KEEYASK GENERATION PROJECT

STAGE IV STUDIES - PHYSICAL ENVIRONMENT

SHORELINE EROSION AND SEDIMENTATION EFFECTS DURING CONSTRUCTION

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KEEYASK GENERATION PROJECT STAGE IV STUDIES-PHYSICAL ENVIRONMENT GN-9.2.10- SHORELINE EROSION AND SEDIMENTATION EFFECTS DURING CONSTRUCTION

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INTEROFFICE MEMORANDUM

From		**TO**	
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SUBJECT **KEEYASK GENERATING STATION – PHYSICAL ENVIRONMENT STUDIES SHORELINE EROSION AND SEDIMENTATION EFFECTS DURING CONSTRUCTION MEMORANDUM GN-9.2.10-REV 0**

Please find the attached report "Keeyask Generation Project Stage IV Studies - Physical Environment: Shoreline Erosion and Sedimentation Effects during Construction GN-9.2.10". This memorandum documents shoreline erosion and sedimentation processes during construction of the Keeyask Generating Station (GS) project used in the Stage IV Engineering and Physical Environment Impact Statement studies.

This technical memorandum is to be used in support of the Keeyask Generating Station Environmental Impact Statement. In order to provide appropriate interpretation and guidance, please consult the Water Resource Engineering Department prior to external distribution.

Please contact me at (204) 360-5028 or JMalenchak@hydro.mb.ca if you have any questions or concerns.

Sincerely,
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1 INTRODUCTION

This memorandum documents shoreline erosion and sedimentation processes during construction of the Keeyask Generating Station (GS) project. The construction activities such as cofferdam construction, river diversion, and construction of the permanent structures will result in changes in water level and flow velocity. These changes in flow regime may lead to shoreline erosion and consequently introduce sediment into the Nelson River. The potential effects of these construction activities on sediment load are assessed in this report.

The proposed Keeyask Generating Station (GS) project is located on the Lower Nelson River at Gull Rapids, approximately 4 km upstream of Stephens Lake and 56 km downstream of Split Lake **(**Figure 1). As a consequence of constructing the Keeyask GS, water levels in the Nelson River will increase in the vicinity of the construction area, as well as in the forebay area. Changes to the water level may lead to changes in erosion processes along the shoreline where flow velocity and shear stress are significant. The extent of these changes depends on the cofferdam stages for GS construction, rate of cofferdam construction, and the flow condition in the Nelson River during construction. A two-stage flow diversion program will be used to divert the Nelson River and allow construction of the GS. Shoreline erosion and sedimentation processes were predicted by conducting one-dimensional hydraulic and sedimentation modelling of different stages of flow diversion. The model predicts shoreline erosion and subsequent sedimentation by first calculating the change in river hydraulics resulting from construction activities. These hydraulic changes are applied to the riverbed and bank materials, which are represented in the model, and changes in shoreline erosion are calculated. The model predicts shoreline erosion and changes in total suspended solids (TSS) that will enter Stephens Lake which is located downstream of the proposed Keeyask GS (Figure 1). Application of this model allows for prediction of the specific location of shoreline erosion and thus identifies areas where mitigation measures may be implemented if necessary. The results of this study also contribute to the assessment of the potential for and magnitude of mineral sediment deposition in Stephens Lake [Ref 1].

2 STUDY APPROACH AND DATA SOURCES

2.1 OVERVIEW TO APPROACH AND OBJECTIVES

This study is intended to provide the required information in assessing the potential impacts of construction activities on both the physical and aquatic environments. Construction activities may result in shoreline erosion and some short-term impacts to the aquatic environment as a result of introduction of sediment into the Nelson River. The introduction of excessive values of sediment load could change the water quality and be harmful to aquatic habitat in many ways such as abrasion of fish gills that ultimately leads to disease and mortality, blocking off light and consequently a reduction of the biological productivity of aquatic habitats, etc. Deposition of fine sediment over a substrate composed of coarse materials could also be detrimental to aquatic organisms. This alteration in the physical environment can decrease egg-to-fry survival rates in fish and can affect macroinvertebrate production among the other adverse effects [Ref 2].

The objectives of this study are the following:

- to assess the shoreline erosion in vicinity of the construction area and the potential changes in sediment load downstream of the project, and
- to estimate required information such as TSS concentration and gradation of suspended load downstream of the project in order to investigate the potential effects to fish and the aquatic habitat in Stephens Lake.

The assessment methodology applied in this study includes modelling of the hydraulic regime and erosion potential. The existing hydraulic environment as well as the hydraulic regime during the construction of the Keeyask GS was studied using a one-dimensional numerical modelling tool HEC-RAS (Hydrologic Engineering Centers River Analysis System, developed by U.S. Army Corps of Engineers). The study considered changes in water levels and velocities under two high flow scenarios i.e. 95th percentile flow (4,855 m^3/s) and 1:20 year peak daily flood flow (6,358 m^3/s).

The 95th percentile flow was used to represent the upper range of typical flows that could occur during construction. The 1:20 year flood (peak daily) has been adopted as the design flood event from the Stage IV River Management during construction studies [Ref 3]. The 1:20 year peak daily discharge is not anticipated to occur during all stages of construction. As an example, river closure (Stage II Diversion) may occur in mid-August, and a 1:20 year mean monthly discharge of 4,347 m^3/s [Ref 4] should be used for this portion of the study. This flood is comparable with the 95th percentile flow but is much less than 6,358 m^3/s that is considered as the design flood event in this study.

During low flow conditions, it is anticipated that water levels and flow velocities would be much less that those experienced by the river shoreline in the existing environment which result in less erosion. Therefore, low flow conditions were considered only for the HEC-RAS hydraulic model calibration.

2.2 STUDY AREA

The study area for the purpose of erosion and sedimentation analyses during construction extends from the upstream end of Gull Lake to the upstream end of Stephens Lake. As shown in Figure 1, the study area includes the Gull Lake area that would experience an increase in water levels due to the construction activities, the construction area, and the area immediately downstream of the project.

2.3 GENERAL ASSUMPTIONS

Several assumptions were made in carrying out different components of the study. This section outlines the general assumptions that are relevant to the analyses discussed herein.

- Flow in the study area is in a steady-state condition,
- No catastrophic natural events (e.g. earthquake, landslides) will occur during construction,
- Climate change related issues are not considered,
- Erosion/sedimentation of peat shorelines was not included as part of this study,
- Erosion of Cofferdam material is not considered (This is addressed in Technical Memorandum GN-9.2.17 [Ref 5]), and
- Only the open water season is considered.

2.4 ASSESSMENT METHODOLOGY

Shoreline erosion and sediment transport in the Nelson River was predicted by conducting hydraulic and sedimentation modelling of the existing project environment as well as for the different stages of construction. The HEC-RAS model (version 4.0) developed by the US Army Corps of Engineers (USACE) was used for this analysis. This model predicts shoreline erosion and subsequent sedimentation by first calculating the changes in river hydraulics resulting from cofferdam construction. These hydraulic changes are applied to the riverbed and bank materials, which are represented in the model, and changes in shoreline erosion are calculated accordingly. The model also predicts changes in total suspended solids (TSS) in the Nelson River that results from shoreline erosion. Application of this model allows for prediction of the specific location of shoreline erosion (if any) and thus identifies areas where mitigation measures may be implemented if necessary. A detailed description of the hydraulic and sedimentation model components is presented in the following sections.

3 EXISTING FLOW AND SEDIMENTATION CONDITION

3.1 GENERAL SITE CONDITIONS

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. Pre-glacial 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 [Ref 6].

3.2 POSTGLACIAL AND GLACIAL DEPOSITS

3.2.1 POSTGLACIAL DEPOSITS

Two types of postglacial deposits have been identified:

a. *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 meters in thickness over the glacial deposits. These fine-grained deposits are commonly varved and tend to be of greater thickness in the topographic lows.

b. *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.

3.2.2 GLACIAL DEPOSITS

The glacial deposits are widespread and consist of 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 relatively low moisture content, and generally have 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. Not all of the areas at the Keeyask GS site encountered these till units. The till units may be separated by discontinuous intertill units, especially in areas of bedrock lows or in drumlin features [Ref 6].

3.3 RIVERBED AND RIVERBANK MATERIALS

The riverbed and riverbank of the Nelson River in the reach under investigation include materials ranging from clay size to cobble/boulder size, and include both cohesive and granular non-cohesive material. Portions of the river bed and banks are also bedrock, and portions of the riverbank upland areas are comprised of peat.

Information on the riverbank and upland area materials is available from the various surface mapping, geotechnical investigations, and shoreline sampling programs that have been conducted for the Keeyask GS (**Section 6**). Information on the material in the riverbed is limited to a few locations. The grain size distribution curves for shoreline materials are also presented in **Section 6**.

3.4 HISTORIC FLOW AND WATER LEVEL CONDITIONS

The Nelson River in the study area is divided into four channels: (i) the south channel, (ii) the middle channel, (iii) the north channel; and (iv) a small cross-flow channel between the middle and south channels (Figure 1). Approximately 75% of the total river discharge presently flows through the south channel.

Flows on the Nelson River downstream of Split Lake show a large seasonal variation, generally with highest flows occurring during the summer months and low flows leading into the fall and the early winter months. Average daily flows of the Nelson River at the outlet of Split Lake recorded since 1977 vary from a minimum of approximately 1,330 m^3/s in October, 2003 up to a maximum of approximately 6,600 m^3/s in August and September, 2005. The water elevation of Gull Lake (at Box Bay Creek and Broken Boat Creek) was between elevations 154.2 m and 154.9 m during the high flow period that occurred during the summer of 2005 [Ref 7]. It should be noted that contribution from the creeks between Split Lake and Gull Rapids to the Nelson River flow is negligible, so the flow at the project area is similar to that at outlet of Split Lake [Ref 8].

3.5 AMBIENT SUSPENDED SEDIMENT CONCENTRATION AND BEDLOAD

Historical field data was used to determine the ambient suspended load concentration within the study area, as outlined in Memorandum GN 9.2.3 [Ref 9]. Based on the field data collected in the open water months of 2001 to 2007, the TSS concentration in the study area generally lies within the range of 5 to 30 mg/L (average 10 to 20 mg/L). Very little bedload was observed in the data collection campaign carried out in the open water period of 2005 to 2007.

4 RIVER MANAGEMENT DURING CONSTRUCTION

A two-stage program of river management will be implemented to divert the Nelson River and allow the construction of the project. The general sequence of the diversion process is depicted in Figure 2A to 2C. Following is a summary of this program based on the information presented in the River Management during Construction Technical Memorandum GN 9.8 [Ref 3].

4.1 STAGE I RIVER MANAGEMENT

In the Stage I Diversion phase of the project, the construction of a series of cofferdams will allow construction of the Principal Structures to take place in the dry. This stage involves blocking off the north and middle channels of the Nelson River. The arrangement of the Stage I Diversion Cofferdams will direct the entire flow of the Nelson River to the southern channel of the river. This will permit the undertaking of excavation works for the Principal Structures, as well as construction of the following structures in-the-dry:

- Powerhouse Intake Channel,
- Powerhouse Complex,
- Powerhouse Tailrace Channel,
- Spillway (Stage II Diversion Structure),
- Spillway Approach Channel,
- Spillway Discharge Channel,
- North Dam, and
- Central Dam.

The cofferdam designs and construction methods will incorporate measures to minimize the erosion of materials during their construction.

The Stage I earthwork structures consist of six cofferdams and one rockfill groin located at the head of the river's northern channel. During the first year of construction, a U-shaped cofferdam will enclose the construction area for the Spillway and its associated Approach and Discharge Channels, which are located on the island adjacent to the north bank of the south channel. An L-shaped Powerhouse Cofferdam, in combination with the Central Dam and North Channel Cofferdams, when constructed, will allow construction of the Central Dam, Powerhouse and Intake Channel and the upstream portion of the Tailrace Channel. A Tailrace summer level cofferdam will be constructed downstream of the Powerhouse Stage I Cofferdam to permit excavation of the downstream portion of the tailrace channel (Figure 2).

Stage I Diversion will last approximately 3.5 years. As a result of the diversion of the river to the south channel, the water levels upstream of the location of the Spillway will increase above the levels that would occur under existing conditions. More detail on the water level increase during Stage I Diversion is discussed in **Section 5**.

4.2 STAGE II RIVER MANAGEMENT

The Stage II Diversion phase of the project will require the construction of the Stage II Island Cofferdam followed by closing off the south channel of the Nelson River by means of two parallel cofferdams, the South Dam Stage II Upstream and Downstream Cofferdams. These will be constructed across the south channel, effectively diverting the river flow through the open sluices of the seven-bay Spillway. During Stage II Diversion, the South Dam will be constructed in the dry, between the South Dam Stage II Upstream and Downstream Cofferdams.

The Nelson River will be closed by advancing the rockfill portion of the South Dam Stage II Upstream Cofferdam from the Stage I Spillway Cofferdam to tie-in to the south bank of the river. Minimal riverbed scour is expected in the gap between the closure leg and the river's south bank since high velocities and ice have been assessed to have already removed the majority of the overburden in this area and left the bed as being bedrock-controlled. In addition, a bedrock outcrop is present on the south shore to elevations above that at which closure will take place.

During the latter phase of Stage II Diversion, the Spillway's rollways will be constructed in a sequential manner resulting in progressive increases in the forebay water levels, as the reservoir is impounded. The construction of the rollways is scheduled to take place after substantial construction of the South Dam.

For the purpose of this study, construction activity during Stage II River Management is divided into the following sub-stages:

Stage IID

In this sub-stage 300 m of the Stage II Upstream Cofferdam will be constructed from the Stage I Spillway Cofferdam towards the south shore. Flow will be directed through both the remaining opening of the south channel and the Spillway's sluiceways.

Stage IIA

The Stage II Cofferdam will be completed, from the Stage I Spillway Cofferdam to the south shore, and the upstream portion of the Stage I Cofferdam will be removed to direct flow through the Spillway. All seven sluiceways of the Spillway will be open with no rollways constructed.

Stage IIB

During this stage, three Spillway's sluiceways will be closed, and the other 4 bays of the Spillway will be completed with the rollways installed.

5 HYDRAULIC MODELING

HEC-RAS software was employed to develop a one dimensional model for the during construction phase of the project to accurately determine water levels and flow velocity in the study area under various flow conditions. The calibrated existing environment model [Ref 10] was modified to model different stages of construction which may potentially cause shoreline erosion and introduce sediment to the Nelson River. The model extends from upstream of Clark Lake to Stephens Lake and covers a length of approximately 55 km.

5.1 MODEL CALIBRATION

The original existing environment HEC-RAS model was calibrated to the measured data collected along the study reach and to the rating curves developed from that data [Ref 10]. The geometry of this model was adjusted to include the cofferdams and other structures and to simulate the various construction activities. These new models for various construction stages, then, were calibrated against the results from a physical model and Flow 3D numerical model [Ref 11]. The Flow 3D model was created to confirm the hydraulic design of the Spillway structures and channels, and confirm the range of velocities which are to be expected throughout the stages of construction. The physical model was built at a 1:120 scale of the construction area to validate the results of the Flow 3D model. The physical model extended from approximately 1500 m upstream and 1200 m downstream of the Spillway. Since the changes to the geometry of the HEC-RAS model was limited to construction area, results from the physical and numerical models were adequate for calibration of new the HEC-RAS models.

The HEC-RAS models for Stage I, IID, IIA, and IIB were calibrated for the 95% and 1:20 year flows using the results from the physical model and Flow 3D. The calibration for lower flows were also performed whenever the results for low flows were available from the physical model and Flow 3D. Table 1 shows a summary of flows with different return periods employed in the calibration of the HEC-RAS model [Ref 7].

Table 1 Selected Flows for HEC-RAS Calibration.

Flow Scenario	Discharge (m^3/s)
5%	2059
50%	3032
95%	4855
1:20 Year Flood	6358

Stage I

In the existing environment approximately 75% of the Nelson River flow runs through its south channel. During Stage I, after construction of the North Channel Cofferdam, all the flow will go through the south channel. The water level at three locations (NL-14, NL-15, and NL-17 shown in Figure 3) within Gull Rapids is available from the physical model. The water level for the flow of 3,930 m^3/s from the HEC-RAS and physical model is displayed in Figure 4. The water level obtained from the physical model at three locations downstream of the Gull Rapids is 0.3 to 0.6 m higher than results from the HEC-RAS model. Considering the uncertainty in the bathymetry around Gull Rapids, this discrepancy between the results from these two models was considered acceptable.

Stage IID

As mentioned in previous section, during this stage the flow will go through both the Spillway and the opening between the incomplete Stage II Upstream Cofferdam and the south shore. The water level is available at four locations (NL-14, NL-15, NL-16, and NL-17) within Gull Rapids (Figure 3) from the Flow 3D model for two flows (3,130 and 5,270 m^3/s) and for three flows (3130, 4500, and 5270 m^3/s) from the physical model. Figure 5 and Figure 6 compare the Stage IID HEC-RAS results with the physical model and Flow 3D results. These figures show a discrepancy of -0.4~0.1 m and -0.3~0.6 m between the HEC-RAS results and Flow 3D and physical model results for low and high flow conditions, respectively.

Stage IIA

For Stage IIA, the water level is available at two locations (NL-15and NL-17) within Gull Rapids (Figure 3) from the physical and Flow 3D models for two high flow conditions i.e. 4,949 and 6,260 m^3/s. The results from HEC-RAS, Flow3D, and physical models are displayed in Figure 7 and Figure 8. For these two flows and at these two locations, the water levels obtained from the HEC-RAS differs from the results from the physical model and Flow 3D by -0.7~0.2 m.

Stage IIB

Figure 9 compares the HEC-RAS model results to the Stage IIB water levels measured in the physical model at location NL-15 (Figure 3) for a flow of 4406 m^3/s. For the same location, the calculated water levels from rating curves developed for Keeyask [Ref 11] are compared with the results from the HEC-RAS model in Figure 10. The HEC-RAS model results are within ± 0.5m of water levels obtained from the physical model and rating curves.

5.2 HYDRAULIC MODELLING RESULTS

The changes in water surface level of the Nelson River during Stage I, IID, IIA, and IIB are presented in this section.

Stage I

Stage I Diversion will last approximately 3.5 years. As a result of the diversion of the river to the south channel, the water level upstream of the Spillway will increase beyond the levels that would occur under existing conditions (Table 2). The water surface profiles for the 95% and 1:20 year flood flows are plotted against the existing environment elevations in Figure 11 and Figure 12. These figures indicate that the Stage I Diversion will cause a backwater effect of approximately 0.9~1.2m in the area adjacent to the Stage I Cofferdam and extends to downstream of Birthday Rapids where the backwater effect is not measurable. Shoreline polygons and the flooded area for 95% and 1:20 year flood flows are displayed in Figure 13 and Figure 14, respectively.

Stage II

The water surface elevation of the Nelson River in Existing Environment and during Stage II (D, A, and B) for 95% and 1:20 year flood flows are plotted in Figure 15 and Figure 16. The backwater effect and water levels during Stage IID scenario are very similar to that of Stage I.

Results for Stage IIA indicate that the backwater effect is more pronounced during this stage compared to Stage IID. The open water backwater effect extends upstream of Birthday Rapids for Stage IIB but ends downstream of the outlet of Clark Lake. Analysis of Stage IIB shows that the shoreline area will experience higher water levels but lower flow velocity during this stage due to staging in the forebay. Stage IIB was not considered in the sedimentation modelling because the erosion potential were found to be less conductive in this stage compared to Stage IIA and Stage IID.

