Keeyask Generation Project

Environmental Impact Statement

Supporting Volume

Physical Environment

KEEYASK
Hydropower Limited Partnership

June 2012

APPENDIX 7A
MODEL DESCRIPTIONS

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7A.0 APPENDIX A – MODEL DESCRIPTIONS

7A.1 PRE AND POST-PROJECT MODELLING

An effective assessment of probable impacts on the sedimentation environment due to the development of the proposed Keeyask GS required a comprehensive understanding of the sedimentation processes in the existing environment as well as an appropriate evaluation of the future sedimentation environment after impoundment. The analytical techniques in assessing the sedimentation environment involved a significant amount of numerical modelling and the uses of GIS tools. The two-dimensional numerical model MIKE21, which was developed by the Danish Hydraulic Institute (DHI) water and environment, was applied to simulate the hydraulic conditions and the mineral sedimentation processes in the Keeyask Project area. MIKE21 is a depth-integrated flow model for free surface flows based on a flexible mesh approach. It represents a state-of-the-art tool for the evaluation of hydrodynamic and sedimentation processes and is used widely as a modelling technique. Two different modules of MIKE21, the Hydrodynamic (HD), and Sand Transport (ST) modules, were applied in this study for the assessment of mineral sedimentation in the existing and post-impoundment conditions. The hydrodynamic computation includes appropriate theories to estimate transport diffusion, eddy viscosity, bottom stress, and wind induced stress associated with a given flow condition. The mineral sedimentation computation includes use of a total load theory as well as a suspended sediment transport theory.

This study considered open water sedimentation scenario only due to the complexities and uncertainties involved in the process of sediment transport under winter conditions. The analytical methodology developed to ensure the outcomes of the assessment required the formulation and application of several models. The following discussions provide descriptions of the models that were applied in this sedimentation study.

7A.1.1 Mineral Sedimentation

Three different models were developed in MIKE21 to assess the overall mineral sedimentation environment in the Project area: existing sedimentation environment model, Post-project sedimentation environment model, and Post-project nearshore sedimentation model. In setting up these different models, several key data sets were required including existing bathymetry, existing and Post-project water level and flow regime, existing shoreline polygons, sedimentation-related field data collected in the past, existing mineral sediment loads, Post-project shorelines and polygons, and Post-project mineral sediment loads.

The study area in this exercise spans from the outlet of Clark Lake to the proposed location of the Keeyask GS. Based on the requirements of several studies, including assessments of mineral erosion, peat disintegration, and the aquatic environment, the study area was divided into nine reaches, as shown in Map 7.2-4. Each of these reaches is further sub-divided into north nearshore, offshore, and south nearshore sub-reaches (Map 7.2-4). Based on the requirements of the aquatic assessments, nearshore was defined in this study as the three meter water depth contour relative to the 95th percentile water level of the proposed Keeyask forebay. The contour was chosen based on information of photic depth data, which attained a maximum of 2.9 m, and also from macrophyte distributions with depth sampled in Stephens Lake during 2005 and 2006 (Cooley and Dolce 2007). The depth criterion was formulated primarily for the lake environment in the immediate forebay. In addition to the depth criteria, a linear distance of 150 m from the shoreline in the riverine reaches was also initially considered as the extent of the nearshore area. Accordingly, in the riverine reaches the nearshore criterion for the model was established as: a 0 m to 3 m depth, or a linear distance of 150 m from the shoreline, whichever is encountered first. Having studied all of the Post-project shoreline polygons and bathymetry, the depth criteria was found to dominate in the riverine reaches.

The simulation of Post-project sedimentation did not include Reach 1 as it is outside the Project's hydraulic zone of influence. The model setup began with the input of appropriate bathymetric and topographic information to define the geometry of the river reach. Following this, each model was provided with external boundaries that were developed using either the existing or predicted geo-referenced shorelines. The upstream boundary for the reach consisted of a user-input discharge rate. The downstream boundary consisted of a user-input water level. The next step involved the development of a computational mesh within the study reach. The mesh was formulated with the mike zero mesh generator module, and consisted of a series of triangular elements that had a maximum area of 3,000 m^2, an approximate resolution of 80 m, and a minimum angle between vertices of 30° and 32°. The model stability was insured by keeping the courant number below 0.5. Based on this requirement, and the adopted mesh dimensions, a time step of 0.2 sec was necessary for the simulations.

The sedimentation component of the model was set up as a mobile bed model. Appropriate characteristics were provided regarding the spatial variation of the thickness and size of the sediment layer(s). Suspended sediment concentrations, which were estimated in Clark Lake using the total load theory of Engelund and Hansen (1967); were considered as the upstream boundary sediment concentration for the Keeyask model. The transport of this sediment load was then simulated by the suspended sediment load theory of Galappatti (1983).

7A.1.1.1 Existing Sedimentation Environment Model

The purpose of this model was to simulate the existing sedimentation environment under variable flow conditions and assess the Project impact by comparing this data with the simulated Post-project sedimentation conditions within the study area. The existing sedimentation environment model was developed using the existing bathymetric and topographic information and was calibrated and validated under variable hydraulic conditions.

The hydrodynamic component of the model was calibrated first by adjusting roughness parameters within the model to match observed water level data. The model was calibrated to match water levels at 35 different gauge locations for three separate flow conditions (2,059 cms, 3,032 cms, and 4,327 cms). The model results were also compared with the simulated water levels estimated by Manitoba Hydro's (2005) MIKE21 model for identical flow conditions. Figure 7A.1-1 illustrates the water level comparison for a flow of 3,032 cms under a steady state condition. The comparisons under all three flow condition show a high correlation between computed water levels and actual water levels. However, both Manitoba

Hydro's model and the model developed for this study had some difficulty matching field water levels at sections where significant head loss and high velocities take place (*e.g.*, Gull Rapids). This is primarily due to the lack of detailed bathymetric data in these areas. Because of safety issues and technical difficulties associated with obtaining bathymetric data from these fast water areas, little data could be gathered in these locations.

After the hydrodynamic performance of the model had been calibrated, work was then undertaken on the calibration and validation of the sedimentation module. The sedimentation model was set up and run to simulate the sediment concentrations for June 2006. The model results were then compared to the field data collected from ten measurement locations over this month.

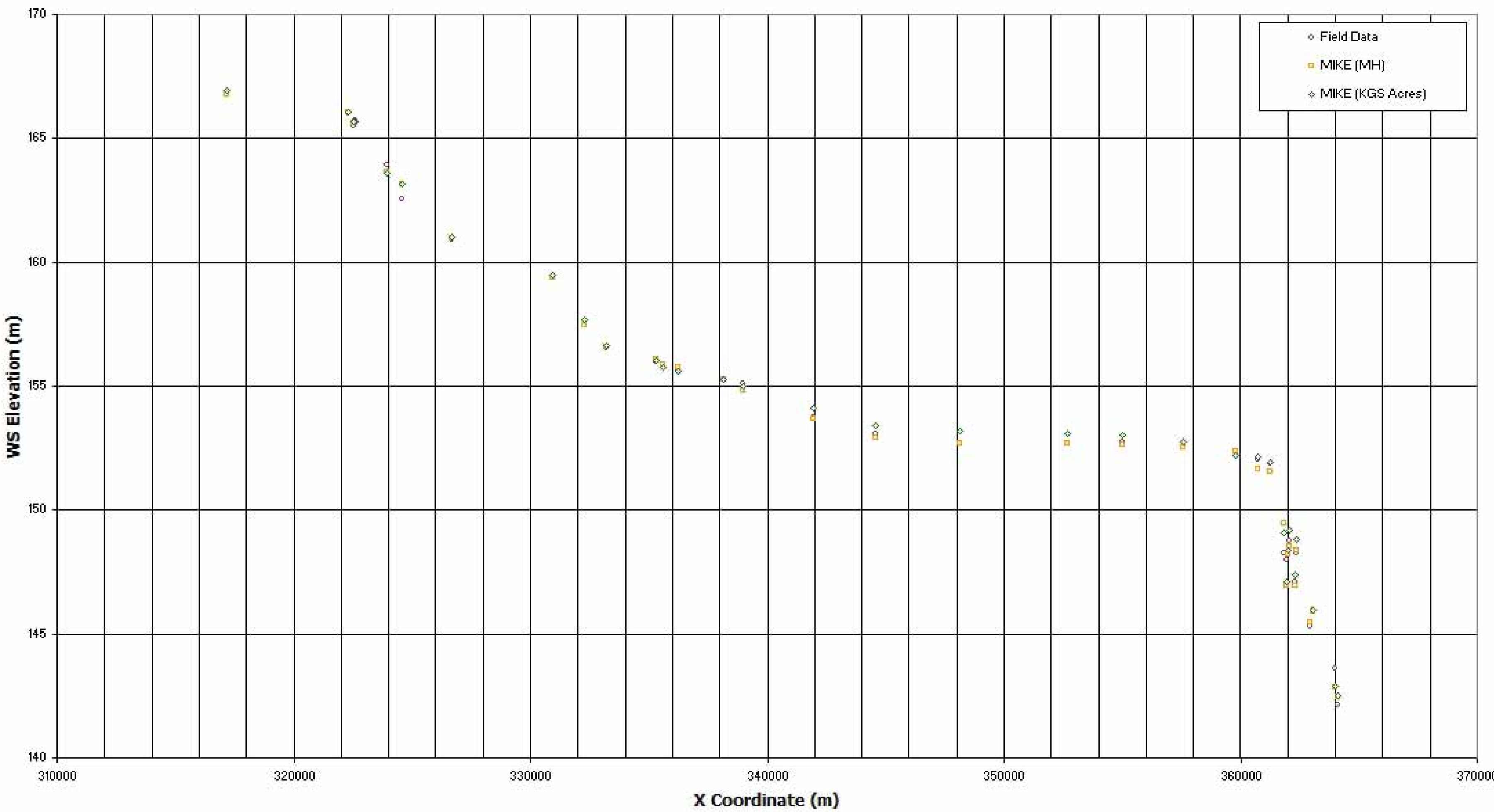

Figure 7A.1-1: MIKE21 Hydrodynamic Model Calibration for 3,032 cms Flow

Figure 7A.1-2 shows a comparison of the field data with the simulated suspended sediment concentrations.

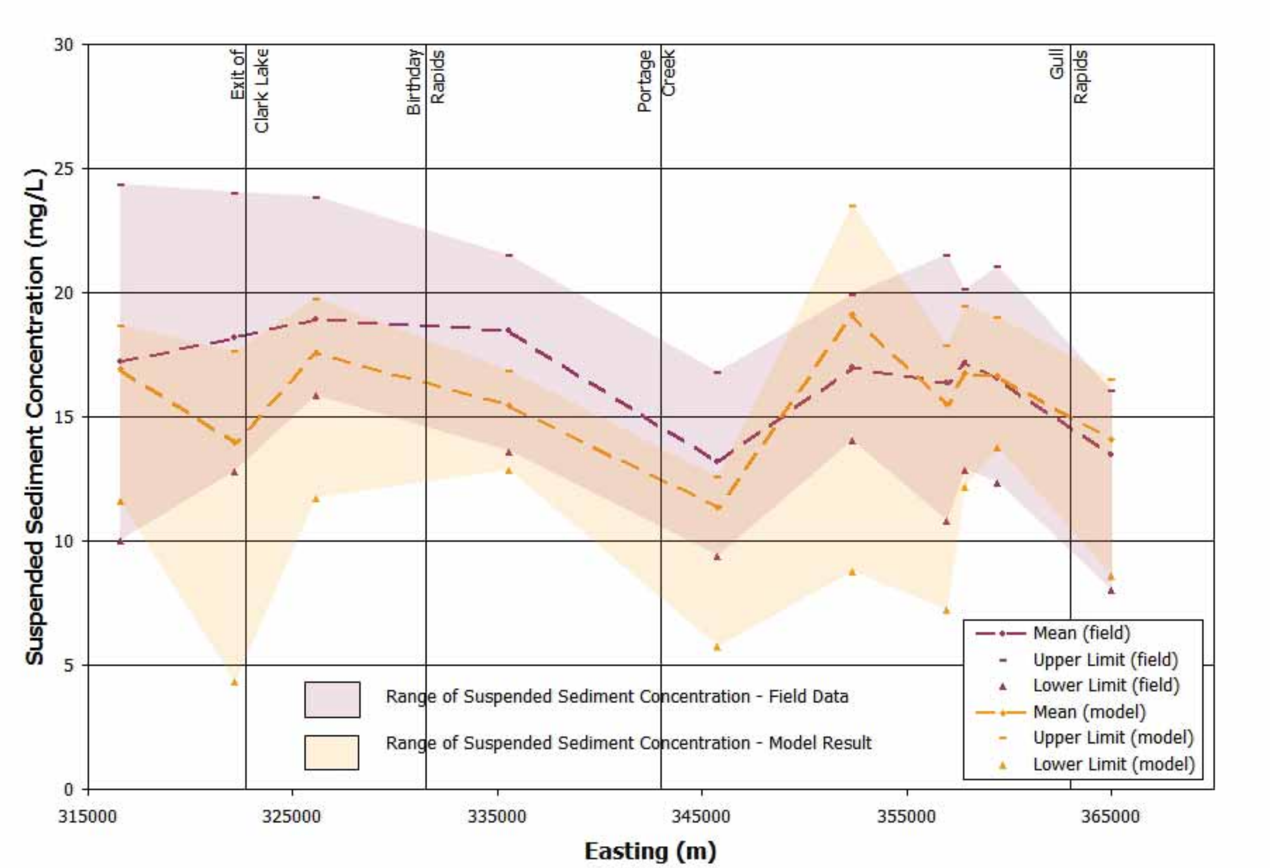

Figure 7A.1-2: Calibration of MIKE21 Model Using Field Data from June 2006

Calibration of the model was carried out by adjusting sediment characteristics within an acceptable limit in the model until a reasonable match could be obtained between the simulated and observed suspended sediment concentrations (Figure 7A.1-2). Once the sedimentation component of the model was calibrated, the model was applied to simulate sediment concentrations that were monitored in four different months during the 2005 and 2006 open water periods. The model results were then compared to field data collected from ten measurement locations over this time period. Overall, the model is considered to be a relatively reliable source for replicating field conditions, although the accuracy of the model results may vary from case to case. For example, the model matched field data reasonably well at the monitoring site downstream of Portage Creek, except in the month of August 2005. Generally, the variations of mean field concentrations and model results remained within +/-15%. According to Ganasut (2005) a discrepancy between computed and observed concentrations of +/-50% is generally accepted. Yuanita and Tingsanchali (2008) obtained accuracy of +/- 29% in their study that applied MIKE21.

7A.1.1.2 Post-Project Sedimentation Environment Model

The development of the Post-project sedimentation environment model was undertaken to simulate the sedimentation environment after impoundment and assess the Project impact under variable flow conditions.

In developing the Post-project model, some modifications had to be made to the existing environment model to represent the Post-project environment. Major modifications included the utilization of Post-project shorelines representing expected conditions 1 year, 5 years, 15 years and 30 years after impoundment, inclusion of newly inundated areas in the model, and the addition of mineral sediment load that would be eroded from the new shore line. The model mesh had to be expanded, particularly in the downstream reaches of the model, to accommodate the larger modelling area that included the flooded area in the forebay. The Post-project model also took into account the mineral sediment loads that would be eroded from the new shoreline under baseload and peaking modes of operation, as estimated by Shore Erosion Studies (Section 6). The added volumes of sediment from shore erosion are injected at various points, on average 100 m spacing in the nearshore wetted area in close proximity to the shoreline. The flow in the study area was assumed to be steady with the forebay level at 159.0 m.

The Post-project sedimentation environment was simulated under the 50th percentile Post-project open water flow condition for different time frames of 1 year, 5 years, 15 years and 30 years after impoundment and for 5th and 95th percentile flow conditions 1 year and 5 years after Project completion. These simulations utilized the eroded shore mineral volumes that were estimated under baseloaded operation of the plant. The Post-project sedimentation environment was also simulated for the 50th and 95th percentile flow conditions using the eroded shore mineral volumes as estimated considering a peaking mode of operation for the time frames of 1 year and 5 years after impoundment.

7A.1.1.3 Post-Project Nearshore Sedimentation Model

In addition to the models discussed above, a conceptual model was also developed using MIKE21 to study the transport of mineral sediment in the nearshore areas. This small scale localized model was developed using a representative post-impoundment nearshore bathymetry profile in the Project area.

This conceptual model considers a nearshore reach of depth ranging from 1 m to 2.2 m. The hydraulic condition simulated for the model provides an alongshore flow velocity of about 0.1 m/s, which is similar to the post-Project flow regime in the nearshore area in the Keeyask forebay. A sediment source which injects a representative concentration of 25 mg/L was added into the system, assuming a relatively large volume of short-term eroded material input from the shore. A sensitivity test was carried out to study the effect of the location of the injection point on the model results. The distance of the sediment injection point from the shoreline was varied from 15 m to 50 m. The mean size of eroded shore material utilized in the model is 0.06 mm representing coarse shore material which constitutes more than 95% of the Post-project eroded material. A conceptual sketch of the model layout is provided in Figure 7A.1-3.

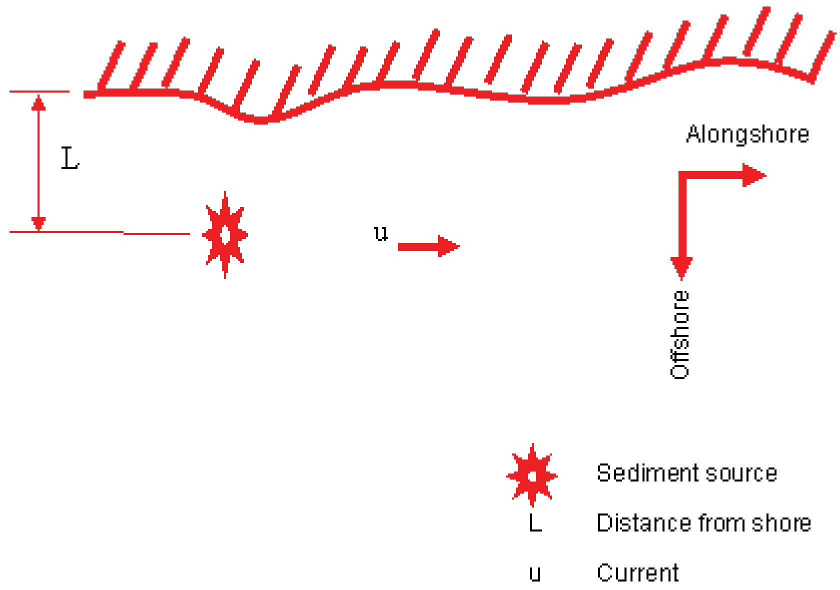

Figure 7A.1-3: Nearshore Sediment Transport Sensitivity Analysis (Conceptual Sketch)

The simulation using the conceptual model showed that the injected materials remain primarily within 100 m of the shoreline (Figure 7A.1-4). This is comparable to the findings of McCullough (McCullough 1987) who performed a study of nearshore sedimentation processes at Southern Indian Lake following its impoundment. McCullough's study was based on fieldwork carried out in 1983. In his study, McCullough measured the ratio of sediment eroded from the shorezone to the sediment deposited in the nearshore zone. Major nearshore deposits typically formed narrow lenses, thickening quickly from the shoreward apex to a maximum at 10 m to 50 m from shore, and tapering gradually to a few centimeters thickness by 100 m to 150 m offshore. Figure 7A.1-5 illustrates that suspended sediment concentrations rapidly decrease downstream of the injection point to near ambient conditions. This suggests that most of the added materials will likely be deposited in the nearshore areas; a short distance downstream of the source. Based on this finding, the magnitude of possible nearshore mineral deposition was estimated using a GIS based model. Eroded shore mineral volumes obtained from Section 6.0 Shoreline Erosion were utilized in this model to assess nearshore deposition, and most of the eroded mineral sediment was found to be coarse textured. Based on the conceptual modelling discussed above, and utilizing the expected post-impoundment nearshore flow velocities, it was judged that 50% to 80% of the coarse eroded volume would be deposited in the nearshore area.

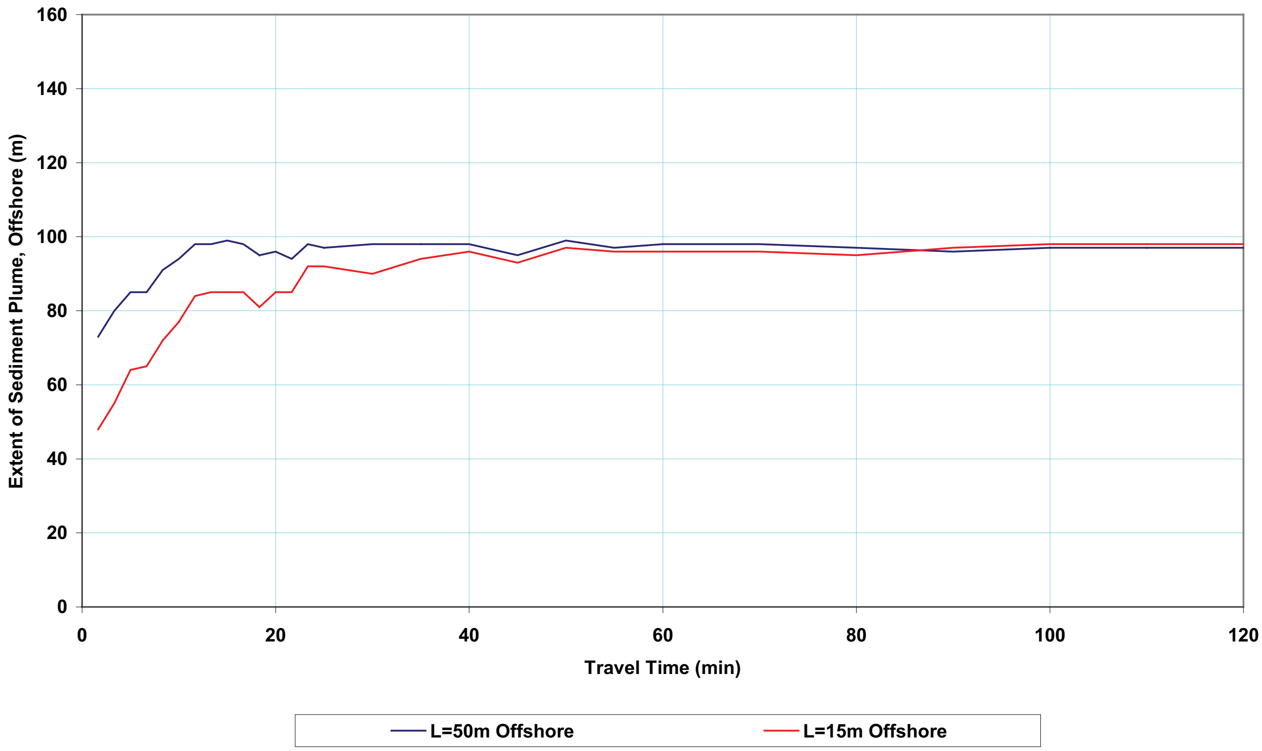

Figure 7A.1-4: Nearshore Sediment Transport – Offshore Extent of Plume

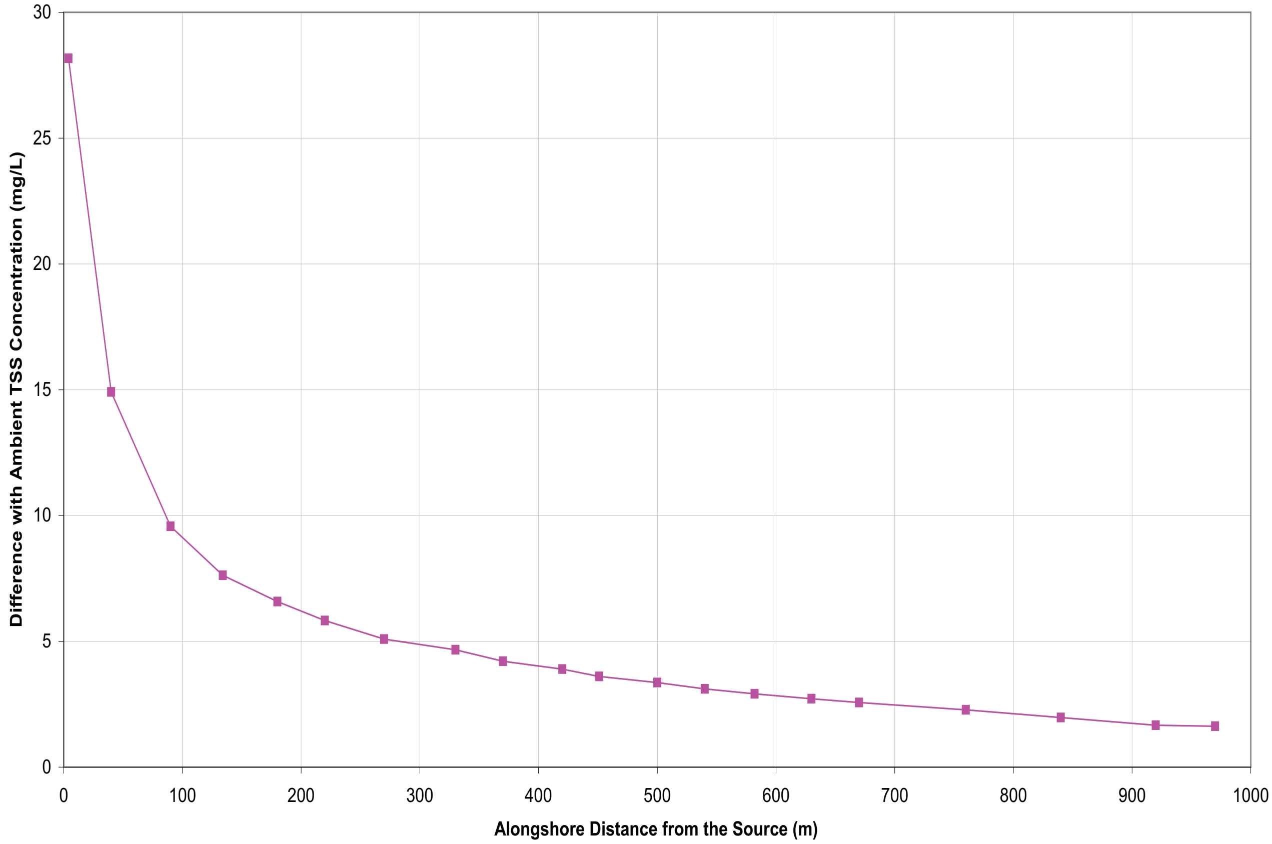

Figure 7A.1-5: Nearshore Sediment Transport – Alongshore Extent of Plume

7A.1.1.4 Limitations of Mineral Sedimentation Models

The numerical model developed for sedimentation analysis is primarily flow driven. In other words, the simulated sediment load will depend on velocity. However, as previously noted, the field data collected suggests that sediment concentration can vary within a range at a given measurement location in a given day. Based on Manitoba Hydro's field measurements, daily discharge in the existing environment does not change significantly. This suggests that the variation in sediment concentration is caused by other local factors, including local disturbances in the water column, meteorological conditions and contributions from local shore erosion. The model is limited in its capacity to include the impacts of local disturbances on sediment concentration. The variation between the measured data and computed data as shown in Figure 7A.1-2 is due to this limitation of the model. From the calibration and verification plots of the model, it appears that the range of model accuracy is approximately +/- 4 mg/L.

The suspended load carried by the Nelson River consists of both non-cohesive and cohesive sediments. However, the ST module of the MIKE21 model used in this analysis is designed for the transport of non-cohesive materials only. Therefore, movement of the cohesive component of the sediment load could only be indirectly simulated. The limitations of the model in computing relatively fine cohesive material were addressed by applying rigorous calibration and validation procedures to confirm the applicability of the model and to develop a parameter set that would adequately replicate the distribution of these fine sediments. The field data suggests that about 10% to 20% of all suspended sediment has a mean diameter of less than 0.004 mm, which is the upper range of clay. Since the majority of the suspended material within the Project area is non-cohesive, the application of a non-cohesive model formulation was considered to be appropriate and necessary.

