KEEYASK GENERATION PROJECT

STAGE IV STUDIES - PHYSICAL ENVIRONMENT

COMPOSITION AND DISTRIBUTION OF SHORELINE AND INLAND PEATLANDS IN THE KEEYASK RESERVOIR AREA AND HISTORICAL TRENDS IN PEATLAND DISINTEGRATION

REV. 0

DELIVERABLE GN 9.2.1

MANITOBA HYDRO FILE: 00195-11100-00152_01

2011/09/18

PREPARED FOR:
HYDRO POWER PLANNING DEPARTMENT
POWER PROJECTS DEVELOPMENT DIVISION
POWER SUPPLY

PREPARED BY:

ECOSTEM LTD.

KEEYASK
GENERATION PROJECT

LETTER OF TRANSMITTAL

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September 18, 2011
Mr. Marc St. Laurent, P. Eng.
Section Head
Keeyask/Burntwood River Planning Section
Hydro Power Planning Department
Manitoba Hydro
360 Portage Ave., PO Box 815 Stn Main
Winnipeg, MB R3C 2P4

Re: DELIVERABLE GN 9.2.1; Manitoba Hydro File: 00195-11100-00152_01

Dear Mr. St. Laurent:

Attached please find ECOSTEM's Technical Memorandum: GN 9.2.1 Composition and Distribution of Shoreline and Inland Peatlands in the Keeyask Reservoir Area and Historical Trends in Peatland Disintegration. This report has been completed in accordance with the scope of work defined for this component of the project and the formatting template provided by Manitoba Hydro.

Please do not hesitate to contact me should you have questions or require additional information.

Sincerely,

James Ehnes, M.Phil., Ph.D.
Terrestrial Ecologist
President
ECOSTEM Ltd.

cc: W. DeWit

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SUMMARY

1. Background

Manitoba Hydro is currently proposing to develop the Keeyask Generation Project on the Nelson River. Experience with flooded areas in northern Canada indicates that altered water levels and river hydraulics can affect peatlands (i.e., wetlands where organic material has accumulated because dead plant material production exceeds decomposition). Flooding has two indirect effects on peatlands. First, intact peatlands along the initial reservoir shoreline break down which, along with mineral bank erosion, contributes to reservoir expansion over time. Second, portions of flooded peat mats float to the surface and either remain in the same general area or are transported elsewhere, sometimes over large distances. Among other things, these peatland effects remove terrestrial habitat and release organic sediment, woody debris, methylated mercury and other materials of concern into the aquatic system.

Peatlands cover approximately 90% of the proposed Keeyask reservoir and adjacent areas. Therefore, it is necessary that peatland processes be studied comprehensively during the project planning phase to identify potential project effects on the environment and to assess the need for and methods to mitigate potential effects.

The purposes of this memorandum are to describe the composition and distribution of shore zone and inland peatlands and to document historical peatland disintegration trends in the Keeyask reservoir area. The shore zone refers to shoreline areas that are influenced by the open water season water regime and the ice regime. The shore zone at a particular location typically includes the following zones that correspond to a water depth gradient: shallow water, beach, bank and the adjacent inland edge that exhibits water regime, ice regime and edge effects. Inland peatlands are those peatland that are beyond the direct influence of water energy and ice action. That is, inland peatlands are peatlands outside of the shore zone.

2. Shore Zone Peatlands

Approximately 245 lineal km of the Nelson River shoreline was mapped and classified in the Keeyask study area using 1:15,000 stereo photos acquired in 2003.

Bank material along the Nelson River shoreline in 2005 was 35% peat, 25% clay dominated, 13% bedrock, 10% heterogeneous mineral material and 8% sand dominated. In general, peat bank occurring outside of sheltered areas had a peat - mineral soil interface that was near or above the 95th percentile of water elevations. Only 5% of the

shoreline had banks higher than 3 m and all of these shore segments were mineral. Beach material along 23% of the shoreline was organic or peat.

Riparian peatlands are those peatland that are adjacent to open water. Their water edges were often floating while their inland edges were anchored to the substrate. Riparian peatlands, which were common in off-system lakes, streams and rivers, were uncommon in the Gull reach of the Nelson River.

Historical changes in Nelson River peat banks were detected by comparing the 1962 bank location in stereo photos with the mapped 2003 bank location. Peat shore segments where the peat bank was resting on mineral or bedrock material that was near or above the 95th percentile water level were ignored. It was assumed that these segments underwent mineral erosion rather than peatland disintegration processes.

Measurable changes in peat bank locations were not detected. It is noteworthy that, in many peat bank segments, there were dead trees or the vegetation cover had converted from trees to tall shrubs at the bank edge. Vegetation changes were probably due to wetter soils developing after the Churchill River Diversion and Lake Winnipeg regulation raised median water elevations.

Organic material input into the Nelson River from peat banks undergoing peatland disintegration processes was not expected to be measurable during the 1962 to 2003 period given that there was no measurable bank recession for those shore segments during that period. Inland peatlands also did not provide organic material input into the Nelson River during this period because their physical limits did not extend to the Nelson River shoreline.

Beach surface morphology changes were observed between 1962 and 2003 in some locations. Although this could suggest that the amount of peat in the beach may have changed between 1962 and 2003, there were other equally likely potential causes of surface morphology changes. For example, peat volume reduction from peat compaction and/or melting excess ice.

Organic material input from bank and beach areas probably occurred during the 2005 to 2007 period when water flows and levels were very high. The effects of high water levels were probably exacerbated on the south shore of the Nelson River where a 2005 fire burned to the shoreline. The combination of these two factors may lead to some peatland disintegration where permafrost melting has already occurred or has been initiated. Water levels were still too high through summer 2009 to conduct field surveys that would visually estimate the extent of affected organic bank and beach material, if any.

3. Inland Peatlands

Soils in the reservoir area were photo-interpreted and mapped from the same stereo photos that were used for the Nelson River shoreline location mapping. Soil profile data collected at approximately 850 soil sample and approximately 840 borehole locations, respectively, were used to validate the photo-interpretation and to describe soil stratigraphy.

Water covered one-third of the inland study area. Approximately 90% of the land area was peatland. Permafrost was widespread and generally occurs in all peatland types except for horizontal and riparian peatlands. The types of permafrost ranged from cold soil temperatures only to ice crystals, ice lenses and ground ice.

The land areas were composed of 37% veneer bog, 23% blanket peatland, 20% peat plateau bog and its transitional types, 13% mineral soil and 7% other peatland types. Veneer bogs were thin peats (i.e., less then 1.5 thick) that generally occurred on gentle slopes and contained discontinuous permafrost. Blanket peatlands were intermediate thickness peats (i.e., up to approximately 2 m thick) that covered gentle slopes and had a featureless surface. Blanket peatlands in the Keeyask area contained discontinuous ground ice permafrost. Peat plateau bogs were ice cored bogs with a relatively flat surface that was elevated from the surroundings and had distinct banks. Ice cores elevated some peat plateau bogs several meters above the surrounding area. Collapse scar peatlands were frost-melt features in peat plateau bogs. Horizontal peatlands were large, flat, featureless bogs and fens that often had a buried water layer and whose peat depth varied greatly but generally were relatively deep.

Mineral soils in the study area were generally found along the upstream reach of the Nelson River or on the upper portions of till ridges and eskers. Riparian peatlands occurred along streams, rivers and lakes. Horizontal peatlands and wet deep peatlands were found in lower topographic positions, often adjacent to riparian peatlands or peat plateau bogs. Veneer bogs typically formed the transition between deep mineral soils and other peatland types. There was a large concentration of peat plateau bog and its transitional stages in the north-central portion of the study area.

Ground ice permafrost made important contributions to peatland composition and soil stratigraphy in the Keeyask area. Peat plateau bog and its transitional stages was the dominant ground ice type in the area. A good understanding of peat plateau bog dynamics was important for the Keeyask environmental assessment due to its prevalence and because it was the pivotal peatland type for post-project peatland disintegration dynamics.

At the local level, ground ice abundance goes through natural cycles due to fire or windthrow. Human induced changes in factors such as hydrology also alter ground ice distribution and abundance.

Climate has an importance influence on the distribution and abundance of different peatland types at the regional level. Climate change produces a natural long-term cycle of ground ice formation and breakdown. Several studies in the scientific literature document a reduction in the total area of permafrost peatlands since the end of the Little Ice Age (~ 150 years ago) with no evidence of subsequent formation. Recent permafrost breakdown is thought to be lagged response to warming that occurred at the end of the Little Ice Age.

Historical changes in Keeyask peat plateau bog area were assessed by comparing changes between 1962 and either 2003 or 2006, depending on photo availability. This was the longest time period where photography of a sufficiently large scale was available for most of the reservoir area.

Peat plateau bogs in the Keeyask area shrank by approximately 20% over the 44 year study period. Area losses for individual peat plateau bogs ranged widely from a minimum of 1% to a maximum of 48%. As expected, burned peat plateau bogs shrank faster than unburned ones. Over 90% of the shrinking area became other peatland types; the rest became open water.

1 PURPOSE OF MEMORANDUM

Manitoba Hydro is a major developer of hydropower resources in Manitoba. Currently, it is evaluating development of the Keeyask Generating Station on the Nelson River (Figure 1). **Peatlands** cover approximately 90% of the proposed Keeyask reservoir and adjacent areas. Consequently, **peatland disintegration** processes are being characterized as part of the engineering design and environmental assessments for the proposed development schemes.

Hydro-electric generating station development alters the natural hydraulic characteristics of a river and water bodies located within the zone of hydraulic influence. The degree of change to the physical environment depends on the scale and design of the development, the physical environment within the reservoir area, and other relevant parameters. Among other changes that may occur in the physical environment, altered water levels and river hydraulics can potentially cause inundated and shoreline **peatlands** to enter the aquatic system and subsequently break down (i.e., **peatland disintegration**), alter shoreline erosion processes, and alter nearshore sediment transport and deposition processes. Changes in hydraulic and erosion-sedimentation characteristics can influence the aquatic environment including water quality and fish habitat. Depending on the project, it is important that **peatland disintegration** and erosion-sedimentation processes be studied comprehensively during the planning phase to identify potential project effects on the environment and to assess the need for and methods to mitigate the potential effects.

The purposes of this memorandum are to describe the composition and distribution of **shore zone** and **inland peatlands** in the Keeyask reservoir area and historical **peatland disintegration** trends in these areas.

This memorandum begins with a description of soils along the Nelson River shoreline and in the inland areas within the proposed Keeyask reservoir area. This description is followed by an analysis of historical **peatland disintegration** in the existing environment. The memorandum includes qualitative estimates of historical organic sediment loads generated by Nelson River peat banks and by **inland peatlands**.

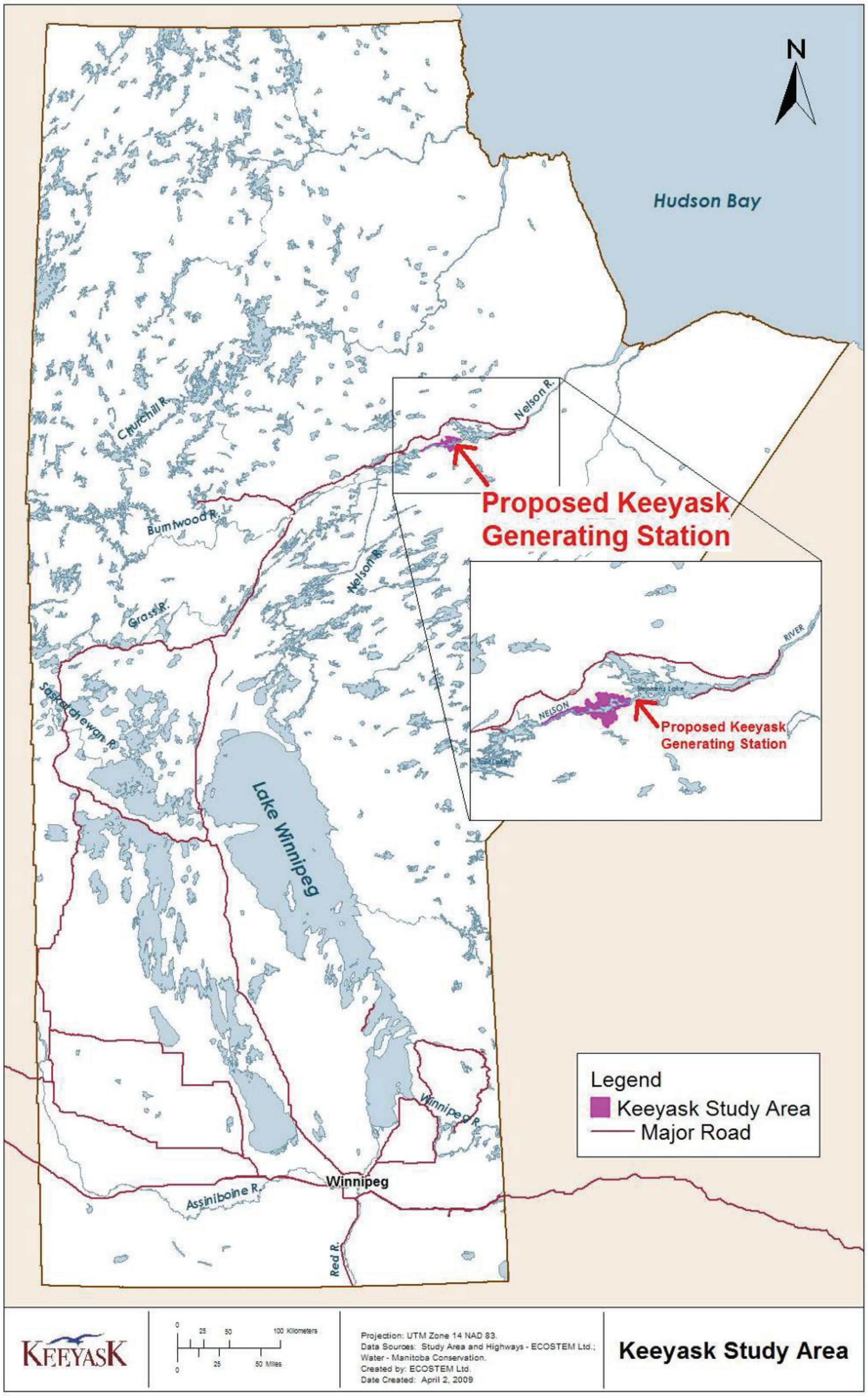


Figure 1 – Location of the Keeyask generating station project and the peatland disintegration study area.

2 LITERATURE REVIEW

2.1 PEATLAND TYPES

2.1.1 WETLANDS

Wetlands are land ecosystems where periodic or prolonged water saturation at or near the soil surface is the dominant factor shaping soil attributes and vegetation composition and distribution. **Wetlands** are either **peatlands** or mineral **wetlands**. **Peatlands** are **wetlands** where organic material has accumulated because dead plant material production exceeds decomposition (National Wetlands Working Group 1997).

This report uses the **wetland** nomenclature and criteria of the Canadian Wetland Classification System (National Wetlands Working Group 1988) , with enhancements to reflect dramatic differences in marsh water regimes along the Nelson River and between the Nelson River and off-system waterbodies and modifications are needed to support the development of a **peatland disintegration** model (see companion memorandum ECOSTEM 2012a). Mitch and Gosselink (2000) point out that the CWCS and the US hydrogeomorphic approach (Smith *et al.* 1995) use the same factors to classify wetlands

Bog, **fen**, **swamp**, **marsh** and **shallow open water** are the five **wetland** classes in the Canadian Wetland Classification System. **Bogs** and **fens** are the two most common types of **peatlands**. **Bogs** receive nutrient inputs from precipitation only whereas **fens** are influenced by mineral enriched ground and/or surface water (National Wetlands Working Group 1988). Peat mosses (*Sphagnum* spp.) are the dominant peat forming vegetation in **bogs**. For this and other reasons, **bogs** are acidic. **Fens** are less acidic than **bogs** and can be sub- divided into poor and rich **fens** along gradients of increasing water levels, pH, alkalinity and dissolved minerals.

Some **swamps** are also **peatlands** (National Wetlands Working Group 1997). A **swamp** is a minerotrophic **wetland** with at least 30% tree and/or tall shrub cover, woody peat and a higher depth to water table than **fens**. This type of **wetland** rarely accumulates peat to a depth greater than 40 cm, although accumulations greater than 1 m are possible (National Wetlands Working Group 1997). Because **swamps** tend to have a well-developed tree layer, organic material in these **wetlands** is primarily deposited as forest peat (Gloosenko and Grondin 1988). Lacustrine **swamps** are subjected to periodic flooding; the organic deposits often have a high mineral content (National Wetlands Working Group 1997). **Swamps** and **marshes** are much more common in the southern landscape than in northern regions (Glooschenko and Grondin 1988, Vitt et al. 2001).

Marsh and **shallow open water** are the remaining **wetland** classes in the Canadian Wetland Classification System (National Wetlands Working Group 1997). A **marsh** has emergent or floating-leaved vegetation covering at least 25% of its surface area and shallow water with levels that fluctuates daily, seasonally or annually. Water in **marshes** is usually nutrient enriched. Shallow water **wetlands** continually have water up to 2 m deep and surface vegetation cover that ranges from 0% to 24%.

It should be noted that several alternative **wetland** classifications exist and their criteria for defining classes that have the same name can differ substantively. For example, Bridgam et. al. (1996) argue that **bogs** and **fens** should be distinguished based on peat pH, peat alkalinity and dominant vegetation. That is, without reference to hydrology, topography, nutrient availability or how they originated. In their view, **bogs** are "acidic, low alkalinity **peatlands**, typically dominated by *Sphagna* (Sphagnum mosses, also called peat mosses), conifers (particularly spruces and pines), and/or various ericaceous shrubs. Similarly, **fens** should broadly refer to somewhat less acidic, more alkaline **peatlands** dominated by graminoids, brown mosses, taller shrubs, and coniferous and/or deciduous trees".

2.1.2 SHORE ZONE PEATLANDS

In this report, the **shore zone** refers to shoreline areas that are influenced by the open water season water regime and the ice regime. The **shore zone** at a particular location typically includes the following zones that correspond to a water depth gradient: shallow water, beach, bank and adjacent inland areas exhibiting water regime, ice regime and edge effects. **Wetlands** from all five classes can occur in the **shore zone** (Figure 2). **Shore zone peatlands** include riparian peatland**s** and the edges of **peatlands** adjacent to the terrestrial habitat shoreline. Riparian peatland**s** (Figure 2) have some or all their area that is floating. Many natural riparian peatland**s** are anchored to the water body substrate on their inland side.

Riparian peatland**s** can be classified as lacustrine or riverine according to their context (Figure 3). **Lacustrine peatlands** occur in lakes and ponds whereas **riverine peatlands** occur in rivers, streams and creeks. A distinction is made between these two general riparian peatland types because water energy, which is a key driver for riparian peatland dynamics, differs substantially in the two aquatic environments. Wave energy is generally the dominant hydraulic driver in the lacustrine environment whereas current dominates the riverine. Riparian peatland**s** generally develop around small lakes that have little wave action (Mitsch and Gosselink 2000).