Table 2 Water Surface Elevation of the Nelson River during Existing Environment and Stage I Diversion for 95th Percentile and 1:20 Years Flood Flow.

	Water Surface Elevation (m)			
	95th Percentile Flow (4,855 m^3/s)		1:20 Year Flood Flow (6,358 m^3/s)	
Location	Existing Environment	Stage I Diversion	Existing Environment	Stage I Diversion
Immediately upstream of the Spillway Stage I Cofferdam	146.9	147.8	147.4	148.5
Downstream end of Gull Lake	153.2	154.2	153.9	155.1
Upstream end of Gull Lake	153.4	154.3	154.1	155.2

Shoreline polygons and flooded areas during Stage IID and IIA are displayed in Figure 17 to Figure 20 for the 95% and 1:20 year flood flows. Table 3 summarizes water levels in the Nelson River upstream of the construction area during Stage IIA during which most changes to the shore erosion rate are expected. This table indicates that during Stage IIA Diversion, a water level increase of approximately 3.2~4.5m is expected in the area adjacent to the Stage I Cofferdam. The backwater effect during this stage will be approximately 0.9~1.2m upstream of Gull Lake (Figures 15 and 16).

Table 3 Water Surface Elevation of the Nelson River during Existing Environment and Stage IIA Diversion for 95th Percentile and 1:20 Year Flood Flows.

	Water Surface Elevation (m)			
	95th Percentile Flow (4,855 m^3/s)		1:20 Year Flood Flow (6,358 m^3/s)	
Location	Existing Environment	Stage IIA Diversion	Existing Environment	Stage IIA Diversion
Immediately upstream of the Spillway Stage II Cofferdam	146.9	150.1	147.4	151.9
Downstream end of Gull Lake	153.2	154.2	153.9	155.2
Upstream end of Gull Lake	153.4	154.3	154.1	155.3

6 EROSION AND SEDIMENT TRANSPORT MODELING

6.1 MODEL DESCRIPTION

The sediment transport model of HEC-RAS is a movable-boundary model capable of simulating changes in river boundaries (bed and banks) due to erosion and deposition under quasi-steady flows. In this model, a flow hydrograph is broken into a series of discrete steady flows of variable discharge and duration. For each flow, the pertinent hydraulic parameters, namely water surface elevation, energy slope, flow velocity, flow depth, etc. are calculated at each cross section. Potential sediment transport rate is then calculated at each cross-section using hydraulic parameters determined in the previous step. In the next step, the volume (or mass) of eroded or deposited materials at each cross-section is computed using the potential rate of sediment transport and the duration of the flow. The shape of each cross-section is adjusted accordingly before each time step in the sediment transport simulation. The simulation continues with the next discharge in the flow hydrograph, and this cycle (flow parameter calculation then sediment transport estimation) is repeated starting with the adjusted geometry.

Using the continuity equation for sediment, changes are calculated temporally and spatially along the study reach for the following parameters: total sediment load, volume and gradation of sediment that is scoured or deposited, armouring of the bed surface, and the cross-section elevation [Ref 12].

To perform a movable sediment transport simulation with HEC-RAS, three groups of data are required: model geometry, flow condition, and sediment properties. In the following, a general description of each group is given, and the pertinent data required for the study reach in the Nelson River is discussed accordingly.

6.2 MODEL PARAMETERS

6.2.1 MODEL GEOMETRY

The HEC-RAS sediment model calculates the water surface and riverbed elevations as they may change from one time step to another. It is, therefore, necessary to introduce the initial geometry of the river under study as the input data to the model. The geometry of the river is represented by cross-sections (which are defined by coordinate points, i.e. stations and elevations) and the distances between them.

In sediment transport modelling of the Nelson River, the same geometry data files that were prepared for hydraulic modelling were used in this study with some modifications, wherever it was necessary. From the hydraulic modelling results it was concluded that the construction effects (including backwater effect and changes in flow velocities) will be limited to a 15km-long reach of the river from Gull Lake to the upstream limit of Stephens Lake. This reach includes the construction area and extends 8 km upstream and 7 km downstream of the construction site. As mentioned, at the upstream end of Gull Lake the flow splits into two branches: north branch (≈ 25% of the flow) and south branch (≈ 75% of the flow). With the latest version of HEC-RAS (v4.0) at the time of this study, sediment transport cannot be simulated simultaneously in river branches. Therefore, the south channel of the river, in Gull Lake area, was considered as the main branch of the river, and the flow from north channel was introduced as a lateral flow to the model. The modified geometries to include the cofferdams and dykes in the different stages of flow diversion are discussed in the hydraulic modelling section.

6.2.2 FLOW DATA

The flow data includes the flow rate and flow duration, i.e. flow hydrograph. In the HEC-RAS sediment transport model, a continuous flow hydrograph is approximated by a sequence of discrete steady flows with specific durations. Hydraulic parameters of the flow are calculated for each flow in the hydrograph using the standard-step method to solve the energy and continuity equations, as done in the hydraulic modelling of steady-state flows. The flow duration should be specified for each flow in the hydrograph. This duration represents the length of time over which flow, stage, temperature, or sediment load are assumed constant [Ref 12].

In the sediment transport simulation of the Nelson River, the water discharge was assumed constant over time, and the discrete flow duration (or time step) was considered 1 hour. Longer and shorter time steps were also examined and the rationale for this consideration is discussed in the model setup section.

6.2.3 SEDIMENT DATA

Sediment data includes the mobile cross-section limit (defined below), bed and shoreline materials gradation, and sediment boundary conditions.

Mobile Cross-section Limit

Once the geometry data is introduced to the model, a segment of each cross-section may be introduced as “movable”. The geometry of the river may change vertically in the model within the movable area of the cross-section due to the flow action.

Since the Nelson River is a bedrock-controlled river in the reach under investigation, only the riverbanks were introduced as movable areas in the model. Information on the riverbank materials were collected during the years of 2003 to 2007 [Ref 13 and 14]. This information is summarized in Figure 21and Figure 22 for bank and beach materials. In these figures, “beach” refers to the nearshore areas adjacent to water that extend from the river shoreline up to the normal high-water line. The area with elevation higher than high-water line (upland area) refers to “bank” in these figures and henceforth in this text. From these figures, the longitudinal extent of movable area at each cross section was introduced into the model. Depending on the water surface elevation during different stages of construction, bank or beach materials were considered in the erosion and sediment transport simulation. More detail on introducing the extent of movable area to the model is discussed in the model setup section.

Information on the thickness of movable materials is limited to the subsurface investigation programs conducted for the Keeyask GS [Ref 15 and 16] and shown in Figure 23. As can be seen in this figure, the boreholes are more scattered in the area where GS structures will be constructed. Only a few boreholes are located close to the river shoreline; therefore, this data does not provide representative information on the thickness of the erodible materials in the study reach. Using boreholes and well logs, DTM (Digital Terrain Model) data, and soil classification as proposed for the Keeyask GS study area, TetrES Inc. developed a groundwater model for area within the Keeyask GS hydraulic zone of influence [Ref 17]. Accordingly, the thickness of the overburden along the shoreline near the proposed Keeyask GS was estimated from this model.

Five longitudinal cross-sectional profiles, along the north and south banks of the south channel were selected (see Figure 24 for the location of these profiles) to represent the bedrock and the ground level elevations, and therefore to estimate the thickness of the overburden (see e.g. Figure 25). According to these profiles, the thickness of overburden, in the area shown in Figure 23, varies between 2.8 and 8.3 m, with the thicker overburden located downstream of Gull Rapids.

Since the thickness of overburden (or erodible material) is an estimated value, a sensitivity analysis was performed to investigate the effect of this parameter in the volume of eroded materials. In this analysis, a constant thickness of 1, 1.5, and 5m were considered along the study reach wherever the shoreline is not classified as bedrock (in Figure 21and Figure 22). The results of this analysis are discussed in the model set up section.

Shoreline Material

The general geology of the site for the Keeyask GS was previously described in **Section 3**. Using maps showing the types and extent of riverbank materials (Figure 21and Figure 22) and the results from subsurface investigation programs conducted for the Keeyask GS studies, KGSAcres [Ref 18] developed a representative gradation curve for each type of shoreline material, including clay (post glacial), sand, gravel and till (Figure 26). These gradation curves were used to define the grain size of materials in the movable area of each cross-section in the study reach. It should be mentioned that these curves have been produced from a visual classification of shoreline materials, and no laboratory testing was performed on soil samples.

However, in order to verify this visual soil classification a shoreline material sampling program was initiated in the summer of 2009 for the area from Gull Lake to downstream of the construction site. The locations of soil sampling sites are shown in Figure 27. The results from this program are discussed in **Section 6.5.3**.

The sediment properties in the model were set to the recommended values in the HEC-RAS reference manual, e.g.; specific gravity=2.65, shape factor=0.6, unit weight of sand and gravel=14.9 kN/m^3, unit weight of silt=10.4 kN/m^3, and unit weight of clay=0.48 kN/m^3 [Ref 12].

Sediment Boundary Conditions

Sediment boundary conditions include sediment inflows (from upstream or local inflows) and sediment properties. Based on the TSS measurement program conducted in 2001-2007, the sediment load carried by the Nelson River has been reported being mostly very fine materials with rates that vary between 5 to 30 mg/L (see **Section 3.5**). The gradation curves of the sediment load were also prepared based on this measurement. The upper and lower limits of suspended sediment sizes, sampled in this program, are shown in Figure 26. These curves indicate that sediments carried by the Nelson River consist of materials with diameter less than 0.1 mm and D_{50} of 0.003 mm.

6.3 MODEL SETUP

A HEC-RAS model was used to simulate erosion, sediment transport, and deposition of shorelines materials in the Nelson River, during the Keeyask GS construction activities. After assembling all pertinent data as described in previous sections (such as geometry, flow conditions, and sediment properties), several sediment models were prepared for different stages of flow diversion. The details of the hydraulic conditions in each scenario were discussed in **Section 4.2**. For simulating the erosion and sedimentation process, three scenarios were considered:

- Existing Environment,
- Stage I Diversion, and
- Stage II Diversion.

Once the geometric and hydraulic data (the same data used in the hydraulic modelling) are introduced into the model, sediment data and a sediment transport function should be defined in the model. Some of this information is similar in all scenarios (e.g. flow rate and sediment properties); however, the type and extent of shoreline materials may vary from one scenario to another. For each scenario, the following parameters were defined in the model:

- flow duration and computation increment (time step), and
- depth of erodible materials.

6.3.1 FLOW DURATION AND COMPUTATIONAL TIME STEP

For the purpose of the present study, the flow rate was assumed to remain constant during the simulation period (steady state). A flow duration of 5 days was considered in the initial assessment of the model. The preliminary results of this assessment showed computational instability during day one and two; however, the model reached an equilibrium stage after day three which was relatively close to the end of the simulation. Therefore, a flow duration of 10 days was considered in all flow scenarios to ensure that the model had reached full equilibrium for all cases.

The flow duration then was subdivided into a series of computational time steps, in which the sediment calculations and flow routing occur. Since the flow rate was considered constant in this study, the flow duration was broken into regular time steps; i.e., constant time steps. The length of the time step usually depends on flow and sediment characteristics and model geometry. Shorter time steps must be selected for floods with sharp rising and falling hydrographs, especially when the flow carries a large volume of sediments. Similarly, a shorter time step is also required when the distance between cross sections is short. Generally, the shorter the time step, the more accurate are the results but the incremental benefits in accuracy diminish as the time steps continue to get smaller. Selecting short time steps is not computationally efficient, as it increases the overall computational time without significant increases in accuracy. This is especially the case for a long-term simulation.

For the present work with a total flow duration of 10 days, it is reasonable to select the length of time steps less than one day. Some recommendations have been made by USACE in selecting an appropriate time step in simulating sediment transport [Ref 19]. Based on these recommendations, a time step interval of 1 hr (Δt=1 hr) was considered in the present study.

6.3.2 DEPTH OF ERODIBLE MATERIALS

As discussed in **Section 3**, the Nelson River is a bedrock-controlled river, and any erosion along the river occurs at the shoreline and banks area. For open-water conditions in the existing environment (pre-construction), the amount of sediment load in the river due to the action of flow on the shoreline materials is not significant [Ref 9]. The river shoreline has historically experienced high flows and ice action over many years and has been eroded during extreme events. However, during construction activities and due to narrowing the flow passage in the south channel, a backwater profile will form. The water level along the river will increase, and this increase, in turn, will expose areas of the river shoreline (with higher elevation) to the flow action. The extent of these areas along each cross section was determined by subtracting the water surface elevations for the existing environment and the backwater profile for each stage of construction. As an example, Figure 28 compares the water surface profile during Stage I Diversion with the profile from the existing environment. In this figure, the area between two profiles shows the area of the river shoreline that will be exposed to the flow action. Similar profiles were prepared for other scenarios to determine the extent of areas susceptible to erosion during river diversion.

6.3.3 SEDIMENT TRANSPORT FUNCTION

Non-cohesive Material

In the latest version of HEC-RAS, there are seven sediment functions for non-cohesive transport to select. These functions are the following:

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

The number of sediment transport functions in literature is not limited to this list, and several tens of functions have been developed to date. Different approaches have been used to develop these functions, and most of these functions are only applicable for specific hydraulic and sediment conditions. Following Yang and Huang (2001), in this study, seven dimensionless parameters were considered to determine the sensitivity of the sediment transport functions to varying flow and sediment conditions [Ref 20]. These dimensionless parameters are:

- dimensionless particle diameter defined as

$$D_{gr} = d\,[\frac{g(\rho_s/\rho - 1)}{\nu^2}]^{1/3}$$

- relative depth (h/d)
- Froude number (Fr)
- relative shear velocity (v_*/w)
- dimensionless unit stream power (uS/w)
- sediment concentration (C)
- discrepancy ratio ($R = C_c/C_m$)

where:

d = sediment particle diameter (mm)
ρ_s = density of sediment (kg/m^3)
ρ = density of water (kg/m^3)
g = gravitational acceleration (m/s^2)
ν = kinetic viscosity of water (m^2/s)
h = flow depth (m)
v_* = shear velocity (m/s)
w = sediment particle fall velocity (m/s)
S = energy or water surface slope
C_c= computed sediment concentration, and
C_m= measured sediment concentration.

These dimensionless parameters were calculated for the study reach, and the results were compared to the work of Yang and Huang [Ref 20]. In this study, the applicability of 13 widely used sediment transport functions was investigated (Table 4). The dots in the table indicate that the particular sediment transport function is applicable based on the dimensionless parameter tested.

According to this table, the following is the list of the most appropriate functions for simulating sediment transport in the Nelson River:

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

These functions are available in the HEC-RAS program and therefore, were considered to assess erosion and sediment transport in the study reach for all scenarios.

Table 4 Summary of Applicability of Sediment Transport Functions in the Study Reach of the Nelson River.

Sediment Transport Function	D_{gr}	h/d_{50}	**Fr**	v_*/w	uS/w	**C**
Ackers-White (1973)	●	●	●	●	●	●
Einstein-bed load (1953)						
Einstein-bed material load (1953)					●	
Engelund-Hansen (1967)	●	●	●	●	●	●
Kalinske (1947)						
Laursen (1958)	●	●	●	●	●	●
Meyer-Peter & Muller (1948)			●		●	
Rottner (1959)				●		●
Schoklitsch (1934)			●	●	●	●
Toffaleti (1968)						
Yang-sand (1973)	●	●	●	●	●	●
Yang-sand (1979)	●	●	●	●	●	●
Yang-gravel (1984)			●		●	●

Cohesive Material

The transport of cohesive sediment is rather complex due to the electrostatic and electrochemical forces that bound sediment particles together. These forces make erosion and sediment transport of cohesive material fundamentally different from the transport of non-cohesive particles (discussed above). In HEC-RAS, there are two methods to calculate cohesive sediment transport:

- using the standard transport functions
- Krone and Partheniades method

The first method simply uses sediment transport functions for non-cohesive particles (selected in the model) for cohesive sediments as well. This method is a very conservative approach and produces enormous transport potential. However, it can be useful in rivers where cohesive material is not being deposited and eroded from the bed and banks in a large amount. Krone and Partheniades is a more involved method that requires information on the properties of cohesive material in the study area such as critical shear threshold for particle erosion, critical shear threshold for mass erosion, mass wasting threshold, mass wasting rate, etc. [Ref 12].

There are no direct measurements of cohesive material parameters in the study reach, and the recommended values in literature vary in a wide range. The first method, therefore, was considered in this study to calculate the transport of cohesive sediments.

6.4 MODEL CALIBRATION

As mentioned previously, in the existing environment the presence of eroded material from the shoreline is not significant within the river flow. In order to verify the applicability of the present model, erosion and sediment transport in the existing environment (pre-construction) was simulated. In this simulation, a flow rate of 4,855 m^3/s (95th percentile flow) with a duration of 10 days was considered. Moreover, the sediment load from the upstream end of the model, being composed of very fine materials, with a suspended concentration of 20 mg/L was assumed. The 20 mg/L represents the existing typical conditions of TSS on the Nelson River. This existing sediment background is selected based on the field data collected in the open water months during the years 2001 to 2007. The TSS concentration in the Keeyask area generally lies within the range of 5 to 30 mg/L [Ref 9].

At station K-Tu-2, downstream of the proposed Keeyask GS (see Figure 1 for location of this station), the model estimated a suspended sediment concentration of 20 mg/L that is equal to the sediment load introduced to the model from the upstream. Since the amount of sediment from shoreline erosion is not significant in the flow, and the incoming sediment load is mostly wash load, all the sediment transport functions estimated the same value for sediment concentration at this station.

Spatial variation of the sediment concentration along the study reach is shown in Figure 29. This profile is prepared using the Yang sediment transport function. As was expected, no increase in sediment load was observed along the reach. However, the hydraulic conditions change from a riverine environment, upstream of Gull Rapids, to a lake environment, in Stephens Lake. This means a decrease in energy slope and flow velocity. This, in turn, causes a reduction in carrying capacity of the river. The sediment concentration shows a decrease due to deposition of materials downstream of Gull Rapids. This reduction in sediment load downstream of Gull Rapids can also be observed from the data collected in the 2005, 2006 and 2007 open water months [Ref 5]. In case of sediment loads with high concentrations, this decrease would be more significant in Stephens Lake, (see Figure 29 for a test scenario with sediment concentration of 70 mg/L).

6.5 EROSION AND SEDIMENTATION MODELLING RESULTS

6.5.1 SEDIMENT LOAD DURING CONSTRUCTION

Stage I Diversion

During Stage I Diversion, the water surface elevation (for 95th percentile flow) will increase approximately 1m immediately upstream of the Spillway Stage I Cofferdam (Figure 11). At the upstream end of Gull Lake, the backwater is approximately 0.4m above the existing environment. The flooded area in this stage was introduced to the model as the movable banks limit. Figure 21and Figure 26 display the type and particle size of erodible materials defined in the model. A thickness of 5 m was assumed for erodible material in the study reach, which provided an unlimited source of sediment available to be eroded (i.e., the 5 m depth of material was not fully eroded). A flow duration of 10 days was used and the flow rate was set to 4,855 m^3/s (95th percentile flow). An incoming sediment load of 20 mg/L from the upstream end of the model was applied. The particle size of this load was assumed to be similar to those observed historically in the river (Figure 26).