It should be noted that there is no theory or formulation available in current science that offers a capability to model the transport of both cohesive and non-cohesive material at the same time. In the absence of such a formulation, it was necessary to select a model that has been widely used and offers a set of appropriate theories. Given that the suspended sediment is mostly non-cohesive, the study selected a non-cohesive total load formulation and a suspended sediment load theory.

The total load theory was primarily applied to simulate the concentration of suspended sediment within Clark Lake, which is located upstream and outside of the zone of hydraulic influence. Once the simulated concentrations in Clark Lake matched the field data reasonably well, that concentration was then transported by the model through the study area using the suspended sediment load formulations.

The model was set up to replicate flow conditions associated with the various field measurements, and the simulated concentrations within the Project areas for these different flow conditions were then compared with the available field data. A reasonable match was obtained between the simulated and field measured suspended sediment concentrations, ensuring that the model was capable of replicating these processes for both cohesive and non-cohesive sediment types. The calibration process involved the selection or setting of material sizes within their normal range in order to obtain a reasonable reproduction of suspended sediment concentrations that are observed in the field.

It is recognized that the applied model was not able to directly simulate the transport processes of the cohesive suspended sediment directly within the study area. However, the positive match obtained with the field data suggests that the model's algorithms are actually quite capable of reproducing the field-measured concentrations with the non-cohesive module. The non-cohesive sediment accounts for approximately 80% to 90% of the total volume.

As previously noted, the sedimentation component of the model was calibrated to June 2006 field data and validated against four other open water months of 2005 and 2006. The comparison of model and field data shows approximately 15% variation which is comparable with other studies.

7A.1.2 Peat Transport

The study area for the peat transport model extends from Birthday Rapids to the proposed Keeyask GS location, where flooded peat lands are expected to occur. This is based on findings from the peatland disintegration studies, in which mobile peat input is insignificant upstream of Birthday Rapids. Thirteen peat transport zones were identified (Section 6.0 Shoreline Erosion), based on sub-dividing the Post-project forebay into components consisting of bays and riverine environments where peat input is expected to occur (Map 7.2-3).

In light of the fact that there is limited documented information on floating peat transport, certain assumptions regarding unknown variables were devised to simplify the transport model. Upon incorporation of those assumptions, the model combined quantitative with qualitative approaches for illustrating transport patterns throughout the proposed Keeyask reservoir.

The model includes a possible mechanism for transport from one point to another. Therefore, the main assumption is that all potentially mobile floating organic peat material is transported from one nearshore to another without disintegration of mass and/or morphology. In reality, floating peat varies in shape and size, making predictions difficult due to different forces and surface vegetation influencing such displacements. To minimize these and other potential influences on displacement, the following conservative assumptions have been employed throughout the development of the model:

- Organic material that is not considered as potentially mobile is assumed to remain in the zone of origin.
- Breakdown due to wave and ice action is not taken into account during transport of mobile floating material.
- This study focuses on displacement rather than factors of resurfacing. Factors affecting resurfacing depend on material composition and associated thickness as well as erosion and other variables. The organic sediment load that was utilized in this study as input in the model contains the mobility variable which incorporates these factors affecting resurfacing. Peat resurfacing/upheaval and mobility predictions were provided from the peatland disintegration modelling.
- Zone 1 acts as a contributor of mobile peat and as an intermediate transport zone between all other surrounding transport zones. As a result, no accumulation is assumed in the riverine portion due to high flows and bedrock controlled shorelines between Birthday Rapids and the proposed lentic forebay environment.
- All peat transport generally follows a linear fetch distance to deposition areas.
- Wind direction and speed is constant throughout the modelling process.
- Only the open water season is modelled.
- A minimum of 5% of the mobile peat is lost from each zone, even if the wind induced current direction shows no displacement outside of the zone. The minimum percentage loss assumption is based on judgment and review of current patterns within each zone. Due to certain bay configurations, there may be instances where peat transport does not occur under the applied wind and current conditions, while others may be conducive to higher movements. As such, the 5% loss is also an attempt to balance higher and potentially lower losses due to both configuration and modelled wind driven current directions.
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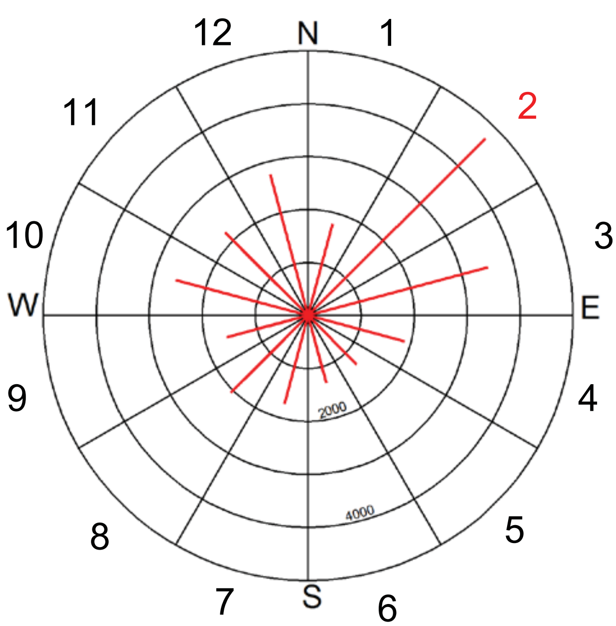
7A.1.2.1 Peat Transport Model

The predictive peat transport model was developed using general assumptions regarding transport by wind induced current during the main open water period. Utilizing organic sediment loads derived from field studies and partitioned into the predetermined zones, the model incorporated a hydraulic model, which was originally developed for mineral sedimentation modelling, and ArcGIS software tools to assess general direction and nearshore deposition within specific Post-project time periods. The peat transport model, which is a conceptual formulation based on linear displacement dominated by wind induced current, assesses peat transport and deposition. This scenario relates to the 50th percentile of potential events such as wind direction. Peat transport zone boundaries remained constant for all modelling periods with only changes to forebay shoreline margins as a result of predictive erosion.

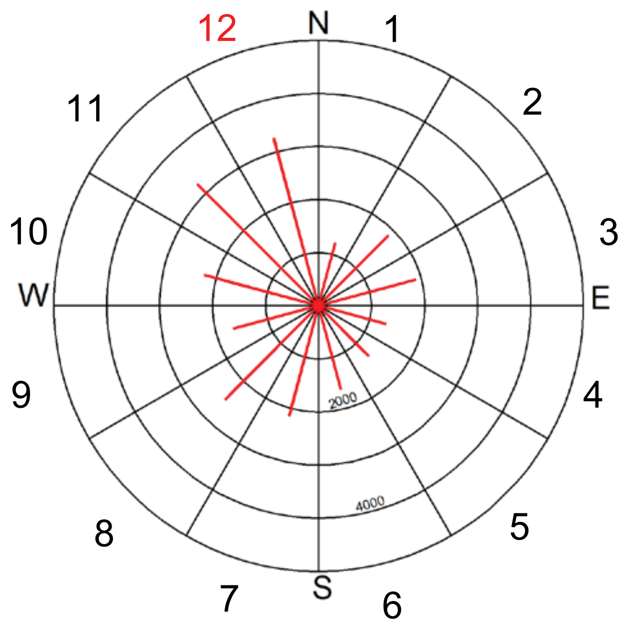
The wind component of the analysis utilized hourly continuous wind direction (in bearings north) and speed data for the period 1971 to 2002 obtained from Environment Canada for the nearest location at Gillam Airport, Manitoba. The wind data was extracted and sorted between May 1 and October 31 inclusive. Wind speed was corrected from the reported speed over land, since wind speed tends to increase over water, due to less friction (Resio and Vincent 1977). Historical wind data was then sorted on a monthly basis into 12 cardinal directions of 30° intervals, commencing from 0°. The selection of the predominant cardinal direction was determined by the location of the highest frequencies of wind data for that month.

Between all six open water months, the general directions of wind fit within two periods, namely May to July and August to October (inclusive), respectively. The first period resided in cardinal Direction 2, while the second period was within cardinal Direction 12. The approximate angles of cardinal Direction 2 and cardinal Direction 12 are 45° and 345°, respectively. The resultant periods are referred to as spring/early summer (May to July) and late summer/fall (August to October) in this report. Figure 7A.1-6 and Figure 7A.1-7 illustrate the total distribution of wind direction counts for both periods.



Spring/Early Summer: Frequency of wind distribution for May to July inclusive. In the northeast, Cardinal Direction 2 (in red) contains the highest total directions for all three months.

Figure 7A.1-6: Frequency of Wind Distribution for May to July (Inclusive)



Late Summer/Fall: Frequency of wind distribution for August to October inclusive. In the northwest, Cardinal Direction 12 (in red) contains the highest total direction for all three months.

Figure 7A.1-7: Frequency of Wind Distribution for August to October (Inclusive)

Wind was introduced in the hydraulic model to produce wind-induced flow directions within all predetermined peat transport zones. The resultant flow directions were then transformed from non-linear to linear angles for GIS analysis as per Williams (1999).

The transport analysis was then carried out in the predictive modelling process, providing data related to displacement and deposition. Using the vectors produced in the trajectory analysis, spatial queries were undertaken to determine the percentage of lines crossing the zone boundaries. Trajectory in this analysis is considered as the linear direction (in bearings) that floating mobile peat travels in water from zonal shorelines. The number of lines representing mobile peat crossing the boundaries were divided by the total trajectory lines for each zone, to establish percentage of mobile peat (in tonnes) displacement towards surrounding zones. The percentage of mobile peat loss was equally divided into gains between adjacent zones.

As discussed in Section 7A.1.2, a minimum mobile peat loss of 5% was established for each zone, since it is unrealistic to assume all mobile peat will move in one direction. Variation in direction is due to a variety of factors such as surficial flow and magnitude, hourly changes in wind direction, islands (obstructions and deflection), depth, and proximity to nearshore areas. However, since the model is a generalization, the minimum amount of peat loss from each zone is an attempt to diminish such variability in the wind driven current.

Except within the riverine section of Zone 1 (Map 7.2-3), the nearshore of the forebay was designated as potential deposition areas, which is consistent with existing results from Hydro-Québec monitoring programs. Analyses were carried out to assess possible gain and loss of peat material mass for each zone.

A sensitivity analysis using 90th percentile wind speed of the dominant direction was carried out to review the direction of peat transport based on wind input and median flows. A further analysis into the secondary dominant direction was also undertaken. Both analyses were used to assess if there were any significant changes to the direction of the wind driven current.

Different environmental conditions affect peat displacement, and the process of peat transport is complex and less understood than that of mineral sediment transport. There is little available information and no studies could be identified that have attempted to model this physical process. Due to the lack of relevant information, the predictive modelling that was utilized in this study included a high degree of uncertainty. As such, various assumptions have been incorporated to simplify the modelling process, as discussed above.

7A.1.2.2 Organic Suspended Sediment Assessment

The potential ranges of daily maximum and minimum organic sedimentation concentrations were estimated using spreadsheet calculations based on the following considerations:

- Estimation of the annual peat load that becomes a suspended peat load entering the water column each day.
- Settling properties of the suspended material.
- Estimation of mixing effects.

Estimates and assumptions made in the analysis were developed based on group discussions of the methods employed in calculating organic suspended sediment load, where discussions included representatives of the physical environment and aquatic environment teams. Estimated annual peat masses (from Section 6.0 Shoreline Erosion) entering the various peat transport zones (Map 7.2-3) were reduced to daily loads and converted to a daily organic suspended sediment load by dividing the peat masses entering the zones by the respective zone volumes. Because settling properties of the Keeyask area peat types were not known, organic suspended sediment settling was estimated using four different assumed settling rate distributions. Effects of flow flushing and mixing, which was not specifically modelled in this or any other workstream, was estimated using results of a winter water temperature and dissolved oxygen model, whereby changes in water temperature were used as a proxy to quantify the degree of flushing that occurs in the various forebay areas.

7A.2 DURING CONSTRUCTION MODELLING

7A.2.1 Erosion During Construction Model

Increased sedimentation within the Nelson River near the Project area may result during construction. The following is a detailed discussion pertaining to the various construction components contributing to the sedimentation.

7A.2.1.1 Material Loss During Cofferdam Construction – Description of Analysis

Material losses which will generate increases in the river's suspended sediment concentration during cofferdam material placement and removal are complex and impossible to quantify on a strictly theoretical basis. Hence they must be based on engineering judgment, previous construction project experience and conservative assumptions.

In the "totally exposed" case, with fill being placed directly into the flowing water of the river, it is assumed that part of the silt and clay fraction of the exposed portion of fill will be entrained into the water, at a rate proportional to the fill placement rate. This is referred to as the "entrainment rate."

In order to facilitate the analysis, for each fill material type, two distinct factors were adopted as was done for the Wuskwatim Project:

- Material Factor (MF), which represents the fine material size fraction of the fill being placed, which is susceptible to becoming entrained into the water during the interval while it is directly exposed to flow.
- Exposure Factor (EF), which is the proportion of the time that the material will actually be exposed to direct erosion by flowing water. It takes into account self armouring action with its coarse material content and protection by coverage with successive fill layers.

The Entrainment Rate (ERate) is calculated based on multiplying the Placement Rate (PRate), by the Dry Unit Weight (DUW) and material size fraction lost into the flow ("Material Factor"), assumed to be 30% for Class A, 10% for Class B and 0.5% for Class C. It is further conservatively assumed that 33% ("Exposure Factor") of the Class A and Class B materials will be exposed to the flow. Class C material is assumed to have a 100% exposure factor due to its large voids.

$$\text{ERate (mg/sec)} = \frac{\text{PRate (m}^3\text{/sec) x DUW (kN/m}^3\text{) x MF x EF x }10^6\text{ mg/kg x }10^3\text{ N/kN}}{9.81\text{ (m/sec}^2\text{)}}$$

The resulting entrainment rate expressed in mg/sec, is then divided by the channel discharge (Q), expressed in l/sec, to arrive at the total suspended solids, mg/L, during actual construction. The daily and weekly suspended sediment concentrations are calculated by factoring this figure by 20/24 for daily and (20x6)/(24x7) for weekly, based on two 10 hour shifts per day and a 6 day week. The analysis method is identical to that employed on the Wuskwatim Project.

The above analysis provides results for the totally mixed case of full dilution by channel discharge. We have also calculated "local" temporarily elevated suspended sediment concentration which would occur in partial flow channels and "partially exposed" cases described below, which would subsequently become fully mixed when they re-enter the main stream. Potential plumes or local higher concentrations which will occur immediately adjacent to the equipment performing the work will be very temporary in nature.

There are two "partially exposed" cases (discussed below as Condition A and Condition B) which will occur at Keeyask, that are different from conditions at Wuskwatim as they involve significant seepage through rockfill zones which subsequently rejoins the main stream flow:

Condition A is where a Class C rockfill embankment has been advanced across the entire channel, cutting off the channel discharge (*i.e.*, the quarry and north channel cofferdams). The subsequent Class A and/or Class B placement is no longer exposed to direct channel flow, but only to the much smaller flow velocities from seepage entering the Class C embankment. In this case an additional reduction factor of 3.3% for Class A and 5% for Class B is applied to the material fraction lost into flow (*i.e.*, 30% x 3.3% for Class A and 10% x 5% for Class B), to recognize the much lower erosive forces. The magnitude of the Reduction Factors appears to be in the right order, based on the following:

- Force and scour rates for materials are known to be directly proportional to the square of flow velocity.

As an example, if flow velocity were decreased by a factor of 0.1, the material erosion rate should be reduced by a factor of 0.01. The reduction factors we are using imply the flow velocity impacting adjacent fill placement due to rockfill seepage is approximately one fifth that of open channel flow velocity, which appears to be in the right order but on the conservative side. Also, the exposure factor is reduced from 33% to 10% to reflect the presence of the Class C rockfill embankment across the entire channel and the resulting reduction in the flow.

Condition B is where a double rockfill groin design has been utilized the subsequent Class A and Class B fill placement is partially sheltered from the river's velocity (*i.e.*, tailrace summer level cofferdam and the spillway cofferdam). However, there will still be seepage water percolating through the rockfill which will flow along the face of the Class A and Class B during its placement. The velocities in this instance would be much lower than where Class A and Class B are exposed directly to the main flow of the river; hence the above reduction factors would be applied to material fraction lost into flow. There is no reduction in exposure factor in this case.

It should be noted that there is no concern at the Keeyask site for erosion of river bed materials during cofferdam construction, as was the case for Wuskwatim. Most of the river's thalweg is clean bedrock and the remainder consists of clean sands, gravels and hard, dense glacial till.

7A.2.1.2 Sedimentation from Construction Diversions

Increased sedimentation within the Nelson River near the Project area may result during construction. This increase may arise due to shoreline erosion which may result from increased water levels or the deflection of water currents in the Project area due to construction staging. Analyses were conducted to specifically determine the potential increase in sedimentation resulting specifically from the construction diversions. The following is a detailed description of the model that was used to estimate increased sedimentation from the construction diversions.

Hydraulic and sedimentation modelling of the different construction stages of the Project was carried out using the USACE model HEC-RAS. HEC-RAS is a one-dimensional model developed by the USACE for simulating steady and unsteady flows. The model can be used for computation of open channel hydraulics, as well as for estimates of sedimentation and erosion. The sedimentation component of the model is capable of simulating changes in river bed and banks due to erosion and deposition of sediment.

7A.2.1.2.1 Inputs

Hydraulic

The hydraulic component of HEC-RAS requires a physical description of the Nelson River, as well as the flows under consideration as input. The river is described within the model with the combination of river cross-sections, reach lengths, roughness coefficients, ineffective flow areas and many other hydraulic parameters. The existing environment HEC-RAS model used for the water regime analyses (Section 4) extends from Clark Lake to Stephens Lake and has been calibrated to accurately represent existing conditions in this region. This model was used as the starting point for the sedimentation modelling, and was modified as required for the construction phases. A detailed description of the existing environment HEC-RAS model and its necessary inputs can be found in the construction period overview of the surface water and ice regimes section (Section 4). The existing environment model was truncated for the sedimentation modelling to a 15 km reach of the river extending between Stephens Lake to the upstream portion of Gull Lake. This reach of river was identified as the zone of hydraulic influence for the sedimentation modelling of construction stages.

Two specific flows were used for the sedimentation modelling, namely the 95th percentile flow of 4,855 cms and the 1:20 year flood flow of 6,358 cms.

Sedimentation

The sediment component of the HEC-RAS model requires a description of the river bed and bank materials in terms of its material type, grain size distribution and cohesiveness. The Nelson River bed material at the Project site ranges from non-erodible bedrock to boulder and cobble. Thus for the purpose of the sedimentation modelling the Nelson River bed was considered as "fixed" or non-erodible.

The river bank material description was taken from numerous sources of information that are documented in the shoreline erosion section (Section 6.1.2.4). Primary sources of information included the ECOSTEM shoreline classification (Maps 7A-1 and 7A-2) for the purpose of identifying river bank material types. The borehole log data was used for the purpose of estimating the overall volume of material that was available to be eroded. A sample of the processed borehole information, indicating the depth of erodible overburden, for the south shore of the Nelson River at the Project location is shown in Figure 7A.2-1. The summer 2009 field data sample collection program was used to identify the grain size distribution of various shoreline material types. The sample grain size distribution curves for all different river bank materials found at one location in the Project area is shown in (Figure 7A.2-2).

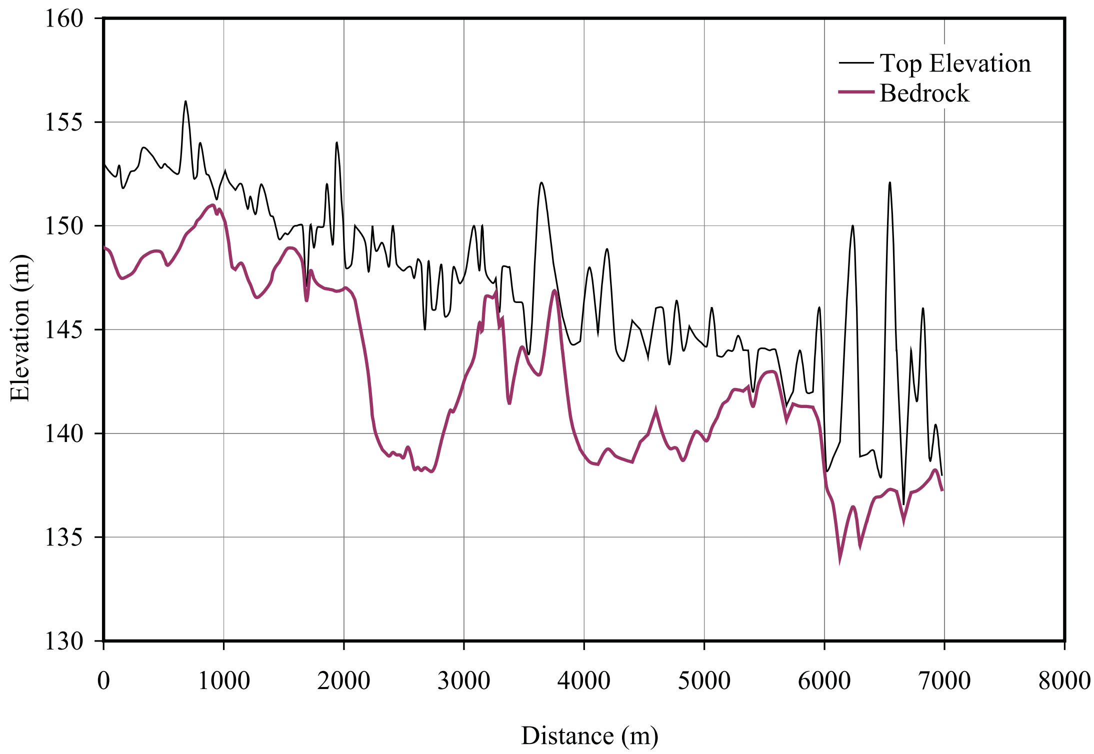


Figure 7A.2-1: Cross-Sectional Profile of Bedrock and Ground Surface Elevation at the South Shore of the Nelson River at the Project Location (from TetrES).

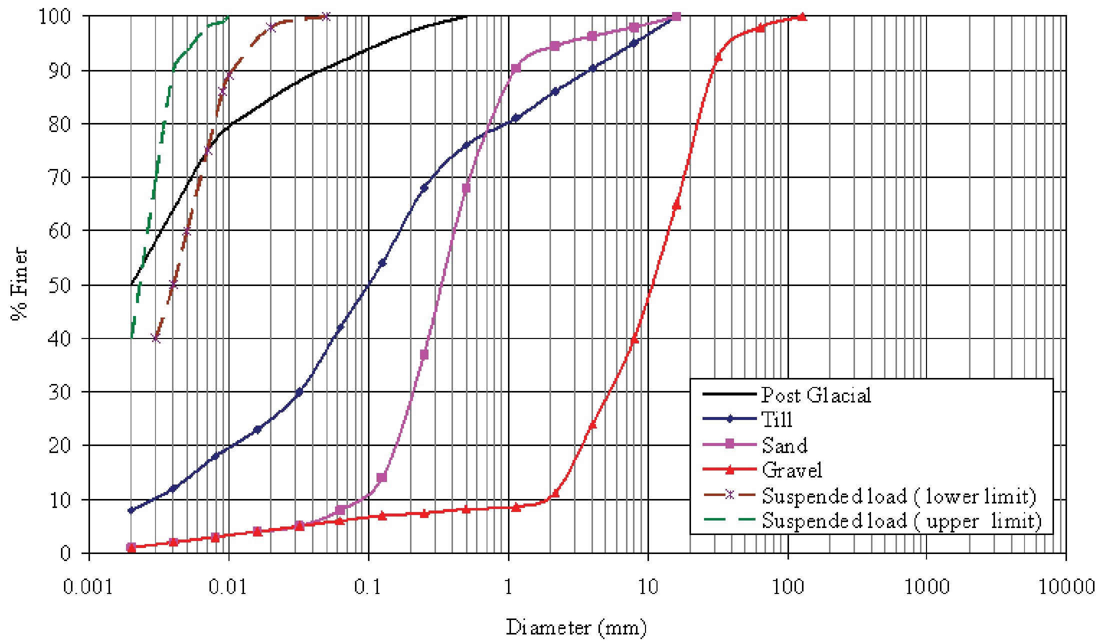


Figure 7A.2-2: Sample Grain Size Distribution Curve

Sediment data for the Nelson River water is also required as input to the model, which is represented in the form of TSS. An extensive mineral sediment concentration program was conducted between 2005 and 2007 to identify the existing conditions for bedload and TSS within the Nelson River at the Project site. A detailed discussion of the results of this program can be found in Section 7.3.2.1 and Appendix D. This monitoring program found that the background TSS in the Nelson River at the Project site ranges from 5 mg/L to 30 mg/L in the open water season, somewhat dependent on the flow within the river. For the purpose of the sedimentation modelling, a background TSS of 20 mg/L was assumed for the 4,855 cms (95th percentile flow) and 6,358 cms (1:20 Year flood flow).

The sedimentation component within HEC-RAS also allows the specification of one of seven different sedimentation/erosion equations (or functions). These equations influence the model's overall prediction of erosion and sedimentation. The equations are as follows:

- Ackers and White;
- Engelund and Hansen;
- Laursen;
- Meyer, Peter and Muller;
- Tofaleti;
- Yang (sand and gravel); and
- Wilcock.

Selection of the appropriate equation(s) for sedimentation modelling is critical for the production of accurate results. The seven available equations were evaluated on the basis of a series of hydraulic parameters to test their relevance and appropriateness for use on the Nelson River. The hydraulic parameters used in the evaluation included the dimensionless particle diameter, dimensionless depth, Froude number, relative shear velocity, unit stream power and sediment load concentration. On the basis of this evaluation, the most appropriate functions for simulating sediment transport on the Nelson River were found to be:

- Ackers and White;
- Engelund and Hansen;
- Laursen; and
- Yang (sand).

All four of these equations were used in the sedimentation modelling for the Project construction diversion stages.

7A.2.1.2.2 Outputs

Hydraulic

Numerous hydraulic outputs are generated by the HEC-RAS model. The primary output sources of key interest to the sedimentation modelling were the changes in water depth, and velocity in the Nelson River produced by the construction diversions. Modelling the change in depth during the different construction stages also allows the predicted change in flooded area for a given flow. This change in flooded area identifies shoreline sections that will be exposed to hydraulic erosive forces, which would otherwise not be inundated by the Nelson River for a given flow in the absence of the construction stages. The change in river velocity identified by the hydraulic modelling will show the change in hydraulic erosive forces that a shoreline will experience due to the construction stages.

Sedimentation

The primary output of the sedimentation component of HEC-RAS is the predicted change in TSS, as well as the volume and grain size distribution of the sediments at the downstream end of the model. Again, for the purpose of the sedimentation modelling the downstream end of the model is K-Tu-2, or the upstream end of Stephens Lake. Review of the grain size distribution of the sediment entering Stephens Lake, and observing the calculated river velocity will allow for prediction of the portion of sediment that is considered to be bedload versus TSS.

Inspection of the modelling output will also allow the opportunity to predict the location of the shoreline where erosion is occurring (if any), and also where the eroded sediments are being deposited.

7A.2.1.2.3 Assumptions

As previously stated, the HEC-RAS model is only one dimensional (1D) with regards to its computational capabilities. By use of a 1D model, the amount of erosion being predicted is being conservatively overestimated. This overestimation is due to the fact that the 1D average velocity in any river cross-section is being applied to the shoreline for the purpose of calculating shoreline erosion. Intuitively it is obvious that the water velocity varies greatly across any river, especially so in the case of the Project area, namely Gull Rapids. The nearshore velocity would in all cases be much less than the centerline or average river velocity.