A) B) C)

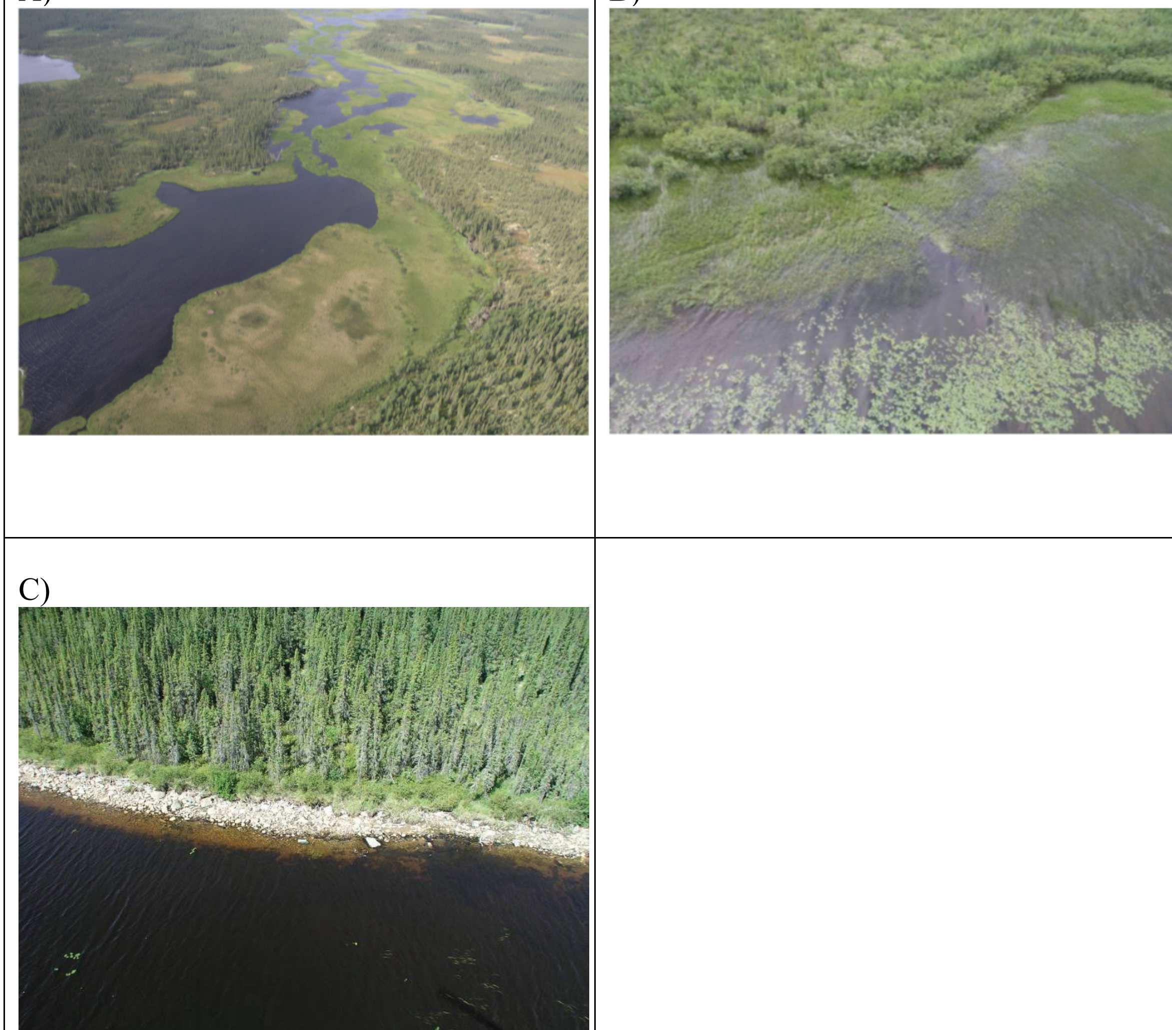


Figure 2 – Photos of different shore zone wetlands found within the study area, including: A) aquatic bog, B) marsh and C) shallow open water.

A)

B)

C)

Figure 3 – Photos of different riparian peatland types found within the study zone, including: A) aquatic islands, B) lacustrine riparian peatland and C) riverine riparian peatland.

2.1.3 INLAND PEATLANDS

Inland peatlands are those that are beyond the direct influence of water energy and ice action. That is, **inland peatlands** are **peatlands** outside of the **shore zone**.

Inland peatlands in the Keeyask area include **veneer bogs**, **blanket peatlands**, **peat plateau bogs**, **collapse scar fens** and **bogs**, **horizontal peatlands** and transitional stages of **peat plateau bog** aggradation or degradation (Figure 4).

Veneer bogs are thin peats (i.e., generally less than 1 m thick) that typically occur on gentle slopes and contain discontinuous **permafrost**. **Blanket peatlands** are intermediate thickness peats (i.e., up to approximately 2 m thick) with a featureless surface that cover gentle slopes. **Blanket peatlands** in the Keeyask area contain discontinuous **massive ice permafrost**. **Peat plateau bogs** are ice cored **bogs** with a relatively flat surface that is elevated from the surroundings and has distinct banks. **Collapse scar fens** and **bogs** are thermokarst features in **peat plateau bogs**. **Horizontal peatlands** are large, flat, featureless **peatlands**; peat depth is generally intermediate to deep but this varies greatly with **wetland** form. **Horizontal peatlands** in the Keeyask area include flat **bogs**, horizontal **fens** and flat **swamps**.

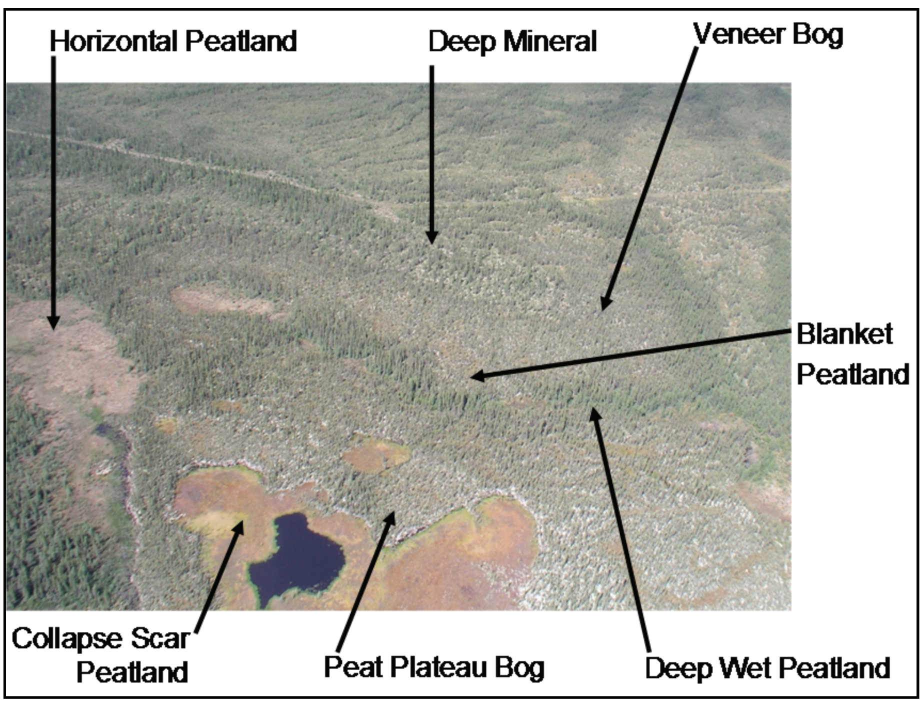


Figure 4 – Common sequence of peatland types found in the Keeyask reservoir area when moving from a hill top (deep dry mineral in the photo) to the lowest nearby elevation.

2.2 PEATLAND ORIGIN AND DEVELOPMENT

Most northern **peatlands** were initiated and have developed through **terrestrialization** or **paludification**. **Terrestrialization** refers to the process whereby all or portions of a water body or waterway are filled in by the horizontal expansion of peat from the shore towards the center of the water body or waterway and by organic sediment deposition (Figure 5). **Paludification** is the process whereby vegetation (primarily *Sphagnum* mosses) on mineral soils progressively creates a wetter moisture regime that eventually leads to the formation of a surface organic layer that expands laterally over time (Figure 5). **Paludification** may have created more **peatland** area than **terrestrialization** (Bauer et al. 2003).

Paludification can be initiated outside of lacustrine basins or riverine valleys in lower slope areas. In upland areas, **paludification** can occur in wet depressions or in areas with a moist to wet moisture regime. **Paludification** can progressively blanket an area in an upslope direction. A riparian peatland that was initiated through **terrestrialization** often expands inland and paludifies adjacent mineral soils. Factors that currently promote **paludification** in new areas include climate change, geomorphological change, beaver dams or forestry practices (Mitsch and Gosselink 2000).

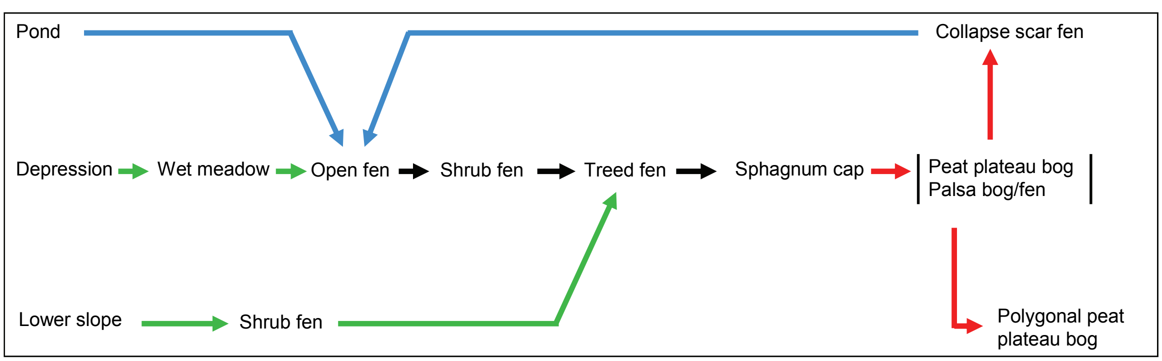


Figure 5 – Pathways of wetland development in northern Canada (After Zoltai et al. 1988a).

Arrow legend: blue=terrestrialization; green=paludification; black=terrestrialization or paludification; red=permafrost dynamics.

2.2.1 SHORE ZONE PEATLANDS

Riparian peatland**s** were common in off-system lakes, streams and rivers. In contrast, riparian peatland**s** were uncommon in the Keeyask reach of the Nelson River. Edges of **inland peatlands** formed the peat shore segments on the Nelson River shoreline. Consequently, most **shore zone peatlands** in the Keeyask area were thought to be the result of **terrestrialization**.

2.2.2 INLAND PEATLANDS

Most **inland peatland** mosaics in the Keeyask area were thought to be derived from a combination of **terrestrialization** and **paludification**. **Paludification** may or may not have been initiated by riparian **terrestrialization**. In the north, **paludification** usually commences once Sphagnum spp. have established. As organic material accumulates, the water table of **peatlands** can slowly elevate over time, causing **peatland** encroachment onto upland areas. The elevated water table can lead to forest flooding and eventual stunting or killing of trees (Keddy 2000).

Permafrost is an important factor in northern **peatland** development. **Permafrost** initially establishes in unfrozen **peatlands** in thin layers under small *Sphagnum* cushions (Zoltai and Tarnocai 1975) or under stands of black spruce (Zoltai 1972) As these pockets accumulate more **permafrost**, they eventually become small peat plateaus which may merge together to form **peat plateau bogs** (Zoltai 1972, Zoltai and Tarnocai 1975).

Ice lens formation within the peat profile increases volume and causes the **peatland** surface to become elevated above the surrounding unfrozen **wetlands** (Zoltai 1972). Buoyancy may further elevate the peat surface because frozen peat is lighter than the underlying saturated, unfrozen **fen** peat. Zoltai (1972) found that peat with **massive ice** can float on the saturated peat below it to the degree that approximately 13% of its surface protrudes above the surrounding water level. This is analogous to an iceberg floating on water.

Peat plateau bogs (Figure 4) have drier soils than the adjacent area because water drains off the elevated surface. This provides a positive feedback for peat plateau vertical growth. Surface peat that is dry during the summer becomes wet and frozen in the fall. Dry peat has a thermal conductivity that is 25 to 30 times lower than wet, frozen peat (Englefield 1995). In the summer, the dry surface peat reduces heat transfer from the warm air to the subsurface. In the winter, the combination of a thinner snow cover (snow blows off elevated plateaus more easily) and the higher thermal conductivity of wet, frozen peat increases heat loss from depth relative to surrounding areas.

Typical successional pathways for **peatlands** in the discontinuous **permafrost** zone are shown in Figure 6. The pathways represented by connecting arrows A and C can be either a **terrestrialization** or **paludification** process. Pathway D is a **permafrost** aggradation process. Pathways E and G are natural **permafrost** degradation processes that follow climate warming or fire, respectively. Windthrow, which refers to a high wind event that blows down patches of trees, can also initiate pathway G. Pathways E and G generate thermokarst features known as **collapse scars**. Holocene **peat plateau bog** dynamics are viewed as cyclic in continental Canada (Zoltai and Tarnocai 1975, Chatwin 1981, Zoltai 1993, Englefield 1995) but this will probably end with climate warming (Camill 1999). Pathways F and I show a **collapse scar** redeveloping into a **permafrost bog**.

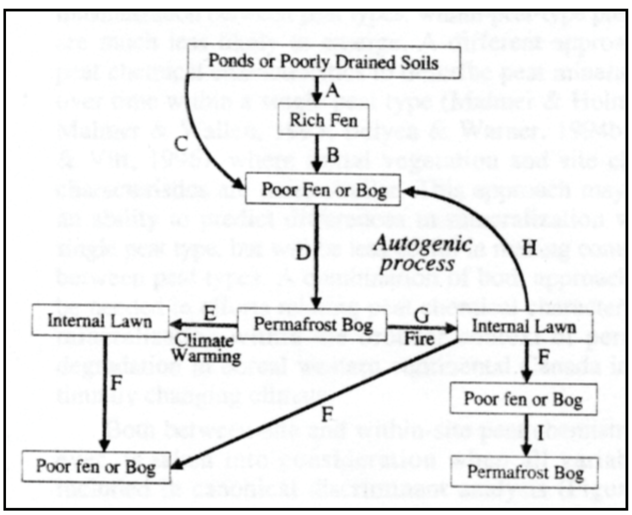


Figure 6 – Historical development of peatlands in the discontinuous permafrost zone of boreal, western Canada. (Source: Turetsky et al. 2000)

2.2.2.1 Ground Ice Degradation In Peat Plateau Bogs

Permafrost degradation in **peat plateau bogs** results from natural and human factors. Natural factors include: 1) aggradation/degradation cycles in response to disturbance or other short term contextual changes; and 2) linear degradation as a result of climatic warming. **Permafrost** degradation can occur when surface vegetation is disturbed by events such as fire or windthrow or when water temperature rises in adjacent areas due to changes in factors such as hydrology. Fire indirectly increases soil temperatures by removing the shade provided by vegetation and blackening the soil surface. Windthrow also indirectly increases soil temperatures by removing the shade provided by overstorey vegetation.

2.2.2.1.1 "Natural" Causes

The typical collapse cycle involves thawing of the **peat plateau bog permafrost**, which causes the surface to drop to the level of the associated unfrozen **wetland**. Such thawing can take place at the periphery or within the centre of a **peat plateau bog**. A single **peat plateau bog** may contain several **collapse scars** at any one time. **Collapse scars** are typically restricted to a few tens of square meters in size (Zoltai et al. 1988a). Lateral **permafrost** melting can continue to progress around the edges of **collapse scars**, as standing water acts as a heat store and conductor (Englefield 1995).

Peat plateau collapse is followed by a drastic change in vegetation, with a shift from a typical 'dry' black spruce-lichen woodland to aquatic habitats associated with open pools of water (thermokarst ponds). These ponds are dominated by aquatic Sphagnum species (Zoltai et al. 1988a). Peat accumulation rates in **collapse scars** are rapid relative to those in **peat plateau bogs** and, therefore, **terrestrialization** of these ponds can proceed relatively rapidly (Camill 1999, Payette et al. 2004). With enough peat deposition, lawn communities (drier than pools), followed by even drier hummock communities, can form over former pools. A typical sequence (Figure 7) of dominant *Sphagnum* mosses follows *S. riparium- S. angustifolium- S. fuscum* for the aquatic to lawn to hummock microsites, respectively, which is often seen as a spatial chronosequence after **collapse scar** formation (Zoltai 1993, Camill 1999). With *Sphagnum* hummocks and dry conditions that promote black spruce recruitment, **permafrost** formation can be initiated again to start another cycle of aggradation. Camill (1999) reports that succession from aquatic to hummock *Sphagnum* communities capable of forming **permafrost** can take as little as 50-80 years. The formation of an elevated **peat plateau bog** may require a much longer period of time (Camill 1999).

As shown in Figure 6, some **collapse scars** redevelop into **peat plateau bogs**. Zoltai (1972) found that both degrading and aggrading stages may co-occur on the same peat plateau. However, not all **peat plateau bog/fen** complexes show evidence of having gone through a collapse cycle (Kuhry 1998).

Natural **peat plateau bog permafrost** melting occurs horizontally and vertically. Horizontal degradation occurs because **peat plateau bogs** generally have a band of open water along their banks. This water conducts heat laterally into the **permafrost** core (Woo et. al. 1992). The effect is increased as the open water warms in the summer.

Vertical degradation within a **peat plateau bog** can occur where water collects in depressions. Water in surface pools warms in the summer and conducts heat vertically into the soil profile. Snow may collect in these depressions and reduce winter cold transfer from the atmosphere into the profile.

Fire has been found to be a major trigger for **permafrost** collapse in **peat plateau bogs** (Couillard and Payette 1985, Zoltai 1993). Zoltai (1993) found evidence of repeating sequences of **permafrost** aggradation/degradation in peat cores from Northwestern Alberta and suggested that cycles attributed to fire could be as short as 600 years. However, not all fires remove sufficient surface organic material to cause subsequent **peat plateau bog** degradation (Thie 1974, Zoltai et al. 1988a, Zoltai 1993, Camill 1999).

Peat plateau degradation may also be initiated by a number of other factors. Cracks in the plateau surface may form due to differential freezing and thawing or vertical expansion of the plateau (Englefield 1995). Uprooted trees or deep desiccation cracks could also initiate thawing (Zoltai and Tarnocai 1975), while pools of standing water may form in 'moats' around the plateau edge (Chatwin 1981), which can conduct heat laterally into the **permafrost** core (Sollid and Sorbel 1974, cited in Englefield 1995). Variability in snowfall might also cause changes in aggradation/degradation dynamics of **permafrost**, with years of heavy snowfall favoring degradation (Thie 1974, Payette et al. 2004), due to the thermal insulation properties of the snow layer during the winter (Sturm 1992).

Climate is a key influence on **permafrost** distribution at the regional level (see Section 2.4).

Englefield (1995) argues that **permafrost** melting in a **peat plateau bog** is primarily horizontal. This can occur as gradual bank surface subsidence (Figure 7) or as blocks of peat breaking off the bank (Zoltai 1988a). Important factors in **peat plateau bog** bank retreat are vegetation, snow cover, standing water, rainfall, drainage, temperature and fire (Englefield 1995).

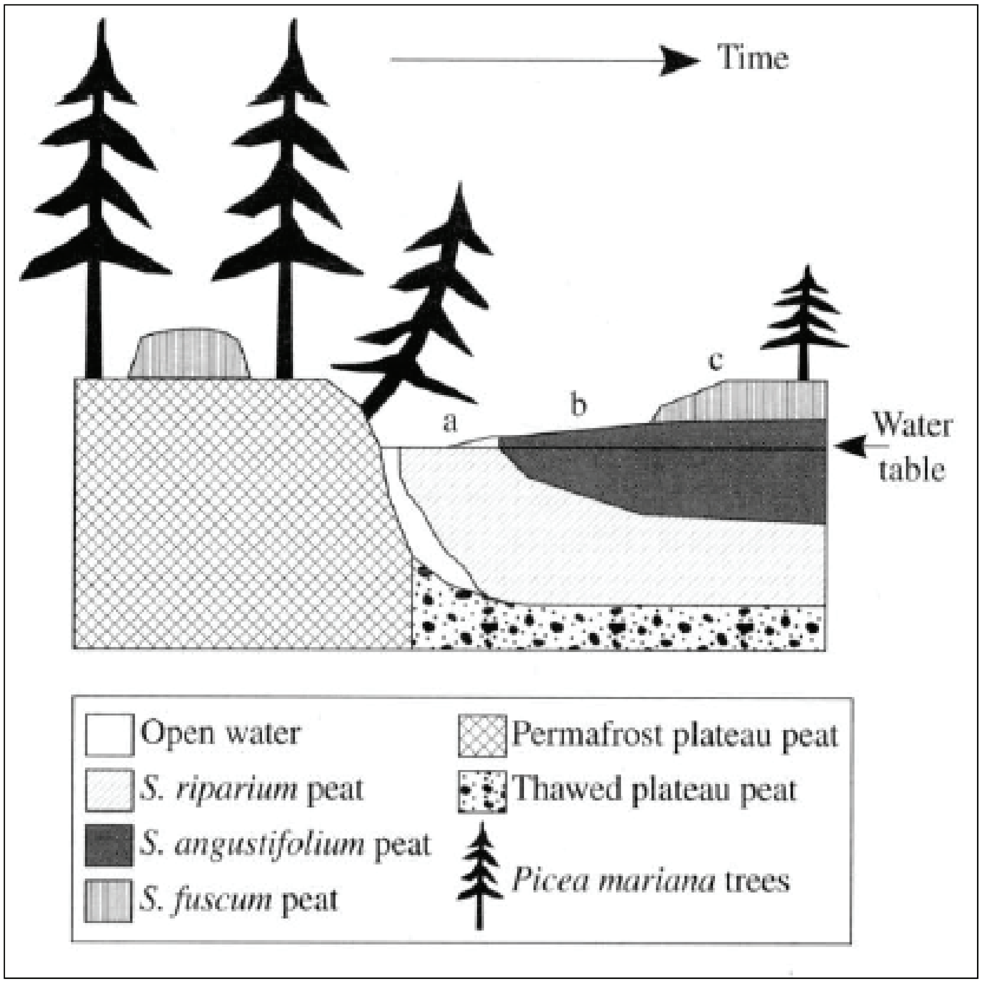


Figure 7 – Hypothetical succession of collapse scar communities as a function of peat accumulation: (a) aquatic Sphagnum communities, (b) lawn Sphagnum communities, and (c) hummock Sphagnum communities (From Camill 1999).