Erosion and sediment transport during Stage I Diversion was simulated considering four, previously selected, sediment transport functions. The Engelund-Hansen function was not numerically stable in the model and therefore the results produced using this function was not considered in this study. A summary of the results from this modelling is shown in Table 5. As can be seen in this table, the sediment load varies from 18 to 27 mg/L at station K-Tu-2 and from 17 to 23 mg/L at station K-Tu-1. Also, it was observed that downstream of the construction site the Yang and Laursen functions predict an increase in sediment load, whereas the Ackers-White function shows a decrease in sediment load.

A similar simulation was performed for the 1:20-year flood (6,358 m^3/s). In this simulation, the erodible area of each cross section was defined in the model using the backwater profile during the flood event (Figure 13). A summary of the results for the sediment concentration during this flood flow is shown in Table 5. At stations K-Tu-2 and K-Tu-1, the predicted sediment load varies from 23 to 27 mg/L and from 18 to 23 mg/L, respectively. Therefore, the selected sediment functions predict either a small drop (2~ 3 mg/L) or a minor increase (1~7 mg/L) in sediment concentration at stations K-Tu-1 and K-Tu-2.

Table 5 Summary of Total Sediment Concentration at Stations K-Tu-1 and K-Tu-2 for Different Flow Scenarios during Stage I Diversion.

Flow Condition	Transport Function	K-Tu-2*	K-Tu-1*
Q= 4,855 m^3/s (95th percentile)	Ackers-White	18	17
	Yang	24	21
	Laursen	27	23
Q= 6,358 m^3/s (20-year flood)	Ackers-White	23	18
	Yang	23	22
	Laursen	27	23

* A sediment background of 20 mg/L was assumed in estimating sediment concentrations at sites K-Tu-1 and K-Tu-2.

Stage IID

The physical hydraulic model showed that the most critical conditions for the flow velocity and water surface elevation are expected in Stage IID when the gap length between the closure leg of the rock groin and the river's south bank is 300 meters. Figure 30 shows the average flow velocity and water surface elevation of the Nelson River in the study reach for both Stage I and Stage IID (95% flow= 4855 m^3/s). As can be observed from this figure, the flow condition is very similar during these two stages, except for a few hundred meters upstream and downstream of the Stage I Spillway Cofferdam. The flow velocity will be higher during Stage IID than during Stage I where flow will be passing through the 300-meter gap between the south shore and the rock groin (Stage II Upstream Cofferdam).

Erosion and sediment transport during Stage IID were simulated employing all data introduced for the Stage I simulations and applying general assumptions for sediment transport modelling with HEC-RAS. In this simulation, three sediment transport functions, namely Yang, Ackers-White, and Laursen, were considered. A summary of the sediment concentration at stations K-Tu-2 and K-Tu-1for 95% flow (4,855 m^3/s) and 1:20-year flood (6,358 m^3/s) is shown in Table 6. During the 95% flow with an assumed ambient TSS of 20 mg/L, the sediment concentration will be in the range of 24 to 32 and 20 to 24 mg/L at stations K-Tu-2 and K-Tu-1, respectively. The Ackers-White function estimated the lower range of values for sediment load, while the upper values were predicted by the Laursen function. During a 1:20-year flood and assuming the same value of TSS as the background sediment load (20 mg/L), sediment concentrations at stations K-Tu-2 and K-Tu-1 are expected to vary in the range of 26 to 34 and 20 to 24 mg/L, respectively. Therefore, the selected sediment functions predict an increase of 1 to 14 mg/L above the background in sediment concentration at stations K-Tu-1 and K-Tu-2.

Table 6 Summary of Total Sediment Concentration at Stations K-Tu-1 and K-Tu-2 for different Flow Scenarios during Stage IID Diversion.

Flow Condition	Transport Function	K-Tu-2*	K-Tu-1*
Q= 4,855 m^3/s (95th percentile)	Ackers-White	24	20
	Yang	27	21
	Laursen	32	24
Q= 6,358 m^3/s (20-year flood)	Ackers-White	26	20
	Yang	33	22
	Laursen	34	24

* A sediment background of 20 mg/L was assumed in estimating sediment concentrations at sites K-Tu-1 and K-Tu-2.

Stage IIA

During Stage IIA, the closure of the south channel of the Nelson River will be completed, and all flow will be passing only through the seven open sluiceways. This reduction of flow passage in this stage, compared to Stage IID, will cause a backwater profile as is shown in Figure 15 and Figure 16. Upstream of the Spillway, the water surface elevation is expected to be 4 meters higher than the water surface elevation during Stage IID. This increase will reduce the average flow velocity a few hundred meters upstream of the Spillway structure. From Figure 31 this decrease in flow velocity can be seen in the area between two vertical dash lines. The area outside of the two dashed lines will experience the same flow conditions as in Stage IID.

The increase in water surface elevation will expose a larger area of shoreline to the flow action and consequently increase the potential for erosion. The sediment concentration in the Nelson River was estimated using the same sediment model used for Stage IID with some modification to the geometry file. This modification included closing the south channel completely and directing the flow through the sluiceways. Table 7 shows a summary of the results for the sediment concentration during Stage IIA at stations K-Tu-2 and K-Tu-1, for both 95% flow and 1:20-year flood conditions. The same three sediment transport functions used in the Stage IID analysis were applied in this simulation. Therefore, the selected sediment functions predict an increase of 1 to 20 mg/L above the background in sediment concentration at stations K-Tu-1 and K-Tu-2.

Table 7 Summary of Total Sediment Concentration at Stations K-Tu-1 and K-Tu-2 for different Flow Scenarios during Stage IIA Diversion.

Flow Condition	Transport Function	K-Tu-2*	K-Tu-1*
Q= 4,855 m^3/s (95th percentile)	Ackers-White	25	21
	Yang	28	23
	Laursen	34	29
Q= 6,358 m^3/s (20-year flood)	Ackers-White	28	23
	Yang	31	24
	Laursen	40	32

* A sediment background of 20 mg/L was assumed in estimating sediment concentrations at sites K-Tu-1 and K-Tu-2.

For the 95% flow condition, it is expected that the sediment concentration at stations K-Tu-2 and K-Tu-1 will increase from 20 mg/L (background TSS) to 25~34 and 21~29 mg/L, respectively. During a 1:20-year flood, sediment concentration would potentially increase from the background load to a maximum of 28~40 mg/L and 23~32 mg/L at the above-mentioned stations.

6.5.2 LONG TERM SEDIMENT CONCENTRATION

For the most critical stage of cofferdam construction activities (Stage IIA), sediment and erosion processes were simulated for a longer period of time, i.e. three months rather than 10 days in the previous analyses. According to the construction schedule at the time of this study, Stage IIA would take 43 days to be completed. Therefore, a three month simulation period is long enough to assess the shoreline erosion during this stage. The results from this simulation (using the Yang equation) are shown in Figure 32. As can be seen in this figure, the level of TSS at site K-Tu-2 decreases exponentially with time and reaches the background TSS (20 mg/L) after 45 days. After this point, the TSS level stays fairly constant for the rest of the simulating period. In the first 10 days, the TSS level drops considerably from 40 to 27 mg/L. A gradual decrease in TSS level from 27 to 20 mg/L (background sediment load) occurs in the next 35 days of the simulation.

6.5.3 EFFECT OF SIZE OF SHORELINE MATERIAL ON SEDIMENT LOAD

As mentioned earlier, the particle size of shoreline material used in this study was prepared base on a visual soil classification. In order to investigate the effect of shoreline material particle size on sediment load, a sensitivity analysis and a new set of simulations using actual sediment gradation curves of shoreline materials from the sampling program (summer 2009) were performed.

Sensitivity Analysis of Shoreline Material Particle Size

Two gradation curves were prepared for each type of shoreline material: a gradation curve with an average grain size 50% finer and another one with a 200% coarser material compared to the original curves used in the previous sediment modelling.

For the 95th percentile flow, the model was run considering the finer and coarser gradation curves mentioned above. The results showed slightly higher sediment load when finer materials were considered. However, no significant changes were observed in the sediment load assuming a shoreline with coarser materials since these materials do not contribute to the suspended load. If eroded from the shore, coarser materials will either deposit along the shore or move downstream as bedload, but not far from where they originated.

Shoreline Material Particle Size from the Summer 2009 Program

In previous sections of this report, shoreline erosion and sedimentation during different stages of construction of the Keeyask generating station were modelled based on a visual assessment of general shoreline material types. Since soil materials and particle size vary along the length of the shoreline and through the cross-sectional profiles from the river's water edge to the top-of-bank, soil samples were obtained for grain size analysis to better represent actual shoreline materials. Particle size distributions based on actual soil samples were assigned to the shorelines and flooded areas for the Existing Environment to Stage I, Stage I to Stage IID, and Stage IID to Stage IIA shoreline polylines and polygons [Ref 21]. Figure 33 shows the flooded areas during the different stages of construction along with the percentage of the each type of soil obtained from shoreline sampling. The shoreline material gradation curves obtained from laboratory testing on shore material samples are shown in Figure 34 for flooded shoreline areas between Existing Environment to Stage I and Stage I to Stage IIA, respectively. The visually classified gradation curve for clay type soils matches well with the actual gradation curves. However some discrepancy can be observed between curves for sand type soils. The D_{50} of the visually classified curves for sand is comparable with the D_{50} of the actual curves, but D_{10} and D_{90} values are different. Due to this reason, a new set of runs was considered for the Stage IIA Diversion which would introduce the largest amount of sediment to the Nelson River compared to other stages of construction. Similar to the previous runs, a sediment background of 20 mg/L was considered in the model. Applying these actual gradation curves, shoreline erosion and sedimentation processes during Stage IIA were simulated using Yang, Ackers-White, and Laursen sediment functions. The estimated sediment concentration, applying actual soil gradation curves in the model, is 10 to 15 percent less than those calculated based on the visually classified gradation curves (Table 8). The selected sediment functions predict an increase of 1 to 14 mg/L above the background in sediment concentration at stations K-Tu-1 and K-Tu-2. These results are less than previous estimate in which visual shore classification was considered (Table 7).

Table 8 Summary of Total Sediment Concentration at Stations K-Tu-1 and K-Tu-2 Applying Actual Soil Gradation Curves (Stage IIA).

Flow Condition	Transport Function	K-Tu-2*	K-Tu-1*
Q= 6,358 m^3/s (20-year flood)	Ackers-White	25	21
	Yang	31	28
	Laursen	34	28

* A sediment background of 20 mg/L was assumed in estimating sediment concentrations at sites K-Tu-1 and K-Tu-2.

6.5.4 GRADATION CURVES OF THE SEDIMENT LOAD

As discussed in **Section 3.5**, the sediment load entering from upstream of the study reach is largely composed of wash load. These materials do not settle out as they move downstream. However, during flow diversion the eroded materials from the shoreline will be added to the flow. The coarser portion of eroded materials will either deposit in areas adjacent to the shoreline, or be transported as bed load. The finer particles from bank erosion, on the other hand, will be added to the suspended load. This, in turn, may change the gradation curve of the suspended load carried by the river. Downstream of the construction area and at stations K-Tu-2 and K-Tu-1, this change in particulate size was investigated. In this investigation, both visual shoreline classification and actual gradation curves from laboratory analyses were considered.

Applying the visual shoreline classification to the model, the gradation curves of total sediment load at stations K-Tu-2 and K-Tu-1 during Stage I, Stage IID, and Stage IIA diversions were determined and shown in Figure 35 to Figure 37**,** respectively. For each station, three gradation curves are presented. Each curve corresponds to the sediment transport function that was employed in the sediment modelling. In these figures, the gradation curve of the inflow sediment load is also shown. Figure 35, in which the gradation curve of sediment load during Stage I Diversion (1:20- year flood) is presented and shows that applying Ackers-White sediment function predicts coarser materials at station K-Tu-2, while Laursen function predicts finer material at this station. The predicted sediment load at this station includes coarser materials compare to the sediments entering from the upstream end of the study reach. However, the carried sediments are still in the range of *very fine silt* to *very fine sand.* The decrease in flow velocity and shear stress in the river reach between station K-Tu-2 and station K-Tu-1 causes a drop in the percentage of the coarser portion of the sediment load. Therefore, the gradation curves of the sediment load at station K-Tu-1 is finer and more uniform comparing to those predicted for station K-Tu-2. Moreover, the gradation curves of the sediment load at station K-Tu-1, predicted by different transport functions, are within the range of the size of the inflowing sediment from upstream (Figure 35). During Stage II Diversion, more shoreline erosion is expected to occur when compared to during Stage I Diversion (Table 5 to Table 7). The eroded materials that become suspended will be mostly silt and sand. Therefore, the gradation curves of the sediment load during Stage II diversion include a higher percentage of coarse materials at stations K-Tu-2 and K-Tu-1 (Figure 36 and Figure 37). Similar to Stage I, more finer sediments are expected at station K-Tu-1 than at station K-Tu-2 during Stage II Diversion. Nonetheless, the sediment load at station K-Tu-1 during this stage is still composed of coarser materials comparing to the inflowing sediment load. The sediment load at this station is still very fine, and at least 92% of the total sediment load contains particles with particle sizes less than 0.063 mm (Figure 36 and Figure 37).

In another attempt, the gradation curves of the sediment load at station K-Tu-2 were determined by applying the actual gradation curves obtained from the 2009 shoreline material sampling. The results for Stage IIA using the 3 different sediment functions are shown in Figure 38. Although D_{50} of the sediment loads at station K-Tu-2 is virtually identical when visual and actual shoreline classifications are considered (~ 0.006 mm and), all three sediment function predicts coarse sediment at this station when visual shoreline classification is considered.

7 SUMMARY AND CONCLUSIONS

Construction activities during river management will introduce additional sediment into the Nelson River due to shoreline erosion as upstream water levels increase and due to changes in flow patterns and velocities. There is a potential that some of the additional sediment will flow downstream, which may affect the sedimentation environment in Stephens Lake.

Shoreline erosion and sedimentation processes during the construction of the Keeyask GS project have been assessed in this study during Stage I and Stage II Diversion. A one-dimensional HEC-RAS model was used for this analysis. Contributions to sediment load from shoreline erosion are predicted for two relatively high flow scenarios; 95th percentile flow and 1:20 year flood (peak daily).

During Stage I Diversion, it is predicted that the additional sediments introduced into the river could potentially elevate the sediment concentrations by 3 mg/L to 7 mg/L in the Nelson River approximately 1 km downstream of Gull Rapids at the K-Tu-02 monitoring location for both the 95th percentile and 1:20 year flood conditions.

During Stage II Diversion, the potential for the maximum rate of shoreline sediment loads occurs when all flow in the Nelson River is being passed through the newly constructed spillway sluice-bays prior to rollway construction. It is predicted that the additional sediments introduced into the river could potentially elevate the suspended sediment concentrations by as much as 5 mg/L to 14 mg/L in the Nelson River approximately 1 km downstream of Gull Rapids at the K-Tu-02 monitoring location for both the 95th percentile and 1:20 year flood conditions. These increased sediment concentrations would to occur within the first few days of Stage II diversion and taper gradually to background sediment concentrations. Since numerous conservative assumptions applied in this study, these predictions represent the upper limit of the expected sediment concentrations downstream of the project due to the shoreline erosion during construction of the Keeyask GS.

The eroded materials from the shoreline will be mostly silt and sand. The coarser portion of these materials will either deposit in areas adjacent to the shoreline, or be transported as bed load. The finer particles from bank erosion will be added to the suspended load and, therefore, change the particulate size of the suspended load carried by the river. The gradation curve of sediments reaching station K-Tu-2 is predicted and shown in Figure 38.

Results of this study contribute to the assessment of the sediment deposition process in Stephens Lake and the prediction of the specific locations of shoreline erosion to identify areas where mitigation measures may be implemented if required. The following should be taken into account when results from this study are being utilized:

- Hydraulic condition during a river diversion activity involves multi-dimensional variability (both temporally and spatially) in the flow regime. A one-dimensional hydraulic model is limited in its capacity to simulate the multi-dimensional variability in flow velocity and water level.

- A range for sediment load has been predicted due to the complexity and uncertainties of the sedimentation analyses. This range is obtained by applying several sediment transport functions in this study.
- The amount of erosion predicted by the model is conservatively overestimated. This is because an average flow velocity obtained from the 1D model is applied to the shoreline for calculating shoreline erosion when the nearshore velocity is expected to be less than the centerline or average velocity.
- Assuming instantaneous construction of the cofferdams, groins and dykes within the sedimentation model 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 over an unrealistic short period of time. A more gradual increase in water levels would result in a slower erosion rate than 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 (5 m represents as infinite sediment depth in this study) to erode and transport. This allows for a conservative estimate of the potential increase in TSS at Stephens Lake.
- The design flows of 4,855 m3/s (95th percentile flow) and 6,358 m3/s (1: 20 Year flood flow) were assumed to be constant and sustained throughout the entire duration of Stage I and Stage II Diversions. The sedimentation model is conservatively over predicting the amount of erosion/sedimentation that is expected to occur by assuming that the design flows are constant at this high level throughout the diversion stages.