All aspects of the two diversion stages such as construction of the cofferdams, groins and dykes are assumed to happen instantaneously. Realistically the components of Stage I and Stage II diversion are going to take weeks or months to occur, which would allow for a gradual increase in water levels. By assuming instantaneous construction within the sedimentation model this results in generating a conservative overestimate of the amount of erosion that would occur due to instantaneous increased water levels resulting in increased overland flooding. A more gradual increase in water levels would result in less erosion that what the sedimentation model is predicting.

Shoreline locations that were considered erodible (*i.e.*, not bedrock) were assumed to have an infinite volume of sediment to erode and transport. Again, this allows for a conservative estimate of the potential increase in TSS at Stephens Lake.

The design flows of 4,855 cms (95th percentile flow) and 6,358 cms (1:20 Year flood flow) were assumed to be constant and sustained throughout the entire duration of Stage I and Stage II diversion. Realistically should a flood event occur on the Nelson River, there would be a gradual change in river flow that would peak at the design discharges, and then reduce over time. By assuming that the design flows are constant throughout the diversion stages the sedimentation model is conservatively over predicting the amount of erosion that is expected to occur.

7A.2.1.2.4 Model Calibration

Hydraulic

The existing environment HEC-RAS geometry data was modified to account for the two diversion stages. These modifications included the incorporation of various cofferdams, dykes and rock groins as discussed in Section 7.4.1. Within the HEC-RAS model, these geometric changes are represented by modification to river cross-sections, river branches, reach lengths, roughness coefficients, expansion and contraction coefficients, ineffective flow areas and other hydraulic parameters. The hydraulic model thus required recalibration in order to accurately predict velocities and water levels in the Nelson River, given the new model geometry.

Numerous other hydraulic modelling studies have been done as part of the Project, which could be incorporated into recalibration of the sedimentation HEC-RAS model. Specifically the results from the physical modelling studies (LaSalle 2005), the FLOW3D modelling for the development of the spillway rating curves (KGS Acres 2009b), and H01F (Teklemariam 2005) modelling studies were used to calibration the hydraulic component of the HEC-RAS model.

The hydraulic model for the Stage I diversion was primarily calibrated using professional judgment and then compared to the H01F modelling results. The modelling results were compared for a variety of flows, however only the results from the 4,855 cms (95th percentile flow) and 6,358 cms (1:20 Year flood flow) are presented herein for the purpose of discussion. A comparison of the HEC-RAS and H01F water surface profiles for 4,855 cms are shown in Figure 7A.2-3. The modelling results compare very favourably and are well within the generally accepted accuracy of hydraulic modelling.

The hydraulic model for the Stage II diversion was calibrated primarily against physical model and FLOW3D modelling results. The physical model and FLOW3D models were used to generate water surface profiles for flows that are approximate to, but not identical to the 4,855 cms (95th percentile flow) and 6,358 cms (1:20 Year flood flow). A comparison of the HEC-RAS model to the physical model and FLOW3D models are shown in Figure 7A.2-4 and Figure 7A.2-5 respectively for flows of 4,949 cms and 6,260 cms. The modelling results compare very favourably for Stage II diversion and are well within the generally accepted accuracy of hydraulic modelling.

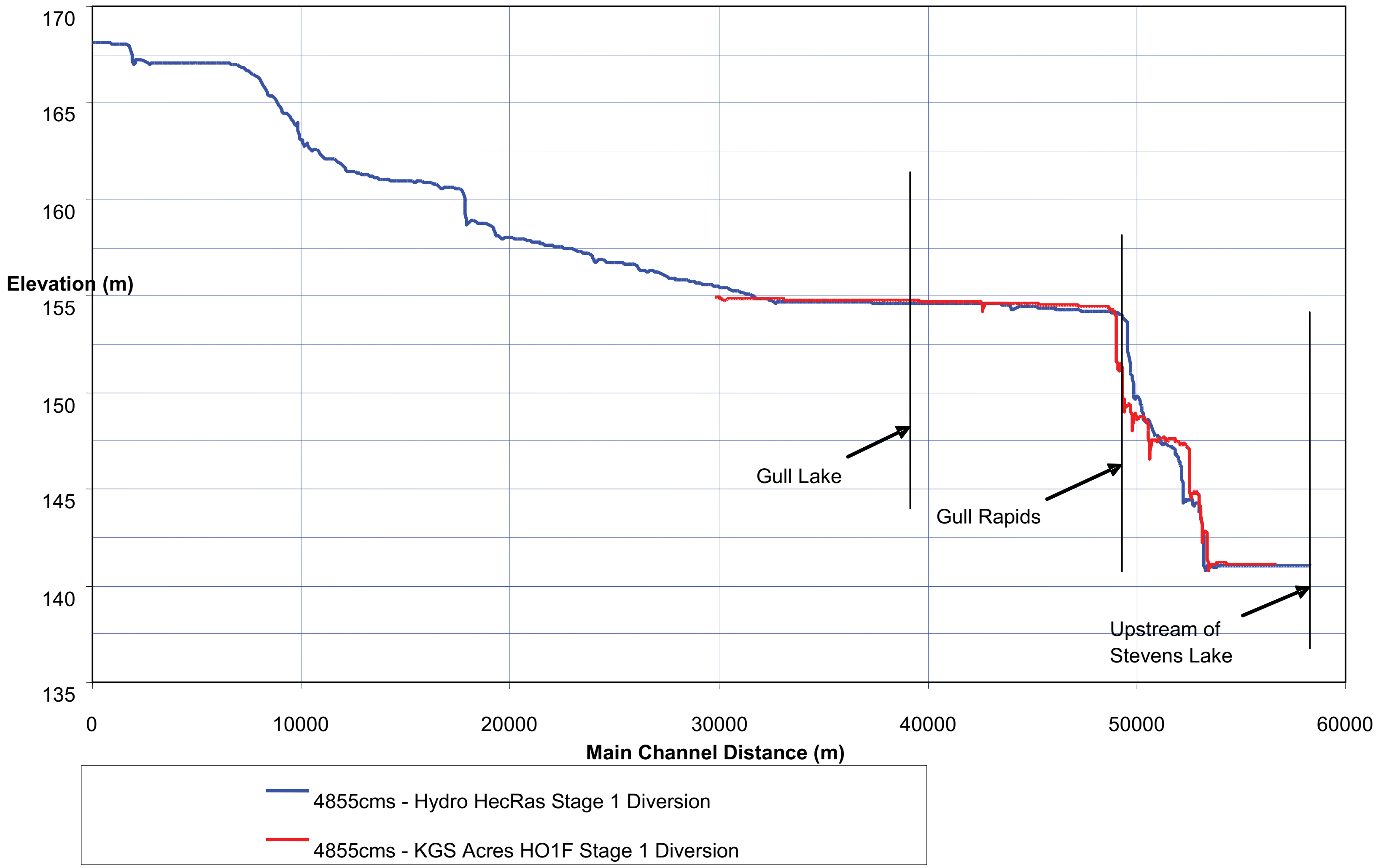


Figure 7A.2-3: HecRas and HO1F Stage 1 Water Surface Profile Comparison

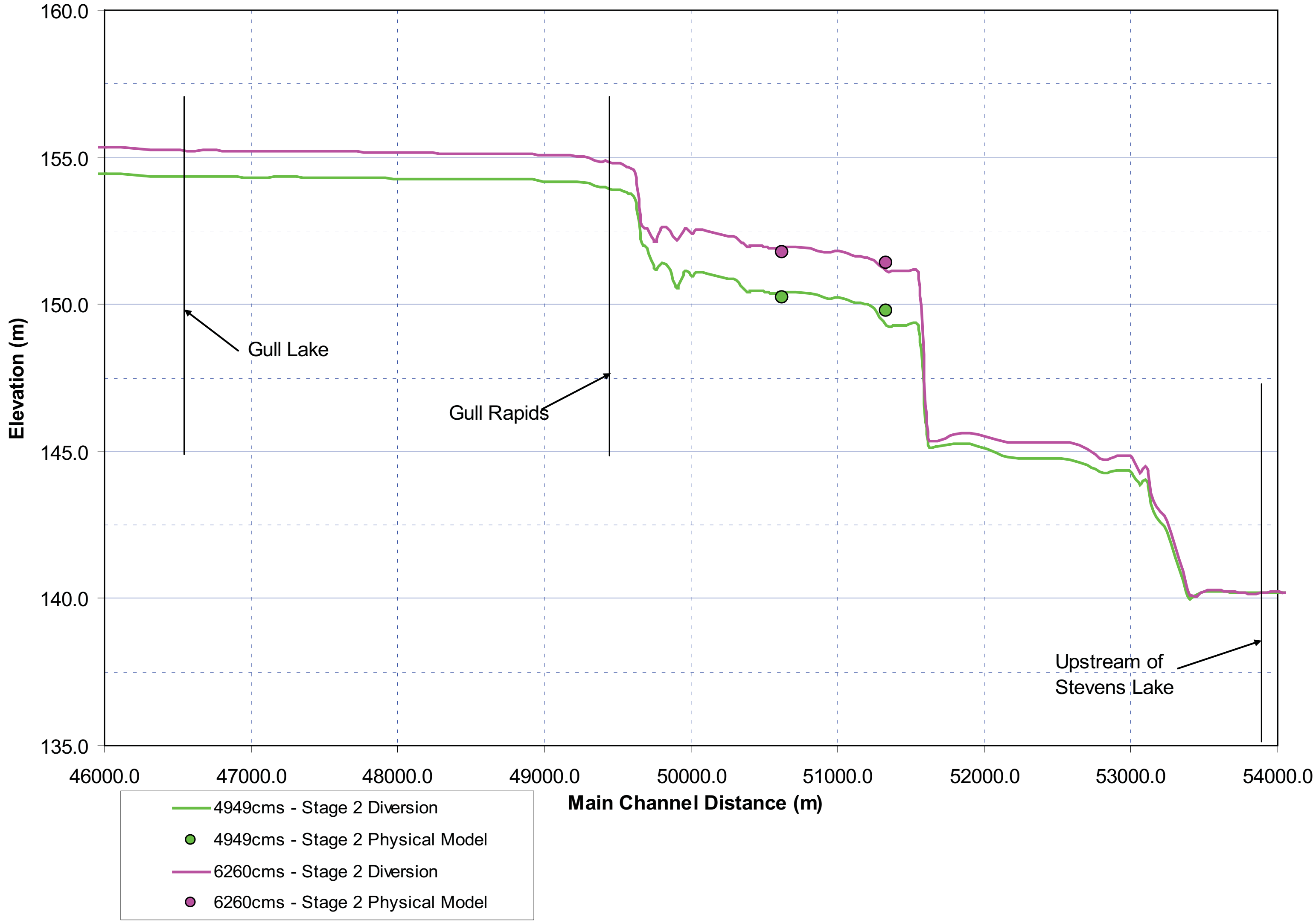


Figure 7A.2-4: HecRas and Physical Model Stage 2 Water Surface Profile Comparison

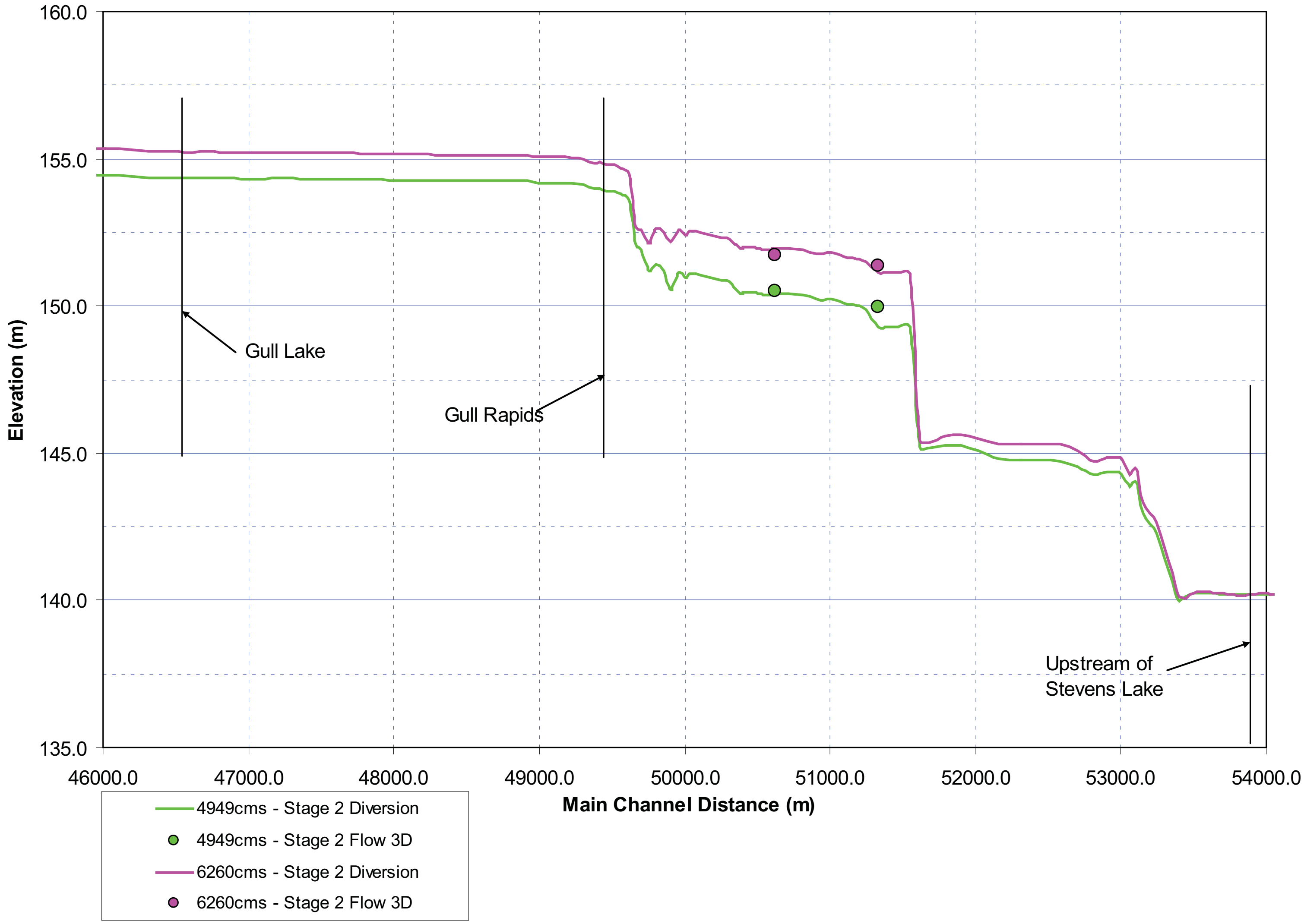


Figure 7A.2-5: HecRas and Flow 3D Stage 2 Water Surface Profile Comparison

Sedimentation

Calibration of the sediment component of the HEC-RAS model was done by comparing modelling results to field data collected between 2005 and 2007 to identify the existing conditions for bedload and TSS within the Nelson River at the Project site. Model inputs were entered into HEC-RAS as specified in Section 1.1.2 and the modelled TSS and bedload were compared to the results of the monitoring program. This comparison was done using the sediment functions Ackers-White (1973), Engelund and Hansen (1967), Laursen (1958) and Yang (1973).

The sediment modelling output (TSS and bedload) showed very favourable comparison to the monitored results for the existing environment for a range of flows. Furthermore, the model showed that there was no active erosion happening within the Project site, such that it would result in a noticeable change in TSS and bedload at the upstream end of Stephens Lake at location K-Tu-2. Thus, for example, a modelled background TSS of 20 mg/L resulted in 20 mg/L at the site K-Tu-2 for the existing environment for the 4,855 cms (95th percentile flow) and 6,358 cms (1:20 Year flood flow).

The sedimentation model was then run for the existing environment and the diversion stages, and the results are discussed in Section 3.1 and Section 3.2.

Given the potential uncertainties that are inherent to sedimentation modelling, a sensitivity analysis was conducted on the grain size distribution of the shoreline material found in the Project site. Sediment along any shoreline for the vast majority of waterways is not entirely homogeneous with regards to grain size distribution. Thus, as part of the calibration process, the grain size distribution of all erodible shoreline materials was altered. The grain size distributions were changed such that the shoreline materials were 50% finer and 100 % coarser than observed through field data collection.

The sensitivity analysis was run for both the prediction of the existing environment conditions as well as for the diversion stages. The modelling results showed no appreciable differences in any case with regards to the prediction of TSS and bedload at the location of K-Tu-2 for all scenarios.

7A.2.2 Stephens Lake Sedimentation During Construction Model

The increase in sediment concentration produced from shoreline erosion during construction activities and material loss from cofferdam removal may have an impact on Stephens Lake. The modelled sedimentation results from the construction activities were used as input to a HEC-6 1D sedimentation model, which was used to simulate the conditions within Stephens Lake. The following is a description of the Stephens Lake model, and the modelling results.

7A.2.2.1 Model Description

The modelling reach spans from the location of the monitoring station K-Tu-02 which is approximately 1 km downstream of Gull Rapids, to Kettle GS (Maps 7.2-1). The model utilized in total of 27 hydraulic sections to model the approximately 35 km reach. Several closely spaced cross sections extracted from an existing HEC-RAS model developed by MH were added between monitoring stations K-Tu-02 and K-Tu-01, which is located approximately 3 km downstream of K-Tu-02.

The model set-up began with the incorporation of bathymetric data originally used in MH's HEC-RAS model and the water depth information collected by Environment Illimite during their ADCP data collection campaign (Environment Illimite 2009). The model was then provided with an upstream boundary condition utilizing a user input water discharge rate and a downstream boundary condition with a user input water level.

Suspended sediment concentrations along with sediment gradation information were required as input at the upstream boundary of the model. The sediment concentrations were represented by a water discharge sediment load curve, which consisted of the range of flows that would reasonably be experienced and their corresponding sediment loads. The water discharge curve presented in Table 7A.2-1 was prepared based on the information collected in the field.

Table 7A.2-1: Water Discharge – Sediment Load Relationship

Flow (cms)	3000	3500	4000	4500	5000	5500	6000
Flow (cfs)	105945	123603	141260	158918	176575	194233	211890
Sediment Load (ton/d)	5714	6667	7619	8572	9524	10476	11429

Two sediment transport formulations were utilized in the model to simulate sediment transport processes in the HEC-6 model. The formulations included Yang (1973) and Ackers-White (1973) transport theories. A technical report developed by Manitoba Hydro (2009) explored suitability of several sediment transport formulations for the Nelson River sediment transport processes and confirmed the applicability of these two transport formulations in the Project area.

The model was simulated for two different flow conditions: 95th percentile flow of 4,855 cms and 1:20 Year flood flow of 6,352 cms.

7A.2.2.2 Assumptions

The following assumptions were made in this modelling exercise:

- In absence of substantial historical sedimentation data, it is assumed that the data collected in 2005, 2006 and 2007 openwater months represent typical ranges of sediment concentrations in Stephens Lake.
- Flow is in a steady state condition.
- Simulations are carried out for pure current mode, *i.e.*, no wind induced stresses are considered.
- The model does not simulate suspended sediment concentration variations due to local turbulence, which may be caused by short term morphological, meteorological and hydrologic changes.

7A.2.2.3 Calibration and Validation

The model was first calibrated to velocity field data collected in August 2007 to ensure its ability to match the existing hydraulic environment. Then the model was calibrated and validated to field suspended sediment concentrations to confirm its strength to simulate sediment concentrations that are observed in the existing environment.

7A.2.2.4 Calibration to Velocity Data

The model was calibrated to 2007 ADCP velocity data for a flow condition of 4,869 cms, which was the average flow during the period of ADCP measurements. The average measured velocities for each cross-section as taken from the station averages of that cross section were compared to the results in the HEC-6 model. While the majority of the model velocities match the measured velocities well (Figure 7A.2-6), it is shown that there are some stations with a greater variability. These stations are close to the rapids where more turbulence occurs and the gap between the minimum and maximum measured velocities is greatest. These results are based on a limited geometry definition.

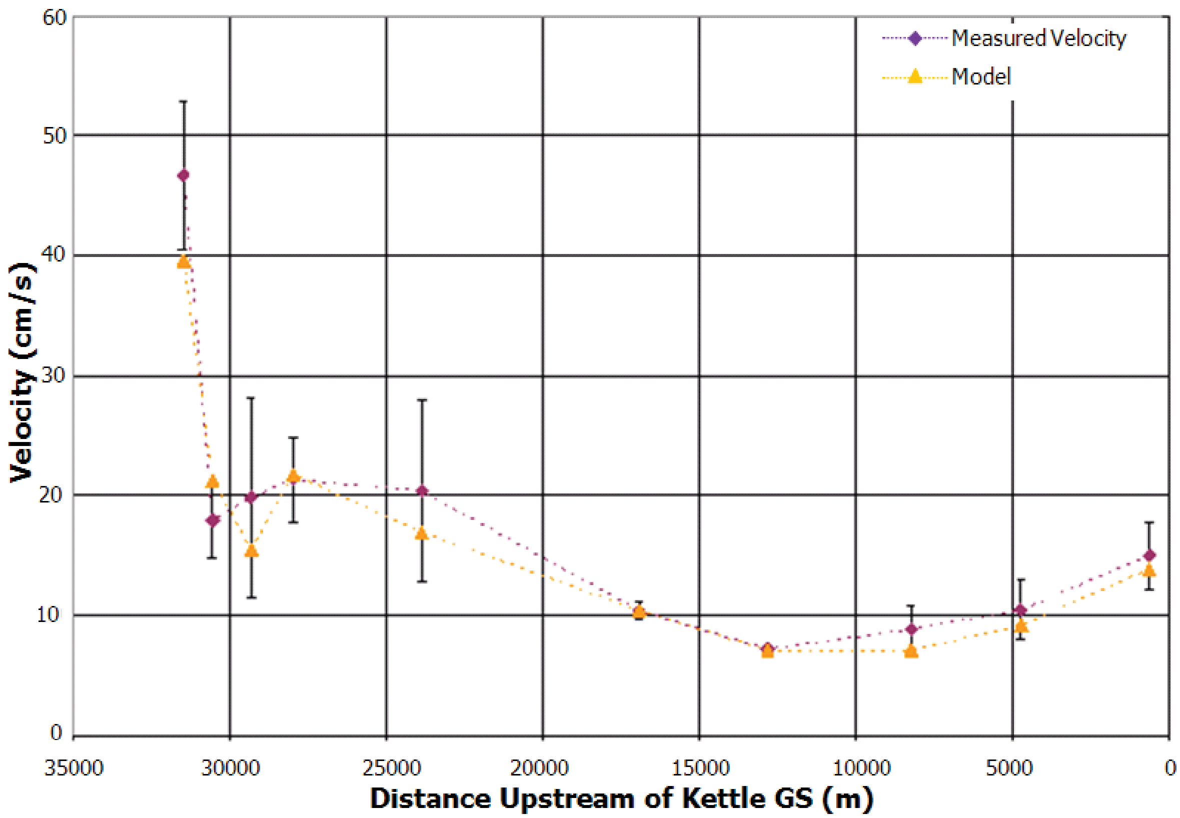


Figure 7A.2-6: Model Calibration – Comparison of Simulated and Measured Velocities

It was also required that the model produce comparable suspended sediment concentrations to those observed in the field at the five monitoring stations (K-Tu-02, K-Tu-01, Sl-S-04, Sl-S-05 and K-Tu-04) in Stephens Lake. Locations of the monitoring stations are shown in Map 7.2-1.

The average sediment concentrations measured in the period of June to September of 2006 and 2007 at the monitoring stations were observed to decrease while moving downstream from Gull Rapids. The average concentrations in 2006 were in the range of 6 mg/L to 12 mg/L, with an average monthly flow range of 3,392 cms to 5,183 cms. The average sediment concentrations in 2007 were in the range of 10 mg/L to 19 mg/L, with an average monthly flow range of 3,515 cms to 4,672 cms.

The model was first calibrated to the suspended sediment concentrations observed in August of 2007 (Figure 7A.2-7). Once the model was calibrated, work was then carried out on the validation of the model. The model was run to simulate sediment movement over three different openwater months of 2006. The model results were then compared to the field data collected at the five monitoring stations. The simulated concentrations matched the field data reasonably well.

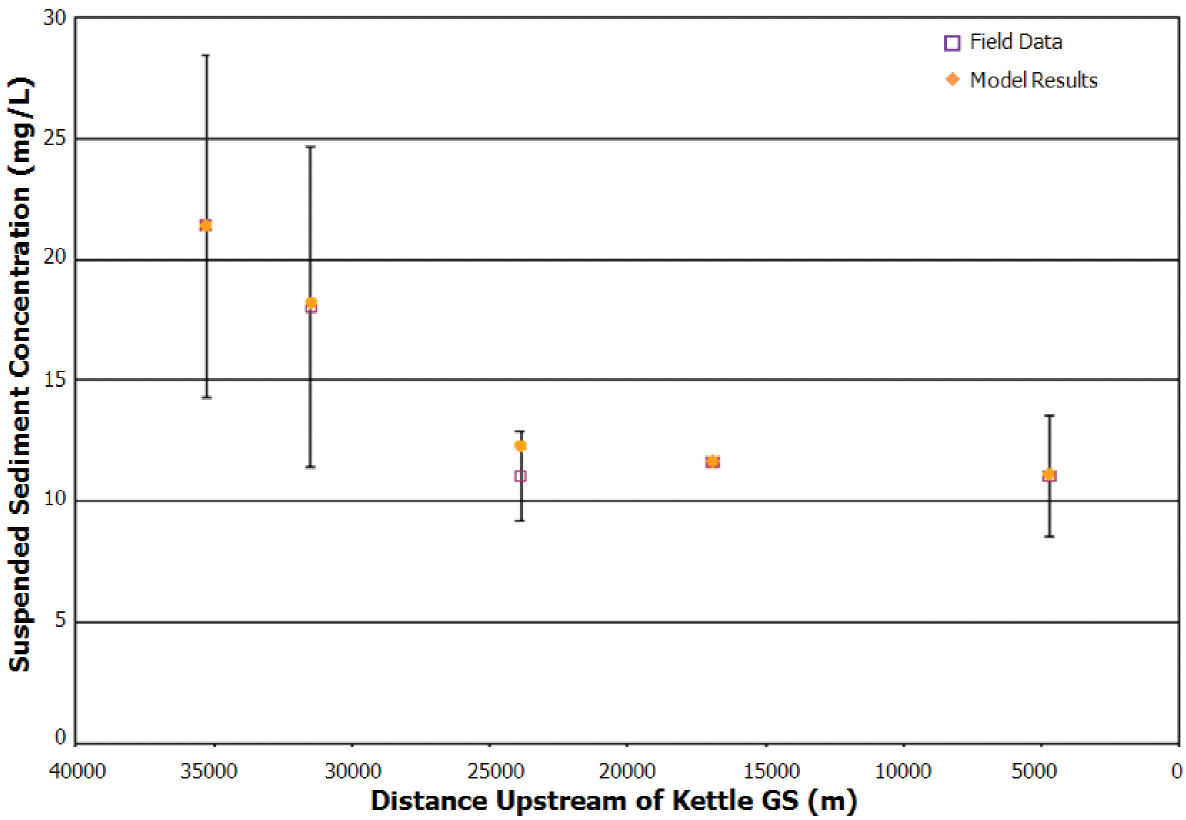


Figure 7A.2-7: Model Calibration – Comparison of Simulated and Measured Suspended Sediment Concentrations (August 2007)

7A.2.2.5 Model Sensitivity

MH's HEC-RAS shore erosion modelling activity utilized three different sediment transport models – Yang (1973), Ackers-White (1973) and Laursen (1958). The gradation curves obtained from the HEC-RAS model are illustrated in Figures 7A.2-8 and 7A.2-9.