Note: Massive ground ice not illustrated in this figure.

2.2.2.1.2 Human Causes

Human activities such as forestry practices, linear construction activities, hydro-electric development and oil and gas activities all have the potential to induce or accelerate the process of **permafrost** degradation. Camill (2000) demonstrates the importance of black spruce trees in the aggradation of **permafrost** in **peat plateau bogs**. Therefore, forestry practices would be expected to have an effect on **peat plateau bogs**. The effects of timber harvesting on a **peat plateau bog** in Manitoba near the southern edge of the discontinuous **permafrost** zone are noted by Zoltai (1972). He found evidence of

permafrost core melting 7 years after trees had been clear-cut on part of the plateau. It is uncertain, however, at what rate the degradation process occurs after the clear-cut and whether it is accelerating or decelerating over time.

Linear construction activities such as the building of roads, transmission corridors or pipelines can also trigger **permafrost** collapse by raising the water table or through direct damage to the frozen peat surface by activities such as bulldozing or ruts induced by heavy traffic (Zoltai et al. 1988a). Work by Magnusson and Stewart (1987) suggests that **permafrost** thawing and subsequent erosion in **peatlands** along hydro-electrical transmission corridors occurs primarily in areas disturbed by heavy vehicles and equipment.

Reservoirs created for hydro-electric generation can also produce significant impacts on **peatlands**. In northern reaches of Canada and Europe, low-lying **peatlands** are the first part of the landscape to be inundated by reservoirs often resulting in floating peat islands. Very little past research has studied the effects of reservoir inundation or water level changes on **peat plateau bogs**. These effects are examined in an associated technical memorandum (ECOSTEM 2012a).

2.3 PEATLAND MOSAICS

When flying at low elevations over northern areas, it becomes apparent that many **peatland** areas are a mosaic of various types of **peatlands** and other **wetland** types (Figure 4). As described above, each of the **peatland** types within the mosaic represents substantially different ecological conditions and substantially different peat development and breakdown dynamics.

Lacustrine **wetland** mosaics may include various combinations of **shallow open water**, **marshes**, open **fens**, shrub **fens**, treed **fens**, **bogs** and **swamps**. Lacustrine **wetland** mosaics generally have the same pattern of **peatland** types. From wettest to driest, these are open water, **marsh**, wet open **fen**, dry open **fen**, treed **fen** and **bog** (Figure 8; Figure 9). These types of **peatland** mosaics develop around small lakes that have little wave action (Mitsch and Gosselink 2000) and, therefore, may not be typical of all regions, but, nonetheless, serve to illustrate a succession in **peatland** types, with progressively increasing **peatland** age from centre toward the edge of the complex. **Marshes** are much less common in northern than in southern Canada (Glooschenko and Grondin 1988, Vitt et al. 2001).

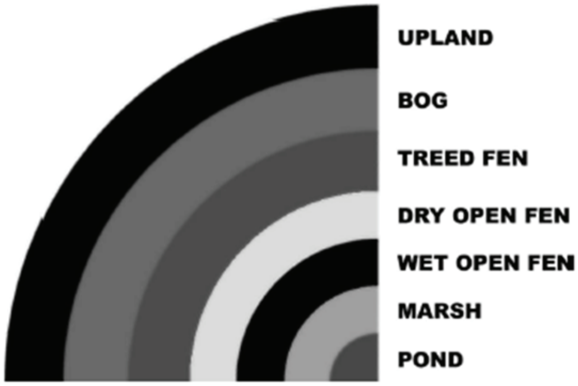


Figure 8 – Conceptual diagram illustrating the distribution of five peatland communities surrounding shallow ponds of the mid-boreal region of Alberta (From Whitehouse and Bayley 2005).

Figure 9 – Riparian peatland mosaic showing sequence similar to that in Figure 8.

2.4 HISTORICAL CHANGES IN THE DISTRIBUTION OF PEATLAND TYPES

Wetlands in the Keeyask region began developing shortly after glacial Lake Agassiz drained. However, **peatland** development may have been delayed by up to 2000 years due to plant migration, unfavorable climatic conditions and/or other environmental factors (Zoltai et al. 1988a). It is thought that peat formation became possible in the northern part of the former Lake Agassiz basin between 4300 and 4800 years BP with the end of a warm and dry period, which had largely precluded prior **peatland** development (Zoltai et al. 1988b). **Peatland** initiation occurred later in the northern part of the former Lake Agassiz basin and much sooner in the Hudson Bay Lowlands.

Climate has an importance influence on the distribution and abundance of different **peatland** types. The southern edge of **peat plateau bog** distribution generally corresponds with the -1˚C isotherm (Vitt et al. 1994). **Permafrost** may have reached its maximum spatial extent during the Little Ice Age (1550-1850 AD; Turetsky et al. 2000).

Several studies document a reduction in the total area of **permafrost peatlands** since the end of the Little Ice Age (~ 150 years ago) with no evidence of subsequent aggradation (Thie 1974, Vitt et al. 1994, Halsey et al. 1995, Vitt et al. 2000). From aerial photography, Thie (1974) studied **permafrost** in **peatlands** at the southern edge of the discontinuous **permafrost** zone in an area north of Lake Winnipeg in Manitoba. Thie (1974) estimates that about 75 % of the **permafrost** in **peatlands** in the study area degraded since the end of the Little Ice Age; many **peat plateau bogs** completely disappeared over a 20 year period (1947-1967). Over the same period, Vitt et al. (2000) estimate a net area loss of 9% of **permafrost peatlands** across boreal continental western Canada. Some locations across boreal continental Canada that once contained **permafrost** have had a complete melting of **permafrost**, moving the current southern limit of **permafrost** north by an average of 39 km, and in some locations, by as much as 200 km (Beilman et al. 2001).

Ongoing **permafrost** degradation is thought to be related to a time lag in **permafrost** melting from the general warming trend that occurred at the end of the Little Ice Age (Vitt et al. 2000, Camill and Clark 1998). This climate change disequilibrium in **permafrost** melting may be attributed to the buffering capacity of local factors (e.g., presence of insulating layer of *S. fuscum*) to mediate the effects of regional climate change (Camill and Clark 1998). Vitt et al. (2000) estimate that, of the **permafrost** that remains in boreal western Canada, 22 % is still in disequilibrium with the climate. The mean annual decrease in **permafrost** area of **peatlands** from western Canada appears to be around 1% or greater, while rates of **permafrost** retreat measured at the plateau-**collapse scar** edge have ranged from 0 to 2.8 m yr^{-1} (Tarnocai 1972; Thie 1974; Reid 1977; Chatwin 1981; Englefield 1995; Camill and Clark 2000; Camill 2005). Camill and Clark (1998) show that the thaw rate increases linearly with mean annual temperature in Northern Manitoba, while Camill (2005) reports that thaw rates have significantly accelerated since 1950. "Current warming trends may eliminate most, if not all, **peatland permafrost** in the [sporadic and discontinuous **permafrost**] zones of Manitoba" (Camill 2005). However, it could still take centuries for **permafrost peatlands** to reach equilibrium with the regional climate (Woo et al. 1992).

3 STUDY AREA

3.1 BOUNDARIES

The Keeyask Generating Station **peatland disintegration** study area is shown in Figure 10 (see Figure 1 for the general location). The small western portion of the study area was not included in the **peatland disintegration** modeling area to reduce computational demands. Potentially affected **peatland** area in the western area is nil to virtually nil.

The **peatland disintegration** study area was 240.5 km^2 in size, 228.9 km^2 of which was the **peatland disintegration** modeling area. **Peatlands** and other land types covered 168.5 km^2, or 74%, of this area. Approximately 220 km of existing Nelson River shoreline fell within this study area. See Section 4.3 describes how the **peatland disintegration** study area was delineated.

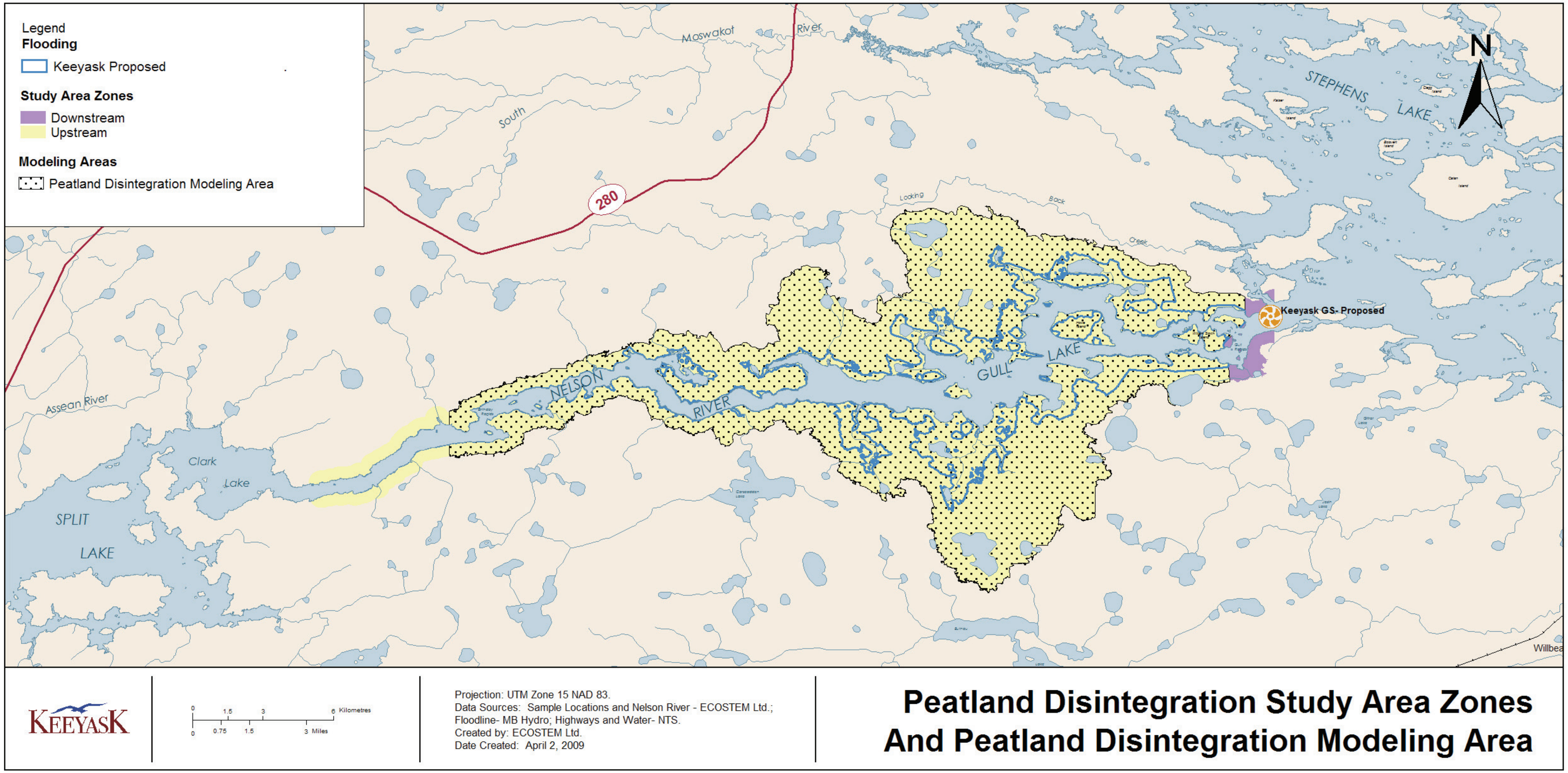


Figure 10 – Study area and peatland disintegration modeling area.

3.2 PHYSICAL SETTING

The study area was within a transitional area. It overlaped three Ecozones (Boreal Shield, Taiga Shield and Hudson Plains) and four Ecoregions (Churchill River Upland, Hayes River Upland, Hudson Bay Lowland, Selwyn Lake Upland) and six Ecodistricts (Smith et al. 1998).

The study area lies within the Canadian Shield. The geological overburden is estimated as being up to 30 meters deep over Precambrian bedrock, which is dominated by greywache gneisses, granite gneisses and granites (Betcher et al. 1995). Multiple glaciations have deposited four till units containing cobbles and boulders, which are overlain with sands and gravels (JDMA 2012). After the last glaciation, thin layers of silts and clays were deposited on the bottom of glacial Lake Agassiz, forming varved clay and silt deposits, which can be quite thick in low-lying areas and thin or locally absent on ridges and knolls (JDMA 2012). Peat veneer and peat blanket deposits developed on the poorly drained flatlands and depressions left after Lake Agassiz drained into the Hudson Bay and the Beaufort sea (JDMA 2012).

Overall terrain is gently sloping. The proposed reservoir area ground surface elevation ranges between 117 and 202 masl (Stantec 2012). Steep sloping drumlins and glaciofluvial ridges occur throughout the area. Varying thicknesses of peat overlay the fine-grained glaciolacustrine clay and silt which is found on the gently sloping terrain. On gentle slopes, **veneer bogs** are common, with shallow to deep **peat plateau bogs** and **fens** common in depressions and potholes. **Veneer bogs**, **peat plateau bogs** and **fens** generally overlay clayey glaciolacustrine sediments (JDMA 2012). Discontinuous **permafrost** is typical of the study area. Melting **permafrost** in peat plateaus has created **collapse scar** formations visible across the landscape (Smith et al. 1998). Lakes of various sizes are also common across the landscape and drainage is generally towards the north and east into the Hudson Bay through the Nelson and Hayes rivers (Smith et al. 1998). Keeyask reservoir **shore zone**s are generally characterized by relatively low bluffs and gently sloping nearshore slopes (JDMA 2012, Stantec 2012).

Organic soils derived from woody forest and sedge peat dominate the study area (ECOSTEM 2012c). The Crysolic soil order is the most common followed by the Organic and Brunisolic orders. The remaining soil orders are uncommon. Fibrisols and Mesisols are dominant great groups in the area and are generally associated with very poorly drained **fens** and Sphagnum **bogs** (ECOSTEM 2012c). Mineral and organic soils in the study area frequently contain **permafrost** at varying depths. Cryosolic soils are mostly found in Sphagnum **bogs**, and to a lesser extent, feathermoss **bogs** and are generally very poorly drained (ECOSTEM 2012c). **Permafrost** activity contributes to surface topography and deeper soil layer processes.

Mineral soils tended to occur on drumlins and glaciofluvial ridges and along the Nelson River. Brunisols tend to be found on gently to strongly rolling topography and are associated with deep dry sites. Brunisols are most commonly associated with glacio-lacustrine and till deposition modes and moderately well drained soils (ECOSTEM 2012c). Luvisolic soils are also present within the study area, especially on nearly level terrain. The luvisols are most commonly found on rapid to moderately well drained soils developed on till or glacio-fluvial deposits.

The nearest climate station to the study area is located at the Gillam airport. The mean annual temperature for this region is approximately –4.1°C and the mean annual precipitation is approximately 500mm, with one third of the precipitation falling as snow (Smith et al. 1998). The average growing season is 131 days, with approximately 880 growing degree-days (Smith et al. 1998). The region lies within a cold, subhumid to humid, Cryoboreal climate and experiences short, cool summers and long, very cold winters.

Climate normals for the area indicate a warming of the local climate[1]. The average number of growing degree days (GDD) per year has gradually increased since the 1951-1980 period. The number of GDDs above 0 and 5 has increased by 104 and 81 days, respectively, from the 1951-1980 period to the 1971-2000 period. The number of GDDs per year is expected to rise again during the 2010 period based on values calculated for the 1981-2007 period.

3.3 LAKE WINNIPEG REGULATION AND THE CHURCHILL RIVER DIVERSION

The implementation of Lake Winnipeg regulation (LWR) and the Churchill River Diversion (CRD) altered flows through the Gull reach of the Nelson River. LWR and CRD changed the timing and seasonality of flows. CRD also increased flows. These changes commenced in 1975 for LWR and in 1976 for CRD.

Increased flows increased water elevations in some areas. Recorded water elevation data were not available to identify sub-reaches where elevation increases were measurable. It was assumed that the general patterns in the Keeyask reach were the same as those

1 Gillam airport weather station data. Values for 1980 and ‘2010’ were calculated from Environment Canada data.

observed on Split Lake. This assumption was valid for Gull Lake during the 1978 to 2007 period when daily water elevations were available for both locations (Figure 11).

Mean water elevations on Split Lake increased by approximately 34 cm following LWR and CRD (Split Lake Cree 1996a,b,c,d). It is unlikely that an elevation change of this magnitude had an immediate effect on **peatland** distribution or abundance since it was well within the natural range of variability. Mean open water levels on Split Lake fluctuated over a range of approximately 190 cm from 1951 to 1974. Mean open water levels did not exceed the 1966 level from 1975 to 1994.

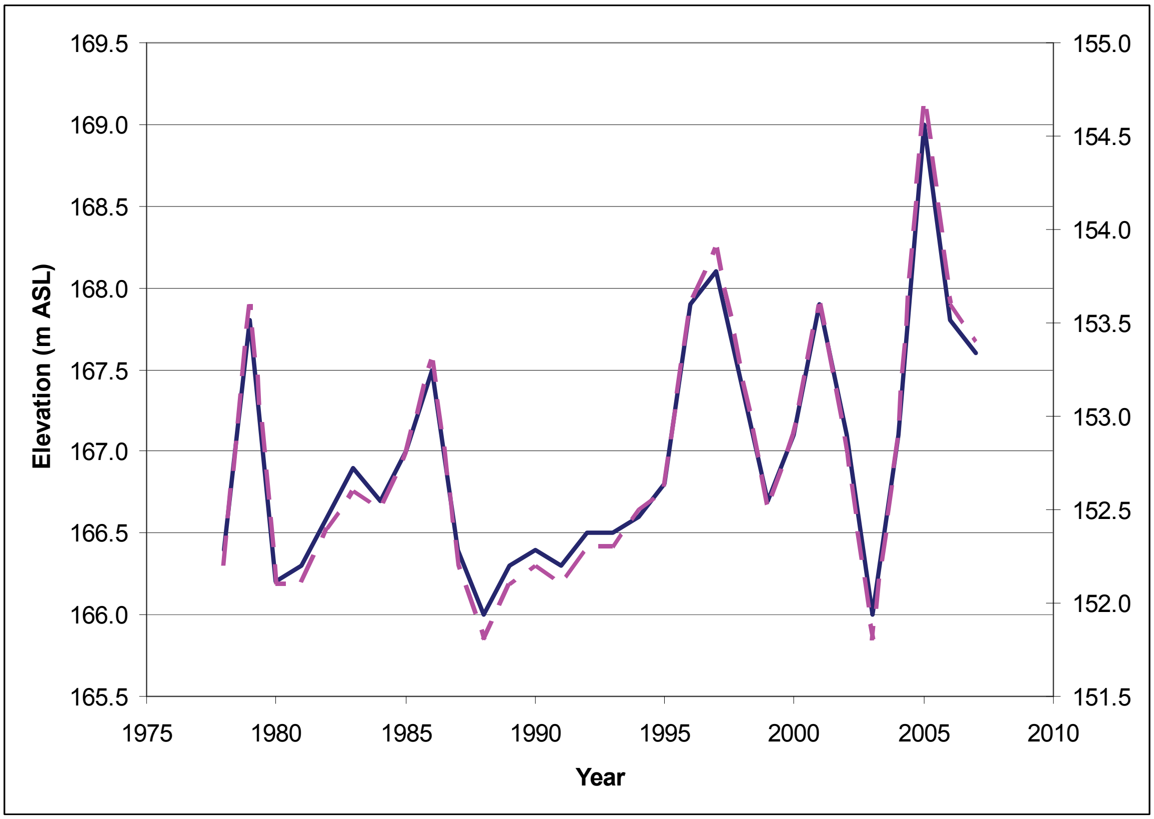


Figure 11 – Mean open water season water elevations on Split Lake (blue line scaled on left axis) and Gull Lake (pink line scaled on right axis) between 1978 and 2007.

4 METHODS

4.1 TYPICAL SOIL PROFILES

A number of studies were conducted to support the proposed Keeyask generating station terrestrial habitat and ecosystem effects assessment and the **peatland disintegration** modeling. Some studies designs were representative for the reservoir area as a whole while others were only representative for selected areas or conditions.

Representative soil profile data for the reservoir area were available from the 2002 soil reconnaissance survey and from upland and **peatland** habitat studies (Figure 12). The objective of the 2002 soil reconnaissance survey was to provide a rapid overview of soils in the area so that subsequent studies could be designed. Soil samples were located on a 500 m triangular grid in the portion of the reservoir that would undergo substantial flooding. At each location, a spade and hand auger were used to collect soil profile information to a depth of 100 to 150 cm, if not impeded by bedrock, impenetrable ground frost or dense stones. Sampling depth tended towards 100 cm in stony or heavy clay mineral soils due to the time required to hand auger to 150 cm. Soil horizons were identified using the criteria from the Canadian System of Soil Classification (Soil Classification Working Group 1998). Information recorded for each horizon included horizon type, depth, hand texture and **stoniness**. Depth to water table, frost and bedrock as well as parent material deposit type, site type, moisture regime and drainage regime were determined for each location.