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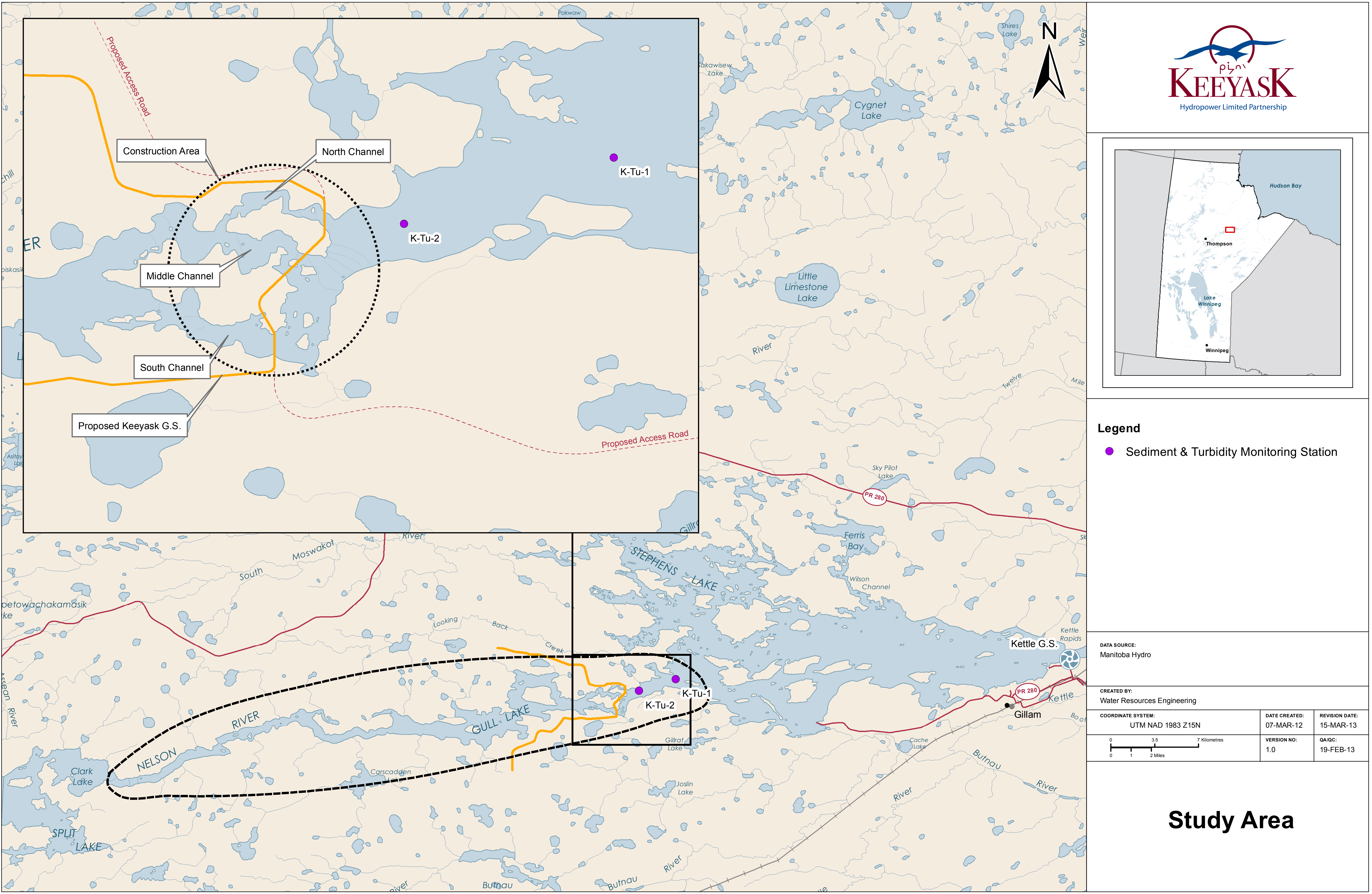


Legend

● Sediment & Turbidity Monitoring Station

DATA SOURCE:
Manitoba Hydro

CREATED BY:
Water Resources Engineering

COORDINATE SYSTEM:
UTM NAD 1983 Z15N

DATE CREATED:
07-MAR-12

REVISION DATE:
15-MAR-13

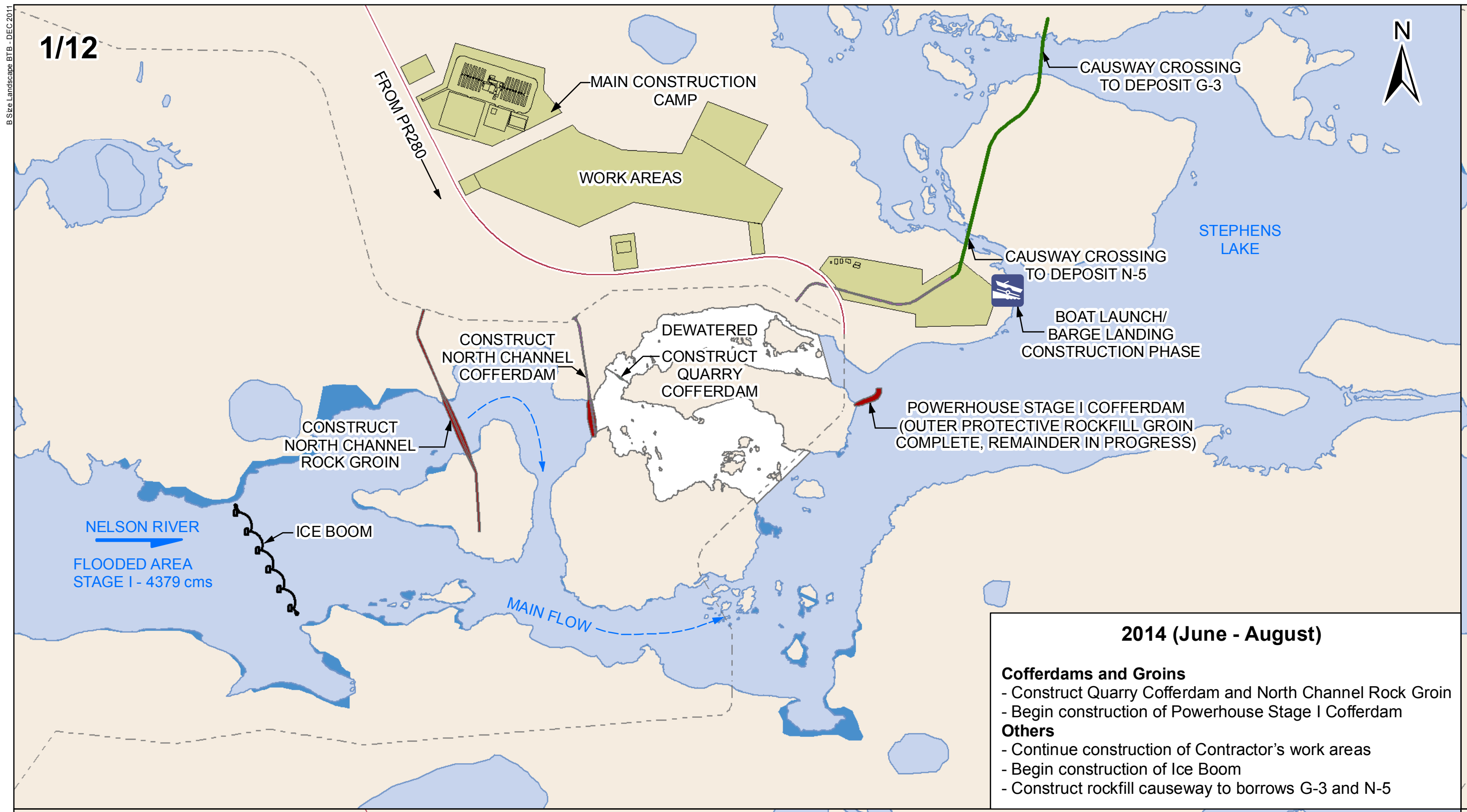
0 3.5 7 Kilometres
0 1 2 Miles

VERSION NO:
1.0

QA/QC:
19-FEB-13

Study Area

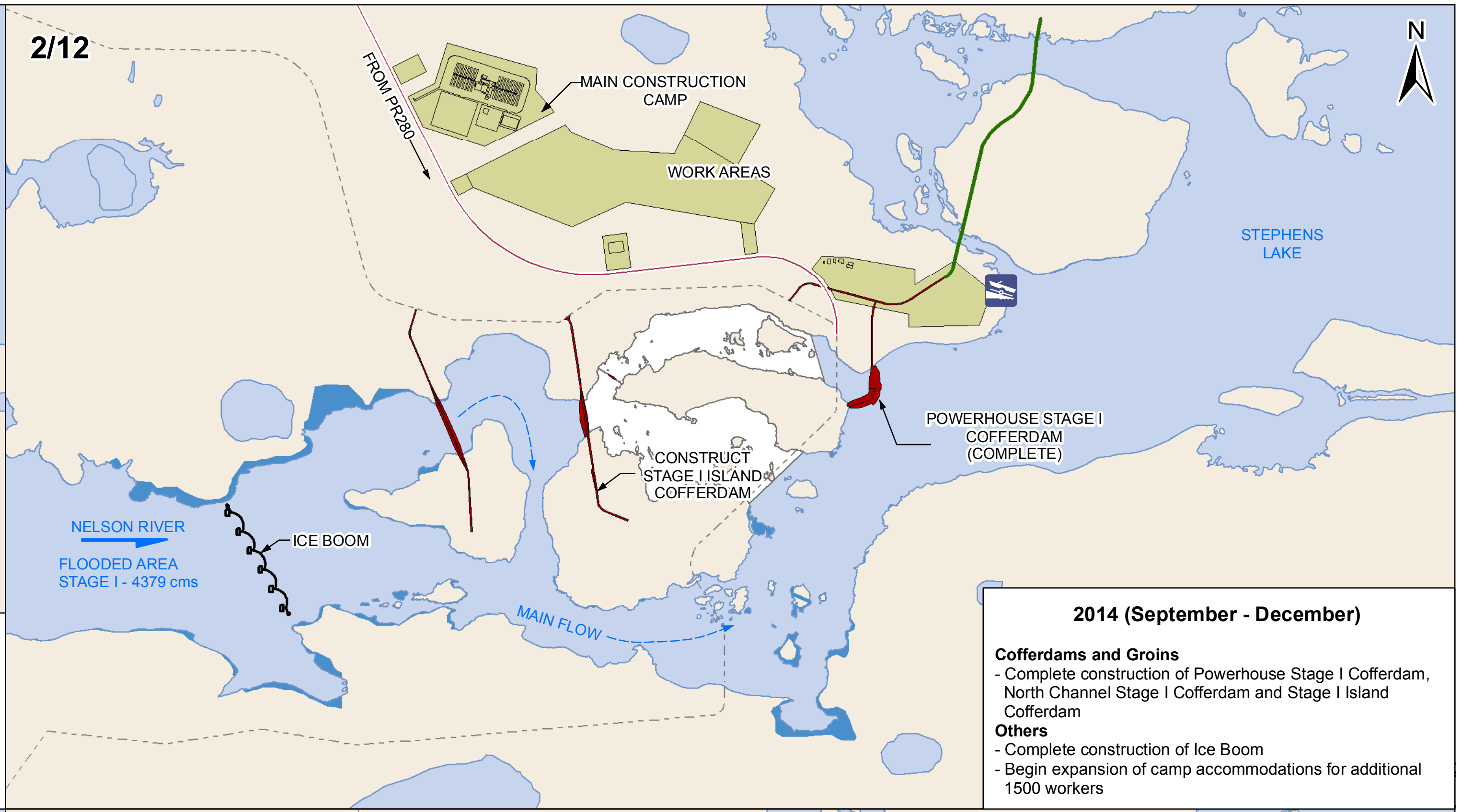
Figure 1



2014 (June - August)

Cofferdams and Groins
- Construct Quarry Cofferdam and North Channel Rock Groin
- Begin construction of Powerhouse Stage I Cofferdam

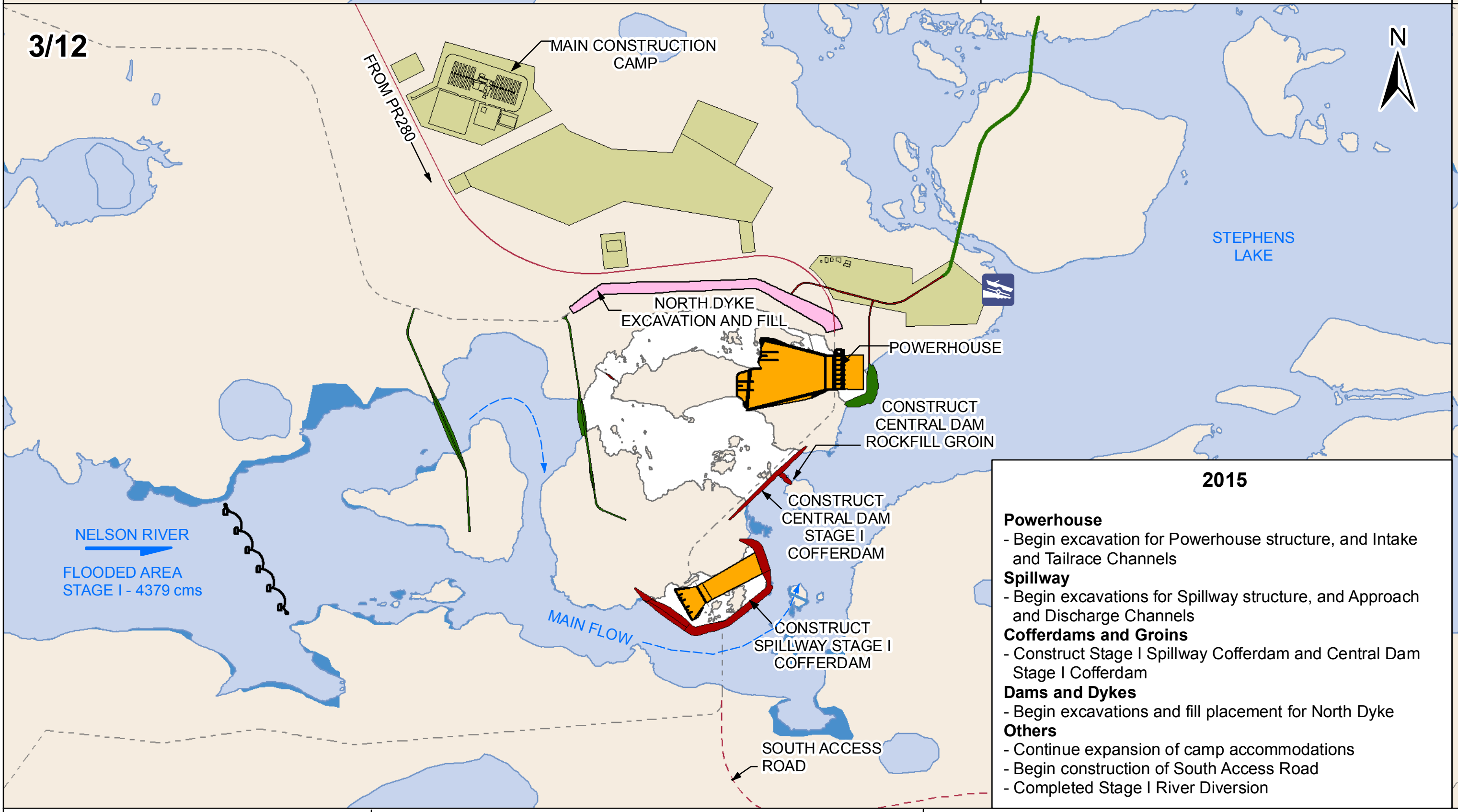
Others
- Continue construction of Contractor’s work areas
- Begin construction of Ice Boom
- Construct rockfill causeway to borrows G-3 and N-5



2014 (September - December)

Cofferdams and Groins
- Complete construction of Powerhouse Stage I Cofferdam, North Channel Stage I Cofferdam and Stage I Island Cofferdam

Others
- Complete construction of Ice Boom
- Begin expansion of camp accommodations for additional 1500 workers



2015

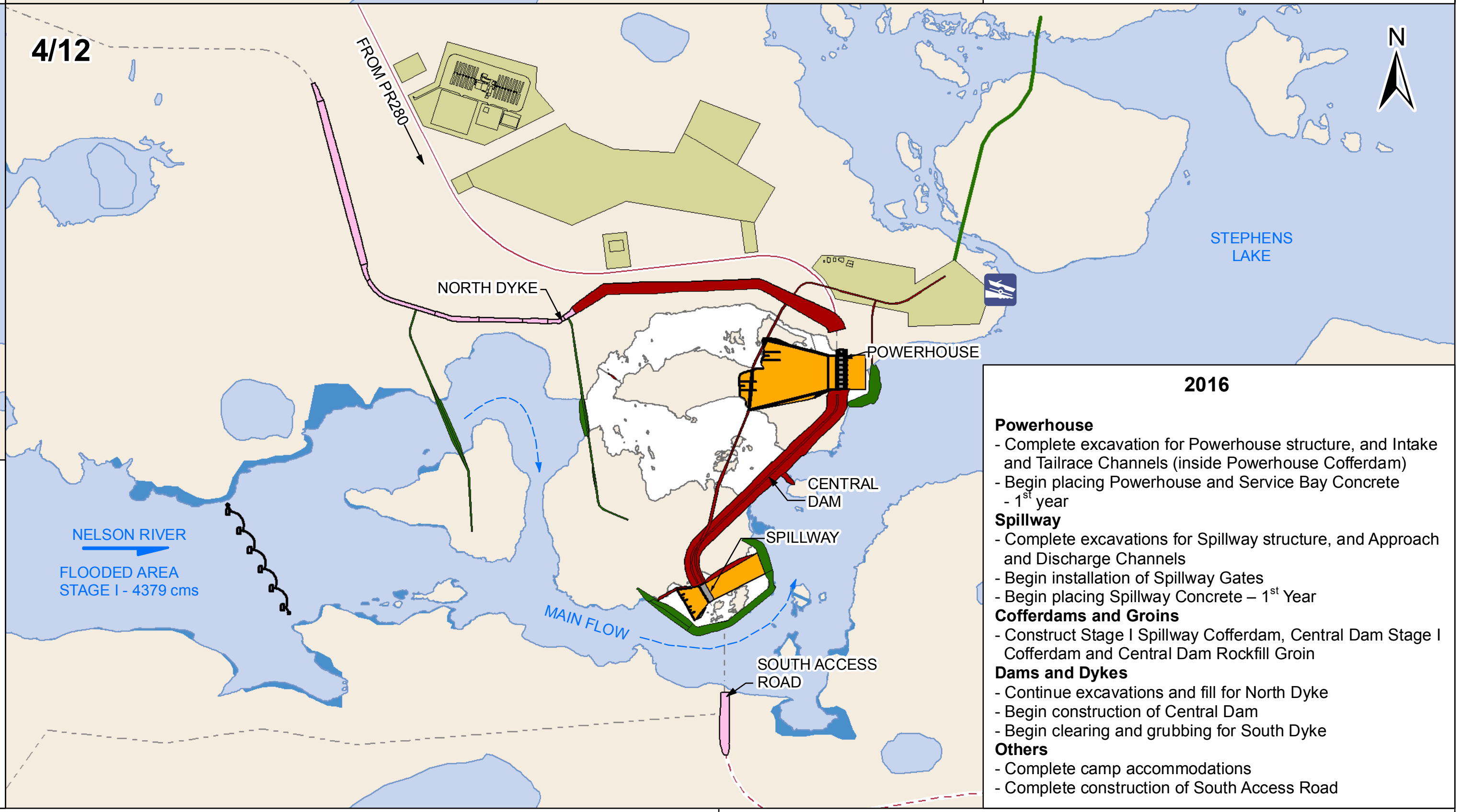
Powerhouse
- Begin excavation for Powerhouse structure, and Intake and Tailrace Channels

Spillway
- Begin excavations for Spillway structure, and Approach and Discharge Channels

Cofferdams and Groins
- Construct Stage I Spillway Cofferdam and Central Dam Stage I Cofferdam

Dams and Dykes
- Begin excavations and fill placement for North Dyke

Others
- Continue expansion of camp accommodations
- Begin construction of South Access Road
- Completed Stage I River Diversion



2016

Powerhouse
- Complete excavation for Powerhouse structure, and Intake and Tailrace Channels (inside Powerhouse Cofferdam)
- Begin placing Powerhouse and Service Bay Concrete - 1^{st} year

Spillway
- Complete excavations for Spillway structure, and Approach and Discharge Channels
- Begin installation of Spillway Gates
- Begin placing Spillway Concrete – 1^{st} Year

Cofferdams and Groins
- Construct Stage I Spillway Cofferdam, Central Dam Stage I Cofferdam and Central Dam Rockfill Groin

Dams and Dykes
- Continue excavations and fill for North Dyke
- Begin construction of Central Dam
- Begin clearing and grubbing for South Dyke

Others
- Complete camp accommodations
- Complete construction of South Access Road

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Hydropower Limited Partnership