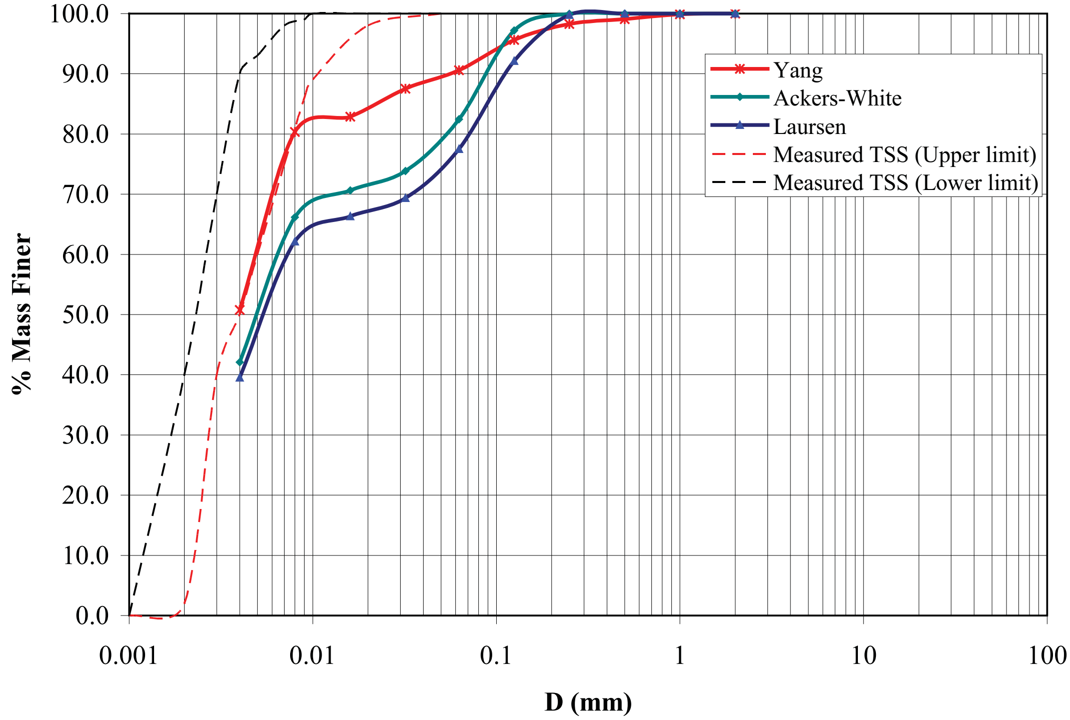


Figure 7A.2-8: Gradation Curves of Sediment Load During Stage II-A Diversion at K-Tu-2 (Dash Lines: Measured TSS in Existing Environment; Solid Lines; Estimated TSS for During Construction)

The HEC-6 model was run using these three gradation curves separately for flow conditions of 4,855 cms (95^{th} percentile flow) and 6,358 cms (1:20 Year flood flow). The sensitivity analyses also utilized both Yang (1973) and Ackers-White (1973) transport formulations in the HEC-6 model to assess the model's ability in transporting the sediment in Stephens Lake. The simulated suspended sediment concentrations were then compared to the average concentrations observed in the field. The simulations of concentration using the Ackers-White (1973) gradation curve obtained from MH's HEC-RAS model match the field data quite well. Variability in flow condition does not seem to affect the TSS concentrations. Also, both transport models in HEC-6 produced very similar suspended sediment concentrations.

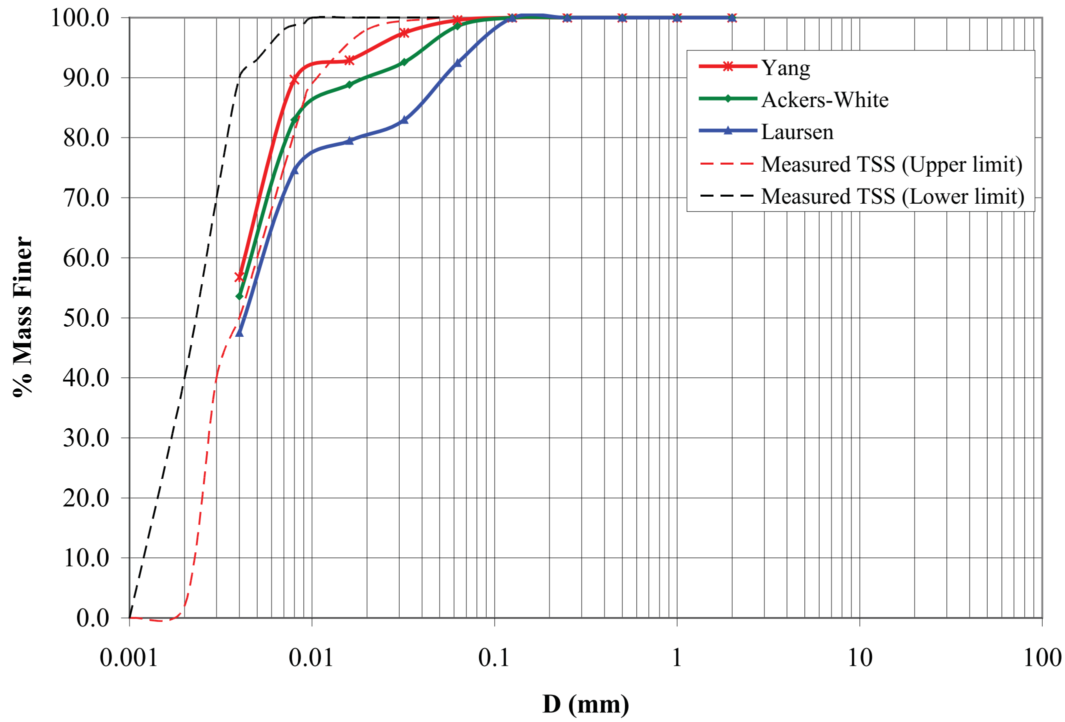


Figure 7A.2-9: Gradation Curves of Sediment Load During Stage II-A Diversion at K-Tu-1 (Dash Lines: Measured TSS in Existing Environment; Solid Lines; Estimated TSS for During Construction)

7A.2.2.6 Limitations of the HEC-6 Model

The numerical model developed for the sedimentation environment in Stephens Lake is a one-dimensional cross-sectional averaged model. Therefore, it does not take into account the variability in hydraulic and sedimentation processes that may exist across the channel and at variable depths. The field data suggests that the sediment concentrations can vary within a range at a given location in a given day (KGS Acres 2008d). Based on Manitoba Hydro's field measurements, daily discharge in the existing environment does not change significantly in the study area which suggests that variation in sediment concentration may be caused by other local factors, including local disturbances in the water column, meteorological conditions and contributions from local shore erosion. The model is limited to its capacity to include the impacts from local disturbances on sediment transport. It appears from the model calibration and verification that the range of model accuracy is approximately +/-4 mg/L.

The suspended load carried by the Nelson River consists of both cohesive and non-cohesive sediments. However, the formulations used in the study are designed for the transport of non-cohesive material only. Therefore, movement of the cohesive component of the sediment load can be indirectly simulated. The limitation of the model in computing relatively fine cohesive material was addressed by applying calibration and validation procedures to confirm the applicability of the model. As discussed Section 2.1.4.2, the sedimentation component of the model was calibrated to August 2007 field data and validated against three other openwater months of 2006.

7A.3 SPATIAL DISTRIBUTION OF DEPOSITION DOWNSTREAM OF GULL RAPIDS

A young of year habitat area for Lake Sturgeon currently exists downstream of Gull Rapids near a sand and gravel/sand bed. Two-dimensional modelling was used to assess the spatial distribution of the potential for suspended material to be deposited near the young of yeah habitat area during the construction of the Keeyask GS and under post-Project conditions.

7A.3.1 Model Description

The existing environment MIKE21 model developed to describe the water regime, was used to create three new models by modifying the existing environment model to reflect the conditions during the construction of the Keeyask GS and the Post-project conditions. The three new models developed by modifying the calibrated existing environment model include a Stage I diversion model, a Stage II diversion model and a Post-project model.

7A.3.2 Methodology

A qualitative analysis using the critical shear stress for erosion was applied to assess the deposition potential for silt, sand and gravel downstream of Gull Rapids near the young of year habitat area for Lake Sturgeon. Modelled depth averaged velocities and water depths from MIKE21 numerical modelling were used to calculate the bed shear stress using the following equation:

$$\tau = \rho g \frac{V^2}{C^2}$$

Where:

- τ = flow shear stress (N/m^2).
- • ϱ = density of water (1000 kg/m^3).
- g = gravity (9.81 m/s2).
- V = depth averaged flow velocity (m/s).
- C = Chezy number.

Table 7A.2-2 illustrates the critical shear stress for erosion of multiple sizes of sediment particles, which range from silt to gravel, as obtained from Shield's curve (Julien 2010). To be conservative, it is assumed that sediment particles have the potential to be deposited if the shear stress on the bed is lower than that particle's critical shear stress for erosion.

Table 7A.2-2: Critical Shear Stress for Erosion

Material	Grain Size (mm)	Critical Shear Stress for Erosion (N/m^2)
Medium Silt	Greater than 0.016	0.065
Coarse Silt	0.031 to 0.0625	0.083
Very Fine Sand	0.0625 to 0.125	0.11
Very Coarse Sand	1 to 2	0.47
Very Fine Gravel	2 to 4	1.26
Very Coarse Gravel	32 to 64	26

7A.3.3 Model Validation

The modelling was validated by using the above methodology under existing environment conditions and comparing the potential deposition pattern results to the existing environment substrate. Map 7A-3 illustrates the deposition potential for silt, sand and gravel, based on the bed shear stress distribution downstream of Gull Rapids under the 50th percentile flow at a Stephens Lake level of 141.1 m along with an outline of the existing substrate. As shown in this map, the deposition potential, based on the shear stress analysis, matches the existing environment substrate reasonably well. The transition from sand to silt deposition under the 50th percentile flow is similar to the substrate.

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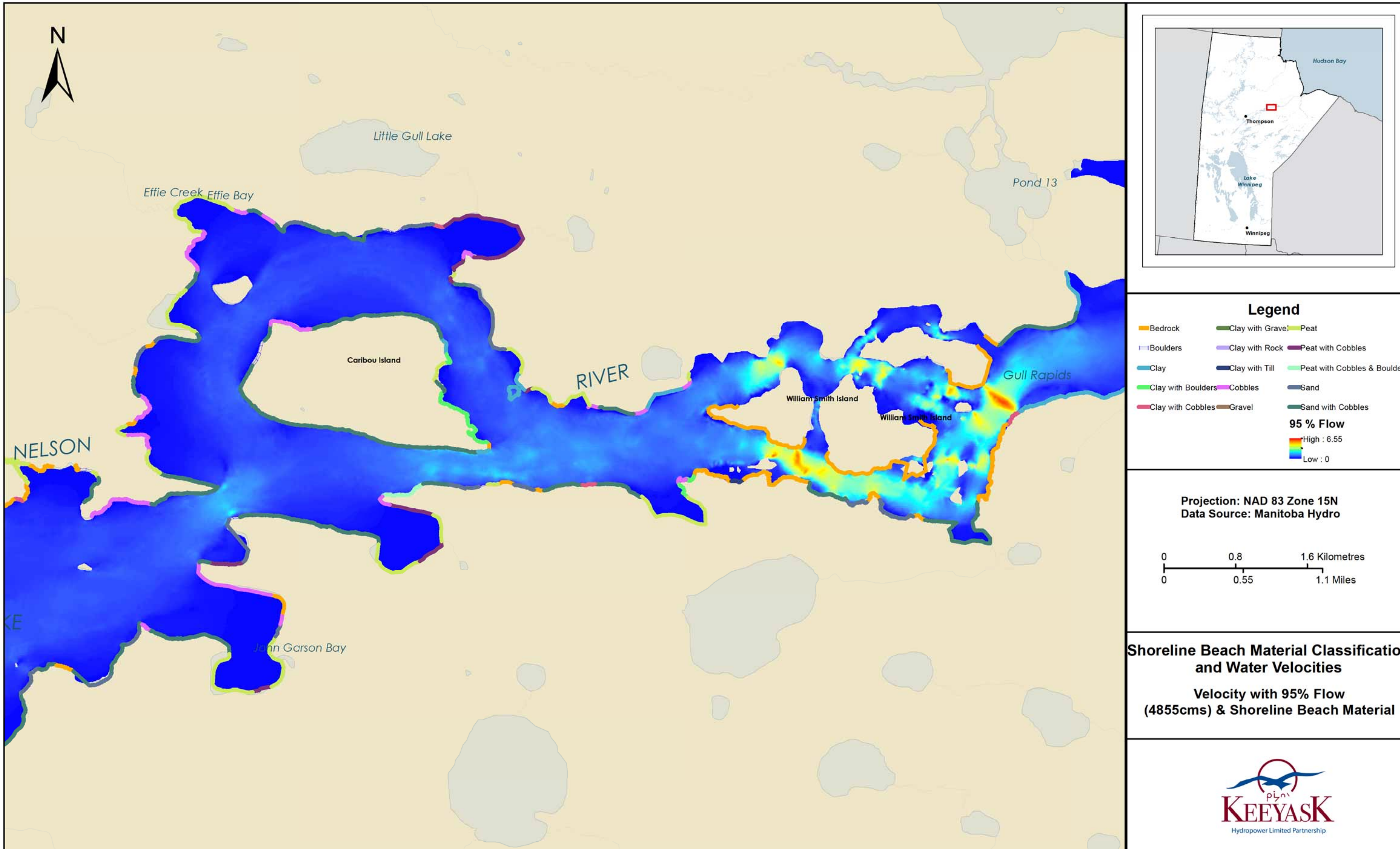
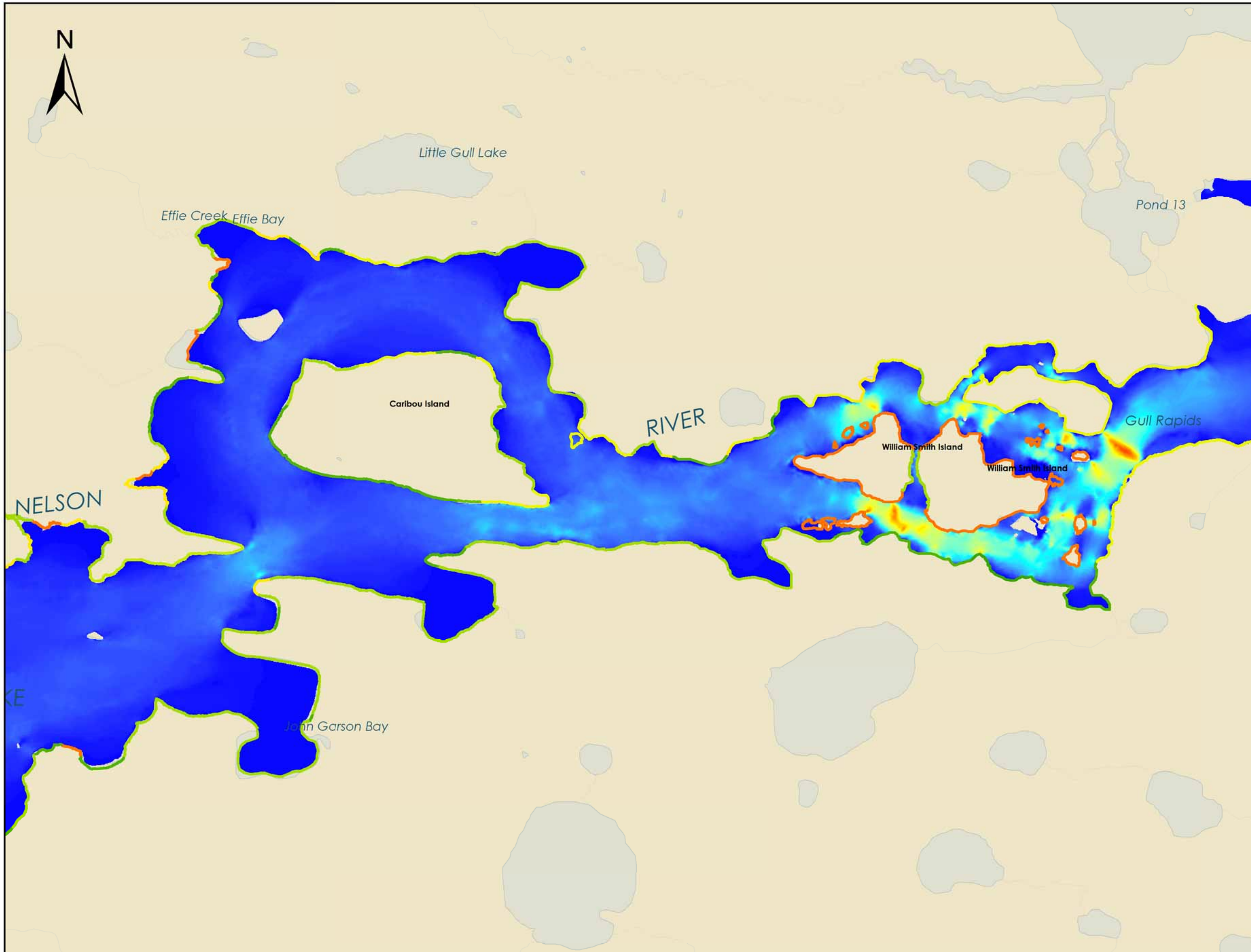


Shoreline Beach Material Classification and Water Velocities

Velocity with 95% Flow (4855cms) & Shoreline Beach Material

Map 7.A-1



Legend

- 01. Bedrock
- 08. Boulder till
- 11. Sand w Cobbles
- 13. Sand
- 15. Sand w Till
- 19. Till
- 23. Clay w Boulders
- 25. Clay w Cobbles
- 29. Clay w 'Till'
- 31. Clay
- 37. Peat w Cobbles
- 39. Peat w Rock
- 41. Peat

95 % Flow

High : 6.55

Low : 0

Projection: NAD 83 Zone 15N
Data Source: Manitoba Hydro

0 0.8 1.6 Kilometres

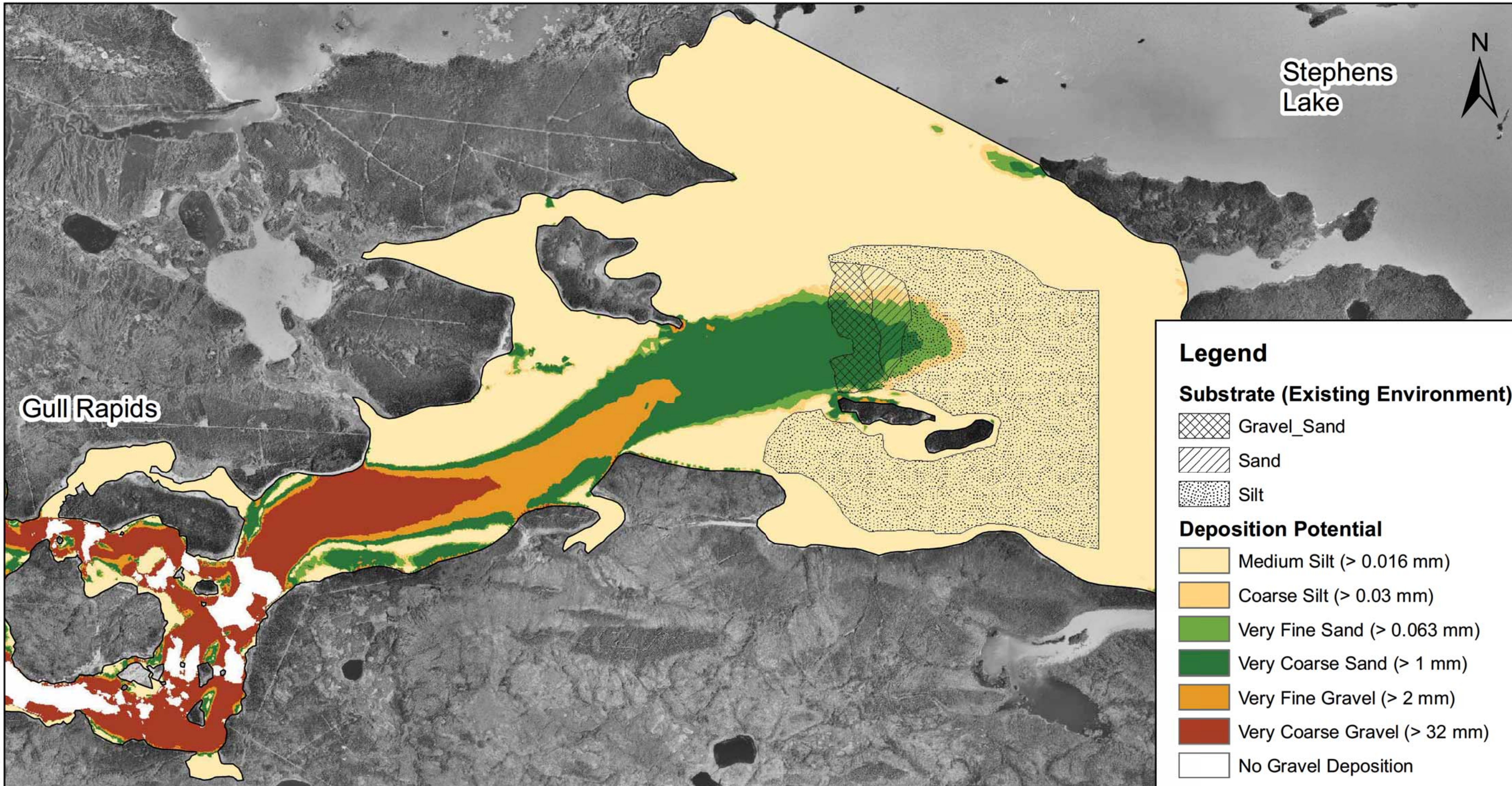
0 0.55 1.1 Miles

Shoreline Bank Material Classification and Water Velocities

Velocity with 95% Flow (4855cms) & Shoreline Bank Material

KEEYASK
Hydropower Limited Partnership

Map 7.A-2



KEEYASK
Hydropower Limited Partnership

0 0.5 1 2 Kilometers
0 0.25 0.5 1 1.5 Miles

Projection: Universal Transverse Mercator Zone 15N, NAD83
Data Sources:
1. Preliminary Keeyask Existing Environment Substrate provided by North-South Consultants, 2011
2. Air Photos provided by Manitoba Hydro, 2006
3. Shoreline created by KGS Acres for reference only

FOR GENERAL REFERENCE ONLY

Deposition Potential - Existing Environment
50th Percentile Flow
Stephens Lake Level = 141.1 m

Map 7.A-3

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APPENDIX 7B

DETAILED DESCRIPTION OF THE ENVIRONMENTAL SETTING FOR MINERAL SEDIMENTATION

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7B.0 DETAILED DESCRIPTION OF THE ENVIRONMENTAL SETTING FOR MINERAL SEDIMENTATION

7B.1 EXISTING ENVIRONMENT

7B.1.1 Upstream Of Project

Sediment processes in the study area as presented herein, are based on the available information discussed in Section 7.2.2.1 as well as the results from the existing environment sedimentation modelling. The analysis includes assessments of suspended sediment concentrations in deep water as well as in nearshore areas, bedload, and sediment budget in the existing environment.

7B.1.1.1 Suspended Sediment

Assessment of the data collected in the open water periods of 2005 to 2007 indicates that the suspended sediment concentration generally lies within the range of 5 mg/L to 30 mg/L (Figure 7B.1-1, Figure 7B.1-2 and Figure 7B.1-3) from Clark Lake to Gull Rapids. Based on the field observations, sediment concentrations can vary within their normal range at a given location in a given day. The variations in the concentration over a short period of time can be due to many reasons, including local turbulences in the waterbody, changes in the meteorological environment, and local bank erosion processes.