Upland and **peatland** habitat studies also provided representative soil data (ECOSTEM 2012c). The objective of these studies was to improve understanding of site level relationships between vegetation, soils, groundwater and other environmental factors. For that reason, the soil profile sampling depth was the shallower of either bedrock contact, 110 cm or **permafrost** refusal. Habitat plots were located using a stratified, random cluster design. The strata were geographic zones. A cluster included at least four of the following ecosite types: deep mineral soil, **veneer bog**, **blanket peatland**, **peat plateau bog**, **collapse scar peatland** or **horizontal peatland**. These ecosite types were thought to be the most common ones in the area based on reconnaissance soil surveys, helicopter surveys, air photos and existing maps. Once a cluster was randomly selected, additional less common ecosite types were added to the cluster if they occurred within a reasonable walking distance.

ECOSTEM (2012c) describes study sampling designs and soil data collection methods in detail. The following provides an overview of soil sampling completed for areas within and near the proposed reservoir.

Soil profile data representative only for selected areas within the reservoir were obtained in 2003, 2004 and 2005. In 2003, sample points were located in **peatlands** where validation of peat type mapping was needed. The data collection protocol for each sample location was the same as for the 2002 reconnaissance survey with two exceptions. First, augering stopped at bedrock contact, **permafrost** refusal or the first few cm of mineral soil (only deep enough to obtain a sample for texture and **stoniness**). In other words, these holes extended to mineral soil or bedrock if not impeded by **permafrost** refusal. Second, **gleying** and/or prominent mottling were recorded.

In 2004, sample points were systematically located along portions of the preliminary predicted non-disintegrating shoreline. The primary objective was to validate preliminary predicted **peatland disintegration** depth to non-disintegrating material predictions. Selected shoreline segments were in the portion of the reservoir where substantial flooding was expected. Most of the non-disintegrating shoreline in these areas was sampled. A secondary objective was to validate soil type mapping. The data collection protocol for each sample location was the same as for the 2002 reconnaissance survey except that: (a) augering stopped at bedrock contact or 30 cm into mineral soil; (b) if peat was frozen, and could not be penetrated by auger, attempts were made to find an alternate unfrozen location within 50 m of the original point (often in a **collapse scar peatland**); and, (c) **gleying** and/or prominent mottling were recorded.

In 2005, the primary objective of the soil sampling was to verify peat, water and excess ice thicknesses in areas difficult to photo-interpret or in areas that had the potential to substantially change **peatland disintegration** predictions if depths to non-disintegrating material were inaccurate. Sample points were subjectively located within these general areas to give the best a priori representation of soil profiles. A secondary objective of this study was to validate soil type mapping. The data collection protocol for each sample location was the same as for the 2002 reconnaissance survey with the following exceptions. Augering stopped at 20 cm into mineral soil. A gas soil auger was used in a pre-selected subset of the peat plots in an effort to penetrate any ground ice present in the soil. If ground ice was impenetrable at the sample location, then attempts were made to do so at up to four alternate points in the vicinity. If this was unsuccessful then information was collected only up to the depth of the impenetrable ice. Augering effort for ground ice was recorded. Data collected for each profile in addition to that for the 2002 reconnaissance survey was as follows. A special horizon modifier was added to identify burned surface soil layers (a large portion of the south side of the river burned in 2005). For frozen horizons, notes were taken on ice structure (e.g. frozen peat but no visible ice, ice crystals, ice in pores, **massive ice**). **Gleying** and/or prominent mottling were also recorded.

Borehole data acquired by Manitoba Hydro supplemented field data collected by ECOSTEM. These boreholes were primarily located along potential dyke lines and in potential borrow areas. Only those boreholes located in terrestrial areas were used (N=858).

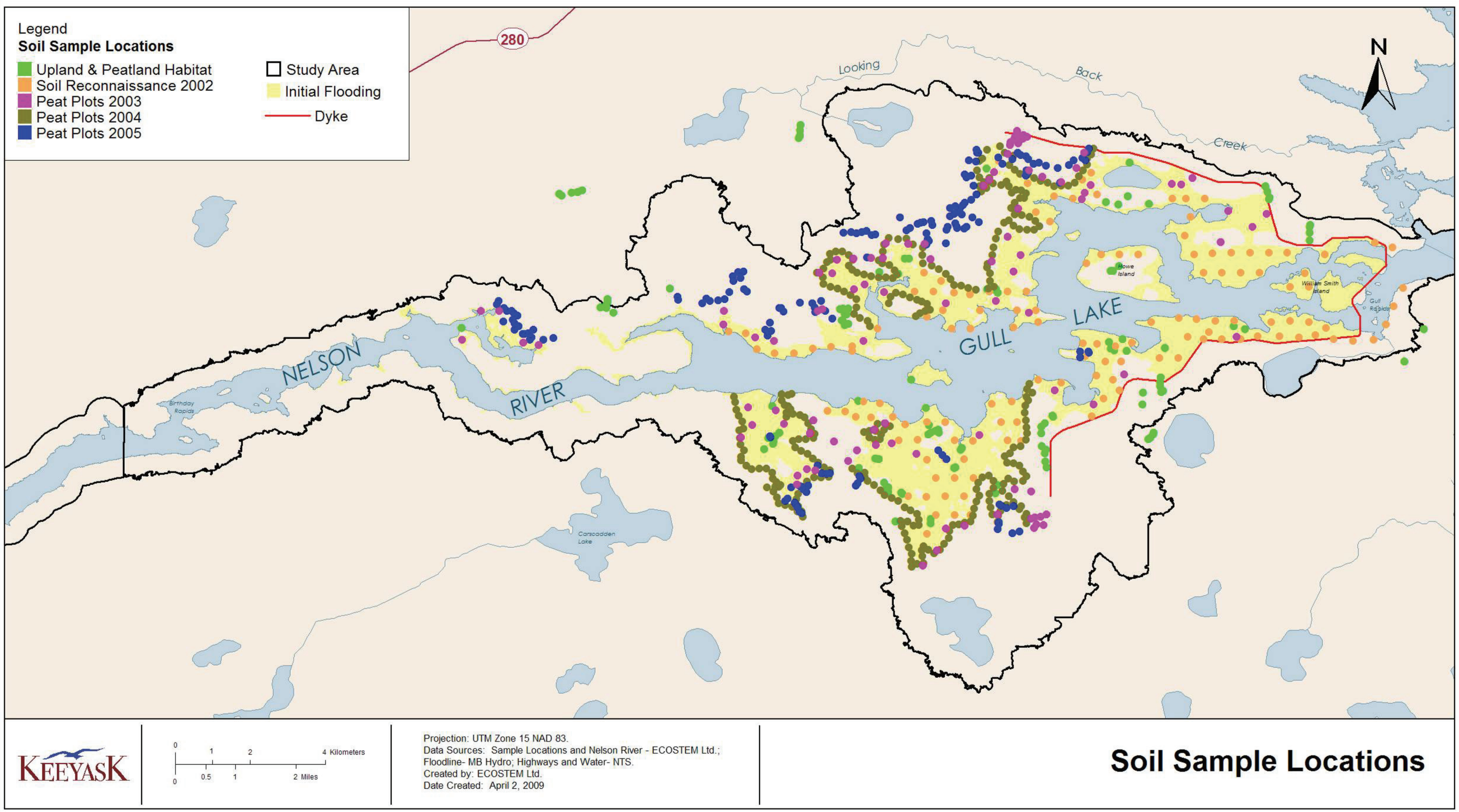


Figure 12 – Soil sample locations by sampling protocol.

4.2 EXISTING STUDY AREA SOILS WITH EMPHASIS ON PEATLANDS AND PEATLAND MOSAICS

4.2.1 NELSON RIVER SHORE ZONE

The Nelson River existing environment terrestrial habitat shoreline was mapped from Clark Lake outlet to Stephens lake inlet. The terrestrial habitat shoreline was defined as the visible historical extent of water and ice regime effects on upland and **peatland** habitat. This generally coincided with the top of bank in mineral soil segments with simple banks. Delineating a shoreline location was more complex in riparian peatland**s** and stepped mineral banks. For riparian peatland**s**, the approximate extent of water in the peat at the 99th percentile water elevation was interpreted. For stepped mineral banks, shelves that appeared to be the result of post-glacial processes rather than more recent water and ice regime effects were ignored. The Manitoba Hydro composite contours and digital elevation model (DEM) assisted with the interpretation once they became available.

The terrestrial habitat shoreline location was mapped from 1:15,000 black and white stereo photos taken on July 8, 2003 using a mirror stereoscope. An Abrams stereoscope was used in locations where higher magnification was needed. The shoreline was heads-up digitized from the traced photos onto digital ortho-images (DOIs) provided by Manitoba Hydro. The DOIs were developed from 1999 stereo photography at a pixel size of 2 m.

The shoreline was segmented where changes in one or more of the following attributes occurred: beach material type, bank material type, beach slope and bank height. The minimum shore segment length was 100 m. All of these attributes were generally mapped from a helicopter on a paper map of the shoreline and verified using oblique still photos taken from a helicopter. The primary exception was the segment upstream of Birthday Rapids. This segment was added in 2005. Extremely high water levels from 2005 to 2007 (Manitoba Hydro 2009a) obscured the beach and most of the bank. Shoreline classification in this reach was based on photos and video acquired prior to 2005. The quality and completeness of these data were much lower than for the rest of the Keeyask reach.

The classified shoreline map evolved over several years. During the first year of mapping (2002), the bank and the upper portion of the beach were exposed. Water levels dropped to the 1st percentile in 2003 ((Manitoba Hydro 2009b) exposing wide beaches along much of the shoreline.

The classification used for beach and bank material types is provided in Table 1. In the bank, heterogeneous material refers to till or till-like deposits. That is, material that is a heterogeneous mixture of size classes. It is not a deposition mode classification. A “prefix class” with heterogeneous indicates that one size class is dominant. For example, “Sand w Heterogeneous material” would be material where sand was dominant but had material from multiple size classes mixed in.

Bank height was typed in classes (Table 2). Bank height was assessed relative to the toe of the bank rather than water elevation on a particular day.

Ecosite type of adjacent upland or **peatland** area was added to each segment from the soils map (see Section 4.2.2).

Table 1

Beach and bank material type classes.

Material Type	
Bedrock	Fine textured w Boulders
Boulders	Fine textured w Cobbles
Cobbles	Fine textured w Gravel
Gravel	Fine textured w Heterogeneous material
Boulder till	Fine textured
Sand w Rock	Peat w Cobbles w Boulders
Sand w Cobbles	Peat w Cobbles
Sand	Peat w Rock
Sand w Heterogeneous material	Peat
Heterogeneous material	Unknown
Fine textured w Rock	

Table 2

Bank height classes (cm).

Class	Height Range (cm)
No bank	0 cm
Low	< ~ 100 cm
Mixture of low and medium	See low and medium
Medium	~100 to 300 cm
High	> ~ 300 cm
Unknown	

4.2.2 INLAND AREAS

ECOSTEM (2012c) describes ecosite and habitat mapping methods in detail. The following provides an overview of the methods.

Soils in the reservoir area were mapped from the same stereo photos that were used for the shoreline location mapping. Polygon boundaries were traced on the air photos using the same method as for the shoreline location. The minimum mappable polygon area was generally 2 ha. Exceptions to this rule were water (400 m^2) and **collapse scar peatlands** in the reservoir area (1,000 m^2). Polygon boundaries traced on the photos were heads-up digitized on the DOIs.

The ecosite classification used for polygon delineation was developed from soil sampling and photo-interpretation conducted in the Keeyask and Conawapa areas. The ecosite classes (Table 3) reflect important ecological differences in soil properties, hydrology and **permafrost**. The photo-interpretation criteria used for ecosite mapping are provided in Table 3.

Similar ecosite classifications were used to classify map polygons and soil sample locations. Conflicts between the typing of a soil sample location and the polygon will occur when the sample location is in a patch that is too small to map as a separate ecosite polygon. For example, a soil sample in a **blanket peatland** smaller than 2 ha located within a **veneer bog** was classified as a **veneer bog** at the soil profile level but as a **blanket peatland** at the patch level.

Table 3

Ecosite classes and criteria.

Name	**Criteria***
Outcrop	Surface organic layer < 20 cm thick; Mineral soil <4 cm thick.
Thin mineral	Surface organic layer < 20 cm thick; Mineral soil >=4 cm and < 100 cm thick.
Deep mineral	Surface organic layer < 20 cm thick; Mineral soil >100 cm thick; moisture regime very fresh or drier.
Wet thin peatland	Surface organic layer > 20 cm and <= 200 cm; Surface level and featureless; Excess ice absent; Often occurs in steeper runnels or in saturated areas adjacent to horizontal or riparian peatlands.
Wet deep peatland	Surface organic layer generally > 200 cm; Surface level and featureless; Excess ice absent; Often occurs in wide, gently sloping runnels or in saturated areas adjacent to horizontal or riparian peatlands.
Veneer bog	Surface organic layer >= 20 cm and < 100 cm. Commonly found on slopes.
Blanket peatland	Surface organic layer > 100 and <= 200 cm; Surface level and featureless; Excess ice is patchy.
Peat plateau bog	Surface organic layer >= 20 cm: Excess ice continuous and distinct bank visible; Surface level.
Peat plateau bog/ collapse scar peatland mosaic	Mixture of peat plateau bog and collapse scar peatlands. Used outside of the reservoir area or in the reservoir where the peat plateau bog was to small to map as a polygon.
Peat plateau bog in disintegration or formation stage	Aggrading or degrading peat plateau bog.
Collapse scar peatland	Surface organic layer >= 20 cm; Floating peatland entirely or mostly surrounded by a peat plateau bog.

Name	Criteria*
Horizontal peatland	Surface organic layer >= 20 cm; Flat, featureless surface; Open water absent or as small pools.
Riparian peatland	Surface organic layer >= 20 cm; Floating; Open water present.
Shore zone-emergent or peatland	Beach area outside of the regulated zone.
Water	Open water with area > 400 m^2; If peat is present it must be >50% saturated (i.e., patches of open water).
Human	Human infrastructure or semi-permanent clearings (e.g., borrow areas).

* Surface organic layer thickness has highest priority in classification.

4.3 NON-DISINTEGRATING SHORELINE AND STUDY AREA DELINEATION

Reservoir flooding leads to breakdown of shoreline **peatlands** and mineral shore erosion. Consequently, the initial reservoir expands over time. To define the **peatland disintegration** modeling portion of the study area, the maximum possible extent of **peatland disintegration** was estimated.

At a given location in a **peatland**, the peat profile will contain peat over mineral soil or bedrock. The profile may also contain ice and/or water. Water percolates through peat at the reservoir edge. Depending on **permafrost** conditions and other factors, water can percolate through the peat until it reaches mineral soil or bedrock at the same subsurface elevation as the open water surface. The shoreline that would occur if all of the peat and ice within this area disappeared is referred to as the non-disintegrating material shoreline. It should be noted that the ground water surface elevation in adjacent **peatlands** may be higher than the open water surface due to water table perching.

The thickness of peat, water and ice at a particular location is referred to as depth to non-disintegrating material. Depths to non-disintegrating material were assigned to each polygon in the ecosite map in two steps. In the first step, median layer thicknesses were estimated for each ecosite type based on the soil profile data from the ECOSTEM field studies that provided a representative sample for the entire reservoir area. Some ecosite types had too few replicates for percentile calculations either because the actual sample size was too small or because a high proportion of the soil profiles were truncated. Soil profiles were truncated because a depth limit was prescribed by the protocol or because ground frost was impenetrable. Calculated values are negatively biased estimates of layer thicknesses for ecosite types where a substantial number of holes were truncated. The representative and non-representative samples were pooled for ecosite types with low replication for percentile layer thickness estimation. The potential bias of this approach is generally expected to be small. The potential implications are described in the results section for situations where this approach is used. In step two, depth to non-disintegrating layer thicknesses that were assigned to polygons were revised for some portions of the reservoir area. This was necessary because available data indicated that some portions of the reservoir were generally either deeper or shallower than average. Professional judgment was used to adjust polygon non-disintegrating thickness values in these areas. Adjustments were made by panning through the map and comparing polygon values to measured depths from Manitoba Hydro boreholes and all soil sampling.

Depth to non-disintegrating material was estimated for two scenarios referred to as the 50^{th} and 95^{th} percentile scenarios. These are the two scenarios being considered for the post-project **peatland disintegration** modeling. Values used for each scenario corresponded with 50^{th} and 95^{th} percentile results for each parameter.

Peatland disintegration in a reservoir area can extend beyond the non-disintegrating material shoreline where reservoir **peatland disintegration** progresses to this shoreline and peat plateau bogs border the distal side of the advancing shoreline. Some **peatland disintegration** in adjacent areas can occur because the thermal and hydrological balance in adjacent **peatlands** changes. In other words, a "domino breakdown effect" in areas beyond the non-disintegrating material shoreline.

The estimated maximum possible extent of **peatland disintegration** was estimated in several steps.

1. Convert the peat plus water plus ice thicknesses (i.e., disintegrating layer thickness) map from a vector to a raster in a raster GIS (IDRISI Andes).
2. Derive the non-disintegrating digital elevation model (DEM) by subtracting disintegrating layer thickness from the surface DEM provided by Manitoba Hydro. Create non-disintegrating DEMs for the 50^{th} and 95^{th} percentile scenarios.
3. Extract the 159 m ASL contour from each non-disintegrating digital elevation model (DEM). The polygon resulting from this contour represents the maximum possible extent of **peatland disintegration** within the reservoir area.

4. Identify additional potential **peatland disintegration** in adjacent areas due to the "domino breakdown effect". Add domino breakdown areas to the 159 m ASL contour polygon from the 95th percentile non-disintegrating DEM.

The study area was delineated by buffering the polygon generated in step 4 by 500 m to generate the **peatland disintegration** modeling portion of the study area (Figure 10).

4.4 HISTORICAL CHANGES IN NELSON RIVER RIPARIAN AND INLAND PEATLANDS

The **peatland disintegration** study area was divided into two zones that reflect very different **peatland disintegration** processes. These are the Nelson River **shore zone** and the inland areas. The rationale is described in Section 2.6.2 of ECOSTEM (2012c).

4.4.1 NELSON RIVER SHORE ZONE

Historical changes in peat shore segments were detected using 1962, 2003 and 2006 historical aerial stereo photos. The 1962 photos were acquired on September 24th at a scale of 1:12,900; the 2003 on July 8th at 1:15,000; and, the 2006 on August 22nd at 1:15,000.

Water levels can influence photo-interpretation of shore **peatland** edges in shallow water areas. During relatively low water levels, the beach is exposed and this can sometimes be difficult to distinguish from **peatland** surfaces. Mean open water levels in 1962 were thought to be below average in 1962 (Section 3.3). Ice occurs in some water areas.

Nelson River peat shoreline locations in 1962 and 2003 were compared to determine if and to what extent peat bank recession had occurred due to **peatland disintegration**. The existing environment terrestrial habitat shoreline was mapped and classified for 2003. Photography from 2006 was used for cross-checks and to validate the mapped 2003 shoreline location. Areas where the interface between peat bank and the underlying mineral or bedrock material was near or above the water level were ignored on the assumption that these segments undergo **mineral erosion** rather than **peatland disintegration** processes. Horizontal differences in 1962 and 2003 shore locations that were less than 10 m were considered were considered to fall within the error margin related to photo-interpretation, differences in photo scales and the positional accuracy of the DOIs.

4.4.2 INLAND AREAS

Historical changes in **peat plateau bog** area were assessed by comparing changes between 1962 and 2006 or between 1962 and 2003 where 2006 photography was not available. This is the longest time period where photography of a suitable scale is available for most of the reservoir area.

A subset of **peat plateau bogs** in the study area were mapped. Criteria for inclusion were distinct banks along most of the perimeter in 1962 and a minimum area of 0.5 ha. **Peat plateau bog** bank edges were traced on the air photos and then heads-up digitized on DOIs for 2006 and 2003 or scanned 1962 photos georeferenced to the DOIs.

5 RESULTS

5.1 PEATLAND DISINTEGRATION STUDY AREA

5.1.1 DEPTH TO NON- DISINTEGRATING MATERIAL

Depth to non-disintegrating material percentile ranges for each ecosite are provided in Table 4. Inter-decile ranges (i.e., 5th to 95th percentile) were generally in accordance with the defined bounds for the ecosite table (Table 3). Some ranges had minimum and/or maximum values that exceeded the patch level ecosite depth bounds. This generally occurred because ecosite type for the soil profile differed from that for the patch that it occurred in because the patch was to small to map as a separate polygon (Section 4.2.2). An apparent inconsistency also occurred if the ecosite type for the profile or the patch was incorrectly classified.