DATA SOURCE:
Manitoba Hydro, KGS Acres, Government of Manitoba

CREATED BY:
Manitoba Hydro - Hydro Power Planning Department

COORDINATE SYSTEM: UTM NAD 1983 Z15N
DATE CREATED: 14-FEB-12
REVISION DATE: 27-FEB-13
VERSION NO: 3.0
QA/QC: JCL/MES/ZZZ

0 0.5 1 Kilometres
0 0.4 0.8 Miles

Legend

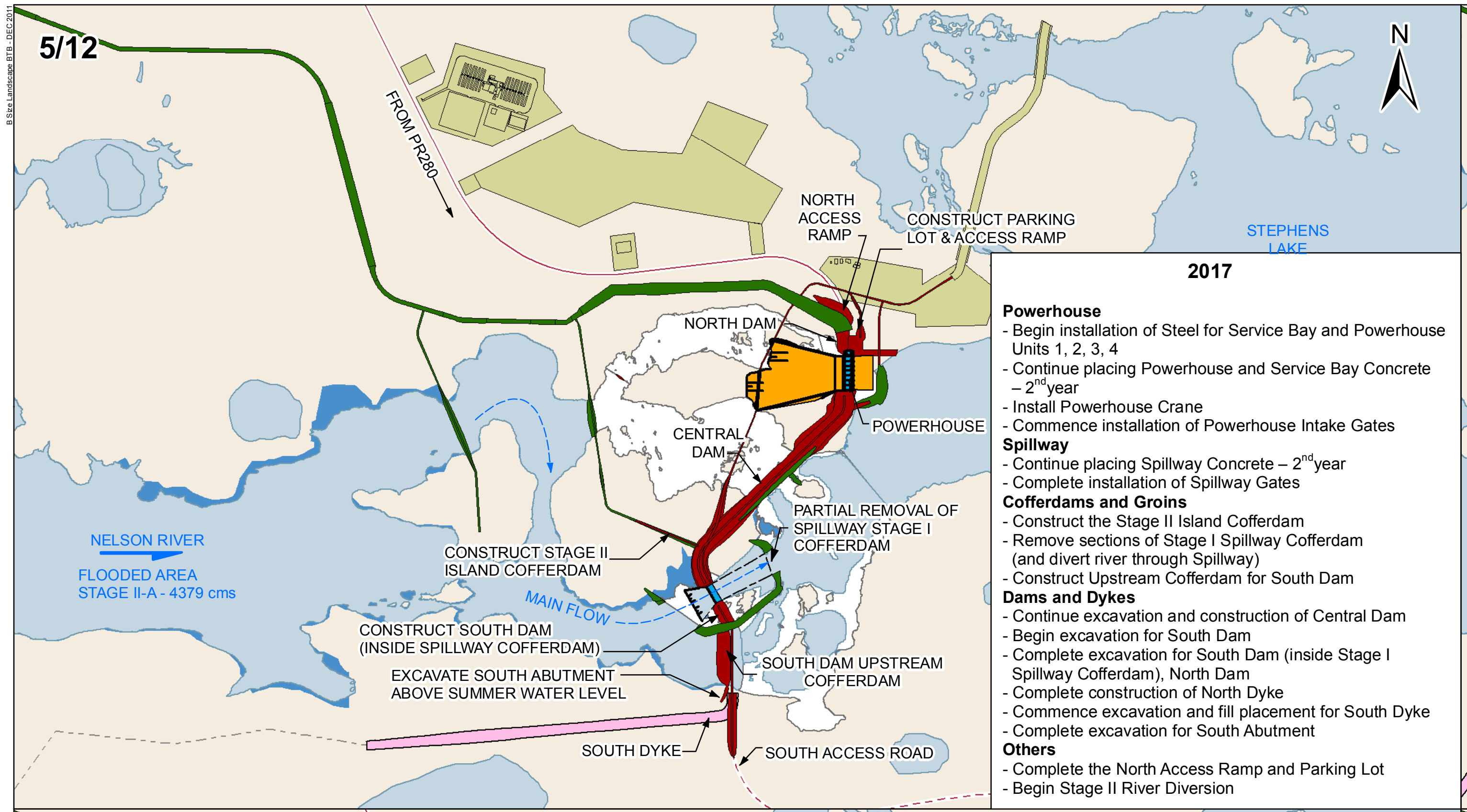
⌇	Planned/Removed Feature	🟩	Earthfill Structure (Complete)	▢	Existing Water Surface Area
⌇	Proposed Access Road	▢	Excavation Area	🟦	Stage I Flooded Area
⌇	Access Road	🟧	Bedrock Excavation Area	▢	Potential Dewatered Area
▢	Work Area and Construction Camp	▢	Concrete/Steel Structure		
🟥	Structure in Progress	⛵	Boat Launch & Barge Landing		

Construction Sequence
Years 2014 to 2016

Figure 2 (Sheet 1 of 3)

B Size Landscape BTB - DEC 2011
File Location: U:\00195_Keeyask\GIS\MXD\Keeyask ConstructionSequence Map1 2013 02 20.mxd

B Size Landscape BTB - DEC 2011



2017

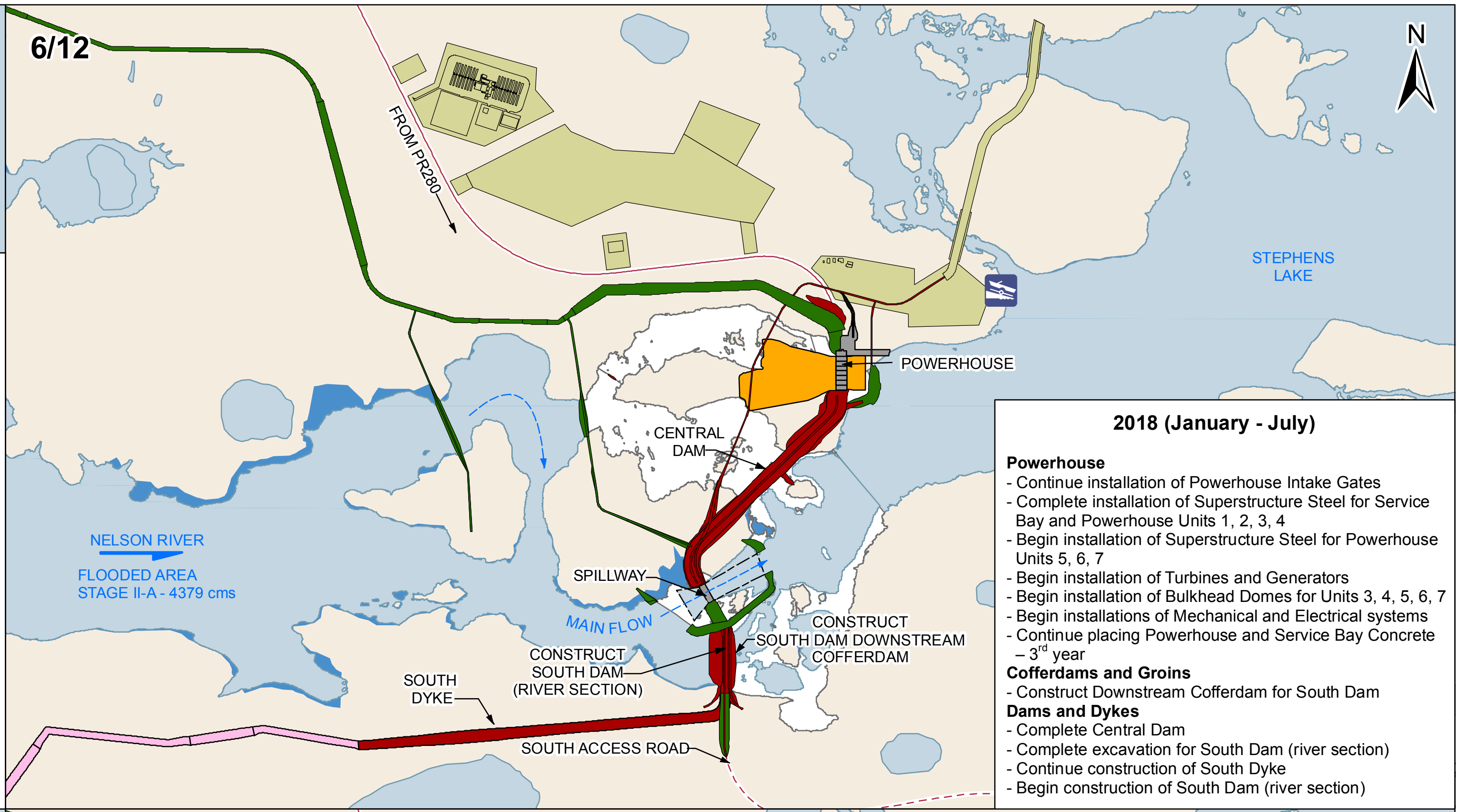
Powerhouse
- Begin installation of Steel for Service Bay and Powerhouse Units 1, 2, 3, 4
- Continue placing Powerhouse and Service Bay Concrete – 2nd year
- Install Powerhouse Crane
- Commence installation of Powerhouse Intake Gates

Spillway
- Continue placing Spillway Concrete – 2nd year
- Complete installation of Spillway Gates

Cofferdams and Groins
- Construct the Stage II Island Cofferdam
- Remove sections of Stage I Spillway Cofferdam (and divert river through Spillway)
- Construct Upstream Cofferdam for South Dam

Dams and Dykes
- Continue excavation and construction of Central Dam
- Begin excavation for South Dam
- Complete excavation for South Dam (inside Stage I Spillway Cofferdam), North Dam
- Complete construction of North Dyke
- Commence excavation and fill placement for South Dyke
- Complete excavation for South Abutment

Others
- Complete the North Access Ramp and Parking Lot
- Begin Stage II River Diversion

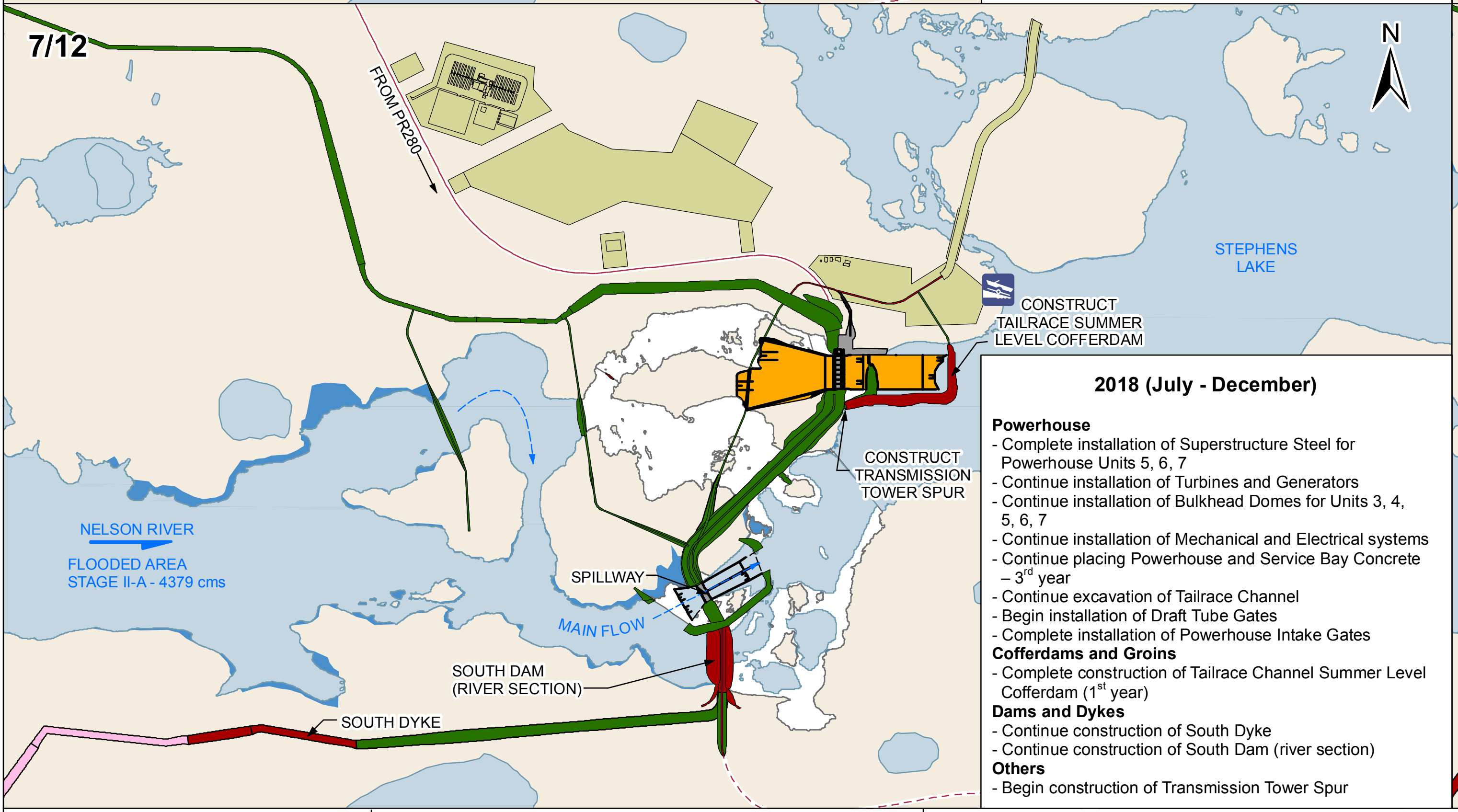


2018 (January - July)

Powerhouse
- Continue installation of Powerhouse Intake Gates
- Complete installation of Superstructure Steel for Service Bay and Powerhouse Units 1, 2, 3, 4
- Begin installation of Superstructure Steel for Powerhouse Units 5, 6, 7
- Begin installation of Turbines and Generators
- Begin installation of Bulkhead Domes for Units 3, 4, 5, 6, 7
- Begin installations of Mechanical and Electrical systems
- Continue placing Powerhouse and Service Bay Concrete – 3rd year

Cofferdams and Groins
- Construct Downstream Cofferdam for South Dam

Dams and Dykes
- Complete Central Dam
- Complete excavation for South Dam (river section)
- Continue construction of South Dyke
- Begin construction of South Dam (river section)



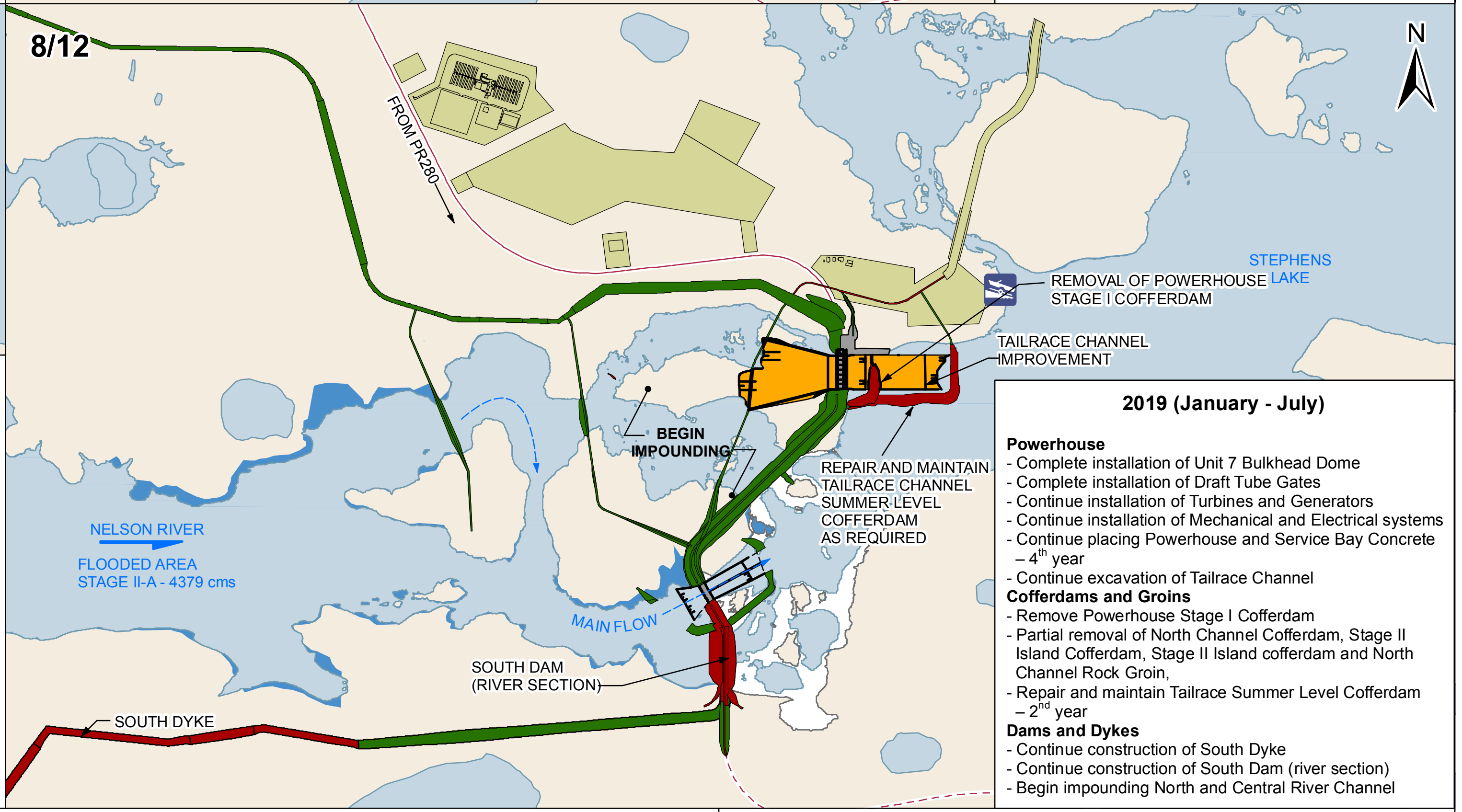
2018 (July - December)

Powerhouse
- Complete installation of Superstructure Steel for Powerhouse Units 5, 6, 7
- Continue installation of Turbines and Generators
- Continue installation of Bulkhead Domes for Units 3, 4, 5, 6, 7
- Continue installation of Mechanical and Electrical systems
- Continue placing Powerhouse and Service Bay Concrete – 3rd year
- Continue excavation of Tailrace Channel
- Begin installation of Draft Tube Gates
- Complete installation of Powerhouse Intake Gates

Cofferdams and Groins
- Complete construction of Tailrace Channel Summer Level Cofferdam (1st year)

Dams and Dykes
- Continue construction of South Dyke
- Continue construction of South Dam (river section)

Others
- Begin construction of Transmission Tower Spur



2019 (January - July)

Powerhouse
- Complete installation of Unit 7 Bulkhead Dome
- Complete installation of Draft Tube Gates
- Continue installation of Turbines and Generators
- Continue installation of Mechanical and Electrical systems
- Continue placing Powerhouse and Service Bay Concrete – 4th year
- Continue excavation of Tailrace Channel

Cofferdams and Groins
- Remove Powerhouse Stage I Cofferdam
- Partial removal of North Channel Cofferdam, Stage II Island Cofferdam, Stage II Island cofferdam and North Channel Rock Groin,
- Repair and maintain Tailrace Summer Level Cofferdam – 2nd year

Dams and Dykes
- Continue construction of South Dyke
- Continue construction of South Dam (river section)
- Begin impounding North and Central River Channel

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DATA SOURCE:
Manitoba Hydro, KGS Acres, Government of Manitoba