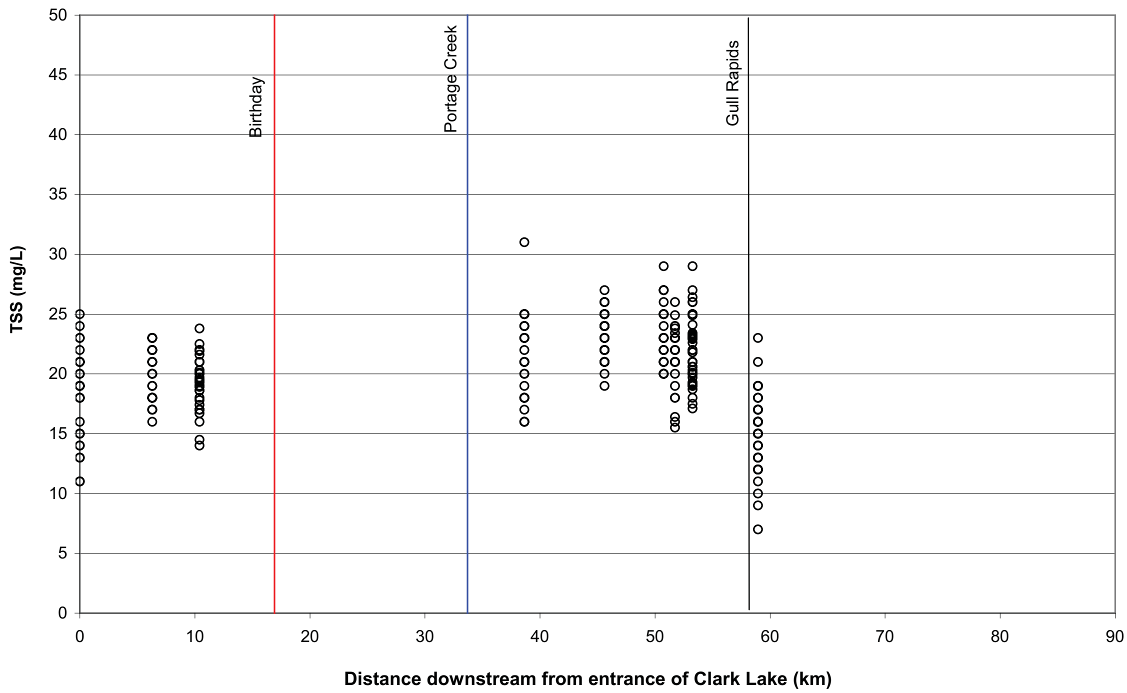

Figure 7B.1-1: TSS Concentration Profile in Longitudinal Direction – 2005 Program

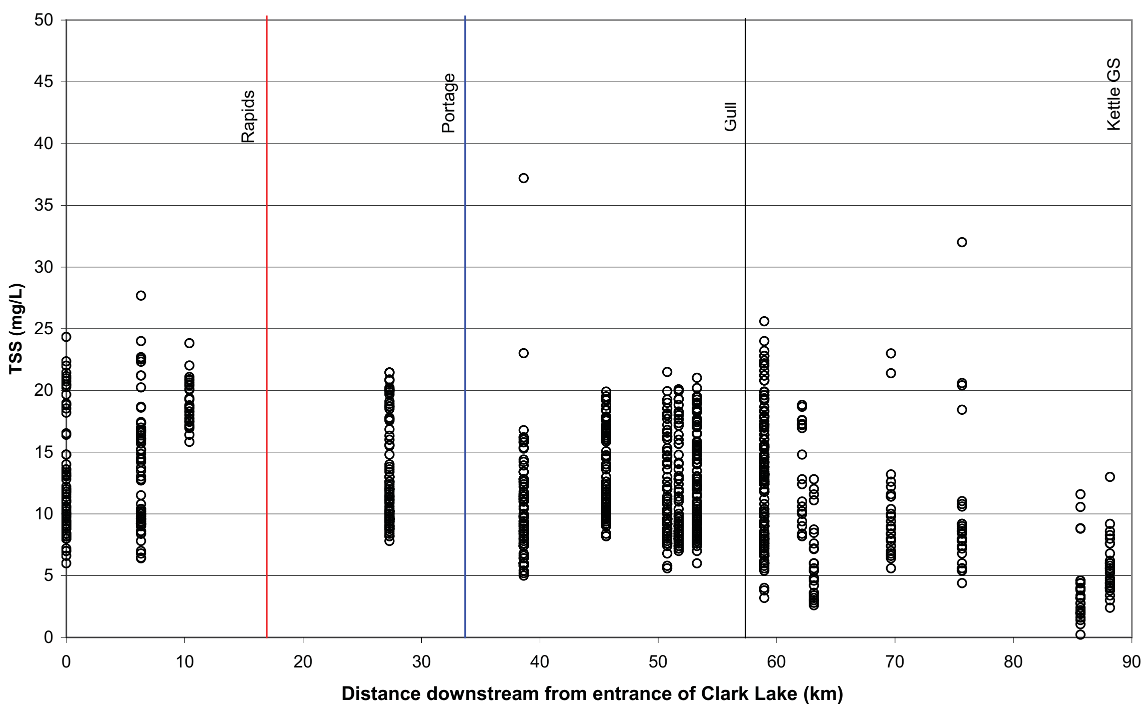

Figure 7B.1-2: TSS Concentration Profile in Longitudinal Direction – 2006 Program

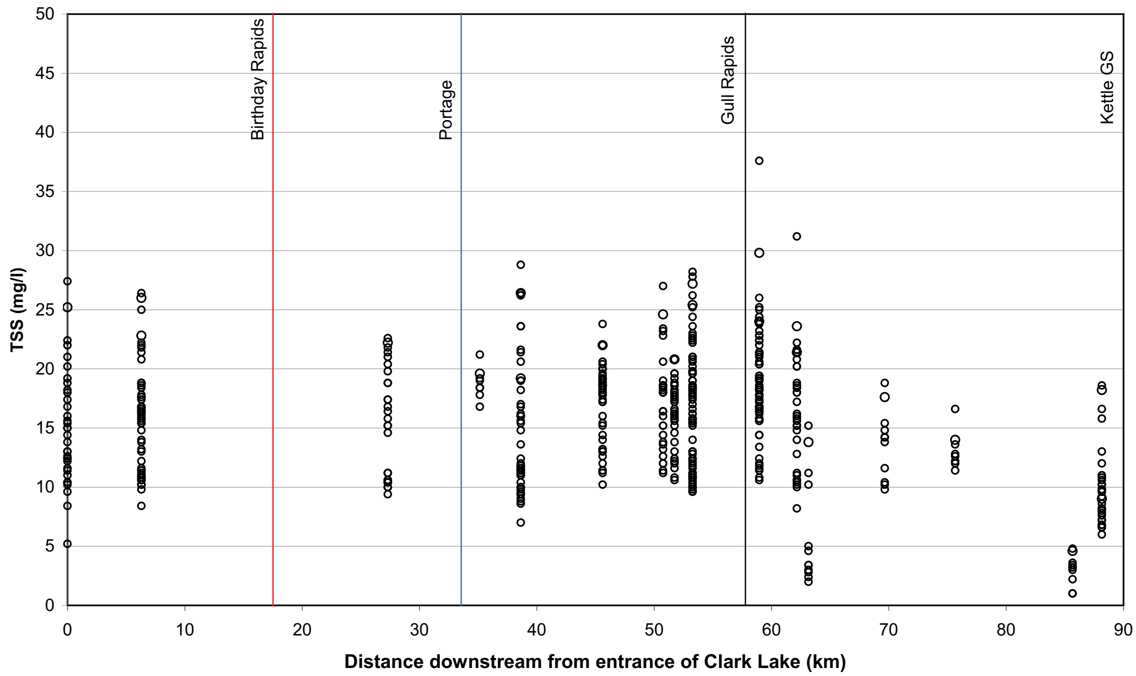

Figure 7B.1-3: TSS Concentration Profile in Longitudinal Direction – 2007 Program

The suspended sediment concentrations observed by scientists Aquatic Environment Supporting Volume (AE SV) in the open water period of 2001 to 2004 also show similar ranges (2 mg/L to 30 mg/L with an average of 12 mg/L) in the study area. A report prepared by Lake Winnipeg, Churchill and Nelson Rivers Study Board in 1975 (Lake Winnipeg, Churchill and Nelson Rivers Study Board 1975) documents a suspended sediment concentration range of 6 mg/L to 25 mg/L with an average of 15 mg/L based on their measurements in 1972 and 1973. Field studies carried out on the Burntwood River and the lower Nelson River reach also show a concentration range of 5 mg/L to 30 mg/L (Acre 2004, Acres 2007b, KGS Acres 2008b and KGS Acres 2008c).

Suspended sediment concentration measurements during the winter months (January to April), of 2008 and 2009 reveal that sediment concentration variations in the winter period are larger than the open water period. A limited data set collected at monitoring locations in Gull Lake shows a concentration range of 3 mg/L to 84 mg/L, with an average of 14.6 mg/L. See Figure 7B.1-4.

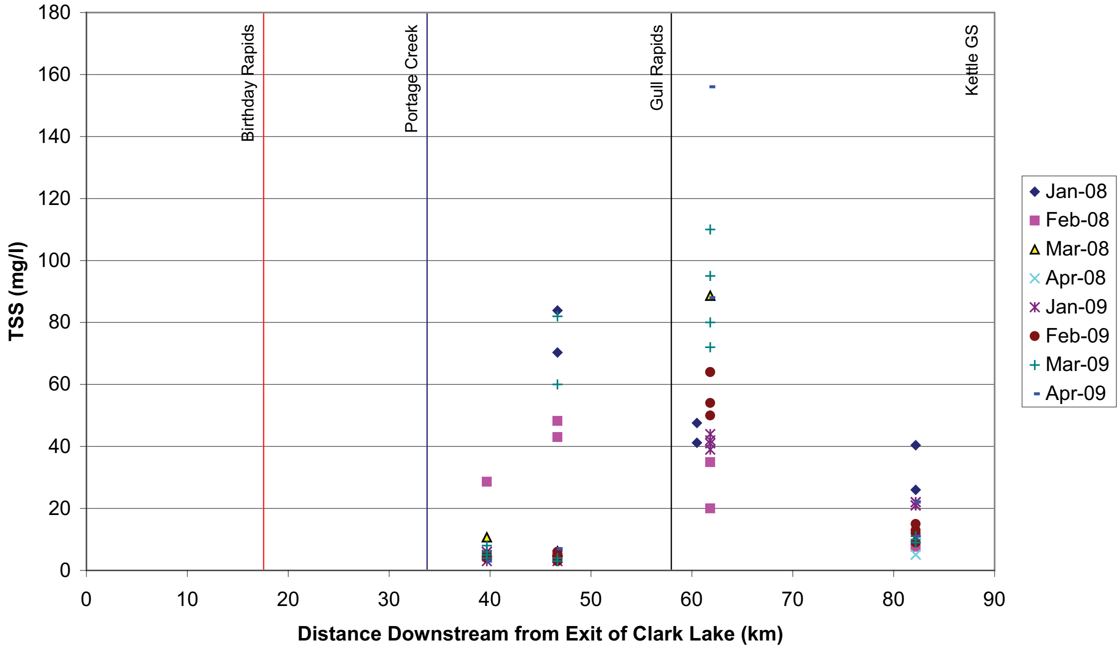

Figure 7B.1-4: Variation in Winter TSS Concentration in 2008 and 2009

Analysis of the particulate size of suspended material collected in the open water period reveals that the suspended sediments are generally composed of clay and silt as well as some fine sand particles. This is true for both the riverine reach downstream of Split Lake, as well as the lacustrine locations in Split Lake and Stephens Lake. Examples of typical particle size distributions (both by mass and count) observed in the study area are provided in Figure 7B.1-5 and Figure 7B.1-6, which indicates that the suspended sediments are generally composed of washload. Similar material composition in suspension was also observed in the Lower Nelson River reach between Kettle GS and Gillam Island (KGS Acres 2008b and KGS Acres 2008c).

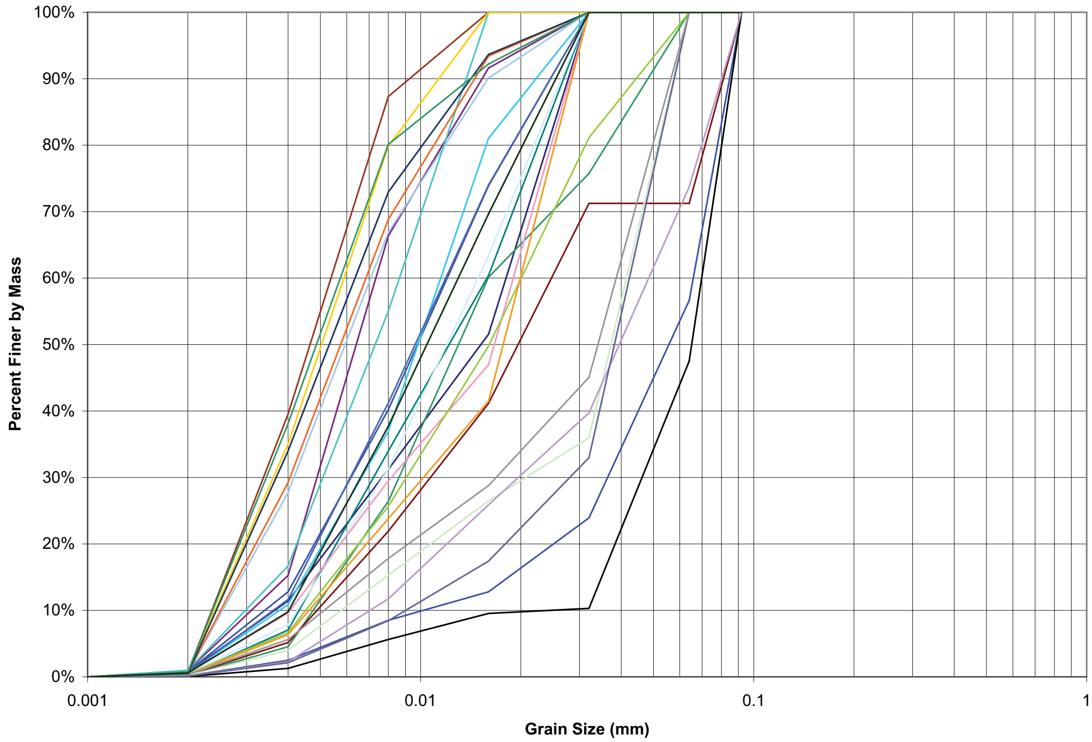

Figure 7B.1-5: Distribution of Particle Size (by Mass) in Suspension at K-S-06 (Upstream of Gull Rapids)

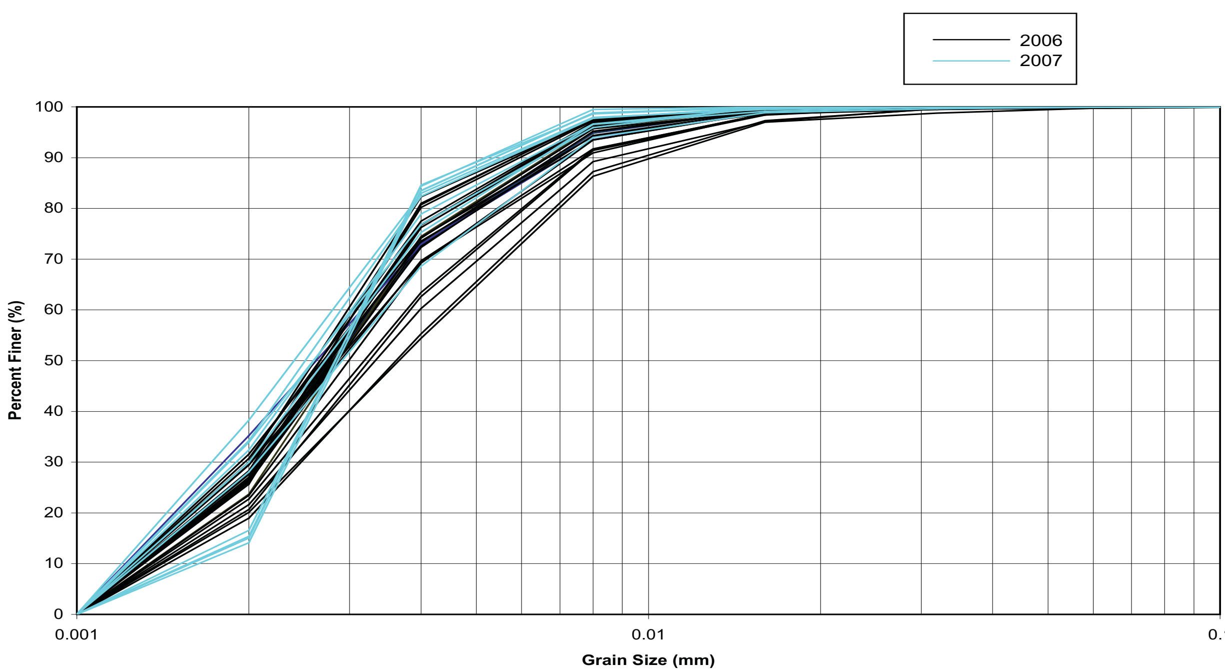

Figure 7B.1-6: Distribution of Particle Size (by Count) in Suspension at K-S-06c (Upstream of Gull Rapids)

There is also little consistent trend in suspended sediment concentration levels with depth. Figure 7B.1-7 shows an example of concentration variation with depth in 2006. Data collected in 2005 and 2007 also show similar trends, or lack thereof. This is expected for washload of fine particulate, which should be well mixed in fluvial environments, and is further indication that the suspended material is not transported bed material load. This observation conforms to the previous field study by Penner *et al.,* (1975).

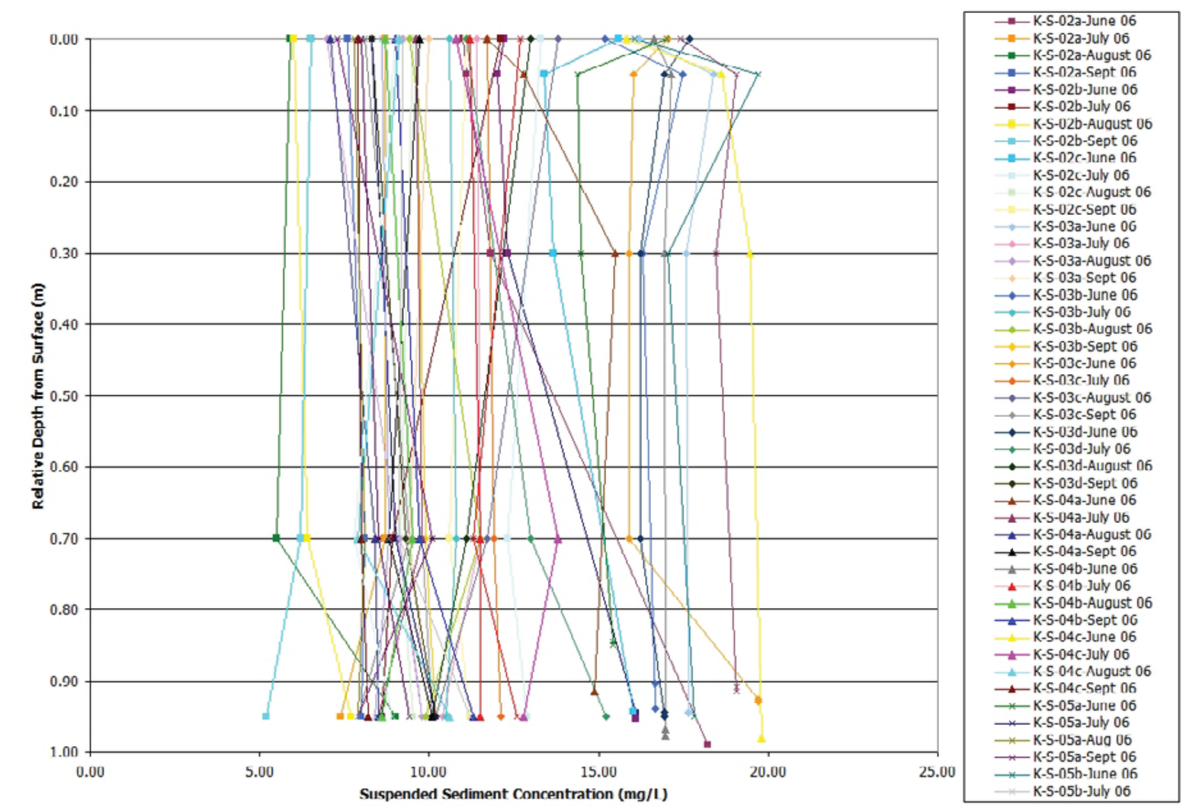

Figure 7B.1-7: Suspended Sediment Concentration Variation with Depth in Gull Lake

The probable trend in suspended sediment concentration variation across the channel in the Project area has also been investigated. As shown in Figure 7B.1-8 and Figure 7B.1-9, no significant variations in concentration could be observed in the open water period of 2006 at the monitoring section of K-S-01, which is located downstream of Birthday Rapids (Map 7C.1-1, Appendix 7C). Some variations in sediment concentration were observed at the monitoring section of K-S-06 located upstream of Gull Rapids (Map 7C.1- 3, Appendix 7C) in the open water months of 2005 and 2006. The range of variations remained within 5 mg/L, which may have possibly arisen due to the flow split downstream of Caribou Island resulting in differences in transport capacity, or changes in local shear stress and the subsequent entrainment of bed material.

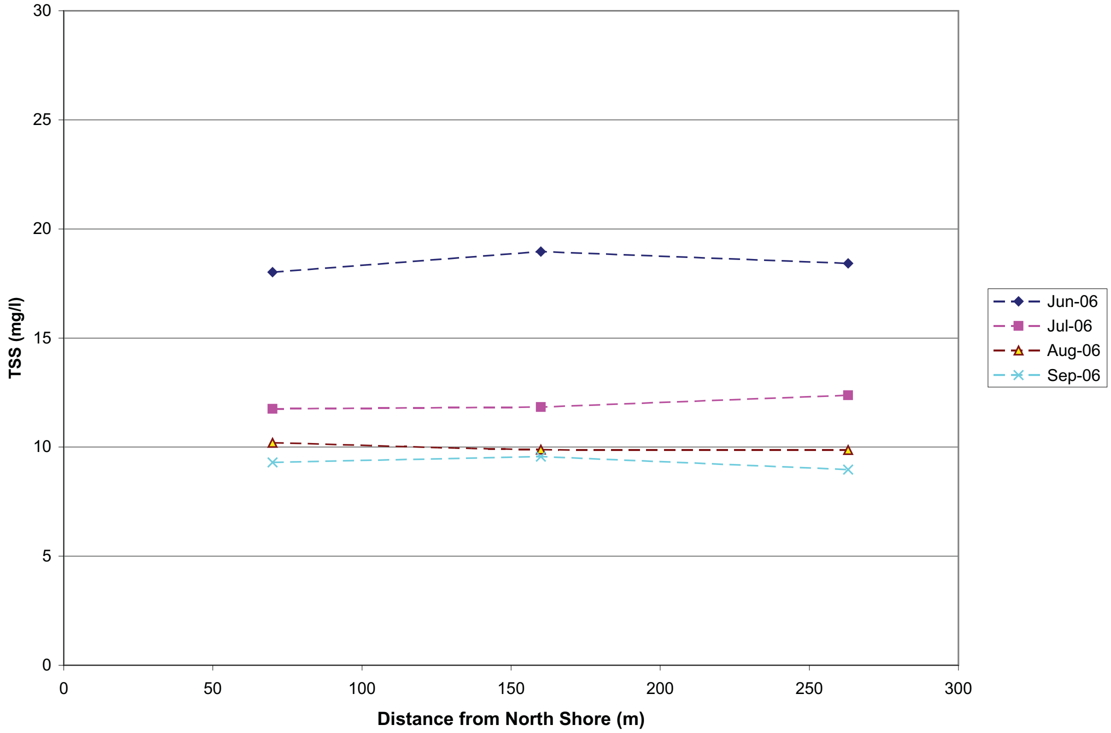

Figure 7B.1-8: Cross-Sectional Variation in Suspended Sediment Concentration at K-S-01 (Downstream of Birthday Rapids)

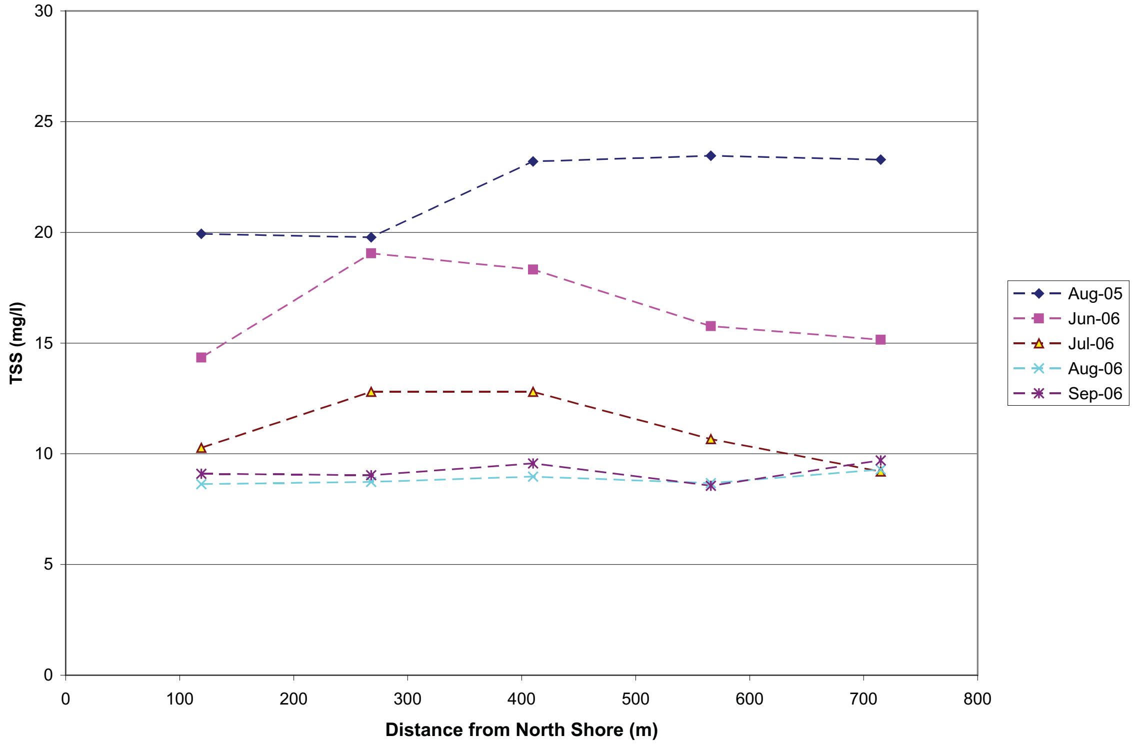

Figure 7B.1-9: Cross-Sectional Variation in Suspended Sediment Concentration at K-S-06 (Upstream of Gull Rapids)

A comparison of suspended sediment concentration data collected from 2005 to 2007 seems to show that average concentration in the high-flow year of 2005 was marginally higher than in 2006 and 2007 (Figure 7B.1-1, Figure 7B.1-2 and Figure 7B.1-3). However, a close investigation of this data reveals that the measured concentrations have poor correlation with instantaneous discharges and the relationship between sediment concentration and discharge is complicated by hysteresis. The low correlation between suspended sediment concentration and instantaneous discharges, even when accounting for hysteric effects (Figure 7B.1-10 and Figure 7B.1-11), indicates that the suspended sediment in the flow is likely not predominately sourced from bank erosion or local failures. This does not mean, however, that local shore erosion in the study area is not occurring. It only means that the presence of eroded material from the shore is not significant in the flow.

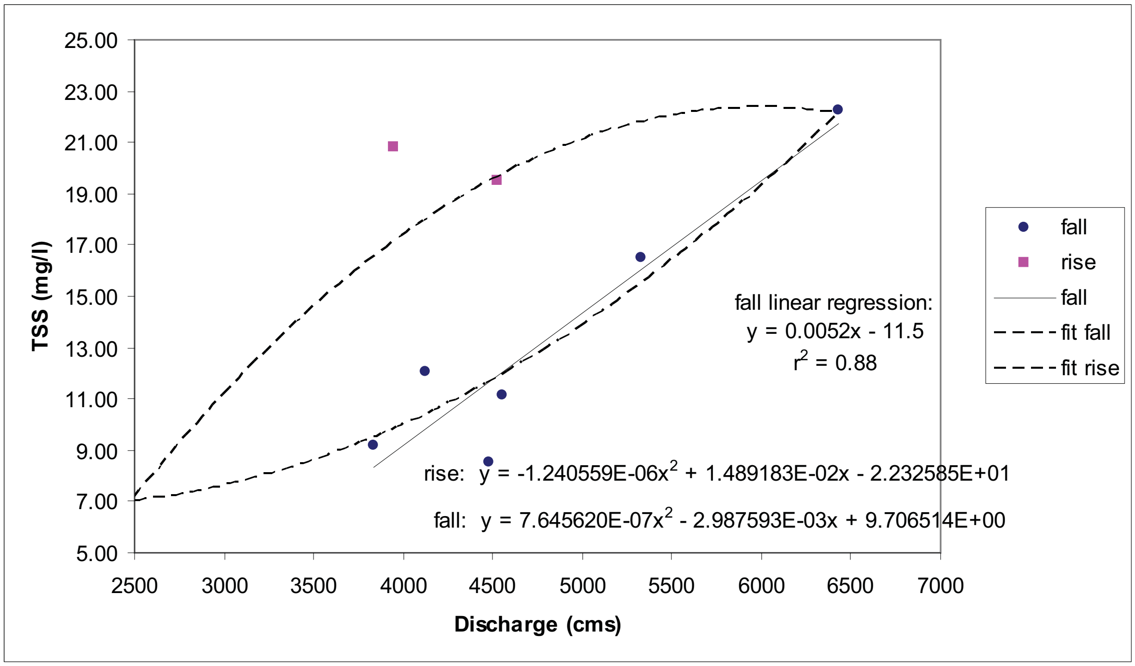

Figure 7B.1-10: Hysteric Suspended Sediment Concentration Rating Curve at K-S-06 (Upstream of Gull Rapids)

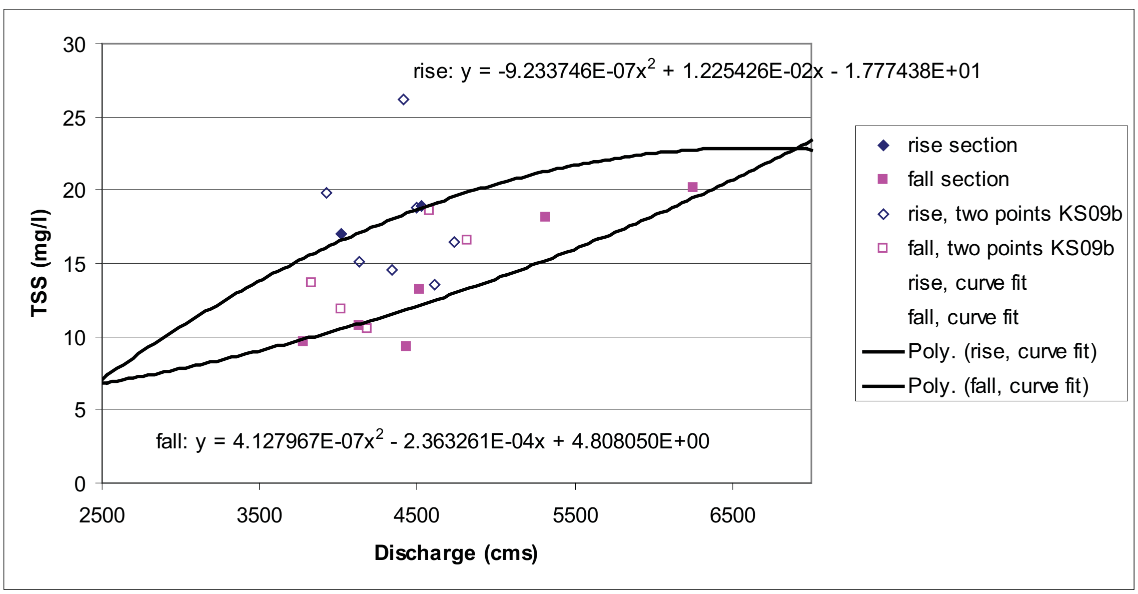

Figure 7B.1-11: Hysteric Suspended Sediment Concentration Rating Curve at K-S-09 (Downstream of Birthday Rapids)

Observation of nearshore suspended sediment concentration levels measured during data collection in the open water months of 2005 to 2007 also reveals that the suspended sediment concentrations remain generally within the range of 2 mg/L to 35 mg/L. However, a few high concentrations (60 mg/L to 125 mg/L) have also been observed in the nearshore areas during data collection.