As noted in the methods, the approach to estimating depth to non-disintegrating material percentiles differed by ecosite type depending on whether adequate replicates were available for percentile estimation. Outcrop and thin mineral ecosite types had too few representative samples to derive percentiles (Table 4) so the pooled sample dataset was used. The potential error from this approach is expected to be very small in relative terms. Median and 95th percentile depth to non-disintegrating material were 5 cm and 8 cm, respectively, for outcrops and 13 cm and 28 cm for thin mineral soils (Table 5).

Deep mineral ecosites had 50 representative samples. Depth to non-disintegrating material was 7 cm and 26 cm for the 50th and 95th percentiles, respectively.

Collapse scar peatlands lacked sufficient representative samples for percentile derivation (Table 4). The wet deep **peatland** and **peat plateau bog** in disintegration or formation stage ecosite types were a transition stage between **peat plateau bog** and **collapse scar peatland** in many locations. **Collapse scar peatlands** differed from wet deep **peatland** and **peat plateau bog** in disintegration or formation stage in that they were wetter and they were generally surrounded by **peat plateau bog**. These three ecosite types were considered to be sufficiently similar to pool for percentile derivation. Estimated depth to non-disintegrating material for **collapse scar peatlands**, Wet deep **peatland** and **peat plateau bog** in disintegration or formation stage was 205 cm and 400 cm for the 50th and 95th percentiles, respectively.

Table 4

Depth to non-disintegrating material (cm) percentiles for representative plots by type of profile truncation.

EcoSite	N	Percentiles (cm)						
		5	10	25	50	75	90	95
Not Truncated								
Outcrop	1							
Thin mineral	1							
Deep mineral	50	2	3	5	7	11	21	26
Wet thin peatland	1							
Veneer bog	86	12	18	24	42	63	77	92
Blanket peatland	16	26	28	46	90	106	117	168
Peat plateau bog	2	41	41	41	41	140	140	140
Peat plateau bog/ collapse scar peatland mosaic	14	30	32	61	73	102	115	130
Peat plateau bog in disintegration or formation stage	3	53	53	53	260	300	300	300
Wet deep peatland	5	15	15	200	226	270	300	300
Collapse scar peatland	9	80	80	105	188	240	400	400
Horizontal peatland	3	120	120	120	138	294	294	294
Riparian peatland	10	48	48	65	90	145	158	315
Truncated- Ran out of auger extensions								
Riparian peatland								
Truncated- Reached maximum depth for the protocol								
Veneer bog	9	100	100	100	110	120	120	120
Blanket peatland	3	100	100	100	100	120	120	120
Peat plateau bog	3	100	100	100	100	120	120	120
Peat plateau bog/ collapse scar peatland mosaic	3	130	130	130	150	150	150	150
Horizontal peatland	3	100	100	100	100	150	150	150
Truncated- Frost/ ice impediment								
Veneer bog	6	51	51	53	62	85	105	105
Blanket peatland	7	54	54	60	74	94	100	100
Peat plateau bog	5	36	36	40	55	63	85	85
Peat plateau bog/ collapse scar peatland mosaic	17	39	54	60	98	110	150	150

Table 5

Depth to non-disintegrating material (cm) percentiles for all plots by type of profile truncation.

EcoSite	N	Percentiles (cm)						
		5	10	25	50	75	90	95
Not Truncated								
Outcrop	7	0	0	0	5	5	8	8
Thin mineral	14	3	4	8	13	24	28	28
Deep mineral	80	2	3	5	9	15	19	25
Wet thin peatland	18	52	52	89	119	165	185	198
Veneer bog	312	14	20	30	45	63	77	90
Blanket peatland	58	26	40	65	93	113	160	168
Peat plateau bog	7	16	16	33	140	240	300	300
Peat plateau / collapse scar mosaic	37	23	30	48	80	115	145	195
Collapse scar peatland	117	57	90	119	189	262	305	350
Horizontal peatland	36	60	113	135	210	278	332	361
Riparian peatland	38	48	65	90	164	318	370	398
Truncated- Ran out of auger extensions								
Riparian peatland	3	275	275	275	320	330	330	330
Truncated- Reached maximum depth for the protocol								
Veneer bog	9	100	100	100	110	120	120	120
Blanket peatland	3	100	100	100	100	120	120	120
Peat plateau bog	3	100	100	100	100	120	120	120
Peat plateau / collapse scar mosaic	3	130	130	130	150	150	150	150
Horizontal peatland	6	100	100	100	100	120	150	150
Truncated- Frost and/ or ice impediment								
Veneer bog	23	38	41	50	55	72	85	85
Blanket peatland	9	42	42	60	74	80	100	100
Peat plateau bog	5	36	36	40	55	63	85	85
Peat plateau / collapse scar mosaic	25	54	54	64	85	100	130	150

A high proportion of the **peat plateau bog** profiles were truncated. Peat, water and ice thicknesses were assigned to a subset of the **peat plateau bog** and **peat plateau bog/ collapse scar peatland** mosaic locations using **peat plateau bog** heights and measurements from adjacent **collapse scar peatlands**. Others have found that peat thickness in peat plateaus is similar to that in adjacent **peatlands** that are in either the aggradation or degradation stages (i.e., **collapse scar peatlands**, Wet deep **peatland** and **peat plateau bog** in disintegration or formation stage) and that the difference in surface elevation is due to ice in the peat plateau (Zoltai 1972). Peat plateau bank heights were measured in the field at a subset of locations. **Peat plateau bog** percentile depths were assigned by adding **peat plateau bog** bank heights to **collapse scar peatland** depths.

The number of representative sample holes was low for estimating **peat plateau bog** bank height percentiles (Table 6). Concomitantly, the differences in median and 95th percentile bank heights between the representative and pooled sample were large. To achieve a compromise between underestimating and overestimating depth to non-disintegrating material in this situation, the mean of the percentile values from the representative and all of the samples was used. On this basis, 50th and 95th percentile **peat plateau bog** heights were 103 cm and 260 cm, respectively (Table 6). When these values were added to **collapse scar peatland** depths, estimated 50th and 95th percentile depths to non-disintegrating material in **peat plateau bogs** were 308 cm and 660 cm, respectively. Ground ice thickness was thought to account for the difference in 50th and 95th percentile difference depths.

Table 6

Peat plateau bog bank height (cm) percentiles.

Sample	N	Percentiles (cm)						
		5	10	25	50	75	90	95
Representative	13	39	76	90	130	150	250	320
All	60	30	40	50	76	120	150	200
Mean					103			260

Table 7

Non-disintegrating material depth (cm) percentiles used for analyses by ecosite type.

EcoSite Type	50th				95th		
	DEM	Final	Difference		DEM	Final	Difference
Outcrop	10	5	-5		20	8	-12
Thin mineral	10	13	3		30	28	-2
Deep mineral	10	7	-3		25	26	1
Wet thin peatland	110	120	10		300	200	-100
Veneer bog	50	42	-8		100	92	-8
Blanket peatland	100	103	3		180	183	3
Peat plateau bog	310	308	-2		570	660	90
Peat plateau bog/ collapse scar peatland mosaic	300	298	-2		560	650	90
Peat plateau bog in disintegration or formation stage	210	205	-5		400	400	0
Wet deep peatland	230	205	-25		350	400	50
Collapse scar peatland	220	205	-15		420	400	-20
Horizontal peatland	200	210	10		360	361	1
Riparian peatland	210	204	-6		400	398	-2

5.1.2 NON- DISINTEGRATING DEM

ECOSTEM soil data and Manitoba Hydro borehole data indicated that depth to non-disintegrating material was either higher or lower than median percentile estimates in some portions of the proposed reservoir. Figure 13 shows areas where depth to non-disintegrating material values for individual polygons were adjusted either above or below percentile depth estimates.

Maps of depth to non-disintegrating material for the 50^{th} and 95^{th} percentiles are provided in Figure 14 and Figure 16. These maps were used in conjunction with the surface DEM to create the non-disintegrating DEMs for the 50^{th} and 95^{th} percentile scenarios (Figure 17 and Figure 18, respectively).

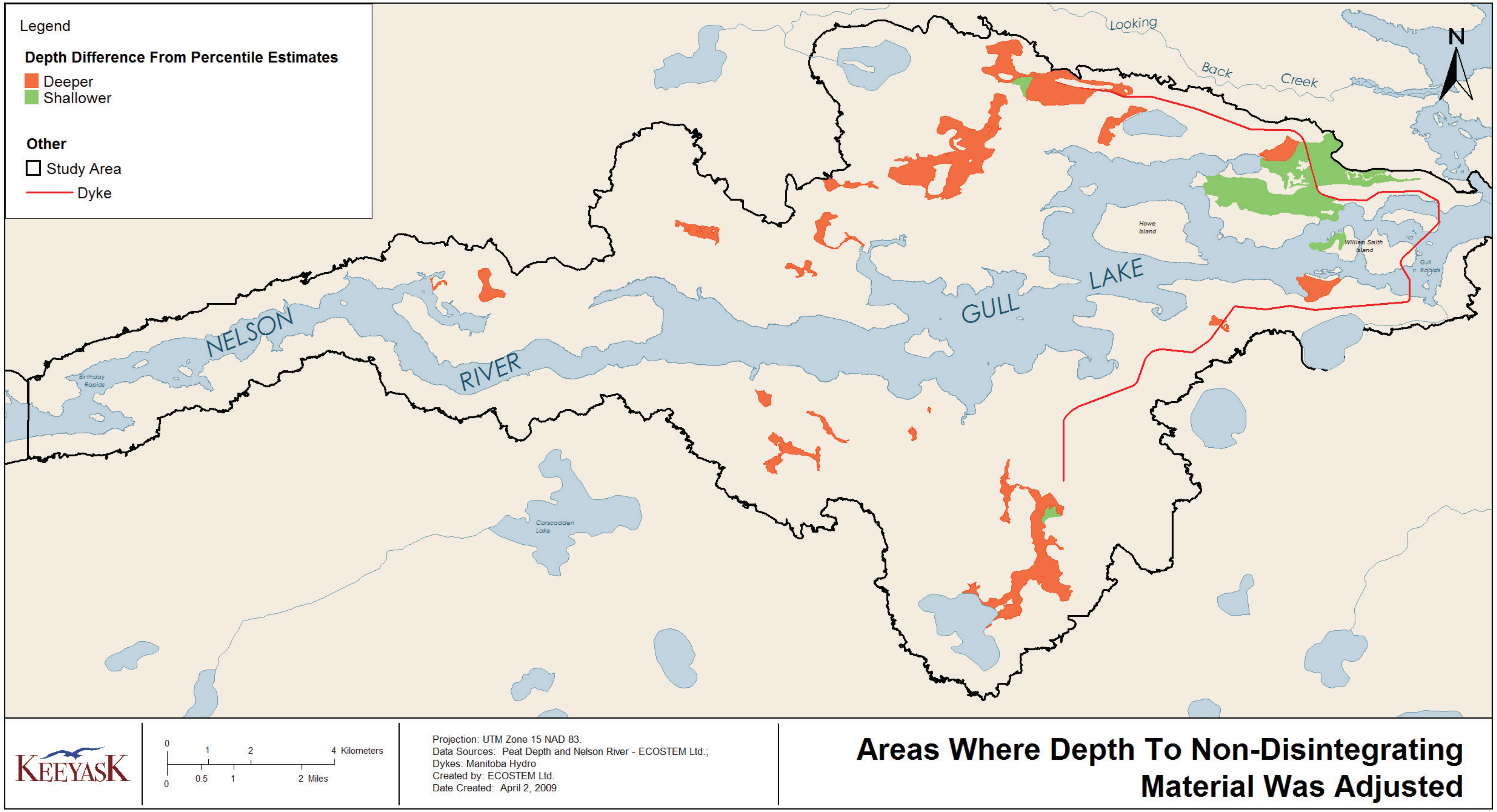


Figure 13 – Areas where depths to non-disintegrating material were adjusted from the percentile depth estimates based on soil or borehole samples.

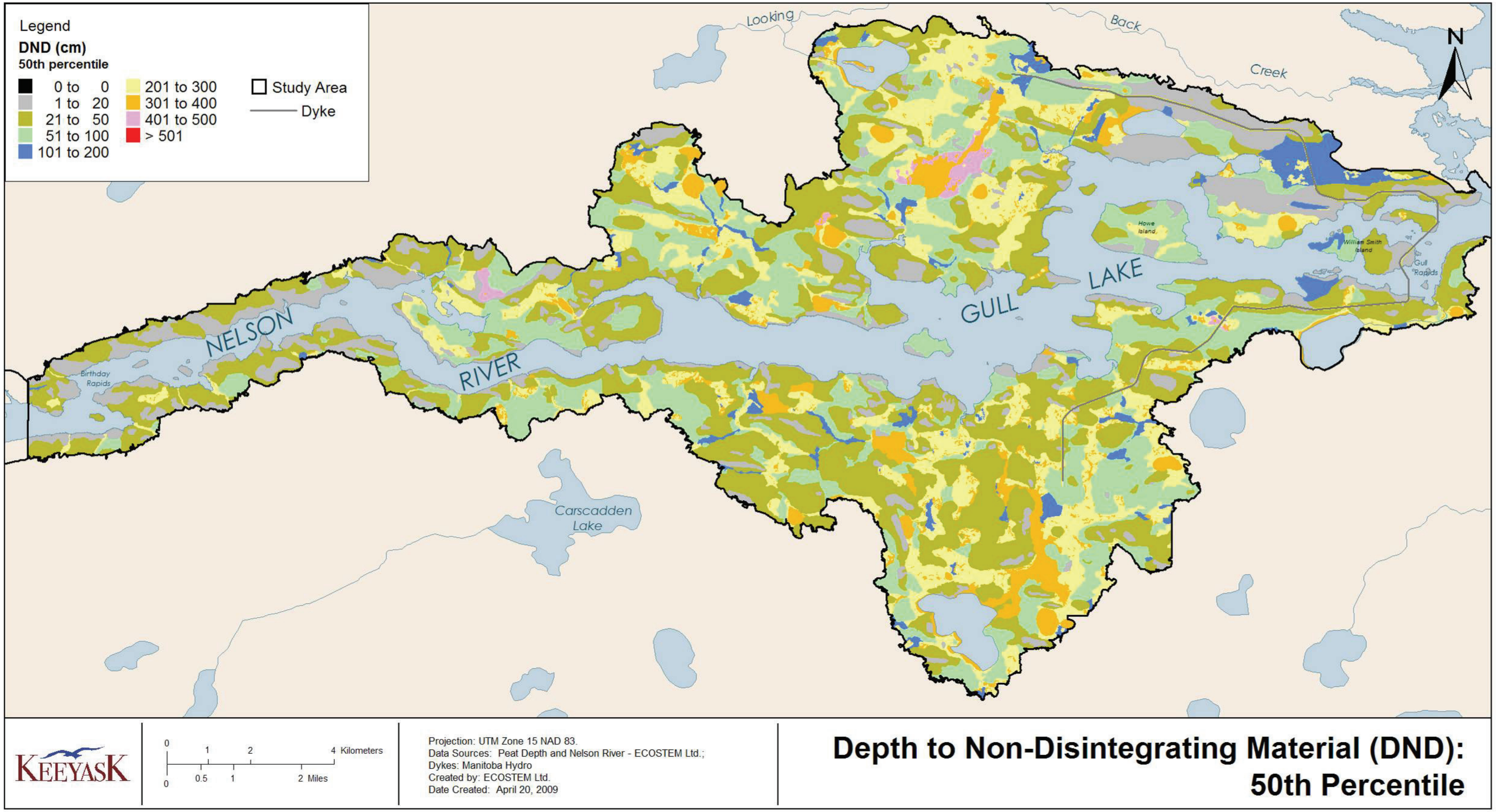


Figure 14 – Depth to non-disintegrating (DND (cm)) material at 50^{th} percentile depths for the proposed Keeyask reservoir area.

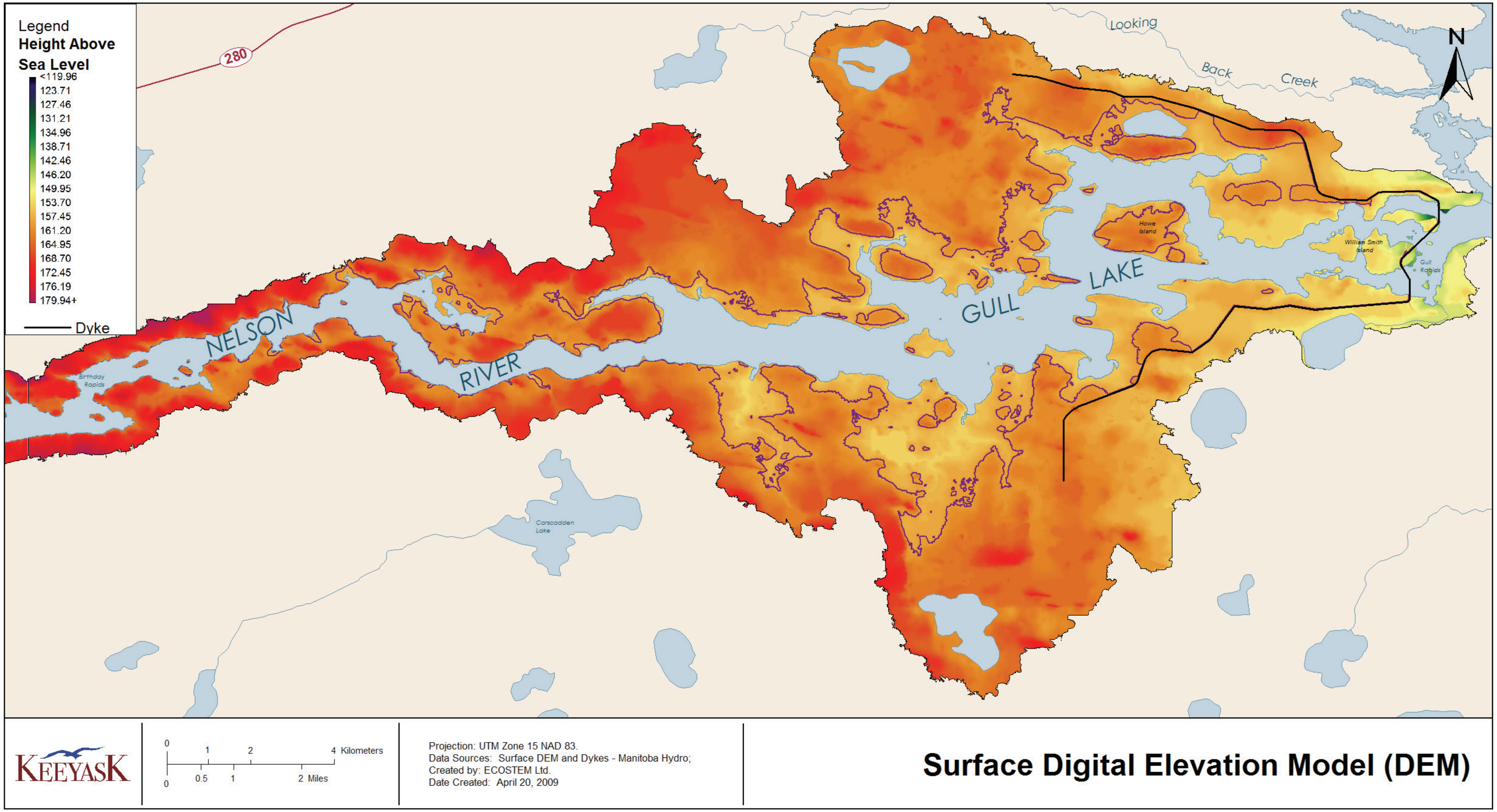


Figure 15 – Surface digital elevation model (DEM) for the proposed Keeyask reservoir area.