CREATED BY:
Manitoba Hydro - Hydro Power Planning Department

COORDINATE SYSTEM:	DATE CREATED:	REVISION DATE:
UTM NAD 1983 Z15N	14-FEB-12	27-FEB-13

0 0.45 0.9 Kilometres
0 0.35 0.7 Miles

VERSION NO: 3.0
QA/QC: JCL/MES/ZZZ

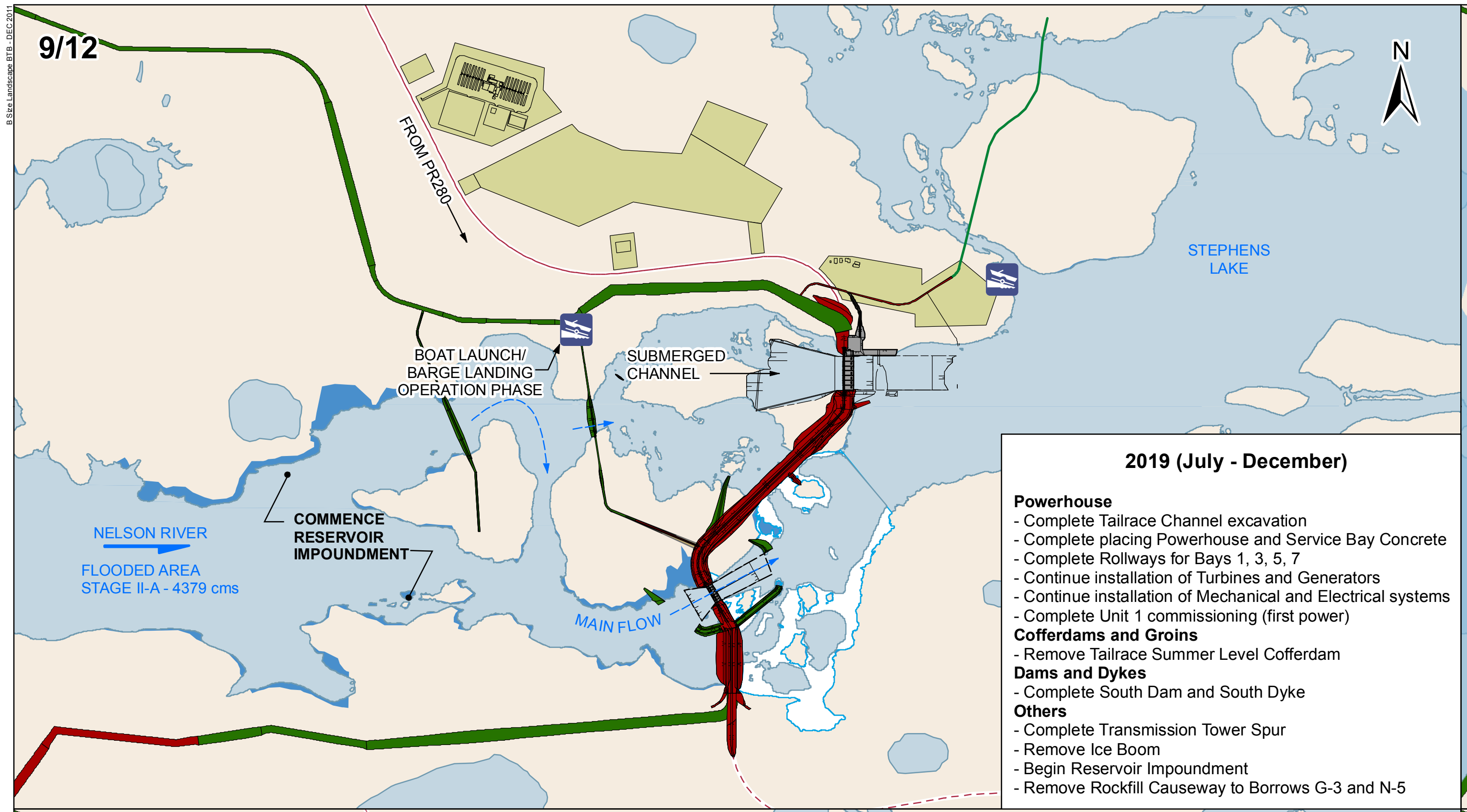
File Location: U:\00195_Keeyask\GIS\MXD\Keeyask ConstructionSequence Map2 2013 02 20.mxd

Legend

⁄╲⁄	Planned/Removed Feature
⁄╲⁄	Proposed Access Road
╱╲╱	Access Road
■	Work Area and Construction Camp
🟥	Structure in Progress
🟩	Earthfill Structure (Complete)
■	Excavation Area
🟧	Bedrock Excavation Area
■	Concrete/Steel Structure
■	Boat Launch & Barge Landing
■	Existing Water Surface Area
🟦	Stage II Flooded Area
☐	Potential Dewatered Area

Construction Sequence
Years 2017 to 2019

Figure 2 (Sheet 2 of 3)



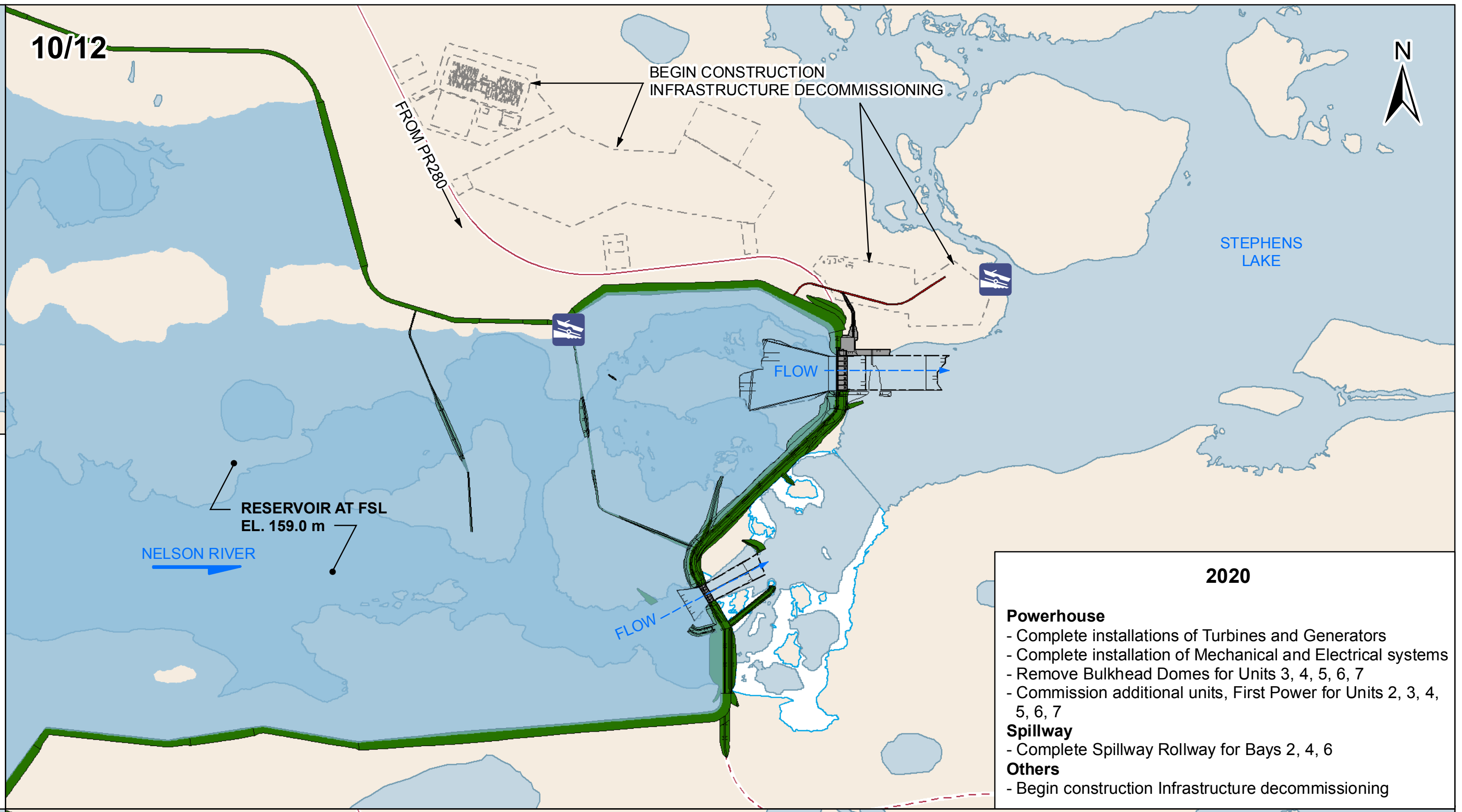
2019 (July - December)

Powerhouse
- Complete Tailrace Channel excavation
- Complete placing Powerhouse and Service Bay Concrete
- Complete Rollways for Bays 1, 3, 5, 7
- Continue installation of Turbines and Generators
- Continue installation of Mechanical and Electrical systems
- Complete Unit 1 commissioning (first power)

Cofferdams and Groins
- Remove Tailrace Summer Level Cofferdam

Dams and Dykes
- Complete South Dam and South Dyke

Others
- Complete Transmission Tower Spur
- Remove Ice Boom
- Begin Reservoir Impoundment
- Remove Rockfill Causeway to Borrows G-3 and N-5

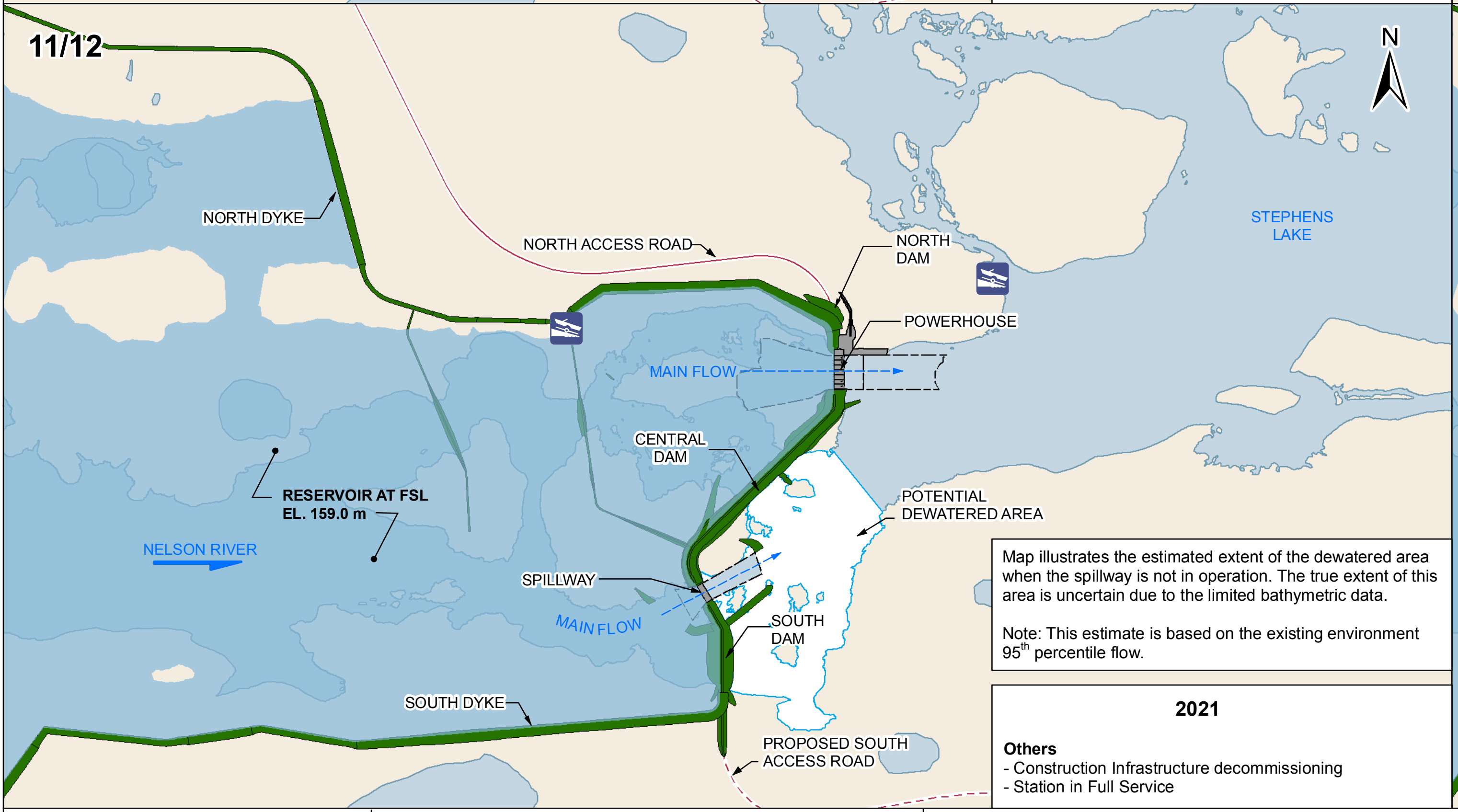


2020

Powerhouse
- Complete installations of Turbines and Generators
- Complete installation of Mechanical and Electrical systems
- Remove Bulkhead Domes for Units 3, 4, 5, 6, 7
- Commission additional units, First Power for Units 2, 3, 4, 5, 6, 7

Spillway
- Complete Spillway Rollway for Bays 2, 4, 6

Others
- Begin construction Infrastructure decommissioning

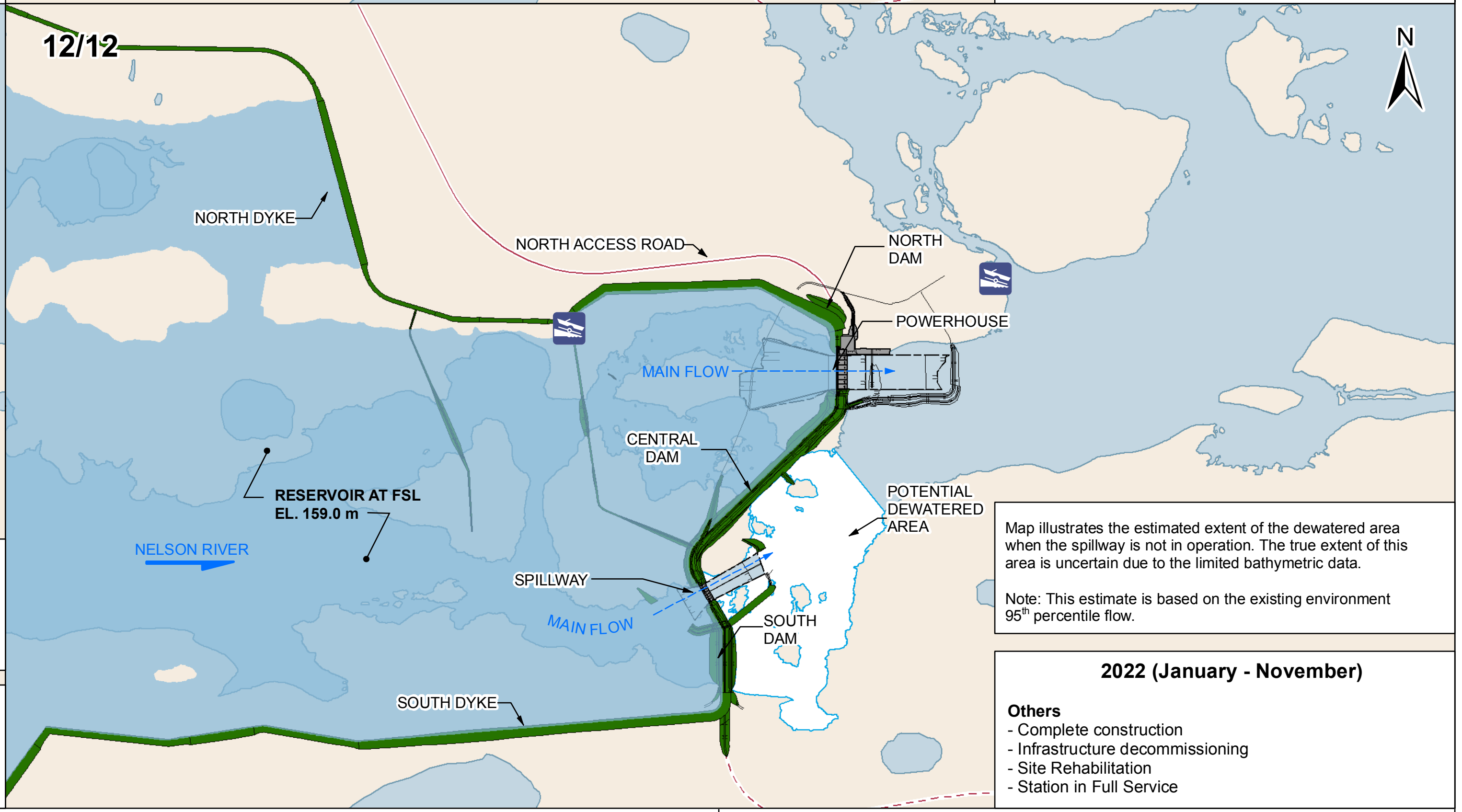


Map illustrates the estimated extent of the dewatered area when the spillway is not in operation. The true extent of this area is uncertain due to the limited bathymetric data.

Note: This estimate is based on the existing environment 95th percentile flow.

2021

Others
- Construction Infrastructure decommissioning
- Station in Full Service



Map illustrates the estimated extent of the dewatered area when the spillway is not in operation. The true extent of this area is uncertain due to the limited bathymetric data.

Note: This estimate is based on the existing environment 95th percentile flow.