Figure 7B.1-12, Figure 7B.1-13, Figure 7B.1-14 and Figure 7B.1-15 illustrate examples of concentration variation in the nearshore areas. An example of sediment plume with high concentration of suspended sediment in nearshore area is shown in Photograph 7-1. It is likely that the measured values do not include most of the short-term event based re-suspension in the shallow nearshore, as safety concerns and logistical challenges often prohibit any sampling and measurement immediately after high wind events and mass shore failures. It is expected that the occurrence of high sediment concentrations resulting from local disturbance would only continue for a relatively short duration.

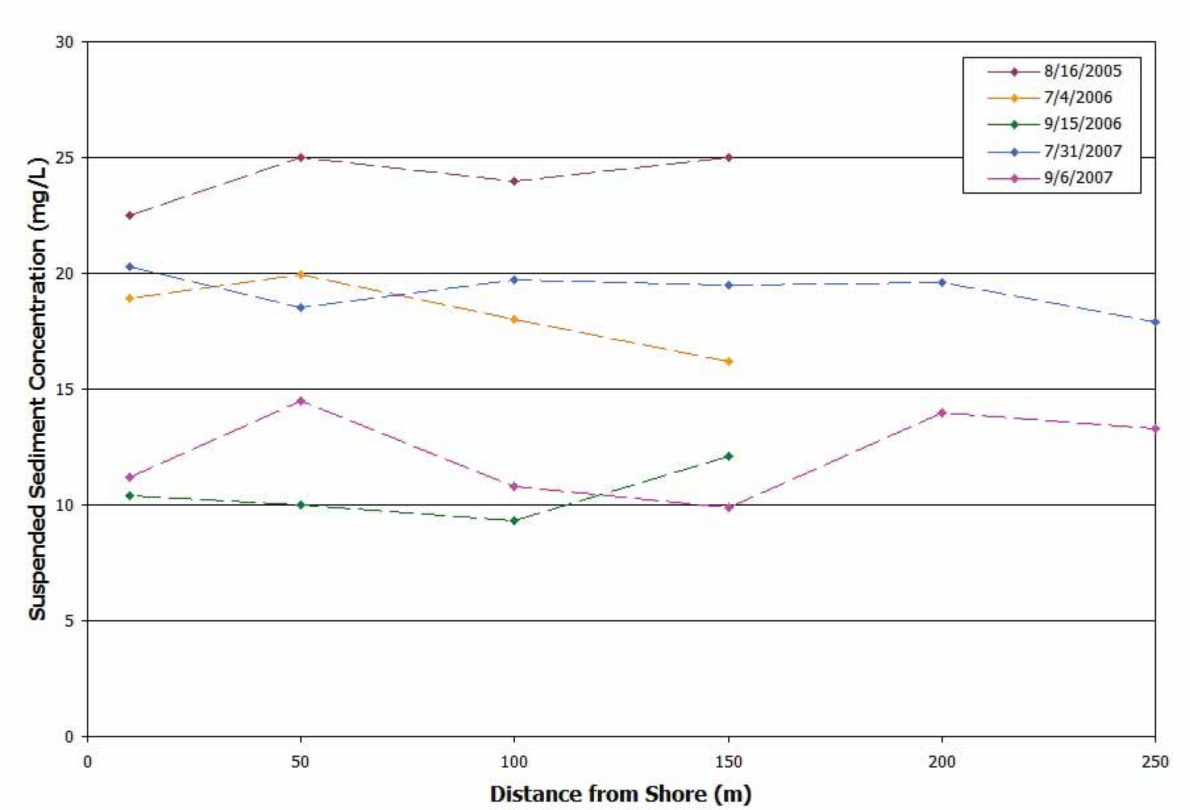

Figure 7B.1-12: Suspended Sediment Concentration Variation at Erosion Transect K-T-1 (Downstream of Birthday Rapids)

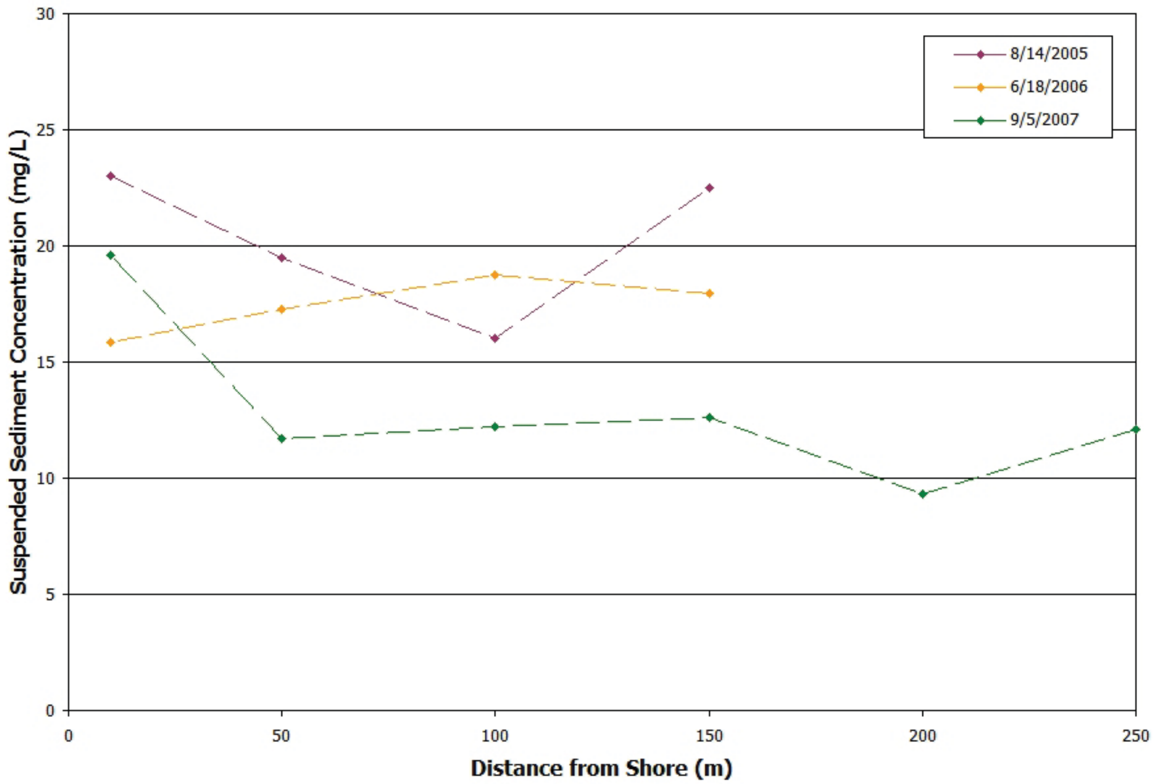

Figure 7B.1-13: Suspended Sediment Concentration Variation at Erosion Transect K-Tc-3 (Gull Lake)

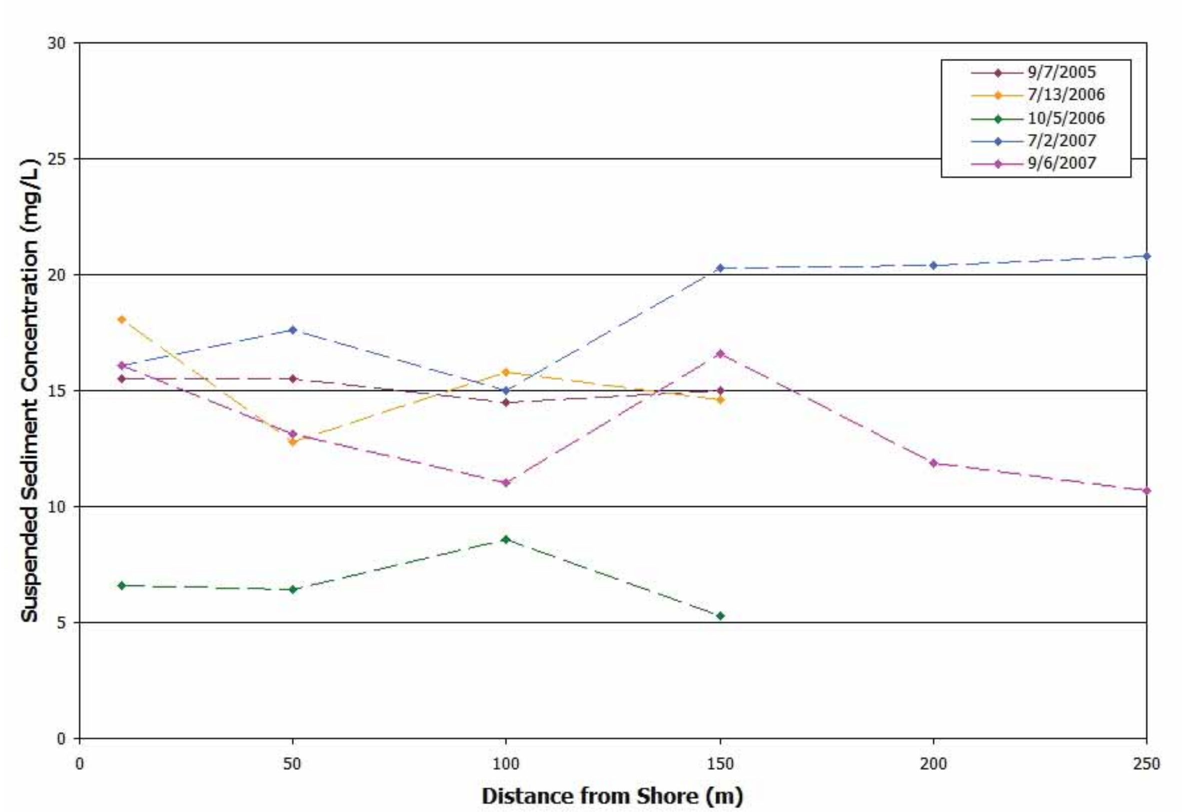

Figure 7B.1-14 Suspended Sediment Concentration Variation at Erosion Transect K-Tc-5 (Downstream of Gull Rapids)

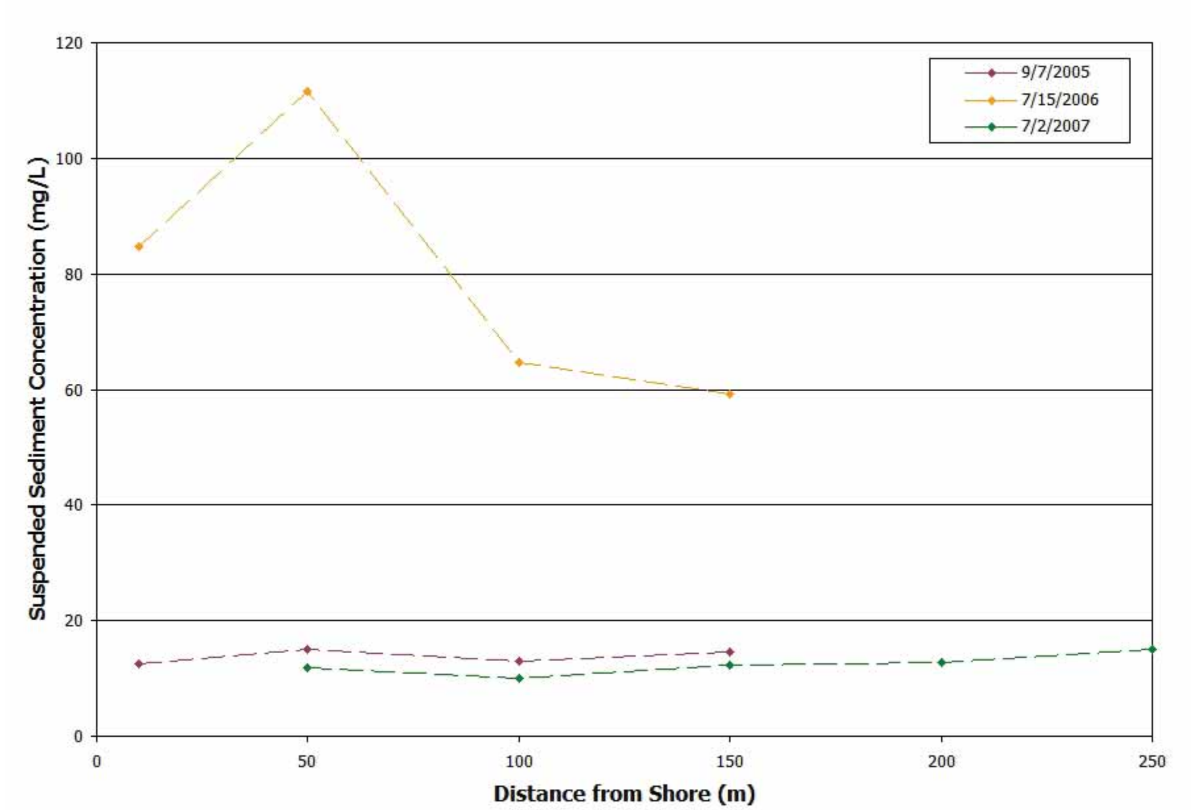

Figure 7B.1-15: Suspended Sediment Concentration Variation at Erosion Transect K-Tc-11 (Stephens Lake)

7B.1.1.2 Bedload and Bed Material

The bedload measurement campaigns in the open water months of 2005 to 2007 included approximately 350 bedload and bed material sampling attempts. However, this yielded few measureable samples. In 2005, sampling activities were carried out at all TSS sampling locations, while the samples were collected at monitoring locations upstream and downstream of Gull Rapids in 2006 and 2007. Bedload and bed material samplers were deployed at five verticals across each section of the monitoring locations. The bedload measurements are listed in Table 7E.4, Appendix 7E. The gradation of bed materials collected in 2006 and 2007 are presented in Figure 7B.1-16 and Figure 7B.1-17 show the gradation of bed material collected in Gull Lake by North/South Consultants Inc. in 2001.

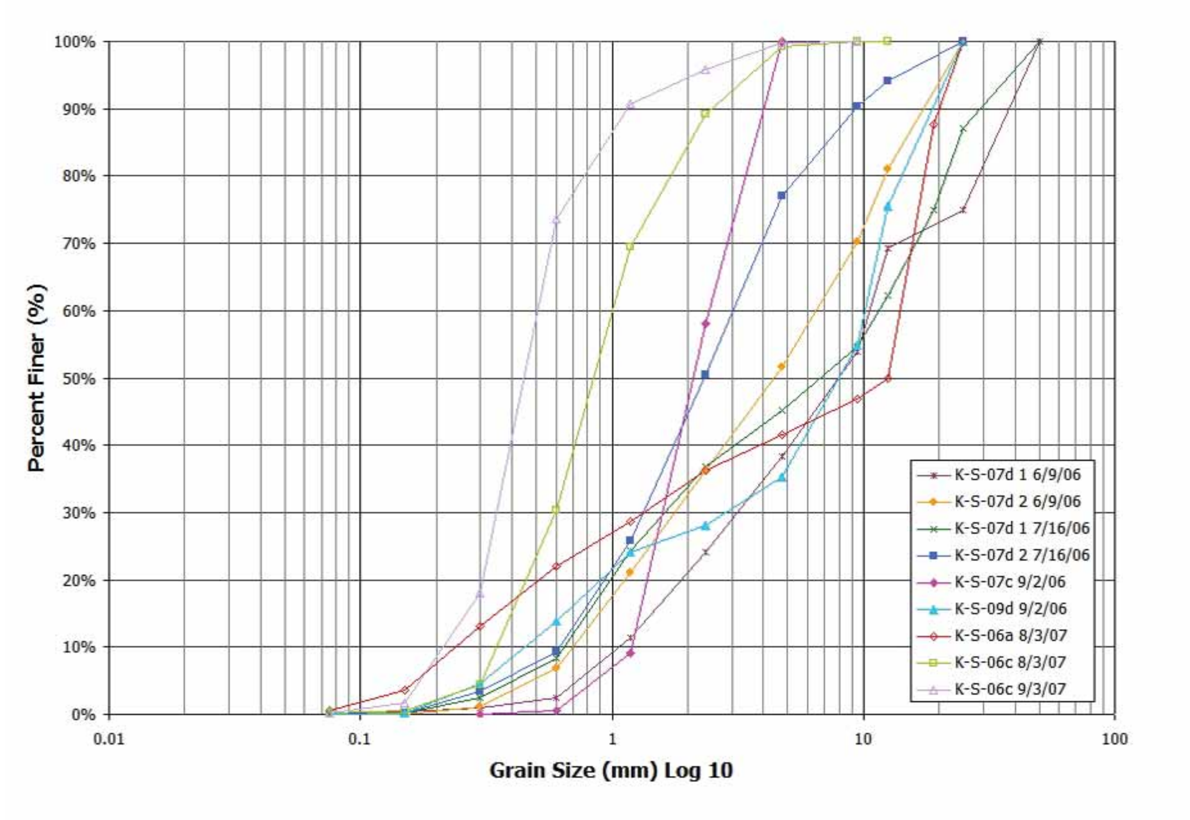

Figure 7B.1-16: Gradation of Bed Material at K-S-06 and K-S-07

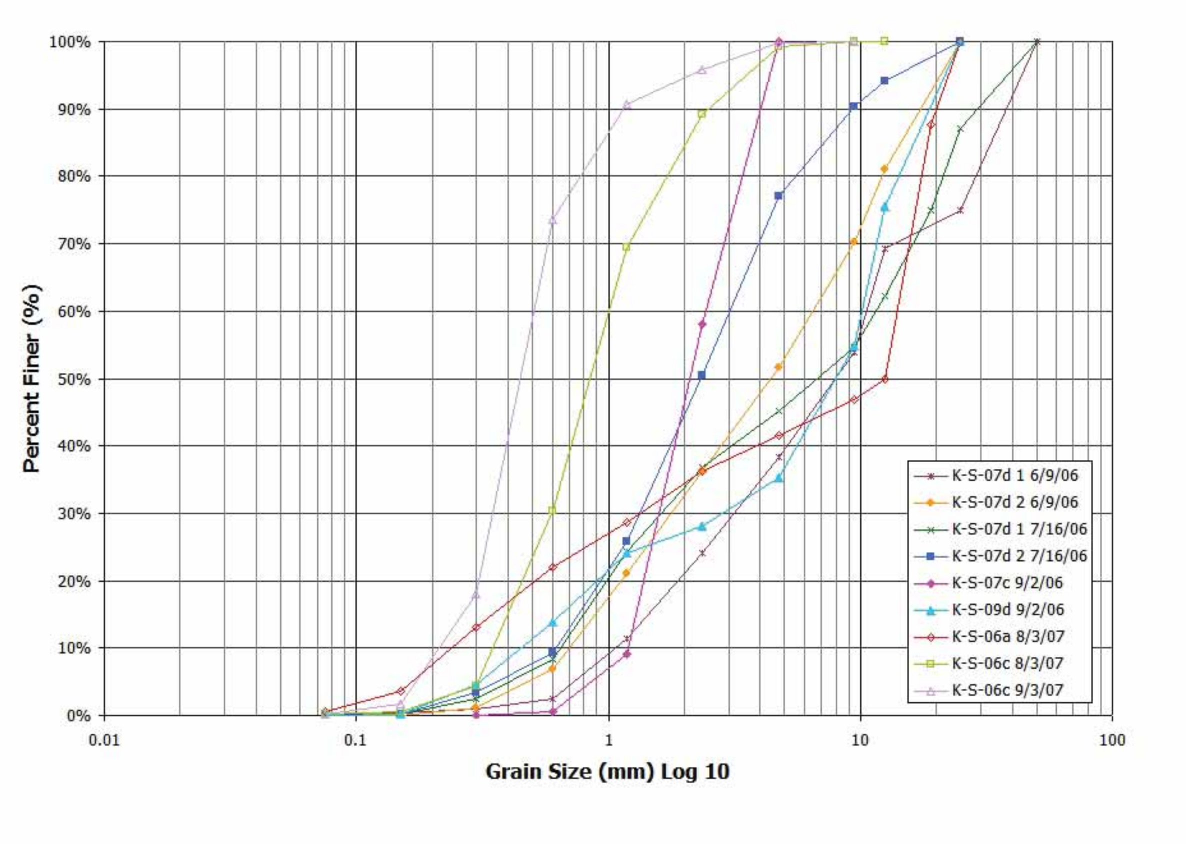

Figure 7B.1-17: Gradation of Bed Material in Gull Lake

7B.1.1.3 Total Sediment Load

In order to assess the load of sediment that the Nelson River carried though the study area in the recent past, estimation of sediment budget at monitoring locations downstream of Clark Lake (K-S-09) and upstream of Gull Rapids (K-S-06) were carried out for the period of 2005, 2006 and 2007.

As discussed in Section 7.3.2.1, bedload within the study area, as observed in the period of 2005 to 2007, is relatively low, and, therefore, is not included in the estimation of sediment load. A total load was calculated at each of the above mentioned monitoring locations, using this section's average suspended sediment concentration multiplied by the channel discharge. The section average TSS concentration was calculated by averaging all available concentration measurements for the section on a given day of measurement. In assessing total load, hysteresis in rating curves at the monitoring locations was also studied. The hysteretic rating curves were used with daily discharge hydrographs for the years 2005, 2006 and 2007 to estimate daily total loads from which annual total loads were calculated. The year 2005 was a high water year with annual average flow of 5,090 cms, whereas the annual average flows in 2006 and 2007 were

4,030 cms and 3,700 cms respectively. Based on Manitoba Hydro's monitoring data from 1977 to 2007, 5,090 cms, 4,030 cms and 3,700 cms represent about 95th, 83rd and 79th percentile open water flows respectively.

Based on the sediment load analysis, the total suspended loads passed through the study area in 2005, 2006 and 2007 were estimated to be 3.1 million-tonnes/year, 1.9 million-tonnes/year and 1.5 million-tonnes/year, respectively. According to the load estimates at the monitoring locations K-S-09 and K-S-06, no significant deposition or accumulation occurred in the Project area in 2005, 2006 and 2007.

The absence of deposition or accumulation of sediment in the Project area under the relatively high flow conditions of 2005 to 2007 suggests that the suspended material, which is predominantly washload, advected through the Nelson River reach from downstream of the exit of Clark Lake to Gull Rapids. Contribution of eroded shore material to the overall sediment budget from within this reach, during these 3 years, was minimal.

In comparison to other major rivers, the Nelson River carries a relatively low sediment load. For example, based on information compiled by the US Geological Survey (2008) reports that the average annual sediment discharges in major rivers in the United States of America, including Mississippi and Yukon Rivers, are greater than 10 million-tonnes/year. Also, several major rivers outside North America *e.g.,* Volga in Russia (Korotaev *et al.,* 2004), Danube in Romania (Sinha and Friend 1994), and Indus River Basin in Pakistan (Ali *et al.,* 2004) carry significantly larges sediment discharges than the Nelson River.

7B.1.2 Downstream of Project

Average concentrations at Stephens Lake sites ranged from 3 mg/L to 15 mg/L in the open water months of 2005 to 2007 with an overall average of approximately 9 mg/L, as shown in Table 7.3-2. This corresponds reasonably well with the average concentration of 13 mg/L estimate that was based on nine samples taken throughout Stephens Lake in July 1974, immediately after impoundment (Penner *et al.,* 1975). It should be noted, however, that the 1974 survey was possibly skewed by a high measured concentration (28 mg/L) at the lake inlet downstream of Gull Rapids. The measured concentration at a monitoring location in the immediate forebay of the Kettle GS in 1974 was 9 mg/L. Similar to the 1974 survey, the average concentration in Stephens Lake was highest (14.1 mg/L) at a monitoring location (SL-S-03), downstream of Gull Rapids during the open water periods of 2005 to 2007. The average concentration at a monitoring location (SL-S-06) in the immediate forebay of the Kettle GS was approximately 7 mg/L during the same monitoring period. Thus, it appears that the concentrations in Stephens Lake decrease in the stream-wise direction. This suggests that some of the suspended clay and fine silt washload transported by the Nelson River is settling in Stephens Lake.

A number of water samples were collected in the winter months of 2008 and 2009, which show that the TSS concentrations varied in Stephens Lake in the range from 5 mg/L to 156 mg/L, with an average of 40.5 mg/L (Figure 7B.1-4). The concentrations were high (20 mg/L to156 mg/L, with an average of 66 mg/L) at the monitoring locations K-Tu-09 and K-Tu-12, which are located at the upstream end of Stephens Lake (Map 7D.1-1 Appendix 7D). The occurrence of such high concentration was likely due to the active shoreline erosion that had resulted from the ice dam in the reach immediately downstream of Gull Rapids. Under present conditions, the large hanging dam that typically occurs in this area results in significant impacts on the river's banks in the winter. The large volumes of ice that are collected in this area also lead to some redirection of flow and the occasional formation of new channel segments. The localized erosion of these banks and channels may increase the overall TSS concentrations in this area, and may lead to some seasonally increased deposition rates within Stephen's Lake. TSS concentrations at a monitoring location K-Tu-04 upstream of Kettle GS showed a range of 5 mg/L to 40 mg/L, with an average of 15 mg/L.

The total suspended sediment load upstream of the Kettle GS has been calculated based on the hysteric rating curve at the monitoring location SL-S-06, located upstream of the generating station (Figure 7B.1-18). In 2005, the sediment load upstream of the Kettle GS was 1.2 million-tonnes, whereas it was 0.8 million-tonnes in 2006. As discussed in Section 7.3.2.2, total sediment loads entering Stephens Lake in 2005 and 2006 were estimated to be 3.1 million-tonnes and 1.9 million-tonnes respectively. Therefore, as expected, sediment was deposited in Stephens Lake in both years of measurement.

