50	50	50
Magnesium (Mg)	mg/kg wwt	45	30	35	45	40	40	40	35	40
Manganese (Mn)	mg/kg	0.020	0.020	0.020	0.020	0.020	0.020	0.020	0.020	0.020
Manganese (Mn)	mg/kg wwt	0.0040	0.0040	0.0040	0.0040	0.0040	0.0040	0.0040	0.0040	0.0040
Mercury (Hg)	mg/kg	0.0050	0.0050	0.0050	0.0050	0.0050	0.0050	0.0050	0.0050	0.0050
Mercury (Hg)	mg/kg wwt	0.0010	0.0010	0.0010	0.0010	0.0010	0.0010	0.0010	0.0010	0.0010
Molybdenum (Mo)	mg/kg	0.020	0.020	0.020	0.020	0.020	0.020	0.020	0.020	0.020
Molybdenum (Mo)	mg/kg wwt	0.0040	0.0040	0.0040	0.0040	0.0040	0.0040	0.0040	0.0040	0.0040
Nickel (Ni)	mg/kg	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10
Nickel (Ni)	mg/kg wwt	0.020	0.020	0.020	0.020	0.020	0.020	0.020	0.020	0.020
Phosphorus (P)	mg/kg	200	200	200	200	200	200	200	200	200
Phosphorus (P)	mg/kg wwt	225	150	175	225	200	200	200	175	200
Potassium (K)	mg/kg	1000	1000	1000	1000	1000	1000	1000	1000	1000
Potassium (K)	mg/kg wwt	900	600	700	900	800	800	800	700	800
Rhenium (Re)	mg/kg	0.010	0.010	0.010	0.010	0.010	0.010	0.010	0.010	0.010
Rhenium (Re)	mg/kg wwt	0.0020	0.0020	0.0020	0.0020	0.0020	0.0020	0.0020	0.0020	0.0020
Rubidium (Rb)	mg/kg	0.050	0.050	0.050	0.050	0.050	0.050	0.050	0.050	0.050
Rubidium (Rb)	mg/kg wwt	0.010	0.010	0.010	0.010	0.010	0.010	0.010	0.010	0.010
Selenium (Se)	mg/kg	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10
Selenium (Se)	mg/kg wwt	0.020	0.020	0.020	0.020	0.020	0.020	0.020	0.020	0.020
Silver (Ag)	mg/kg	0.0050	0.0050	0.0050	0.0050	0.0050	0.0050	0.0050	0.0050	0.0050
Silver (Ag)	mg/kg wwt	0.0010	0.0010	0.0010	0.0010	0.0010	0.0010	0.0010	0.0010	0.0010
Sodium (Na)	mg/kg	1000	1000	1000	1000	1000	1000	1000	1000	1000
Sodium (Na)	mg/kg wwt	900	600	700	900	800	800	800	700	800
Strontium (Sr)	mg/kg	0.050	0.050	0.050	0.050	0.050	0.050	0.050	0.050	0.050
Strontium (Sr)	mg/kg wwt	0.010	0.010	0.010	0.010	0.010	0.010	0.010	0.010	0.010
Tellurium (Te)	mg/kg	0.020	0.020	0.020	0.020	0.020	0.020	0.020	0.020	0.020
Tellurium (Te)	mg/kg wwt	0.0040	0.0040	0.0040	0.0040	0.0040	0.0040	0.0040	0.0040	0.0040
Thallium (Tl)	mg/kg	0.0020	0.0020	0.0020	0.0020	0.0020	0.0020	0.0020	0.0020	0.0020
Thallium (Tl)	mg/kg wwt	0.00040	0.00040	0.00040	0.00040	0.00040	0.00040	0.00040	0.00040	0.00040
Thorium (Th)	mg/kg	0.010	0.010	0.010	0.010	0.010	0.010	0.010	0.010	0.010
Thorium (Th)	mg/kg wwt	0.0020	0.0020	0.0020	0.0020	0.0020	0.0020	0.0020	0.0020	0.0020
Tin (Sn)	mg/kg	0.020	0.020	0.020	0.020	0.020	0.020	0.020	0.020	0.020
Tin (Sn)	mg/kg wwt	0.0040	0.0040	0.0040	0.0040	0.0040	0.0040	0.0040	0.0040	0.0040
Titanium (Ti)	mg/kg	0.050	0.050	0.050	0.050	0.050	0.050	0.050	0.050	0.050
Titanium (Ti)	mg/kg wwt	0.010	0.010	0.010	0.010	0.010	0.010	0.010	0.010	0.010
Uranium (U)	mg/kg	0.0020	0.0020	0.0020	0.0020	0.0020	0.0020	0.0020	0.0020	0.0020
Uranium (U)	mg/kg wwt	0.00040	0.00040	0.00040	0.00040	0.00040	0.00040	0.00040	0.00040	0.00040
Vanadium (V)	mg/kg	0.020	0.020	0.020	0.020	0.020	0.020	0.020	0.020	0.020
Vanadium (V)	mg/kg wwt	0.0040	0.0040	0.0040	0.0040	0.0040	0.0040	0.0040	0.0040	0.0040
Yttrium (Y)	mg/kg	0.010	0.010	0.010	0.010	0.010	0.010	0.010	0.010	0.010
Yttrium (Y)	mg/kg wwt	0.0020	0.0020	0.0020	0.0020	0.0020	0.0020	0.0020	0.0020	0.0020
Zinc (Zn)	mg/kg	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50
Zinc (Zn)	mg/kg wwt	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10
Zirconium (Zr)	mg/kg	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20
Zirconium (Zr)	mg/kg wwt	0.040	0.040	0.040	0.040	0.040	0.040	0.040	0.040	0.040

Appendix 7

Hope Bay Belt Project Ecosystem Maps