2022 (January - November)

Others
- Complete construction
- Infrastructure decommissioning
- Site Rehabilitation
- Station in Full Service

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DATA SOURCE:
Manitoba Hydro, KGS Acres, Government of Manitoba

CREATED BY:
Manitoba Hydro - Hydro Power Planning Department

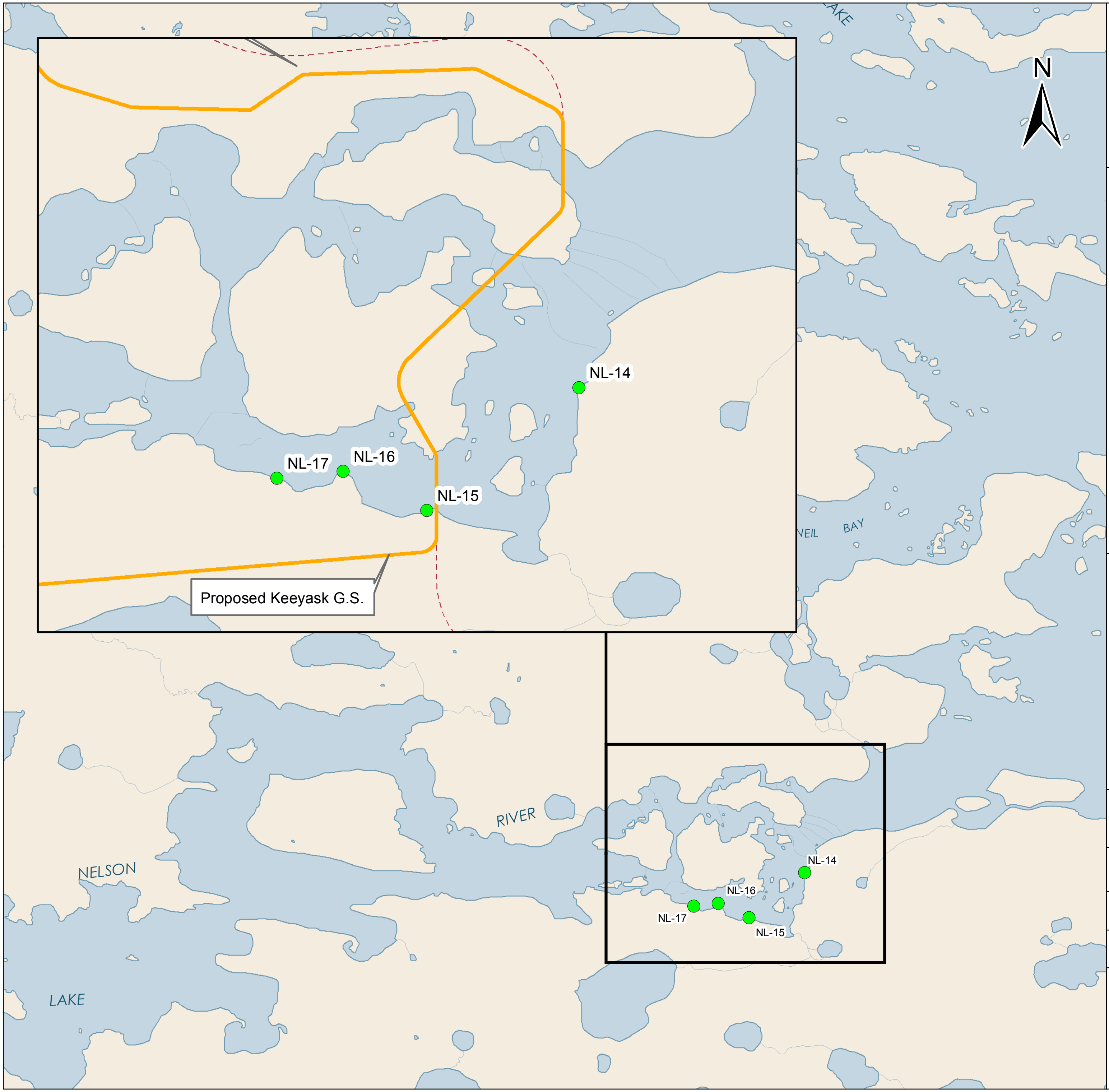
COORDINATE SYSTEM:	DATE CREATED:	REVISION DATE:
UTM NAD 1983 Z15N	14-FEB-12	27-FEB-13
0 0.45 0.9 Kilometres 0 0.4 0.8 Miles	VERSION NO: 2.0	QA/QC: JCL/MES/ZZZ

Legend

⋰⋱	Planned/Removed Feature	🟩	Earthfill Structure (Complete)	▨	Existing Water Surface Area
⋰⋱	Proposed Access Road	▨	Excavation Area	🟦	Stage II Flooded Area
/\/	Access Road	🟧	Bedrock Excavation Area	▨	Initial Reservoir Area (Forebay Level = 159 m)
▨	Work Area and Construction Camp	▨	Concrete/Steel Structure	☐	Potential Dewatered Area
🟥	Structure in Progress	⚓	Boat Launch & Barge Landing		

Construction Sequence
Years 2019 to 2022

Figure 2 (Sheet 3 of 3)



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Legend

● Physical Model Water Level Gauge

DATA SOURCE:
Manitoba Hydro

CREATED BY:
Water Resources Engineering

COORDINATE SYSTEM: UTM NAD 1983 Z15N	**DATE CREATED:** 14-MAR-12	**REVISION DATE:** 26-FEB-13
0 0.75 1.5 Kilometres 0 0.2 0.4 Miles	**VERSION NO:** 1.0	**QA/QC:** 20-FEB-13

Physical Model Water Level Gauges

Figure 3

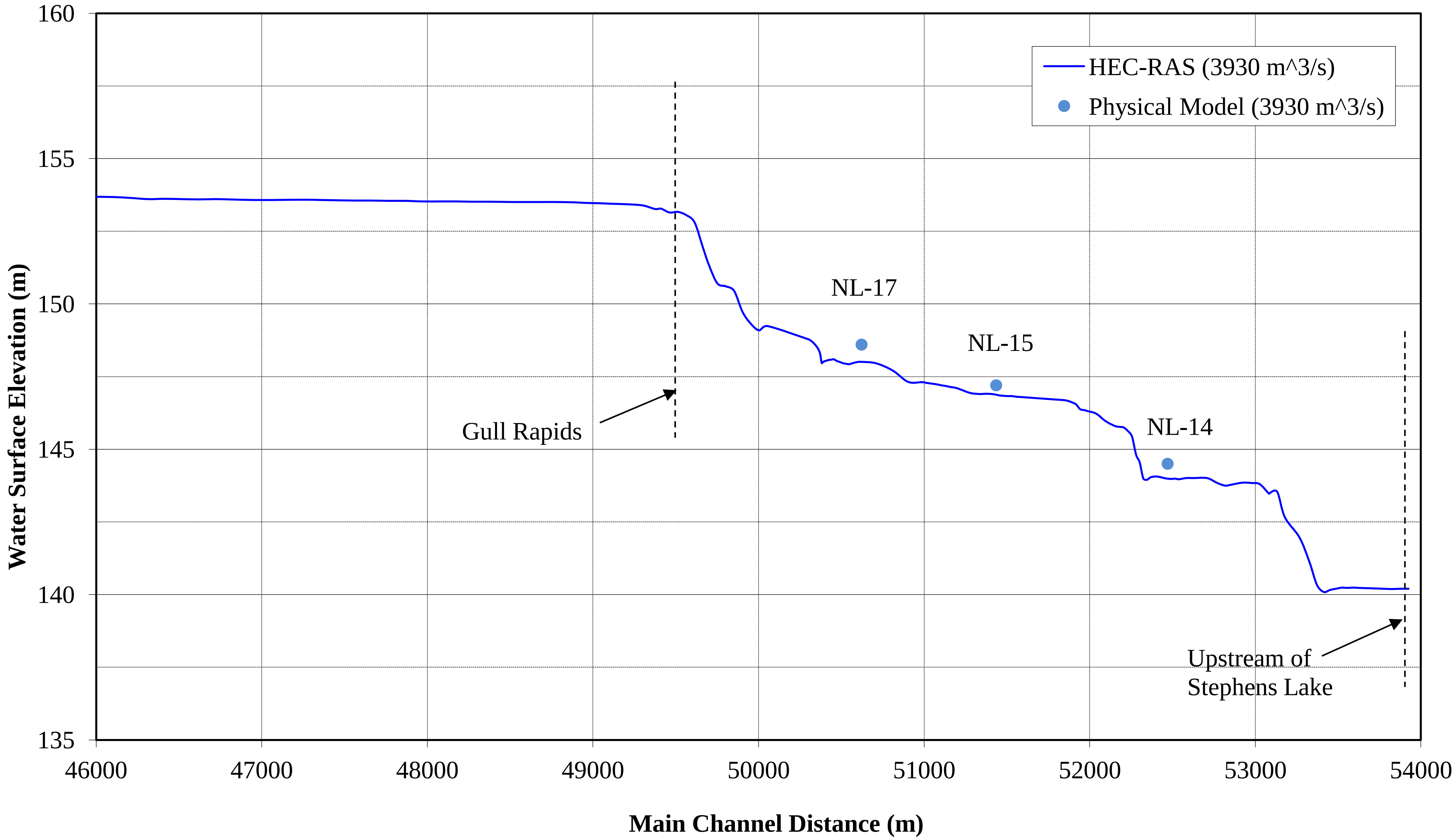


Figure 4 HEC-RAS Model Calibration Results for Stage I Diversion (Comparison with Physical Model)

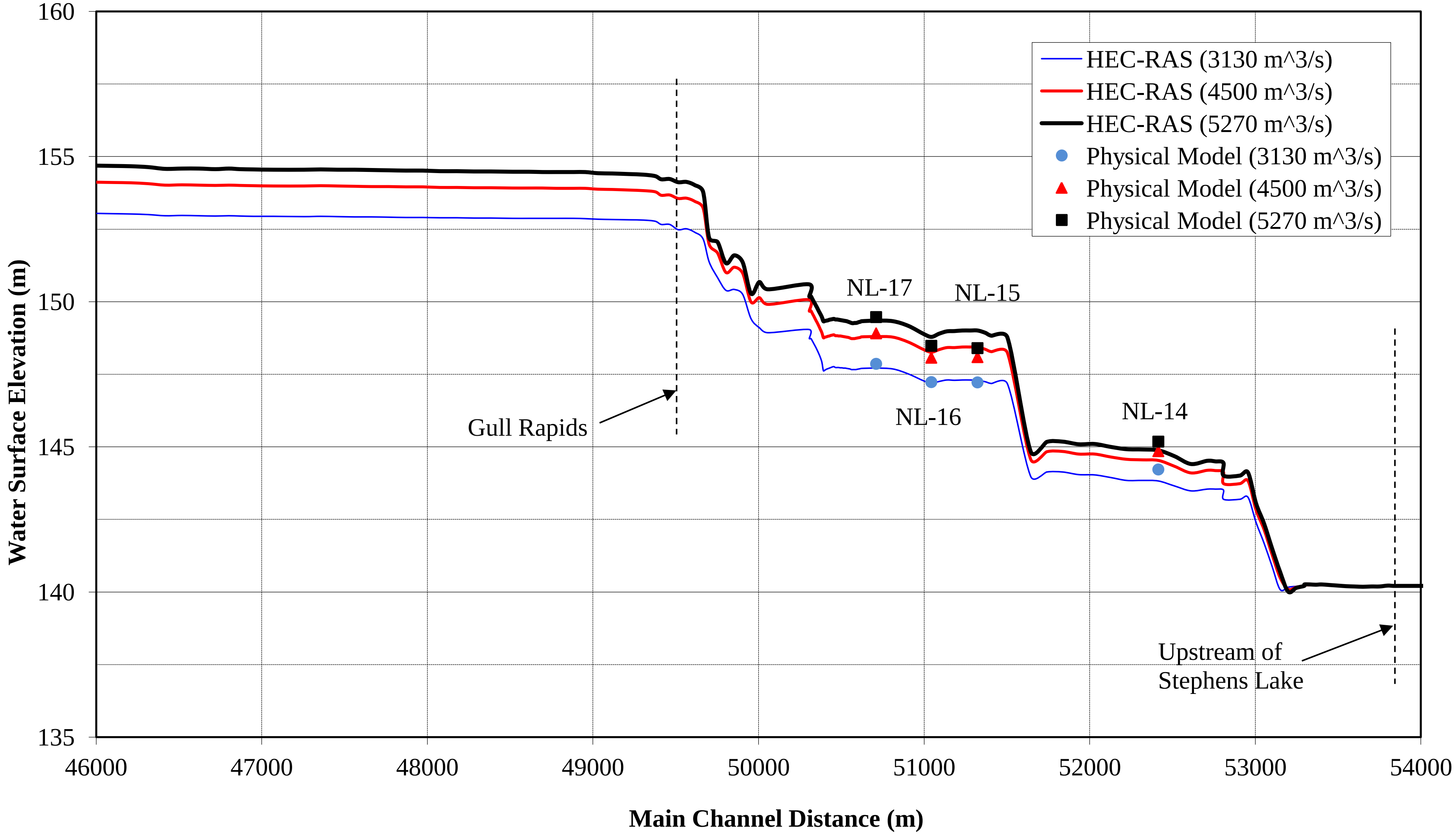


Figure 5 HEC-RAS Model Calibration Results for Stage IID Diversion (Comparison with Physical Model)

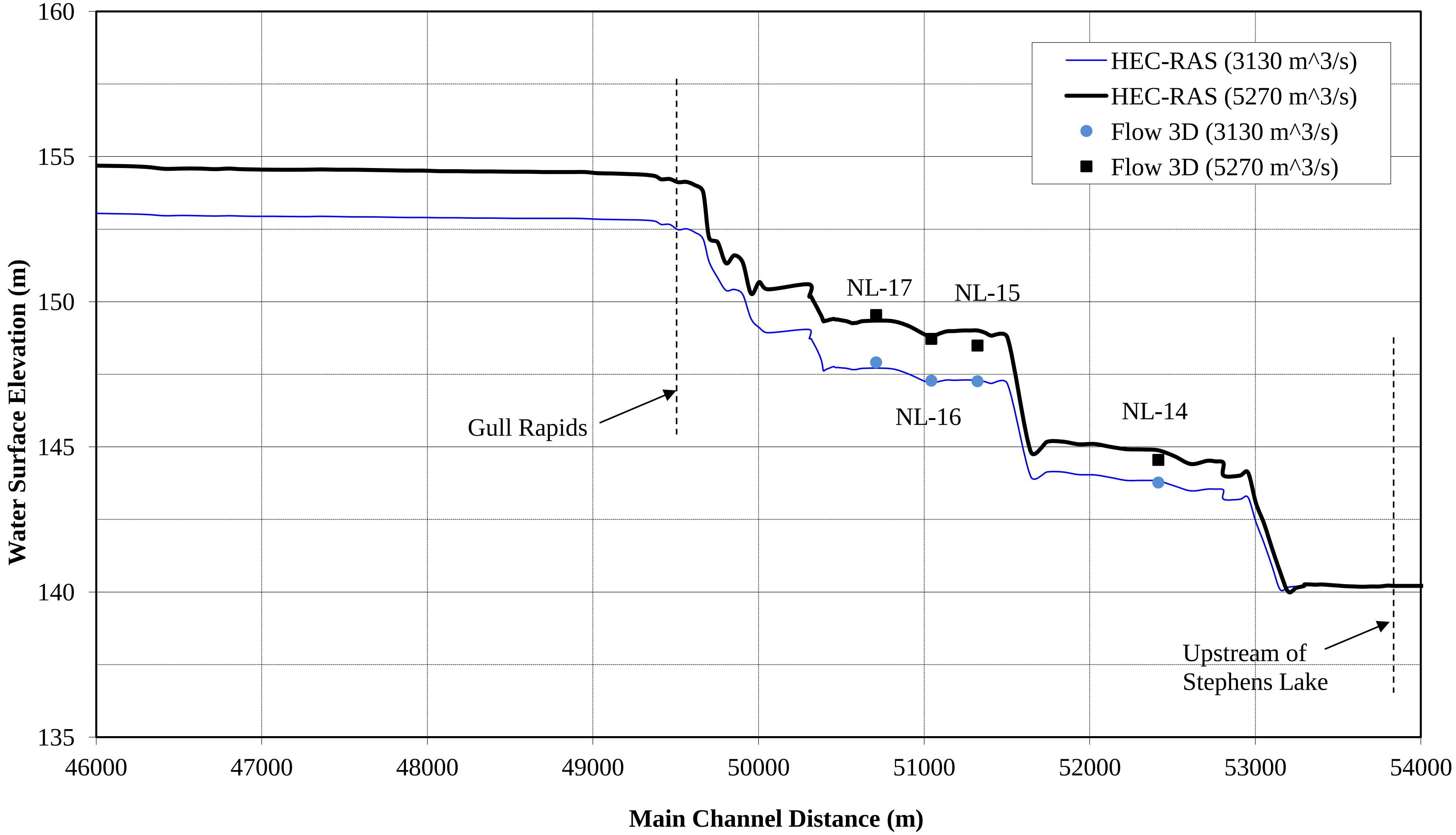


Figure 6 HEC-RAS Model Calibration Results for Stage IID Diversion (Comparison with Flow 3D)

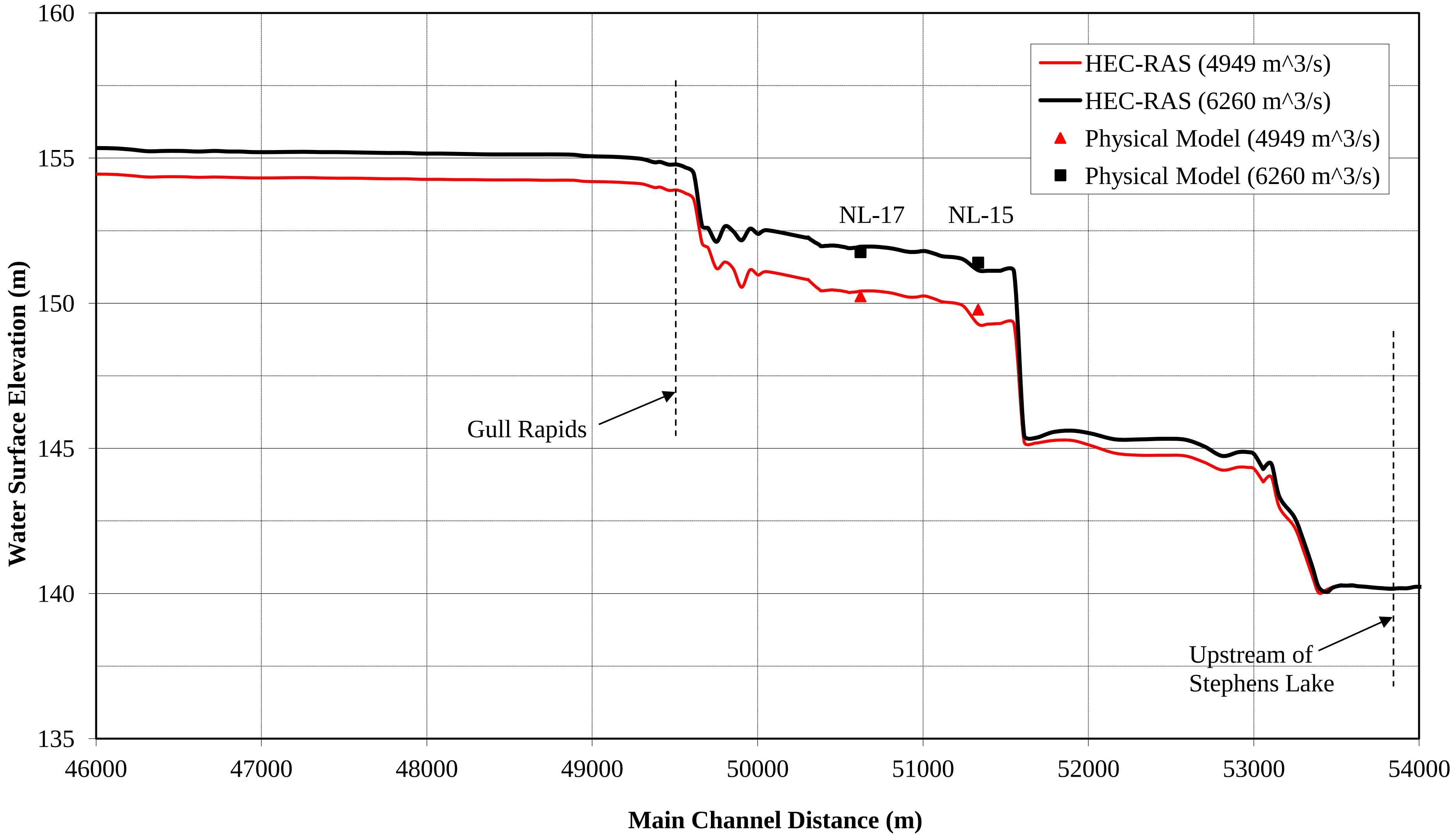


Figure 7 HEC-RAS Model Calibration Results for Stage IIA Diversion (Comparison with Physical Model)