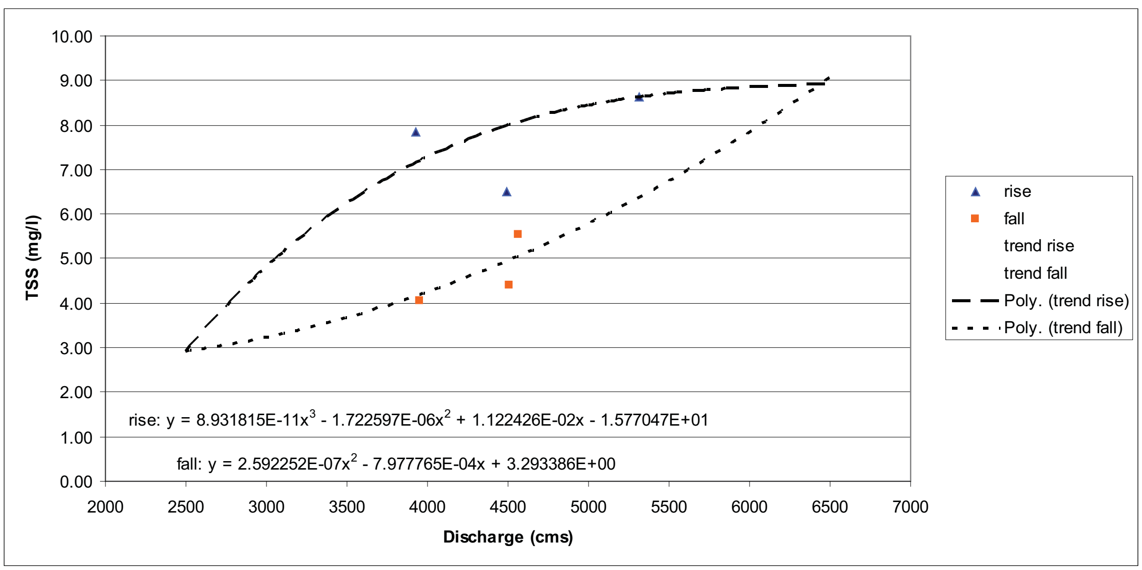

Figure 7B.1-18: Hysteric TSS Rating Curve at SL-S-06 (Upstream of Kettle GS)

7B.2 FUTURE CONDITIONS/TRENDS

A qualitative analysis was carried out to assess potential changes in the future sedimentation environment. The following key assumptions, in additions to the general assumptions listed in Section 7.2.3, were made in the analysis:

- No man-made changes (*e.g.*, construction of dam, diversion of channel) will take place in the Project area.
- The watershed will not undergo any significant changes.
- Future flow regime in the Project area will remain the same as in the past flow regime.

The study included a qualitative assessment of possible changes in the factors, including river morphology, shore erosion and water regime, which may influence the future sedimentation environment.

7B.2.1 River Morphology

As a part of the study, the geometric properties *e.g.*, depth, width and slope of the riverine reach between Clark Lake and Gull Lake were studied using an empirical approach similar to regime theory, which presumes that given sufficient time, a river flowing in its alluvium reaches an equilibrium state. The study results show that the channel geometry varies with the changes in the normal ranges of instantaneous discharge that are experienced in the existing environment. Significant changes in the channel geometry are not expected, unless a very large change in the river's flow regimes were to occur. Channel morphology of the study area between Clark Lake and Gull Rapids was studied by comparing aerial photographs taken over the last two decades. According to the study result, the Nelson River in the study area has reached a near equilibrium condition. The presence of significant bedrock control helps the river to maintain its alignment and channel geometry. As discussed in Shoreline Erosion Processes Section 6, the shorelines in Gull Lake also remained generally stable. However, localized variations in the channel morphology might still exist. For example, there have been changes in the shorelines of a major island upstream of Gull Rapids due to ice related erosion.

7B.2.2 Shoreline Erosion

A report by JD Mollard and Associates and KGS Acres (2008) suggests that the bank materials in the existing Project area consist of non-eroding bedrock, erodible mineral sediment, and peat. According to the same study, average annual bank recession rates remained low, particularly in the riverine reach over the last two decades. As discussed in Section 6.0 Shoreline Erosion with the assumption that the historical range and statistical distribution of water levels, river discharge rates, wind conditions, ice processes and bank material types will remain relatively consistent beyond 30 years, erosion rates projected during the first 30 years after the proposed in-service date of 2017 are expected to continue beyond that time period. Main factors that may alter the observed long-term rates are changes in bank material (*e.g.*, stabilization of shore zones against bedrock), persistent low or high flow and water levels, or a significant long-term change in wind patterns, frequencies and velocities.

7B.2.3 Downstream

Peatland disintegration processes in the Project area were discussed in a study report by ECOSTEM (2008), which suggests that the disintegration of peat bank in the future conditions would be very low to minimal.

7B.2.4 Water Regime

The water regime in the study area is generally seasonally classified as an open water regime and a winter regime. Considering the assumptions previously stated in Section 7.2.3 and Section 7.3.1.2, and the understanding that the river has reached a near stable state, the open water regime is not expected to be different from its existing environment.

Assuming that there will be no changes in the climatic and watershed conditions in the future, the winter regime should continue to be the same as the existing regime without the development of the Project (KGS Acres 2008e). The same study predicts that the severity of ice processes will vary from year to year depending on specific meteorological conditions, but in general the major ice processes will not be changed.

7B.2.5 Study Assessment

As discussed above, the driving factors are not expected to change from their existing state, for the case where the development of the proposed Keeyask GS Project is not undertaken. Therefore, it is expected that the existing sedimentation environment would continue to be relatively the same in the future environment.

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APPENDIX 7C

FIELD MAPS (OPENWATER)

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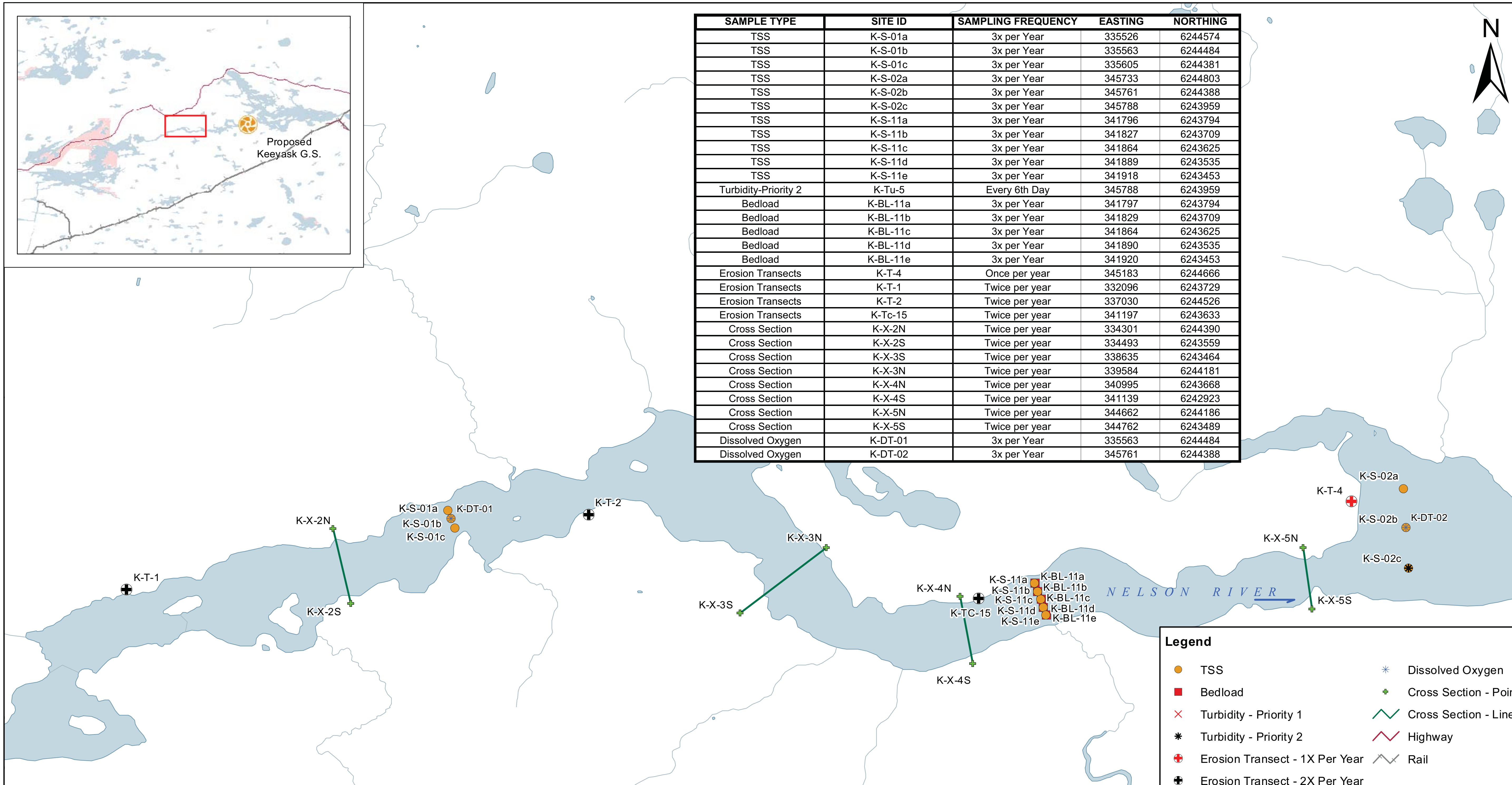


SAMPLE TYPE	SITE ID	SAMPLING FREQUENCY	EASTING	NORTHING
TSS	K-S-01a	3x per Year	335526	6244574
TSS	K-S-01b	3x per Year	335563	6244484
TSS	K-S-01c	3x per Year	335605	6244381
TSS	K-S-02a	3x per Year	345733	6244803
TSS	K-S-02b	3x per Year	345761	6244388
TSS	K-S-02c	3x per Year	345788	6243959
TSS	K-S-11a	3x per Year	341796	6243794
TSS	K-S-11b	3x per Year	341827	6243709
TSS	K-S-11c	3x per Year	341864	6243625
TSS	K-S-11d	3x per Year	341889	6243535
TSS	K-S-11e	3x per Year	341918	6243453
Turbidity-Priority 2	K-Tu-5	Every 6th Day	345788	6243959
Bedload	K-BL-11a	3x per Year	341797	6243794
Bedload	K-BL-11b	3x per Year	341829	6243709
Bedload	K-BL-11c	3x per Year	341864	6243625
Bedload	K-BL-11d	3x per Year	341890	6243535
Bedload	K-BL-11e	3x per Year	341920	6243453
Erosion Transects	K-T-4	Once per year	345183	6244666
Erosion Transects	K-T-1	Twice per year	332096	6243729
Erosion Transects	K-T-2	Twice per year	337030	6244526
Erosion Transects	K-Tc-15	Twice per year	341197	6243633
Cross Section	K-X-2N	Twice per year	334301	6244390
Cross Section	K-X-2S	Twice per year	334493	6243559
Cross Section	K-X-3S	Twice per year	338635	6243464
Cross Section	K-X-3N	Twice per year	339584	6244181
Cross Section	K-X-4N	Twice per year	340995	6243668
Cross Section	K-X-4S	Twice per year	341139	6242923
Cross Section	K-X-5N	Twice per year	344662	6244186
Cross Section	K-X-5S	Twice per year	344762	6243489
Dissolved Oxygen	K-DT-01	3x per Year	335563	6244484
Dissolved Oxygen	K-DT-02	3x per Year	345761	6244388

KEEYASK Hydropower Limited Partnership

0 1 2 Kilometers
0 0.5 1 Miles

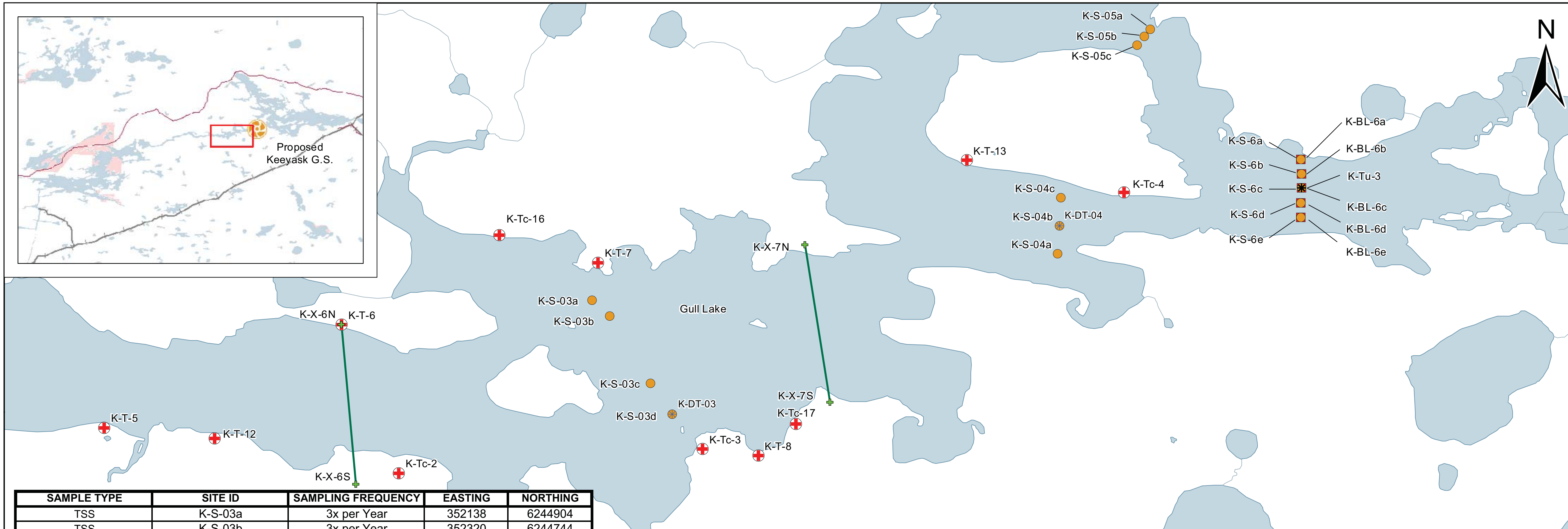
Projection: Universal Transverse Mercator Zone 15N, NAD 83

Data Source:
1. Lakes and rivers provided by Geogratis, 2004
2. Sampling locations provided by Mantioba Hydro. 2007

NOTES:
1. All values shown are in metres.
2. Site locations were identified and historically monitored by Manitoba Hydro or were identified collaboratively by Manitoba Hydro KGS Acres Ltd., and J D Mollard and Associates for this project.

2007 Sampling Locations
Birthday Rapids to Kahpowinic Bay

Map 7.C-1



SAMPLE TYPE	SITE ID	SAMPLING FREQUENCY	EASTING	NORTHING
TSS	K-S-03a	3x per Year	352138	6244904
TSS	K-S-03b	3x per Year	352320	6244744
TSS	K-S-03c	3x per Year	352738	6244051
TSS	K-S-03d	3x per Year	352965	6243731
TSS	K-S-04a	3x per Year	356931	6245383
TSS	K-S-04b	3x per Year	356949	6245672
TSS	K-S-04c	3x per Year	356967	6245960
TSS	K-S-05a	3x per Year	357884	6247694
TSS	K-S-05b	3x per Year	357825	6247620
TSS	K-S-05c	3x per Year	357754	6247530
TSS	K-S-06a	3x per Year	359438	6246355
TSS	K-S-06b	3x per Year	359445	6246206
TSS	K-S-06c	3x per Year	359444	6246064
TSS	K-S-06d	3x per Year	359437	6245908
TSS	K-S-06e	3x per Year	359438	6245759
Bedload	K-BL-6a	3x per Year	359438	6246355
Bedload	K-BL-6b	3x per Year	359444	6246206
Bedload	K-BL-6c	3x per Year	359444	6246064
Bedload	K-BL-6d	3x per Year	359438	6245908
Bedload	K-BL-6e	3x per Year	359438	6245759
Turbidity-Priority 2	K-Tu-3	Every 6th Day	359444	6246064

SAMPLE TYPE	SITE ID	SAMPLING FREQUENCY	EASTING	NORTHING
Erosion Transects	K-T-5	Once per Year	347108	6243591
Erosion Transects	K-T-12	Once per Year	348242	6243416
Erosion Transects	K-Tc-2	Once per Year	350144	6243126
Erosion Transects	K-T-6	Once per Year	349555	6244654
Erosion Transects	K-Tc-16	Once per Year	351192	6245646
Erosion Transects	K-T-7	Once per Year	352200	6245292
Erosion Transects	K-Tc-3	Once per Year	353273	6243373
Erosion Transects	K-T-8	Once per Year	353846	6243303
Erosion Transects	K-Tc-17	Once per Year	354234	6243634
Erosion Transects	K-Tc-13	Once per Year	378886	6247086
Erosion Transects	K-Tc-4	Once per Year	357613	6246013
Cross Section	K-X-6N	Twice per Year	349552	6244667
Cross Section	K-X-6S	Twice per Year	349708	6242994
Cross Section	K-X-7N	Twice per Year	354329	6245489
Cross Section	K-X-7S	Twice per Year	354593	6243840
Dissolved Oxygen	K-DT-03	3x per Year	352965	6243731
Dissolved Oxygen	K-DT-04	3x per Year	356949	6245672

Legend

- TSS
- Bedload
- Turbidity - Priority 2
- Erosion Transect - 1X Per Year
- Dissolved Oxygen
- Cross Section - Point
- Cross Section - Line
- Highway
- Rail

KEEYASK
Hydropower Limited Partnership

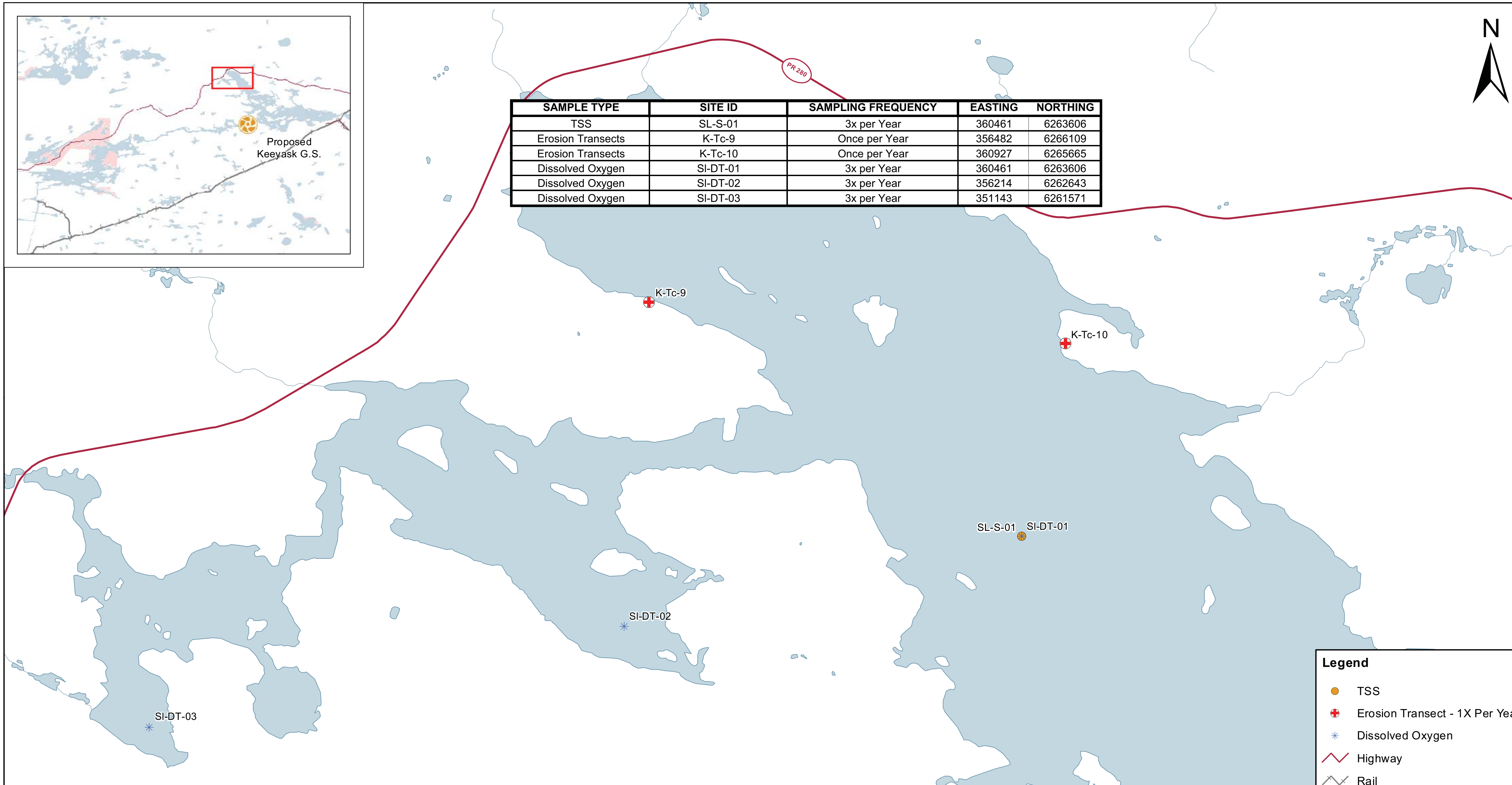
0 1 2 Kilometers
0 0.5 1 Miles

Projection: Universal Transverse Mercator Zone 15N, NAD 83

Data Source:
1. Lakes and rivers provided by Geogratis, 2004
2. Sampling locations provided by Manitoba Hydro. 2007

NOTES:
1. All values shown are in metres.
2. Site locations were identified and historically monitored by Manitoba Hydro or were identified collaboratively by Manitoba Hydro KGS Acres Ltd., and J D Mollard and Associates for this project.

2007 Sampling Locations
Rabbit Creek to Gull Lake



SAMPLE TYPE	SITE ID	SAMPLING FREQUENCY	EASTING	NORTHING
TSS	SL-S-01	3x per Year	360461	6263606
Erosion Transects	K-Tc-9	Once per Year	356482	6266109
Erosion Transects	K-Tc-10	Once per Year	360927	6265665
Dissolved Oxygen	SI-DT-01	3x per Year	360461	6263606
Dissolved Oxygen	SI-DT-02	3x per Year	356214	6262643
Dissolved Oxygen	SI-DT-03	3x per Year	351143	6261571

KEEYASK
Hydropower Limited Partnership

0 1 2 Kilometers
0 0.5 1 Miles

Projection: Universal Transverse Mercator Zone 15N, NAD 83

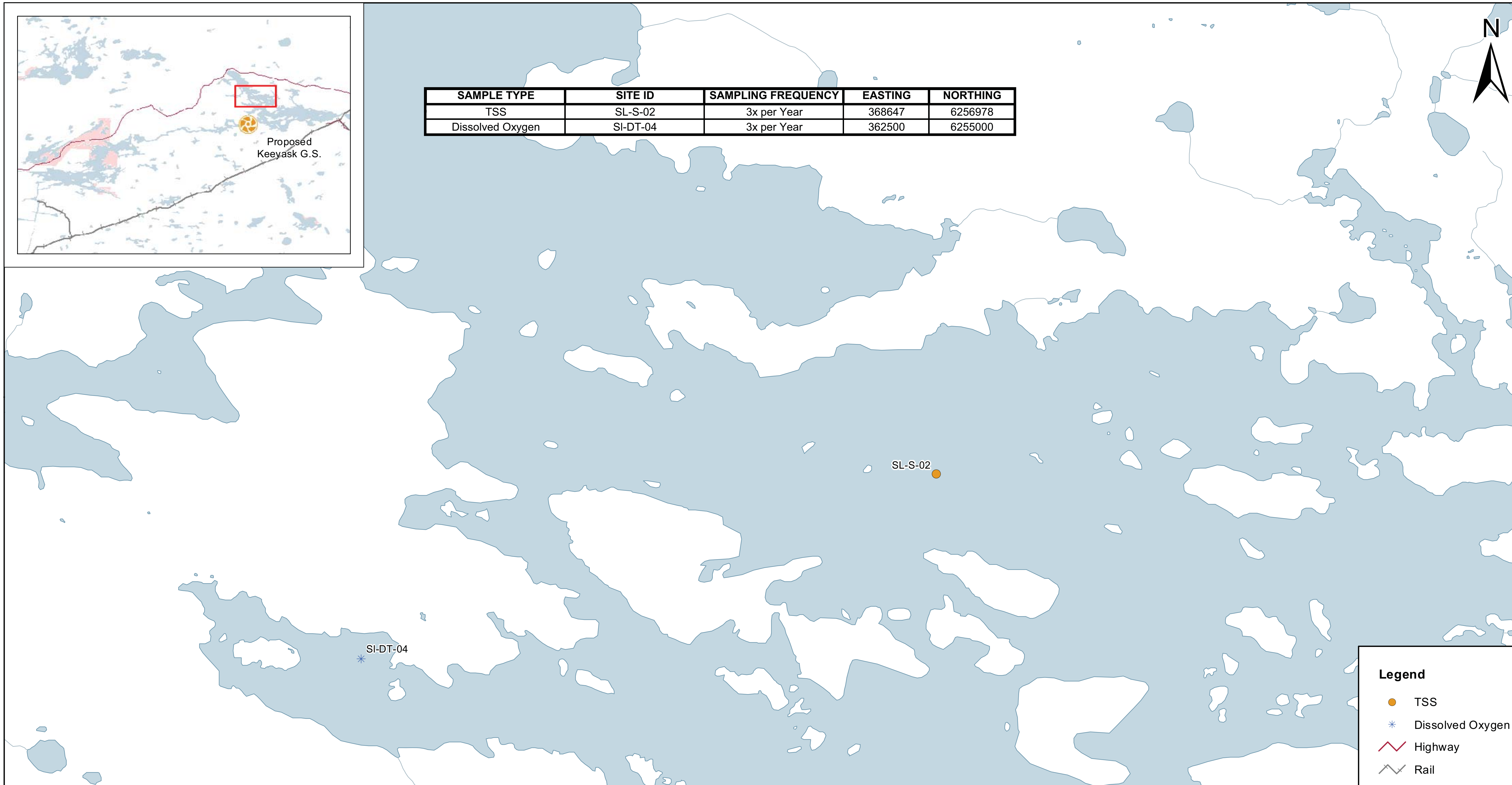
Data Source:
1. Lakes and rivers provided by Geogratis, 2004
2. Sampling locations provided by Manitoba Hydro. 2007

NOTES:
1. All values shown are in metres.
2. Site locations were identified and historically monitored by Manitoba Hydro or were identified collaboratively by Manitoba Hydro KGS Acres Ltd., and J D Mollard and Associates for this project.