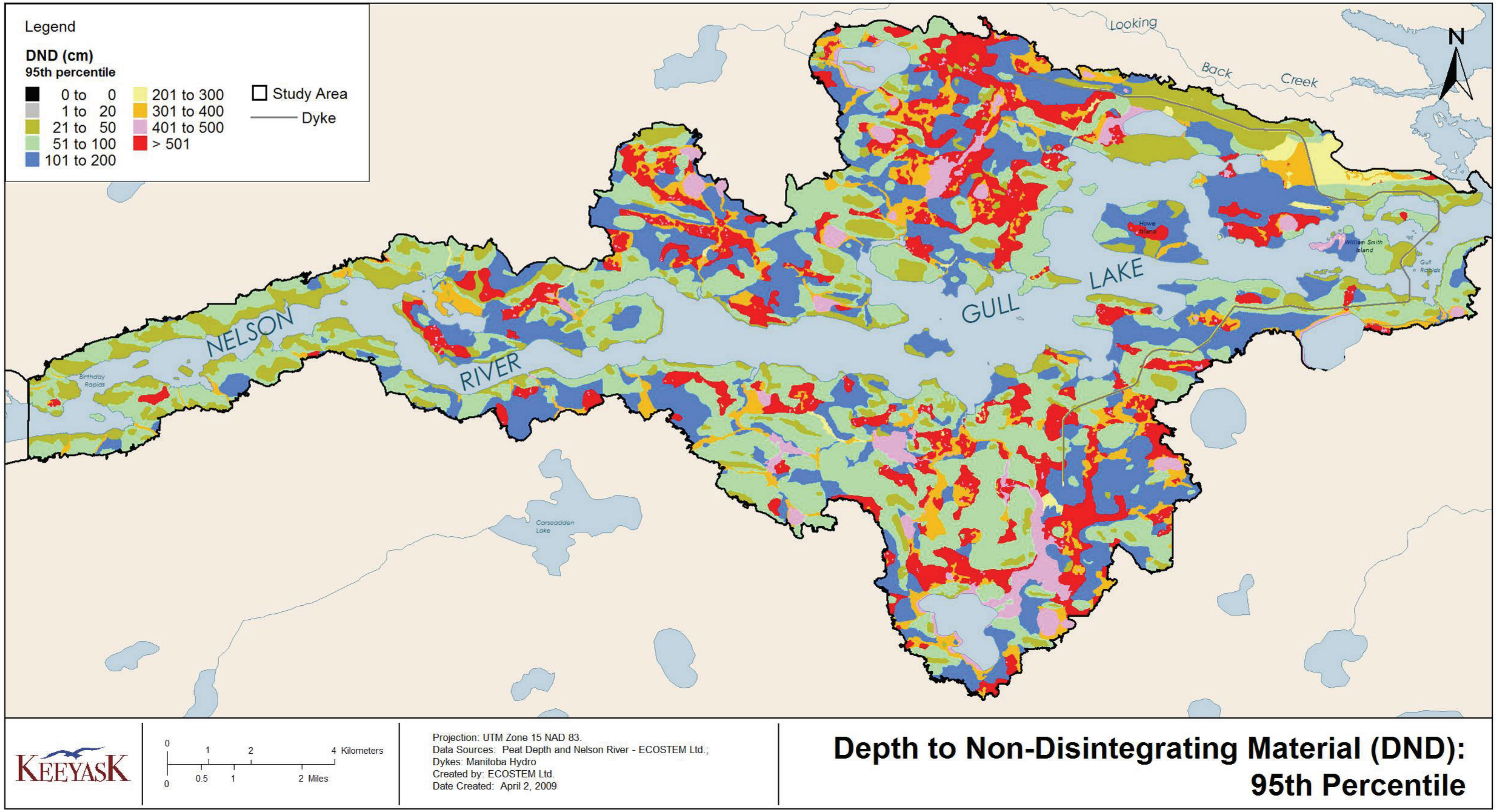


Figure 16 – Depth to non-disintegrating (DND (cm)) material at 95th percentile depths.

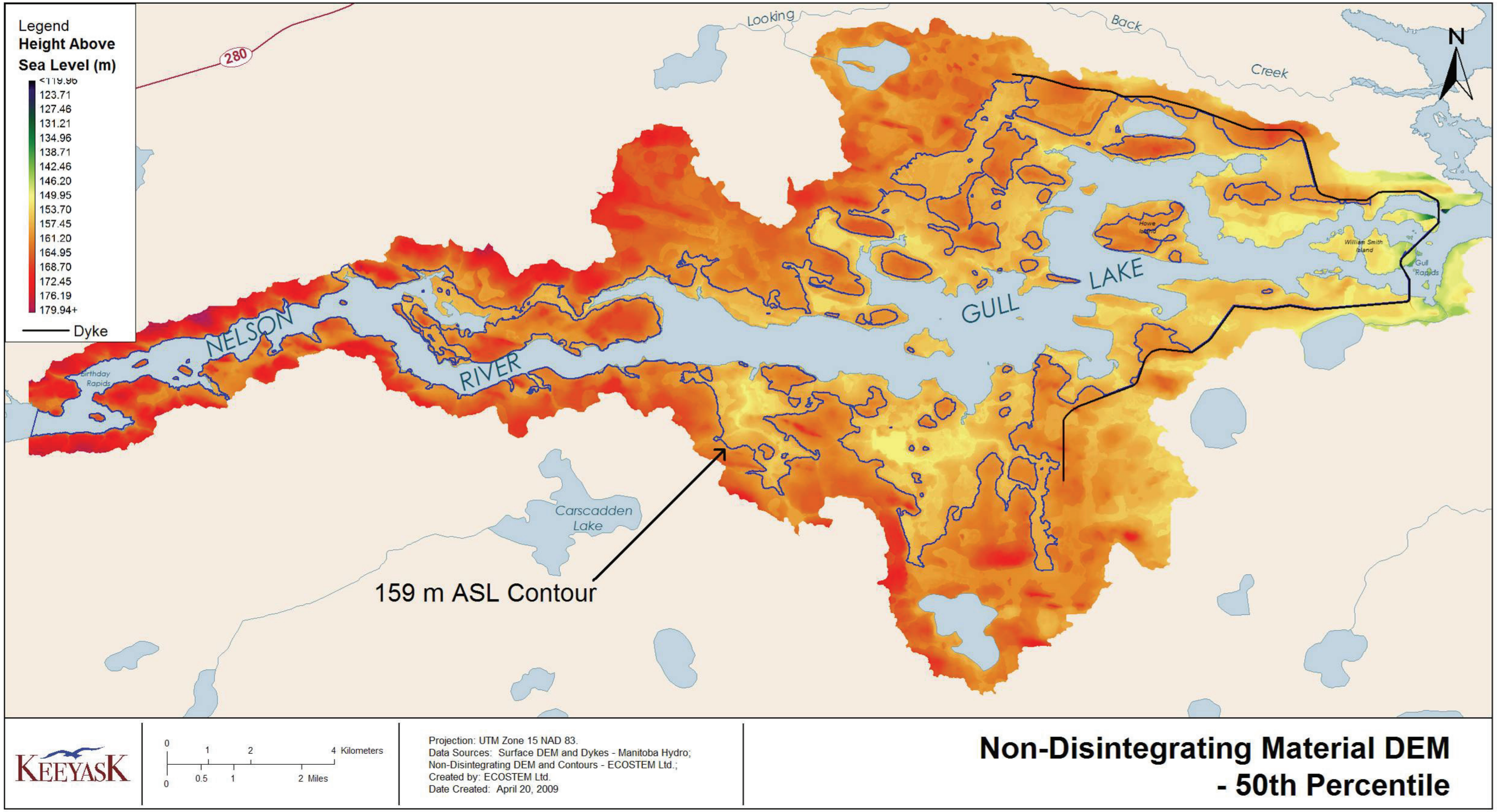


Figure 17 – Non-disintegrating material digital elevation model for the 50th percentile scenario.

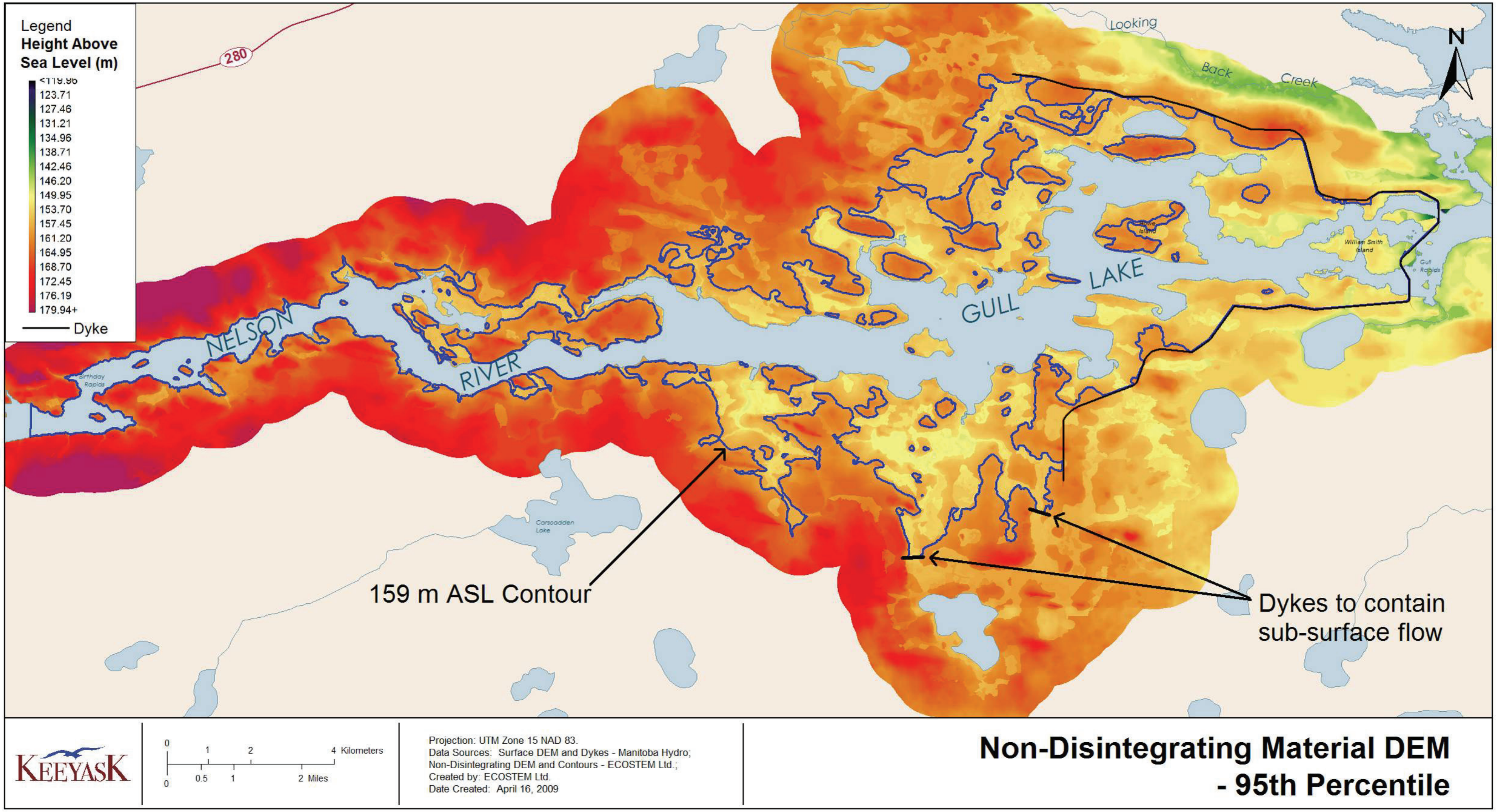


Figure 18 – Non-disintegrating material digital elevation model for the 95th percentile scenario.

5.1.3 Study Area Development

Median and 95th percentile 159 m ASL contours are compared in Figure 19. Note that the 95th percentile scenario contour was truncated in two locations in the southeast reservoir area. If predicted depths to non-disintegrating material were accurate in these areas then subsurface water could flow past the end of the south dyke. Dykes will be constructed in these locations if field verification determines that actual conditions are as deep as predicted in the 95th percentile scenario.

The areas inside the 159 m contour for the 50th percentile and 95th percentile scenario were 10,540 ha and 11,250 ha, respectively. Using the 95th percentile rather than the 50th percentile scenario increased the area within the 159 m non-disintegrating contour by 710 ha or 7.1 km^2. The potential **peatland disintegration** "domino effect" area (Section 4.3) was approximately 6,575 ha in area. A 500 m buffer of the combined 95th percentile non-disintegrating shoreline and the domino effect area yielded **peatland disintegration** modeling study area that was 22,889 ha or 229 km^2 in area (Figure 10).

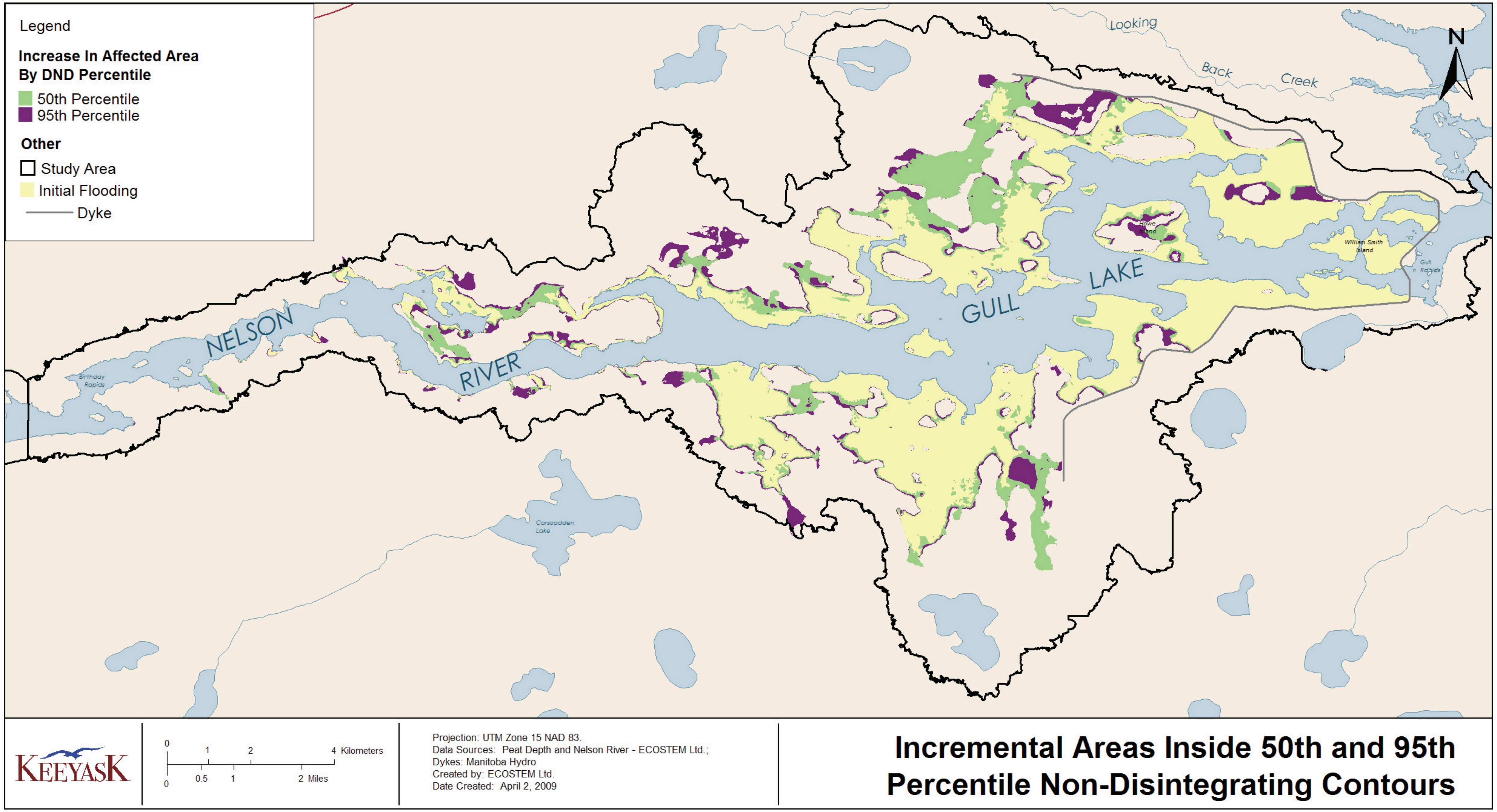


Figure 19 – Comparison of non-disintegrating material 159 m ASL contour in 50^{th} and 95^{th} percentile scenarios.

5.2 PEATLANDS IN THE EXISTING ENVIRONMENT

5.2.1 NELSON RIVER SHORE PEATLANDS

5.2.1.1 Existing Distribution

Approximately 245 lineal km of terrestrial habitat shoreline was mapped and classified in the Gull reach (Figure 20). Additional shoreline in the Clark Lake/ Split Lake and the Stephens Lake reaches were mapped for other studies but were not classified. The total shoreline lengths were 270 km in the Clark/ Split reach and 955 km in the Stephens Lake reach. The following **shore zone** descriptions apply to the Gull reach only.

Beach material was organic/peat along approximately 23% of the shoreline (Table 8). Cobble protruded through the peat in approximately 10% of the peat shore. Peat beach was generally located in sheltered areas (Figure 21).

Peat was more common in the bank than in the beach, comprising 35% of the bank on a length basis (Table 9). Peat beach generally had a peat bank (i.e., 87% of peat beach length). Photos of peat beaches and banks at low water are shown in Figure 22.

Unlike peat beach, peat bank occurred along the main stem shore (Figure 23). Most of these peat banks were above mineral or bedrock beach. It appeared that peat/mineral interface in peat banks on the main stem were located above the 95th percentile of water elevations. None of the main stem peat bank occurred in the narrow riverine segments of the river. This could be due to a combination of factors including few **inland peatlands** extending to the river bank and more prevalent ice scouring (Figure 24). Peat bank was found in a channel through one of the Gull Rapids islands. This channel was created when extreme ice conditions diverted river flow. The affected **peatland** is a **peat plateau bog** (Figure 25).

Mineral and peat bank heights vary over a wide range in the Gull reach (Table 10). Five percent of the total shoreline length has bank heights greater than 3 m. None of the high banks are peat (Table 11). The majority of peat banks (i.e., 87%) are less than 1 m high. High banks are concentrated in the Gull Rapids area and in a few segments of the riverine portions of the Gull reach (Figure 26).

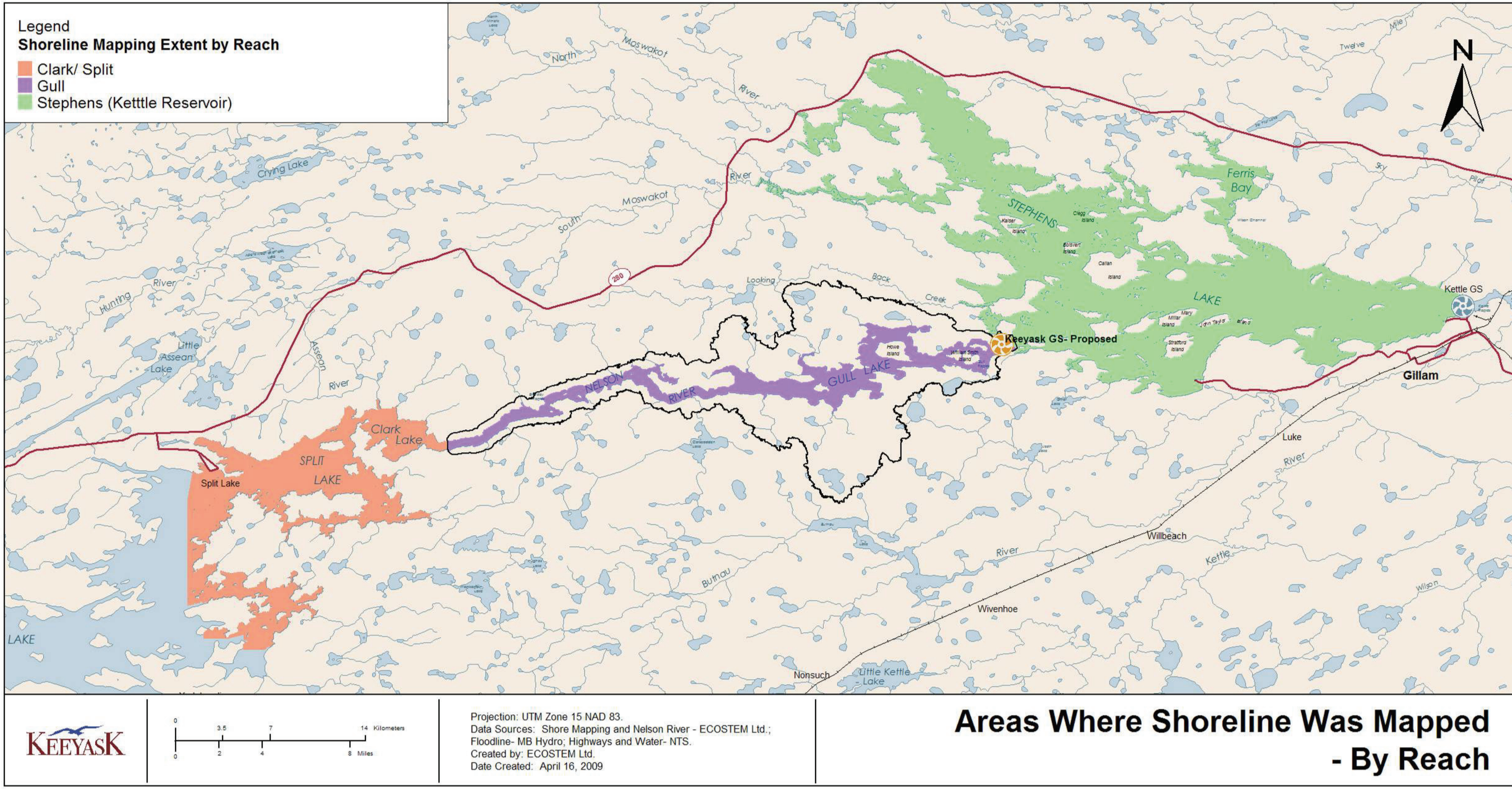


Figure 20 – Extent of terrestrial habitat shoreline mapping.

Table 8

Shoreline beach material composition as a percentage of peat shoreline (m) for the Keeyask reach area (see Figure 20 for extent).

Beach Material Type	Island Shoreline (%)	Mainland Shoreline (%)	Total Shoreline (%)	Total Shoreline (m)
Bedrock	54	17	23	55,964
Boulders	3	2	2	5,879
Cobbles	3	12	10	24,986
Gravel		1	1	2,661
Sand w Rock		1	1	1,565
Sand w Cobbles	17	12	13	32,445
Sand	6	5	5	12,283
Cobbles with Sand		2	1	3,639
Heterogeneous mineral		1	1	1,267
Clay with Rock		1	1	2,039
Clay with Boulders	4	1	1	2,569
Clay with Cobbles	1	4	4	9,341
Clay with Gravel		1	1	2,554
Clay with mixture		1	0	1,214
Clay	5	6	6	15,359
Organic/peat with Cobbles and/or boulders		0	0	584
Organic/peat with Cobbles		3	2	5,557
Organic/p	2	25	21	52,211
Unknown	6	5	5	13,348
All	100	100	100	245,465
Length (m)	40,316	205,149	245,465	245,465

* A value of 0 indicates a percentage that rounds to 0; a blank indicates that the type is absent.

Figure 21 – Shoreline beach material type for the Keeyask reach area.

Table 9

Shoreline bank material composition as a percentage of peat shoreline (m) for the Keeyask reach area (see Figure 20 for extent).

Bank Material Type	Islands Shoreline (%)	Mainland Shoreline (%)	Total Shoreline (%)	Total Shoreline (m)
Bedrock	40	6	12	28,536
Boulder till		1	1	1,624
Sand with Cobbles	1		0	282
Sand	8	5	6	13,723
Sand with Till		2	2	4,228
Heterogeneous mineral	2	12	10	25,025
Clay with Boulders		0	0	217
Clay with Cobbles		0	0	734
Clay with mixture		7	6	13,879
Clay	16	20	19	46,709
Peat with Cobbles		0	0	335
Peat with Rock		1	1	2,292
Peat	16	38	34	83,706
Unknown	17	8	10	24,175
	100	100	100	245,465
Length (m)	40,316	205,149	245,465	245,465

* A value of 0 indicates a percentage that rounds to 0; a blank indicates that the type is absent.

(A) Peat beach and bank

(B) Peat beach and bank

(C) Peat beach and bank

(D) Peat beach and bank

(A) Mineral beach and peat bank

Figure 22 – Photos of Nelson River shoreline beach and bank at low water in 2003.

Figure 23 – Shoreline bank material type for the Keeyask reach area.

Figure 24 – Ice scouring of trees and banks in the Keeyask reach.

(Photo credit: Manitoba Hydro)

Figure 25 – Channel in Gull Rapids island showing bank of peat plateau bog.

Table 10

Shoreline bank height composition as a percentage of peat shoreline (m) for the Keeyask reach area (see Figure 20 for extent).

Bank Height	Islands Shoreline (%)	Mainland Shoreline (%)	Total Shoreline (%)	Total Shoreline (m)
None	0	0	0	99
Low: < ~1m	26	53	48	118,833
Medium: ~1 to 3 m	52	24	29	70,429
Mixture of low and medium	1	2	2	3,771
High: >~ 3 m	7	5	5	13,482
Unknown	13	16	16	38,851
Length (m)	40,316	205,149	245,465	245,465

* A value of 0 indicates a percentage that rounds to 0; a blank indicates that the type is absent.

Table 11

Shoreline bank height in peat shore segments as a percentage of peat for the Keeyask reach area (see Figure 20 for extent).

Bank Height	Peat (%)
None	0
Low: < ~1m	87
Medium: ~1 to 3 m	11
Mixture of low and medium	1
High: >~ 3 m	0
Unknown	1
Length (m)	83,706

Figure 26 – Shore bank height for the Keeyask reach area.

5.2.2 INLAND PEATLANDS

5.2.2.1 Distribution

Water covered 33% of the **peatland disintegration** modeling portion of the study area (Table 12). Mineral soil ecosite types covered 13% of the **peatland disintegration** modeling portion of the study area. **Veneer bog** comprised the highest percentage of land area (i.e., 37%) followed by **blanket peatland** (23%) and the three types of **peat plateau bog** (approximately 19%). **Collapse scar peatland** cover was slightly underestimated in the table since **collapse scar peatlands** comprised a minor component of the **peat plateau bog/collapse scar peatland** mosaic ecosite type. Even after considering this bias, **collapse scar peatlands** probably accounted for less than 1% of the land area. Wet deep **peatland** and **peat plateau bog** in disintegration or formation stage, the other types similar to **collapse scar peatland**, only covered 3% of the land area. A detailed description of soil stratigraphy by ecosite type is provided in ECOSTEM (2012C).

Ecosite types were not evenly distributed within the study area (Figure 27). Mineral soil ecosite types were generally found along the upstream segment of the Nelson River, on till ridges or on eskers. As expected, riparian peatland**s** occurred along streams, rivers and lakes. **Horizontal peatlands** and wet deep **peatlands** were found in lower topographic positions, often adjacent to riparian peatland**s** or **peat plateau bogs** (Figure 4). **Veneer bogs** typically formed a transition between deep mineral soils and other **peatland** types. **Peat plateau bog** transitional stages included the **peat plateau bog** disintegrating or forming ecosite type and the collapse scar ecosite type. There was a large concentration of **peat plateau bog** and its transitional stages in the north-central area. The **peat plateau bog** along the recently formed channel between the two islands in Gull Rapids did not appear on the map because it was too narrow to meet the minimum polygon size for mapping.

Table 12

Ecosite composition of the peatland disintegration modeling portion of the study area.

Ecosite	Percentage of Land Area	Area (ha)
Outcrop	0	5
Thin mineral	1	239
Deep mineral	12	2,043
Wet thin peatland	0	53
Veneer bog	37	6,243
Blanket peatland	23	3,826
Peat plateau bog	3	440
Peat plateau bog/ collapse scar peatland mosaic	14	2,325
Peat plateau bog disintegrating or forming	2	407
Collapse scar peatland	0	56
Wet deep peatland	1	209
Horizontal peatland	2	367
Riparian peatland	4	641
Water		5,916
Human	1	119
All	100	16,975
Total area including water (ha)		22,891

* A value of 0 indicates a percentage that rounds to 0; a blank indicates that the type is absent.

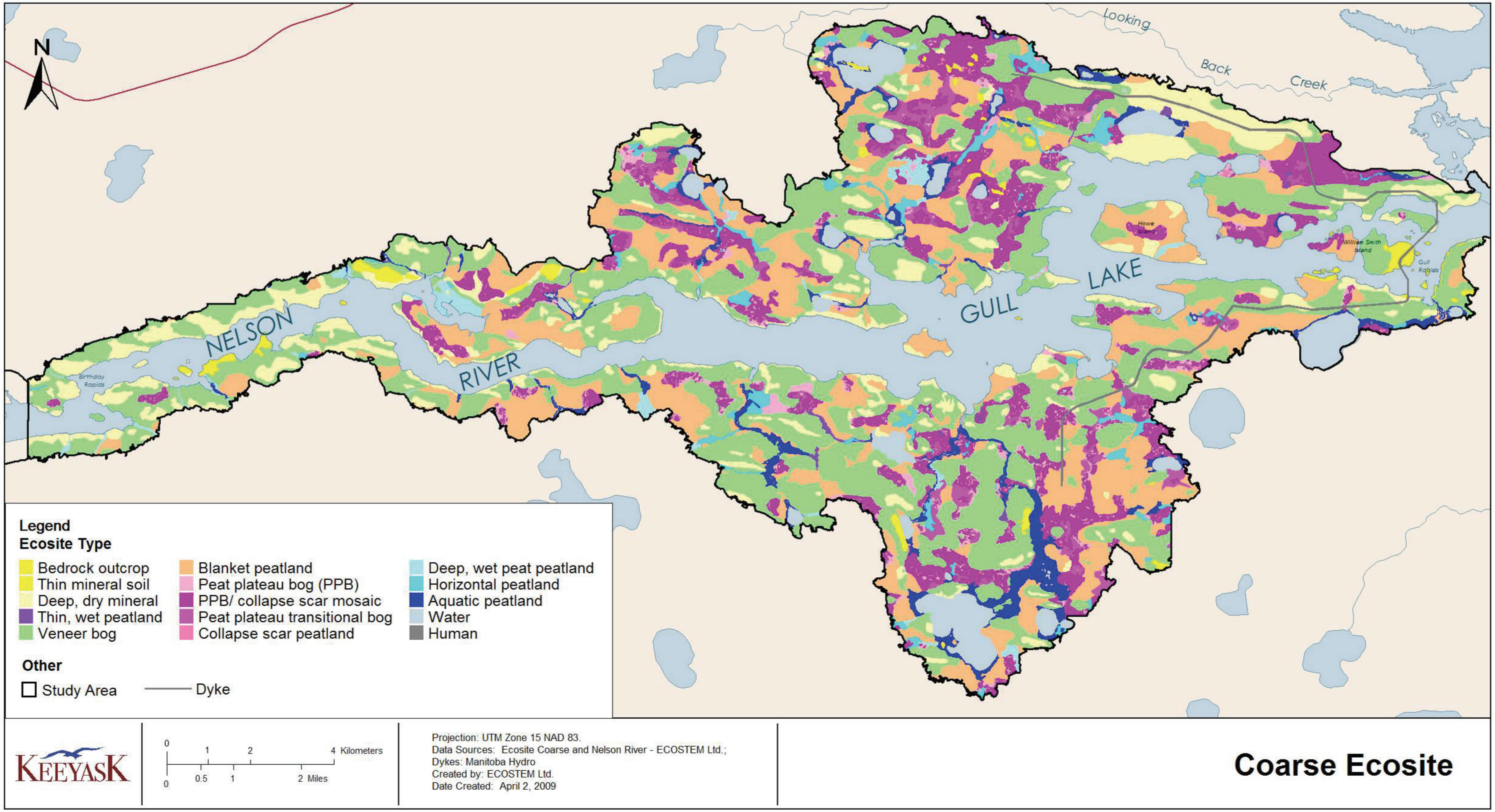


Figure 27 – Ecosite map for the peatland disintegration modeling portion of the study area.

5.2.2.2 Surface Permafrost

Soil profiles that had frost after August 1st were considered to contain **permafrost**. As explained in Section 2.2.2.1, the generally dry state of peat that occurred from mid July to late August would dramatically reduce frost melting during August.

The mainland protocol was the only representative protocol that included locations sampled after August 1st. Deep mineral, **veneer bog** and **peat plateau bog**/**collapse scar peatland** mosaic were the only ecosite types with a sufficient number of representative samples to directly calculate **surface permafrost** occurrence percentages (Table 13).

The percentage of locations with **surface permafrost** was 0% in deep mineral soils and 55% in **veneer bogs**. All of the **peat plateau bog**/**collapse scar peatland** mosaic locations had **permafrost**. However, this was an actually an estimate for **peat plateau bog** because none of the late season profiles were in **collapse scar peatlands**. The **peat plateau bog**/**collapse scar peatland permafrost** percentage was estimated as 90%. The 10% reduction reflects the mean percentage of **collapse scar peatland** covered in **peat plateau bog**/**collapse scar peatland** mosaics.

Soil profiles were sampled in 124 locations between July 19 and 29 in 2002. As expected, the percentage of these profiles with organic layer frost in deep mineral soils and **veneer bogs** (Table 14) was higher than found during late summer (Table 13).

The relationship between organic layer **permafrost** in **veneer bogs**, **blanket peatlands** and **peat plateau bogs** was assumed to be the same as the relationship of organic layer frost occurrence across these ecosite types in late July 2002. On this basis, the percentage of **blanket peatland** samples with **permafrost** was estimated to be 67%.

All representative and non-representative samples were pooled to estimate **permafrost** percentages in the organic layers for the remaining ecosite types (Table 15). Table 16 provides the **permafrost** percentages that were used to describe **permafrost** in the reservoir area. **Permafrost** distribution within an ecosite patch was assumed to be equal to the proportion of profiles with **permafrost** in that ecosite type.

Permafrost was generally absent in the organic layer of mineral soils in the study area and sporadic in thin wet peat (Table 16). **Veneer bogs** and **blanket peatlands** had patchy **permafrost** with **blanket peatlands** having a higher percentage of their area in **permafrost**. **Peat plateau bogs** contained continuous **permafrost**. **Permafrost** was generally not found in horizontal and riparian peatlands.

An important **permafrost** distinction was between **permafrost** presence and the proportion of that **permafrost** that was **massive ice** (i.e., nearly pure ground ice).

Massive ice permafrost had much different implications for **peatland disintegration** dynamics and other processes.

All of the **peat plateau bogs** contained **massive ice permafrost**. The percentage of profiles with **massive ice** in Table 17 was less than 100% because some holes are in **collapse scar peatlands** or in another ecosite type that was too small to map as a separate polygon. On this basis, it should be recognized that the patch level **massive ice** percentage estimates in Table 17 were underestimates of the occurrence of **massive ice** for ecosite at the site level. Approximately 33% of the **permafrost** in **blanket peatlands** was **massive ice**. In general, none of the other organic ecosite types except for **peat plateau bog** forming or breaking down had **massive ice**.

Surface **permafrost** occurred in 63% of the **peatland disintegration** modeling portion of the study area (Table 18). Continuous and discontinuous surface **permafrost** was widely distributed throughout the area (Figure 28).

Table 13

Percentage of representative soil samples with permafrost in the organic layers. Based on frost present in the soil profile after August 1st.

EcoSite	Percentage		N
	Measured	Adopted	
Deep mineral	0	0	16
Veneer bog	55	55	11
Peat plateau bog		100	
Peat plateau bog/Collapse scar mosaic	100	90	17
All			44

* A value of 0 indicates a percentage that rounds to 0; a blank indicates that the type is absent.

Table 14

Percentage of soil samples with frost present in the organic layers in late July 2002.

EcoSite	Percentage	N
Deep Mineral	40	10
Veneer bog	72	60
Blanket peatland	78	27
Peat plateau bog/Collapse scar mosaic	100	15
Collapse scar peatland	11	9
All		124

Table 15

Percentage of all soil samples with permafrost in the organic layers based on frost present in the soil profile after August 1st.

EcoSite	Percentage	N
Bedrock Outcrop	0	7
Thin Mineral	0	12
Thin Wet Peat	11	19
Collapse scar peatland	0	107
Horizontal peatland	5	37
Riparian peatland	0	34
All		216

* A value of 0 indicates a percentage that rounds to 0; a blank indicates that the type is absent.

Table 16

Adopted percentages of profiles with permafrost for each ecosite type.

EcoSite	Percentage
Bedrock Outcrop	0
Thin Mineral	0
Deep Mineral	0
Thin Wet Peat	11
Veneer bog	55
Blanket peatland	67
Peat plateau bog	100
Peat plateau bog/collapse scar Mosaic	90
Collapse scar peatland	0
Horizontal peatland	5
Riparian peatland	0

* A value of 0 indicates a percentage that rounds to 0; a blank indicates that the type is absent.

Table 17

Percentage of soil profiles with massive ice by ecosite type.

EcoSite	Percentage	N
Deep Mineral	0	4
Thin Wet Peat	0	1
Veneer bog	11	46
Blanket peatland	33	21
Peat plateau bog	67	6
Peat plateau bog/Collapse scar mosaic	44	18
Wet deep peatland	0	3
All	24	99

* A value of 0 indicates a percentage that rounds to 0; a blank indicates that the type is absent.

Table 18

Organic layer permafrost in the peatland disintegration modeling portion of the study area by distribution type.

Type	Ecosites Included	Percentage
None	Bedrock outcrop, mineral, Wet deep peatland, collapse scar peatland, horizontal peatland, riparian peatland	23
Sporadic	Thin wet peat	0
Discontinuous	Veneer bog, blanket peatland	60
Continuous	Peat plateau bog, peat plateau bog/collapse scar peatland mosaic	16
Total land area (ha)		16,975

* A value of 0 indicates a percentage that rounds to 0; a blank indicates that the type is absent.

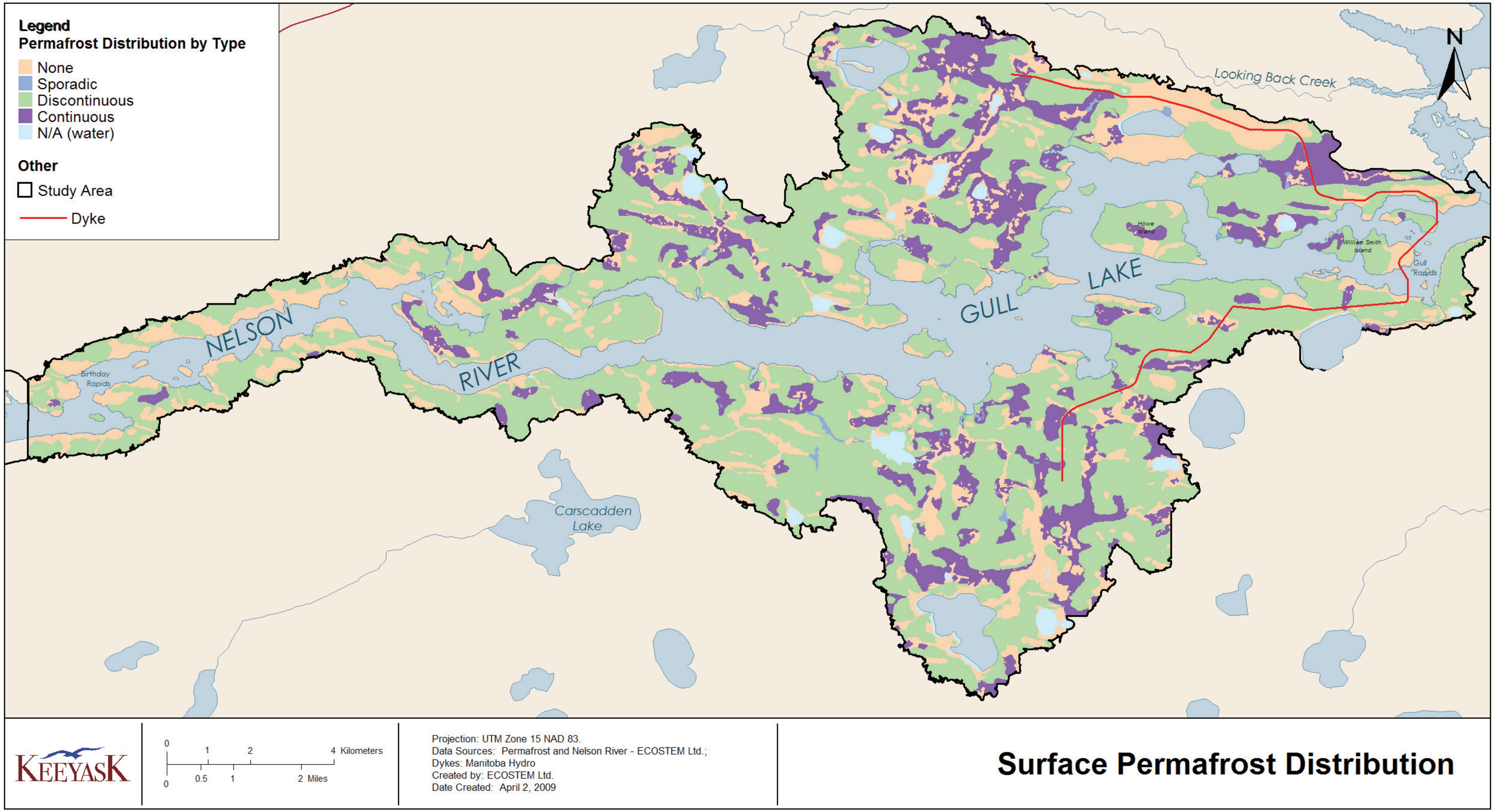


Figure 28 – Surface permafrost distribution in the peatland disintegration modeling portion of the study area.