2007 Sampling Locations
Stephens Lake

Map 7.C-3

SAMPLE TYPE	SITE ID	SAMPLING FREQUENCY	EASTING	NORTHING
TSS	SL-S-02	3x per Year	368647	6256978
Dissolved Oxygen	SI-DT-04	3x per Year	362500	6255000



KEEYASK
Hydropower Limited Partnership

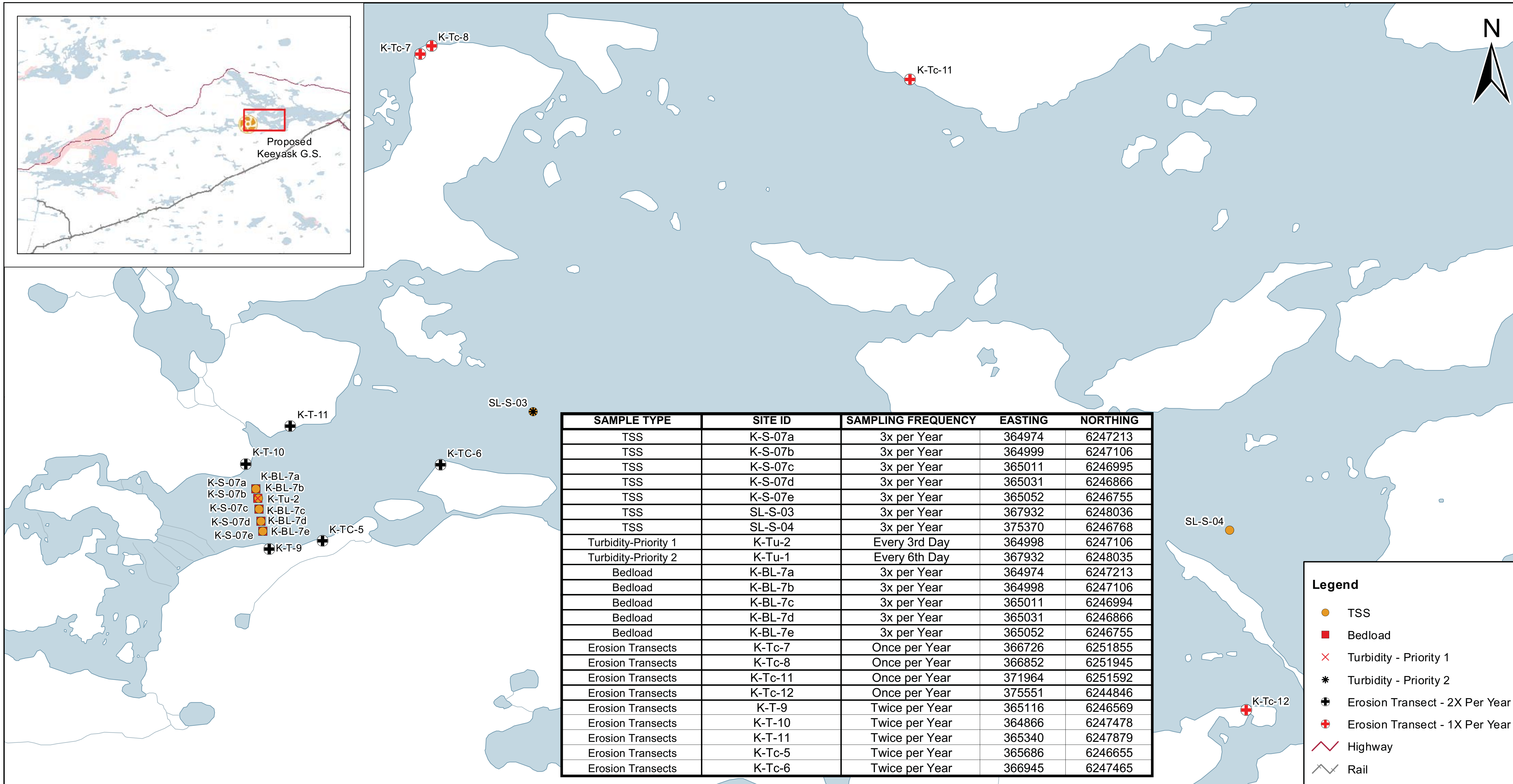
Projection: Universal Transverse Mercator Zone 15N, NAD 83

Data Source:
1. Lakes and rivers provided by Geogratis, 2004
2. Sampling locations provided by Mantioba Hydro. 2007

NOTES:
1. All values shown are in metres.
2. Site locations were identified and historically monitored by Manitoba Hydro or were identified collaboratively by Manitoba Hydro KGS Acres Ltd., and J D Mollard and Associates for this project.

2007 Sampling Locations

Stephens Lake



SAMPLE TYPE	SITE ID	SAMPLING FREQUENCY	EASTING	NORTHING
TSS	K-S-07a	3x per Year	364974	6247213
TSS	K-S-07b	3x per Year	364999	6247106
TSS	K-S-07c	3x per Year	365011	6246995
TSS	K-S-07d	3x per Year	365031	6246866
TSS	K-S-07e	3x per Year	365052	6246755
TSS	SL-S-03	3x per Year	367932	6248036
TSS	SL-S-04	3x per Year	375370	6246768
Turbidity-Priority 1	K-Tu-2	Every 3rd Day	364998	6247106
Turbidity-Priority 2	K-Tu-1	Every 6th Day	367932	6248035
Bedload	K-BL-7a	3x per Year	364974	6247213
Bedload	K-BL-7b	3x per Year	364998	6247106
Bedload	K-BL-7c	3x per Year	365011	6246994
Bedload	K-BL-7d	3x per Year	365031	6246866
Bedload	K-BL-7e	3x per Year	365052	6246755
Erosion Transects	K-Tc-7	Once per Year	366726	6251855
Erosion Transects	K-Tc-8	Once per Year	366852	6251945
Erosion Transects	K-Tc-11	Once per Year	371964	6251592
Erosion Transects	K-Tc-12	Once per Year	375551	6244846
Erosion Transects	K-T-9	Twice per Year	365116	6246569
Erosion Transects	K-T-10	Twice per Year	364866	6247478
Erosion Transects	K-T-11	Twice per Year	365340	6247879
Erosion Transects	K-Tc-5	Twice per Year	365686	6246655
Erosion Transects	K-Tc-6	Twice per Year	366945	6247465

KEEYASK
Hydropower Limited Partnership

0 1 2 Kilometers
0 0.5 1 Miles

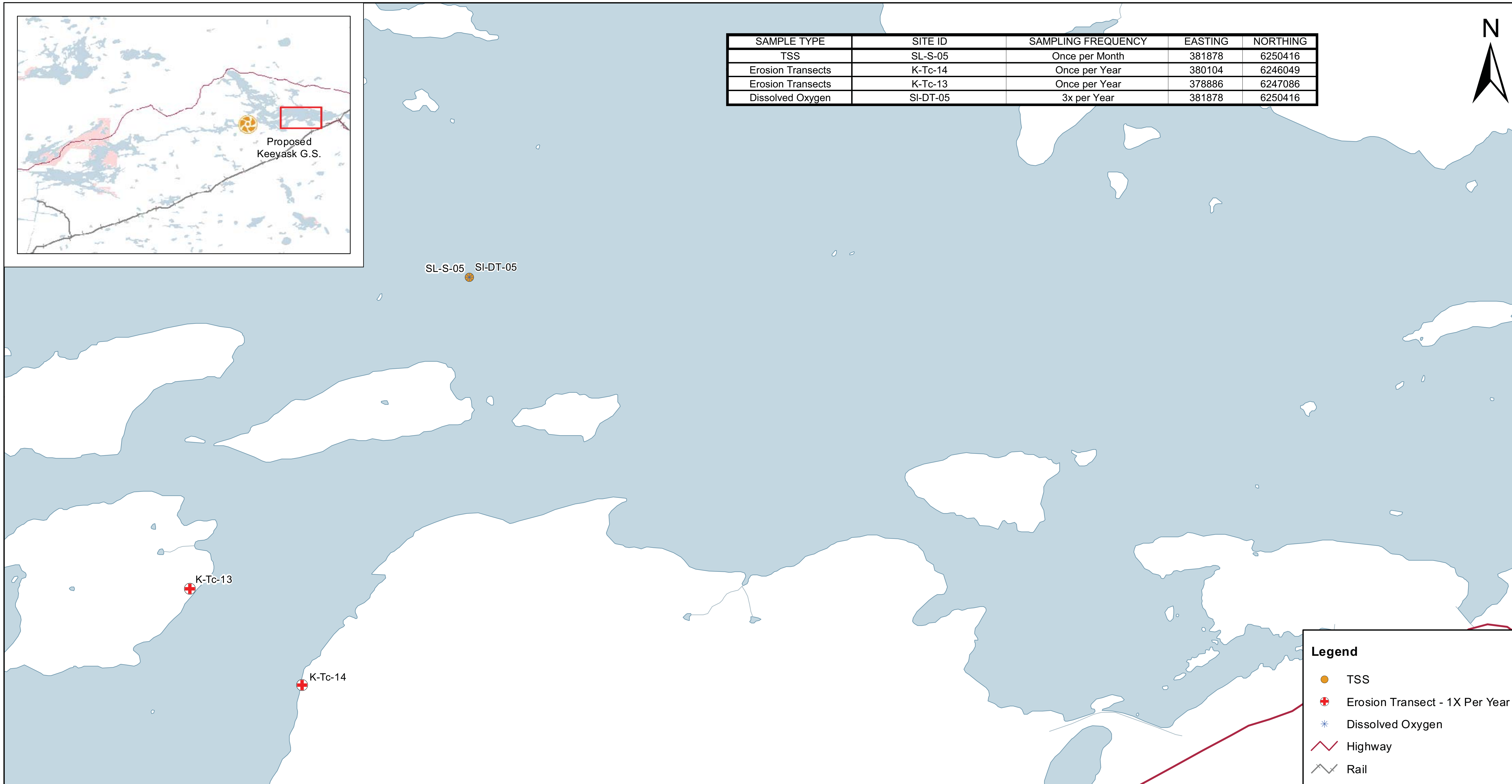
Projection: Universal Transverse Mercator Zone 15N, NAD 83

Data Source:
1. Lakes and rivers provided by Geogratis, 2004
2. Sampling locations provided by Manitoba Hydro. 2007

NOTES:
1. All values shown are in metres.
2. Site locations were identified and historically monitored by Manitoba Hydro or were identified collaboratively by Manitoba Hydro KGS Acres Ltd., and J D Mollard and Associates for this project.

2007 Sampling Locations
Stephens Lake

Map 7.C-5



SAMPLE TYPE	SITE ID	SAMPLING FREQUENCY	EASTING	NORTHING
TSS	SL-S-05	Once per Month	381878	6250416
Erosion Transects	K-Tc-14	Once per Year	380104	6246049
Erosion Transects	K-Tc-13	Once per Year	378886	6247086
Dissolved Oxygen	SI-DT-05	3x per Year	381878	6250416

KEEYASK Hydropower Limited Partnership

0 1 2 Kilometers
0 0.5 1 Miles

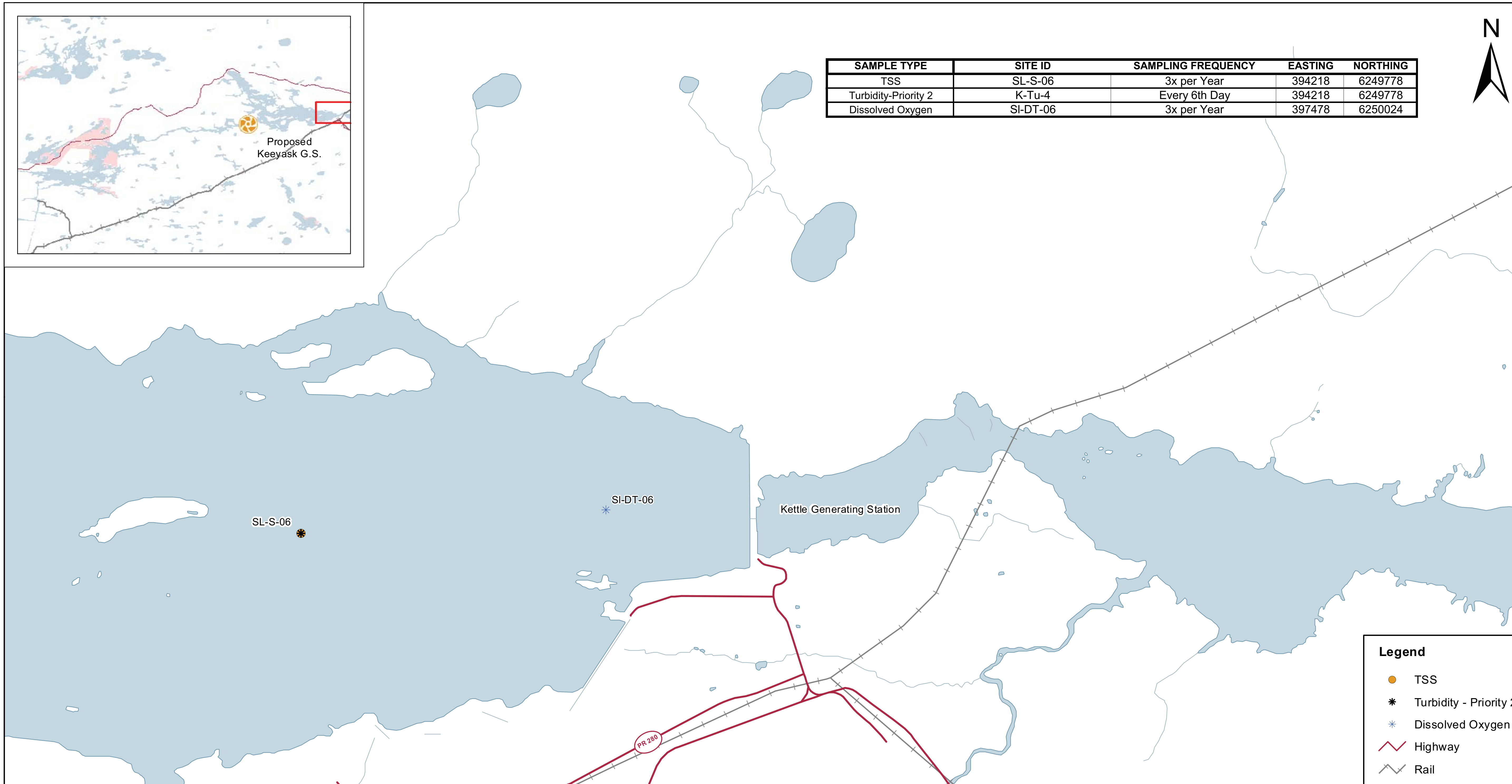
Projection: Universal Transverse Mercator Zone 15N, NAD 83

Data Source:
1. Lakes and rivers provided by Geogratis, 2004
2. Sampling locations provided by Mantioba Hydro. 2007

NOTES:
1. All values shown are in metres.
2. Site locations were identified and historically monitored by Manitoba Hydro or were identified collaboratively by Manitoba Hydro KGS Acres Ltd., and J D Mollard and Associates for this project.

2007 Sampling Locations
Stephens Lake

SAMPLE TYPE	SITE ID	SAMPLING FREQUENCY	EASTING	NORTHING
TSS	SL-S-06	3x per Year	394218	6249778
Turbidity-Priority 2	K-Tu-4	Every 6th Day	394218	6249778
Dissolved Oxygen	SI-DT-06	3x per Year	397478	6250024



KEEYASK Hydropower Limited Partnership

0 1 2 Kilometers
0 0.5 1 Miles

Projection: Universal Transverse Mercator Zone 15N, NAD 83

Data Source:
1. Lakes and rivers provided by Geogratis, 2004
2. Sampling locations provided by Mantioba Hydro. 2007

NOTES:
1. All values shown are in metres.
2. Site locations were identified and historically monitored by Manitoba Hydro or were identified collaboratively by Manitoba Hydro KGS Acres Ltd., and J D Mollard and Associates for this project.

2007 Sampling Locations

Stephens Lake

Map 7.C-7

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APPENDIX 7D

MONITORING LOCATIONS (WINTER)

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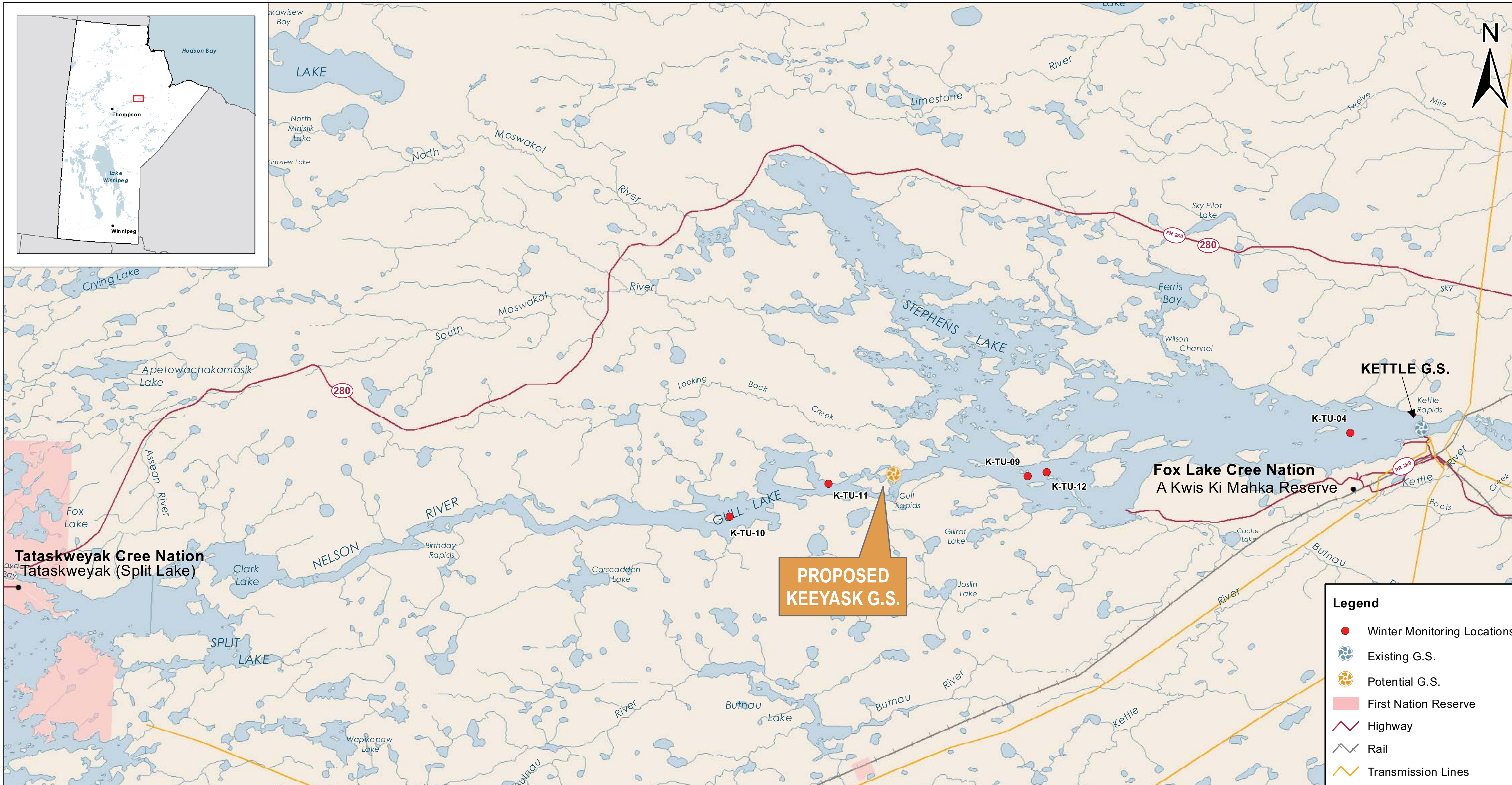

KEEYASK Hydropower Limited Partnership

0 2.5 5 10 15 Kilometers
0 2 4 8 Miles

Projection: Universal Transverse Mercator Zone 15N, NAD 83

Data Source:
1. Lakes and Rivers Provided by Geogratis, 2004

Sedimentation Locations of Winter Monitoring in 2008

Map 7.D-1

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APPENDIX 7E

SEDIMENTATION FIELD DATA 2005 TO 2007

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Table 7E.1-1: Suspended Sediment Concentration Measured in 2005

Site	Month	No. of Samples	Mean (mg/L)	Median (mg/L)	Max (mg/L)	Min (mg/L)	Standard Dev. (mg/L)
K-S-2	Aug	34	21.1	21.1	30.6	15.8	3.5
K-S-3	Aug	58	21.5	22.9	26.9	11.6	3.9
K-S-4	Aug	34	22.9	22.8	28.5	16.4	2.8
K-S-5	Aug	28	21.8	22.4	25.6	15.5	2.2
K-S-6	Aug	56	21.7	21.0	28.7	17.1	2.7
K-S-7	Aug	56	15.3	15.6	22.8	7.2	2.8
K-S-8	Aug	30	18.2	18.9	24.9	11.1	3.8
K-S-9	Aug	36	20.1	20.4	23.3	16.0	2.1
K-S-10	Aug	38	19.2	19.4	23.8	14.4	2.1

Table 7E.1-2: Suspended Sediment Concentration Measured in 2006

Site	Month	No. of Samples	Mean (mg/L)	Median (mg/L)	Max (mg/L)	Min (mg/L)	Standard Dev. (mg/L)
K-S-1	Jun	24	18.5	18.8	21.5	13.6	2.2
	Jul	18	12.0	11.7	16.0	9.2	1.8
	Aug	18	10.7	10.3	13.0	8.8	1.2
	Sep	18	9.3	9.0	12.4	7.8	1.1
K-S-2	Jun	24	13.6	12.8	23.0	9.4	2.8
	Jul	18	10.3	9.2	16.2	6.8	2.9
	Aug	17	7.5	7.4	9.8	5.2	1.7
	Sep	18	8.3	7.7	11.6	5.0	2.2
K-S-3	Jun	32	17.0	16.8	19.9	14.0	1.5
	Jul	24	11.7	11.5	19.2	9.6	1.9
	Aug	24	10.7	10.0	18.4	8.2	2.2
	Sep	24	9.7	9.6	11.2	8.2	0.7
K-S-4	Jun	24	16.4	16.4	21.5	10.8	2.6
	Jul	18	11.1	10.9	14.2	8.4	1.8
	Aug	18	8.7	8.7	12.0	5.8	1.3
	Sep	18	9.2	9.0	14.6	5.6	2.0
K-S-5	Jun	24	17.2	17.7	20.1	12.9	2.2
	Jul	18	10.4	10.1	13.6	8.2	1.7
	Aug	18	8.3	8.3	10.0	7.0	0.8
	Sep	18	8.6	8.5	12.8	7.2	1.3
K-S-6	Jun	40	16.5	16.5	21.0	12.3	2.2
	Jul	30	11.1	11.5	15.6	6.0	2.0
	Aug	30	8.5	8.4	10.2	7.0	0.8
	Sep	30	9.2	8.7	17.4	7.4	2.0
K-S-7	Jun	40	13.4	13.2	16.0	8.0	1.5
	Jul	40	19.4	19.3	29.5	14.6	3.2
	Aug	60	8.5	8.3	14.6	3.2	2.4
K-S-8	Jun	24	17.2	18.8	24.3	10.0	4.3
	Jul	20	9.0	9.2	12.8	6.0	1.8
	Aug	18	12.4	11.9	22.0	8.0	3.8

Site	Month	No. of Samples	Mean (mg/L)	Median (mg/L)	Max (mg/L)	Min (mg/L)	Standard Dev. (mg/L)
	Sep	18	9.1	9.1	13.2	8.0	1.2
K-S-9	Jun	24	18.2	17.2	24.0	12.8	3.2
	Jul	17	13.2	13.7	27.7	6.4	5.1
	Aug	18	9.3	9.4	10.8	7.0	0.9
	Sep	18	9.6	9.7	10.4	8.4	0.6
K-S-10	Jun	32	18.9	18.6	23.8	15.8	1.8

Table 7E.1-3: Suspended Sediment Concentration Measured in 2007

Site	Month	No. of Samples	Mean (mg/L)	Median (mg/L)	Max (mg/L)	Min (mg/L)	Standard Dev. (mg/L)
K-S-1	Jun	6	16.5	16.5	18.8	14.6	1.6
	Jul	12	19.4	20.1	22.6	15.2	2.6
	Aug	11	11.0	10.4	16.8	9.4	2.0
K-S-2	Jun	10	12.9	11.3	21.6	8.0	4.9
	Jul	12	12.5	11.3	19.2	8.6	3.9
	Aug	12	10.7	11.0	15.6	7.0	2.0
K-S-3	Jun	15	18.8	18.8	20.0	17.2	0.8
	Jul	16	18.8	19.1	23.8	13.2	2.8
	Aug	16	13.7	13.0	18.6	10.2	2.8
K-S-4	Jun	12	19.0	18.3	27.0	13.6	4.0
	Jul	12	18.1	18.3	23.4	6.8	4.9
	Aug	12	14.3	12.9	18.6	11.2	3.1
K-S-5	Jun	12	17.9	17.6	20.8	15.6	1.5
	Jul	12	17.5	17.5	20.8	15.2	1.7
	Aug	12	13.6	12.7	18.0	10.6	2.5
K-S-6	Jun	14	20.3	20.0	27.8	15.2	3.6
	Jul	20	19.5	18.5	25.2	15.4	3.1
	Aug	20	12.1	11.5	16.6	9.6	2.0
K-S-7	Jun	10	19.1	19.2	25.0	8.2	5.0
	Jul	20	18.0	17.8	22.8	14.4	2.2
K-S-8	Jun	12	15.0	15.2	22.4	10.4	3.4
	Jul	12	18.2	18.7	27.4	9.0	5.4
	Aug	12	12.0	11.3	18.8	5.2	3.8
K-S-9	Jun	8	17.1	17.0	18.8	15.6	1.3
	Jul	12	18.9	18.7	25.0	14.0	3.4
	Aug	12	10.7	10.9	12.2	8.4	1.0
K-S-11	Jun	10	19.8	18.7	29.2	16.8	3.5

Table 7E.1-4: Summary of Bedload Measured in 2005, 2006 and 2007

Date of Measurement	Discharge m^3/s	Station	Sample	Bedload Transport Rate g/m/s	D_{50}, mm
2005	>60001	K-S-06b	1/1	0.21	
2005	>60001	K-S-06c	1/1	0.46	
2005	>60001	K-S-06d	1/1	0.22	
2005	>60001	K-S-07d	1/1	0.28	
6/9/2006	5331	K-S-07d [1]	3/5	5.08	8.2
6/9/2006	5331	K-S-07d [2]	5/5	3.78	4.5
7/16/2006	4507	K-S-07d [1]	4/5	12.80	7.0
7/16/2006	4507	K-S-07d [2]	1/5	2.01	2.3
9/2/2006	3908	K-S-07c	5/5	1.16	2.5
9/2/2006	3908	K-S-07d	3/5	0.85	8.2
8/3/2007	4699	K-S-06a		2.01	12.5
8/3/2007	4699	K-S-06c [1]		8.73	1.0
8/3/2007	4699	K-S-06c [2]		3.14	0.5
7/5/2006	4497	Bed Material K-Tc-02	2/5		0.3[2]

[1] The date of bedload sampling is not known to the authors, but suspended sediment measurements occurred in August and September 2005, and flow was >6,000 m^3/s throughout this period.

[2] This was a shoreline bed material sample (at K-Tc-2).

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APPENDIX 7F

EROSION DURING CONSTRUCTION – GENERAL SITE CONDITIONS

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7F.0 EROSION DURING CONSTRUCTION – GENERAL SITE CONDITIONS

7F.1 MATERIAL REMOVAL DURING COFFERDAM CONSTRUCTION - GENERAL SITE CONDITION

For the purpose of assessing erosion potential during construction, it is important to understand the general site condition of the area that would likely be impacted by the construction activities. This section summarizes the general site conditions.

As discussed in Section 2 and Section 5, the site for the Keeyask GS is contained within the Canadian Shield and is underlain by variable thicknesses of up to 30 m of overburden over competent precambrian bedrock. In general, the overburden stratigraphy consists of a thin organic cover on postglacial lacustrine clay which overlies deposits of glacial outwash, till or the bedrock directly. Preglacial deposits of sand and silty sand are also occasionally found in bedrock lows. All or some of these deposits are exposed on the riverbanks/riverbed at various locations in the study area.

Two types of postglacial deposits have been identified:

- Lake Agassiz silts and clays: A relatively thin layer of clays and silts was deposited on the bottom of glacial Lake Agassiz. The silts and clays form a veneer of up to several metres in thickness over the glacial deposits. These fine-grained deposits are commonly varved and tend to be of greater thickness in the topographic lows.
- Alluvium: alluvium generally consists of cobbles and boulders overlying sands and gravels and is locally present in the base of present-day stream and river channels.

The glacial deposits are widespread and consist of layers deposited by several glacial ice sheets that advanced over the Gull Rapids area and deposited till and stratified water lain deposits. The tills containing discontinuous occurrences of permafrost are generally well graded, compact, have a relatively low moisture content, and generally have a low ice content when frozen.

Three separate till or till-like horizons have been identified at the Keeyask site. The upper silty sand/sandy silt till unit (Till 1), whose presence is the most widespread over the Keeyask area, generally consists of a light brown horizon (Till 1a) overlying a grey horizon (Till 1b) with essentially identical soil gradations. Beneath the silty sand/sandy silt till units, Till 2 and Till 3 consist of grey, low plasticity clays. However, all three till units were not necessarily encountered in all of the boreholes drilled in the area of the proposed Keeyask GS. The till units may be separated by discontinuous intertill units, especially in areas of bedrock lows or in drumlin features.