5.3 HISTORICAL TRENDS IN PEATLAND DISINTEGRATION

5.3.1 NELSON RIVER SHORE PEATLANDS

No measurable changes in 1962 and 2006 peat bank locations were detected through inspection of aerial photos. An example of a stable peat bank is shown in Figure 29. The peat bank location is identified by the yellow arrows in this figure. Peat and organic material on the water side of these arrows is beach exposed by low water levels. The peat bank position relative to the stream bed appears stable between the photo years. Some important things to note when interpreting this photo comparison are that the photos were taken at different scales and flight bearings, the radial distortion in each photo differs because the example location is in a different position in each photo, the 1962 photos were taken in late September after ice had formed on the water in some locations and water levels are low in both photos. To demonstrate the effect of water levels on the perceived shoreline location, the mapped 2003 shoreline is shown superimposed on the 1999 and 2006 DOIs in Figure 30.

Potential peat bank location changes were observed in the long inlet on the north side of the Nelson River near the west end of the **peatland disintegration** modeling portion of the study area (Figure 31). However, closer inspection indicated that changes were tree mortality resulting from fire and probably wetter soils rather than shoreline location changes. It was noteworthy that, in many locations, there were dead trees or the conversion of vegetation cover from trees to tall shrubs at the bank edge. These vegetation changes probably resulted from wetter soils following post-CRD and LWR median water elevation increases.

The beach or riparian peatlands were a potential source of organic material input into the aquatic system. Surface morphology changes in beach peat between 1962 and 2003 were observed in some locations. Although this could suggest that the amount of peat in the beach may have changed between 1962 and 2003, there could be other equally likely causes of surface morphology changes. For example, peat volume reduction from peat compaction and/or melting excess ice. The beach was a highly dynamic area representing the recent balance between deposition and removal. Photography from other years could not be used to derive a weak inference as to whether or not a trend from 1962 to 2003 existed. The beach area generally had ice in the 1986 photos and the beach was under water in 2006.

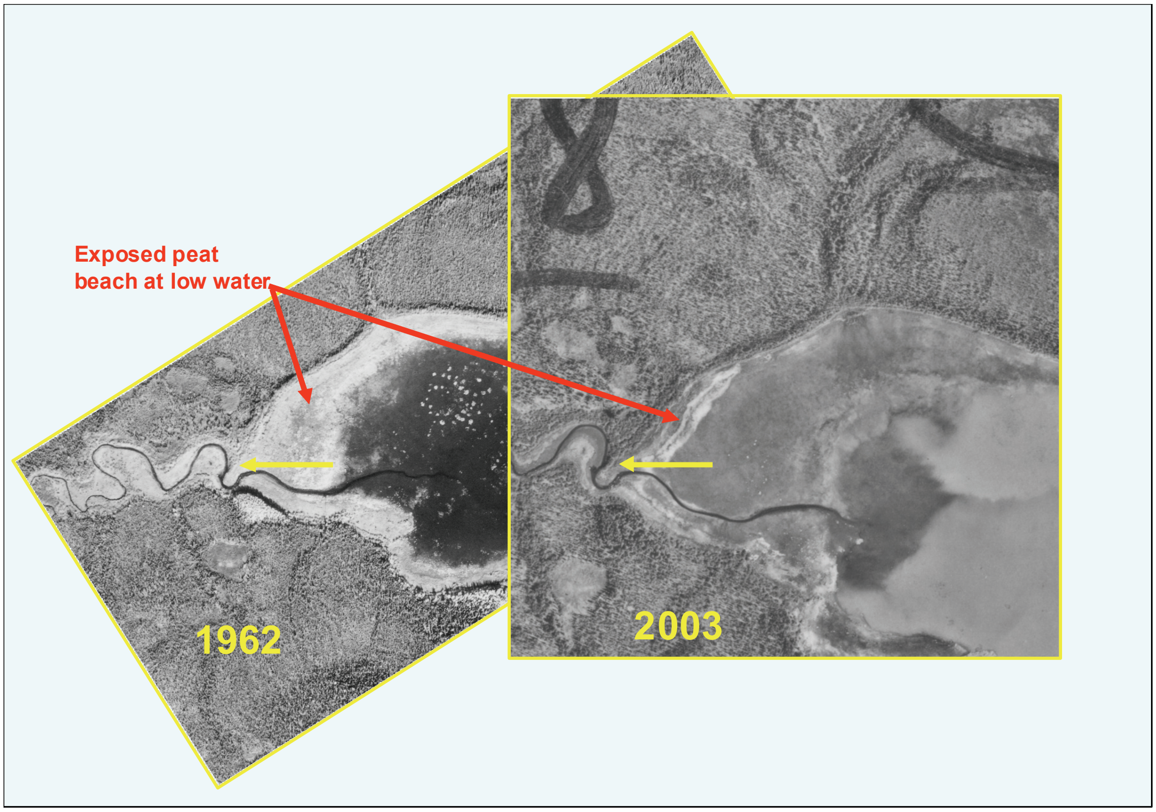
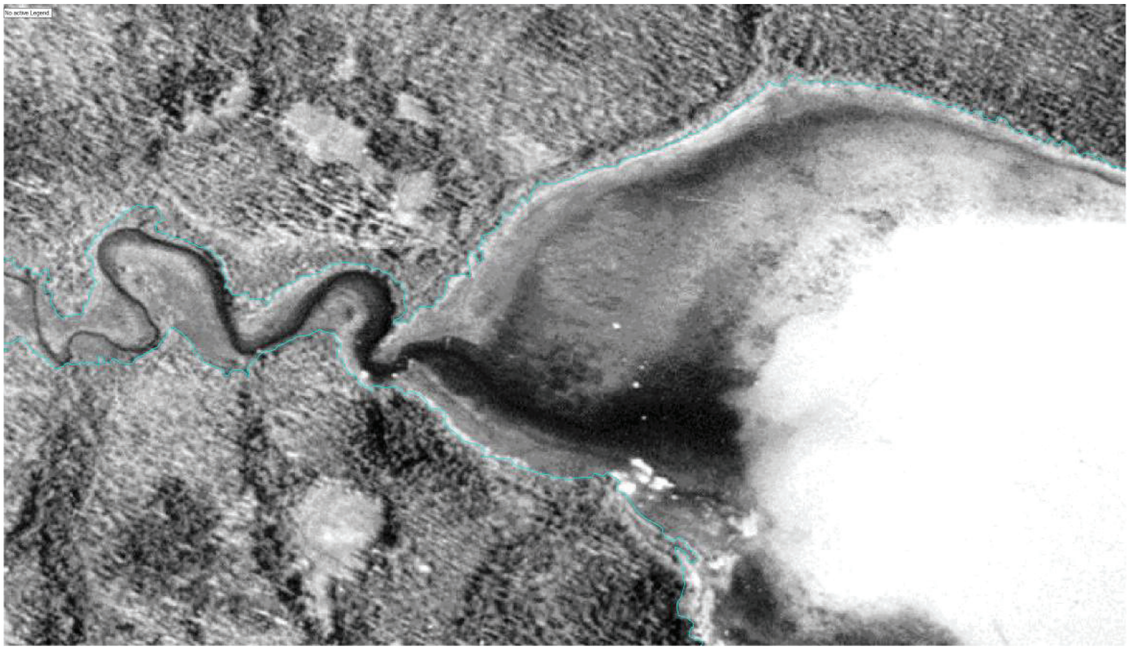
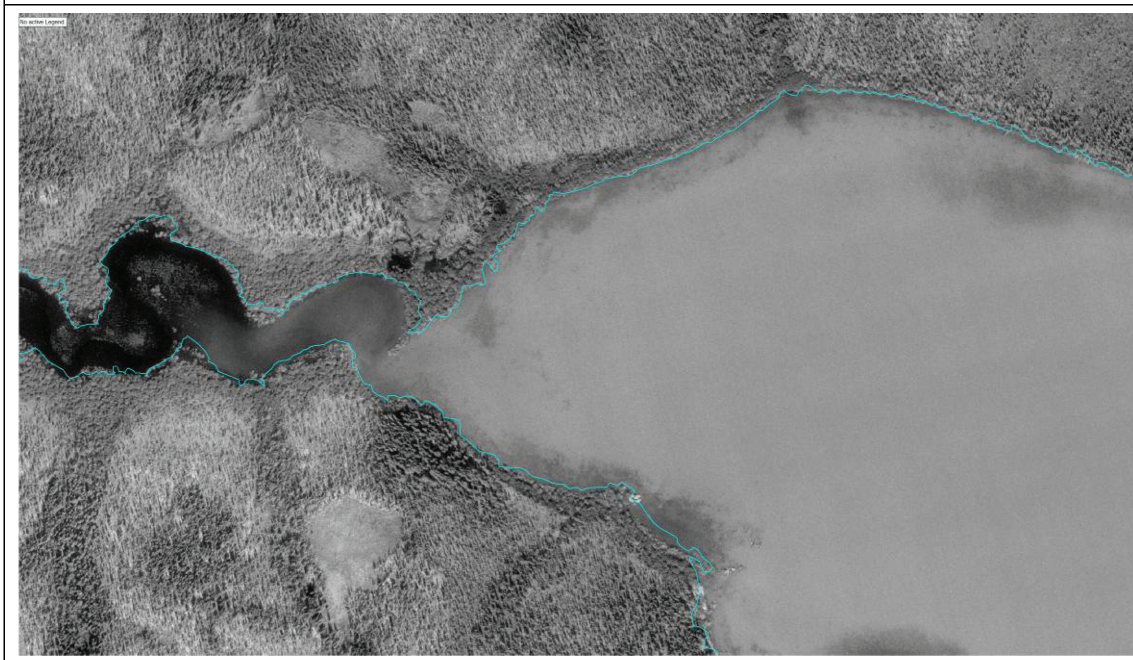


Figure 29 – Comparison of 1962 and 2003 peat bank positions in the northwest portion of Gull Lake.

Yellow arrows highlight an example location where the peat bank was stable. The location of northwest Gull Lake is identified in Figure 31.



(a) 2003 shoreline on 1999 DOI



(b) 2003 shoreline on 2006 DOI

Figure 30 – Mapped 2003 shoreline superimposed on 1999 and 2006 DOIs for area in previous figure.

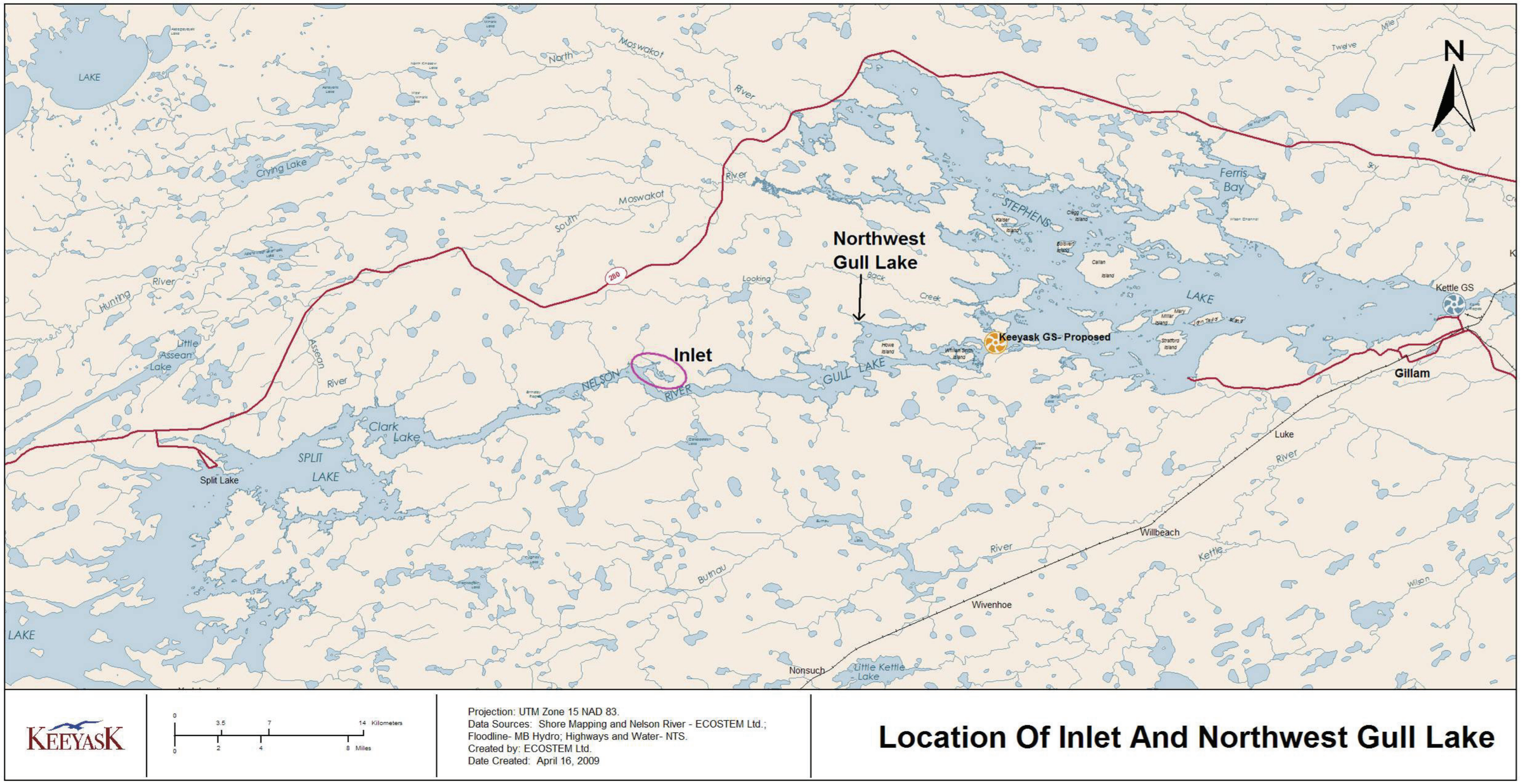


Figure 31 – Location of inlet and northwest Gull Lake.

5.3.2 INLAND

Peat plateau bog area declined between 1962 and the existing environment (either 2006 or 2003 depending on which was the most recent photography year available for the location). The mean and the median area loss was approximately 20% (Table 19). Percentage losses at the 5^{th} to 95^{th} percentiles were 5% to 41%. Area losses for individual **peat plateau bogs** ranged widely from a minimum of 1% to a maximum of 48% (Table 20).

The effects of initial area (i.e., **peat plateau bog** area in 1962) and burn on percentage area loss between 1962 and the existing environment were tested using multiple linear regression. The regression model was highly significant ($P < 0.001$) and had an adjusted R-squared of 0.61. Burn was highly significant but initial area was not.

As discussed in a companion technical memorandum (ECOSTEM 2012b), the above findings were consistent with other literature reports.

Table 19

Peat plateau bog area loss (% and m^2; N=28) between 1962 and existing environment (either 2006 or 2003 depending on which was the most recent photography year available for the location).

Statistic	Percentage	m^2
Mean	20	6,693
Median	19	5,506
5^{th} percentile	5	1,471
95^{th} percentile	41	15,854

Table 20

Changes in individual peat plateau bog patches.

Peat plateau bog #	Area Loss		Year Used for Existing Environment
	Percentage	m^2	
1	14	2,696	2006
2	15	6,677	2006
3	23	6,310	2006
4	17	5,504	2006
5	38	10,799	2006
6	21	15,496	2006
7	1	1,127	2006
8	11	10,343	2006
9	22	1,783	2006
10	22	18,300	2006
11	11	5,040	2006
12	5	1,428	2006
13	39	5,690	2006
14	42	4,739	2006
15	6	4,836	2006
16	16	9,894	2003
17	16	6,524	2003
18	23	12,437	2003
19	8	4,517	2003
20	48	2,457	2003
21	18	1,550	2003
22	33	4,264	2003
23	7	4,559	2003
24	22	3,718	2003

Peat plateau bog #	Area Loss		Year Used for Existing Environment
	Percentage	m^2	
25	27	5,508	2003
26	22	6,090	2003
27	13	9,062	2003
28	23	16,046	2006
All	15	187,394	

5.4 HISTORICAL ORGANIC SEDIMENT VOLUME INPUT

Organic material input into the Nelson River from peat banks undergoing **peatland disintegration** processes was not expected to be measurable during the 1962 to 2003 period given that there was no measurable peat bank recession for those shore segments during that period. **Inland peatlands** also did not provide organic material input into the Nelson River during this period because their limits did not extend to the Nelson River shoreline.

Organic material input into the Nelson River from beach areas may have occurred during the 1962 to 2003 period. Surface morphology changes in beach peat between 1962 and 2003 were observed in some locations. Although this could suggest that the amount of peat in the beach may have changed between 1962 and 2003, there were other equally likely potential causes of surface morphology changes. For example, peat volume reduction from peat compaction and/or melting excess ice. Unfortunately, ice in the 1986 photos precluded the inclusion of an intermediate time step comparison.

Organic material input from bank and beach areas probably occurred during the 2005 to 2007 period when water flows and levels were very high. A comparison of 1999, 2003 and 2006 water levels is provided in Figure 29 and Figure 30. Water levels were still too high in the summers of 2007 to 2009 to conduct field surveys that would visually estimate the amount of affected organic bank and beach material. The effects of high water levels were probably exacerbated on the south shore where the 2005 fire burned to the shoreline. The combination of these two factors may lead to some **peatland disintegration** where **permafrost** melting has already occurred or has been initiated.

GLOSSARY

blanket peatland — **Bog, fen** or mixtures of these types with intermediate thickness peats (i.e., up to approximately 2 m thick) with a featureless surface that cover gentle slopes.

bog — **Peatland** that receives nutrient inputs from precipitation and dryfall only.

collapse scar peatland — A **fen** or **bog** which is a thermokarst feature in a **peat plateau bog**.

fen — **Peatland** in which the vegetation is influenced by mineral enriched ground and/or surface water.

gleying — Process whereby a mineral soil changes color from an earthy reddish/yellow to a bluish/grey, due to waterlogging, and the resultant loss of iron compounds and oxygen.

horizontal peatland — Large, flat, featureless **peatland**; peat depth is generally intermediate to deep. May have a buried water layer.

ice lens — Lens-shaped body of ice of any dimension, usually oriented horizontally.

inland peatland — **Peatland** that is beyond the direct influence of a water body's water regime and ice regime.

lacustrine peatland — **Peatland** which occurs in or adjacent to a water body or a waterway and for which wave energy is generally the dominant hydraulic driver.

marsh — **Wetland** which has emergent or floating-leaved vegetation covering at least 25% of its surface area and shallow water with levels that fluctuates daily, seasonally or annually.

massive ice permafrost — Nearly pure ground ice. Can be several meters thick in a peat plateau bog.

paludification — Process whereby vegetation (primarily Sphagnum mosses) on mineral soils progressively creates a wetter moisture regime that eventually leads to the formation of a surface organic layer that expands laterally over time.

peat plateau bog	Ice cored **bog** with a relatively flat surface that is elevated from the surroundings and has distinct banks.
peatland	**Wetland** where organic material has accumulated because dead plant material production exceeds decomposition.
peatland disintegration	Processes related to: peat resurfacing; breakdown of non-flooded and resurfaced peatlands/peat mats; and, peat formation on peatlands and peat mats that have hydrological connections to a regulated area.
permafrost	Ground area where the temperature remains below 0°C for two or more consecutive years.
riparian peatland	**Peatland** that borders a water body. Edge is often floating.
shallow open water	**Wetland** class determined by the presence of persistent open water up to 2 m deep and surface vegetation cover that ranges from 0% to 24%.
shore zone	Areas along the shore of a waterbody including the shallow water, beach, bank and surrounding inland which are affected by edge effects.
stoniness	Percentage of soil layer volume occupied by stones.
surface permafrost	Permafrost occurring in the top 2 m of the soil profile.
swamp	A minerotrophic **wetland** with at least 30% tree and/or tall shrub cover, woody peat and a higher depth to water table than **fens**. Can be a peatland or a mineral soil wetland.
terrestrialization	The process whereby all or portions of a water body or waterway are filled in by the horizontal expansion of peat from the shore towards the center of the water body or waterway and organic sediment deposition.
veneer bog	**Bog** with thin peats (i.e., generally less than 1 m thick). Generally occurs on gentle slopes and contains discontinuous **permafrost** in the Keeyask region.
wetland	Land ecosystem where periodic or prolonged water saturation at or near the soil surface is the dominant factor

shaping soil attributes and vegetation composition and distribution.

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APPENDIX A - ABBREVIATIONS

ASL ....above sea level

BP...............................before present

˚C ....degrees Celsius

cm...............................centimeter

CRD ....Churchill River Diversion

DEM...........................digital elevation model

DOI ....digital ortho-images

GIS ....Geographic Information System

GDD...........................growing degree days

GS ....generating station

ha................................hectare

km ....kilometer

km^2 ....square kilometer

LWR...........................Lake Winnipeg Regulation

m ....meter

m^2 ....square meter

m^3 ....cubic meter

$m\ yr^{-1}$ ....meters per year