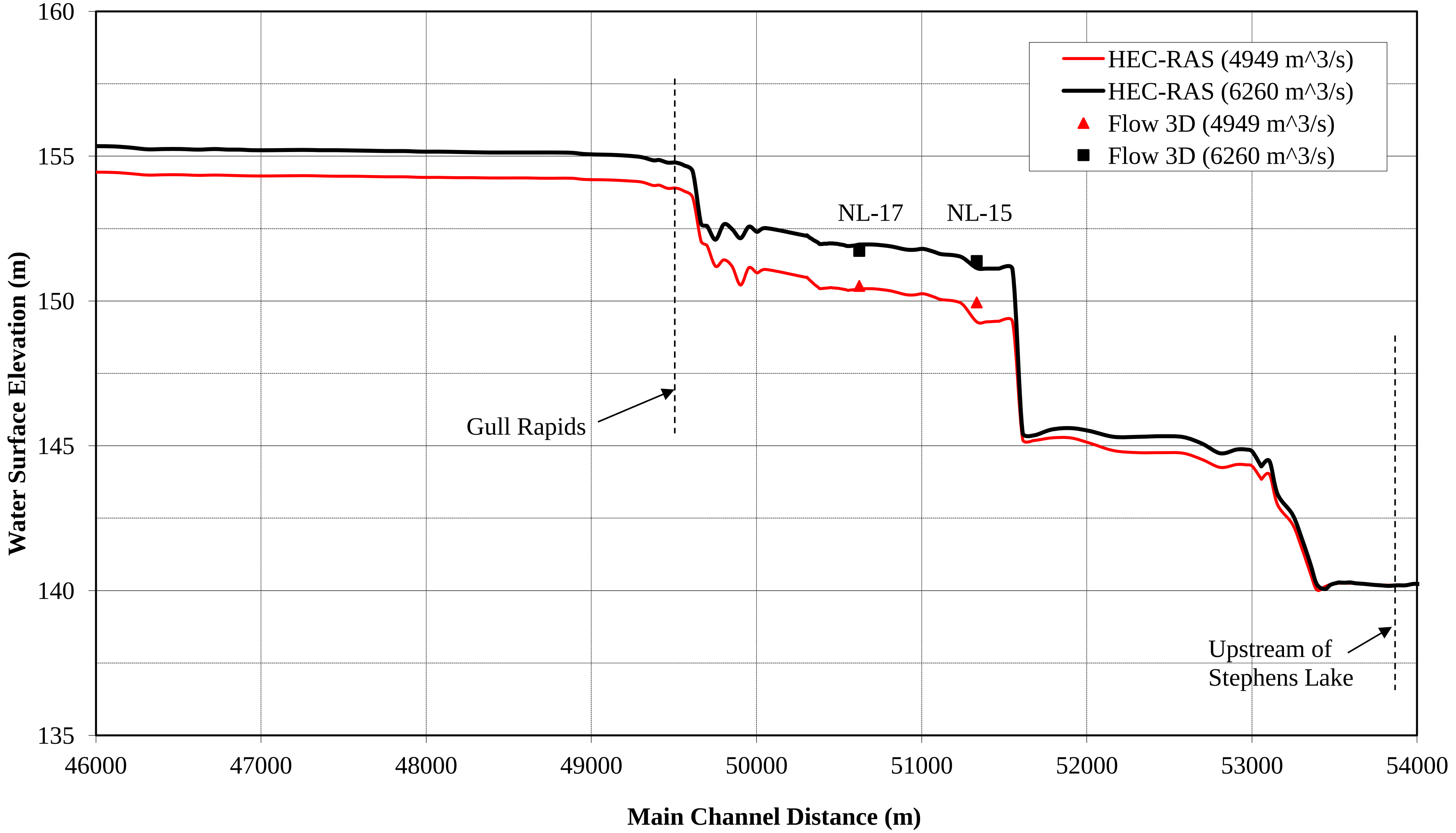


Figure 8 HEC-RAS Model Calibration Results for Stage IIA Diversion (Comparison with Flow 3D)

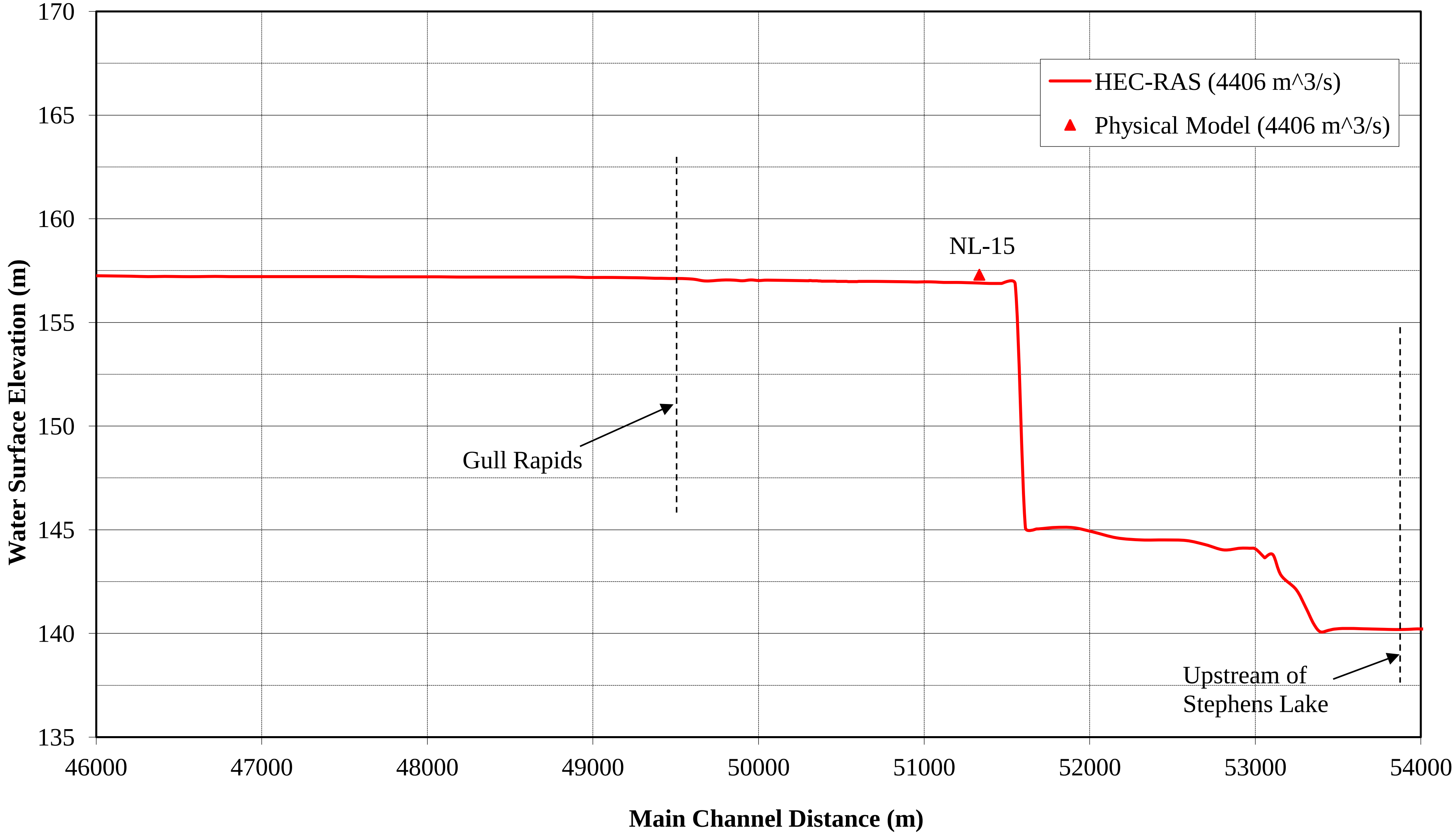


Figure 9 HEC-RAS Model Calibration Results for Stage IIB Diversion (Comparison with Physical Model)

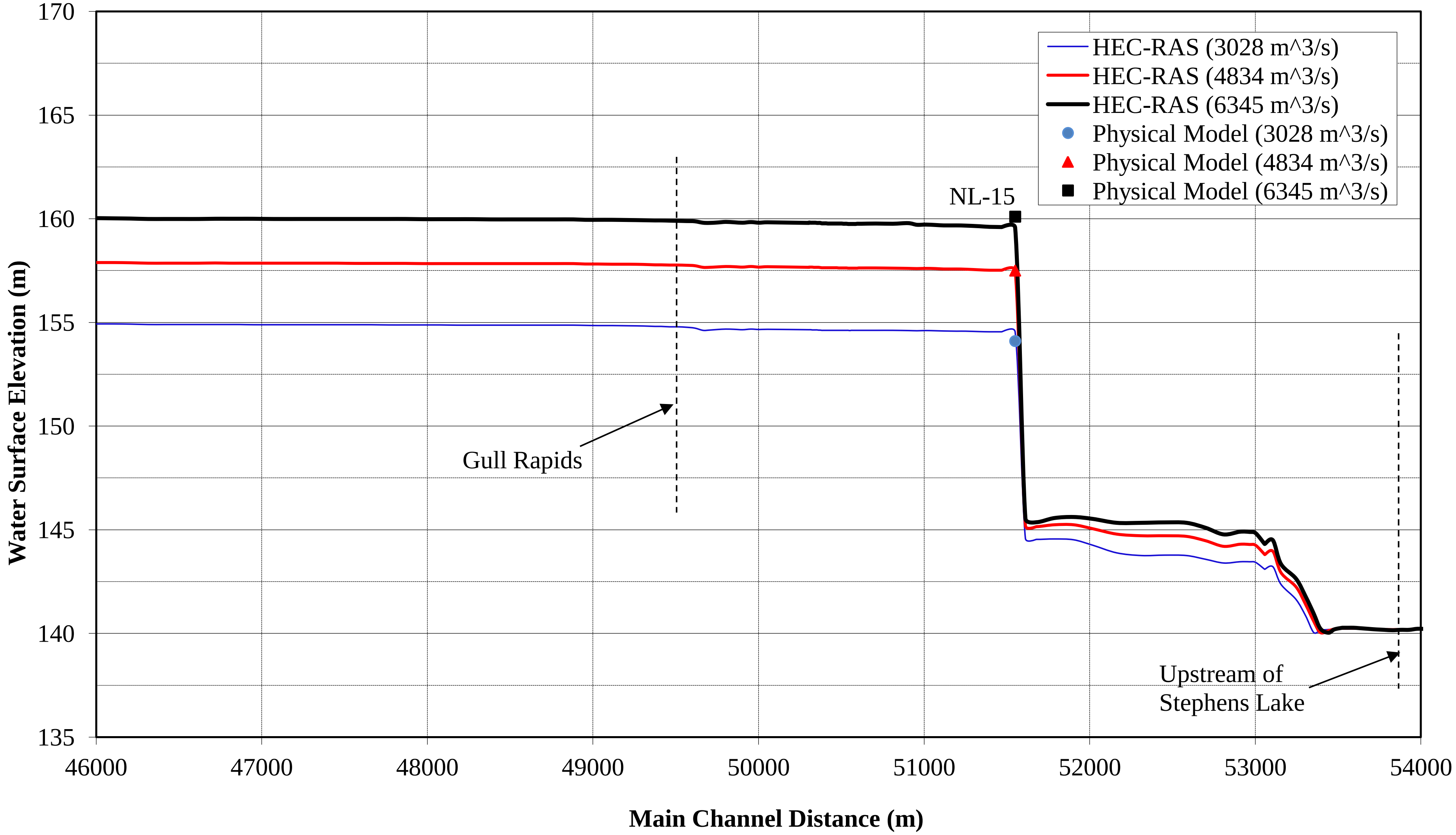


Figure 10 HEC-RAS Model Calibration Results for Stage IIB Diversion (Comparison with Physical Model)

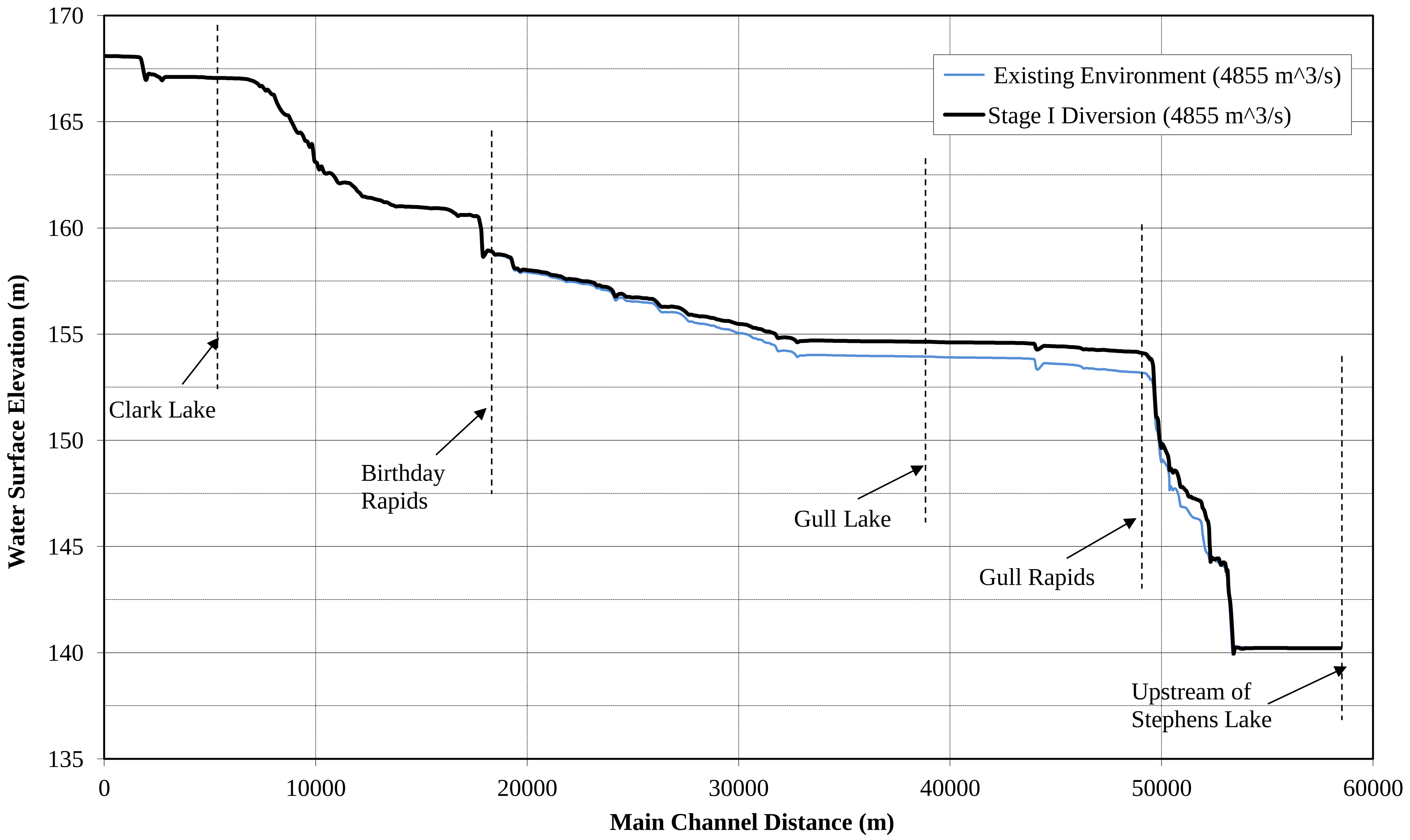


Figure 11 Water Surface Elevation in the Nelson River in Existing Environment and during Stage I Diversion (Q=4855 m^3/s)

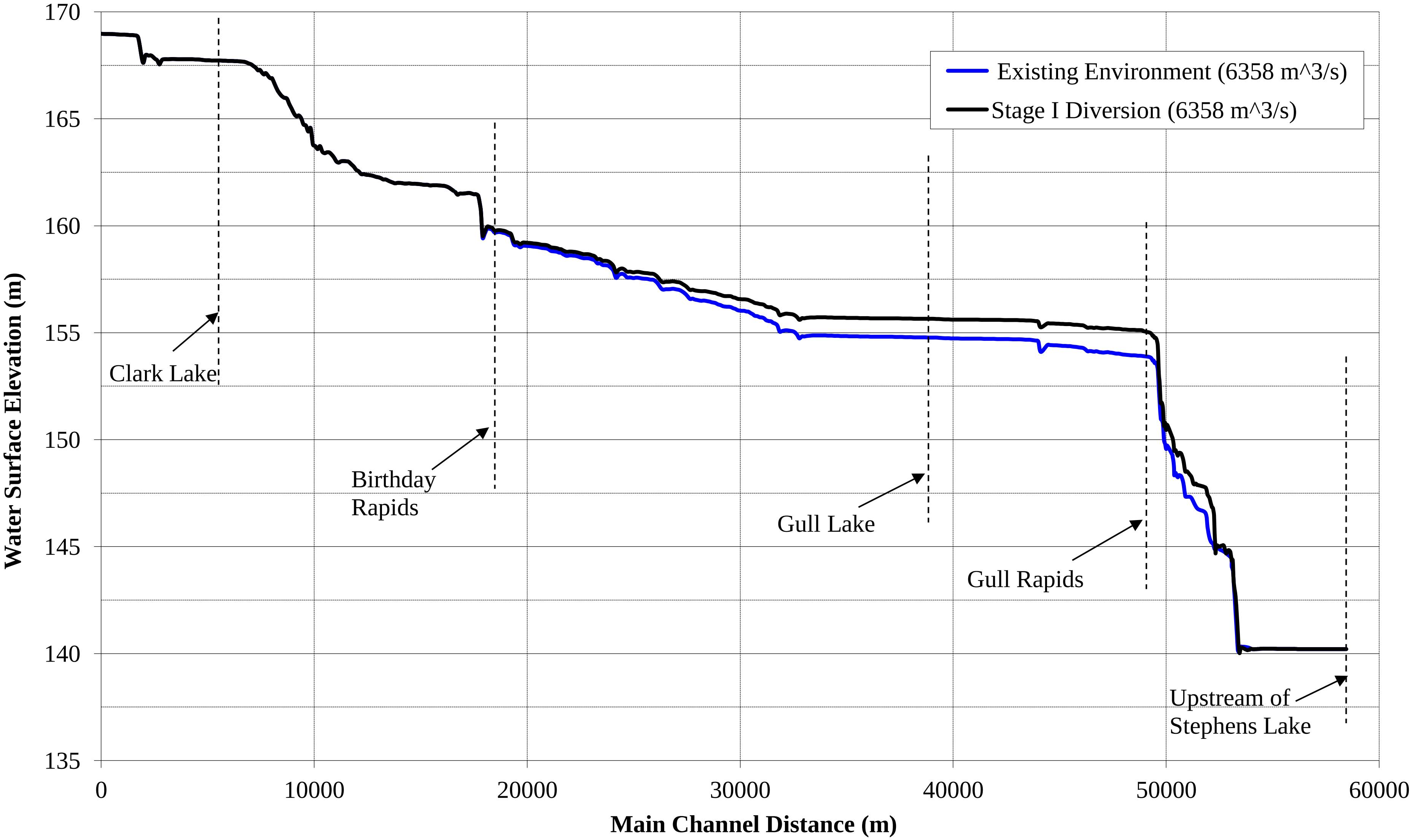
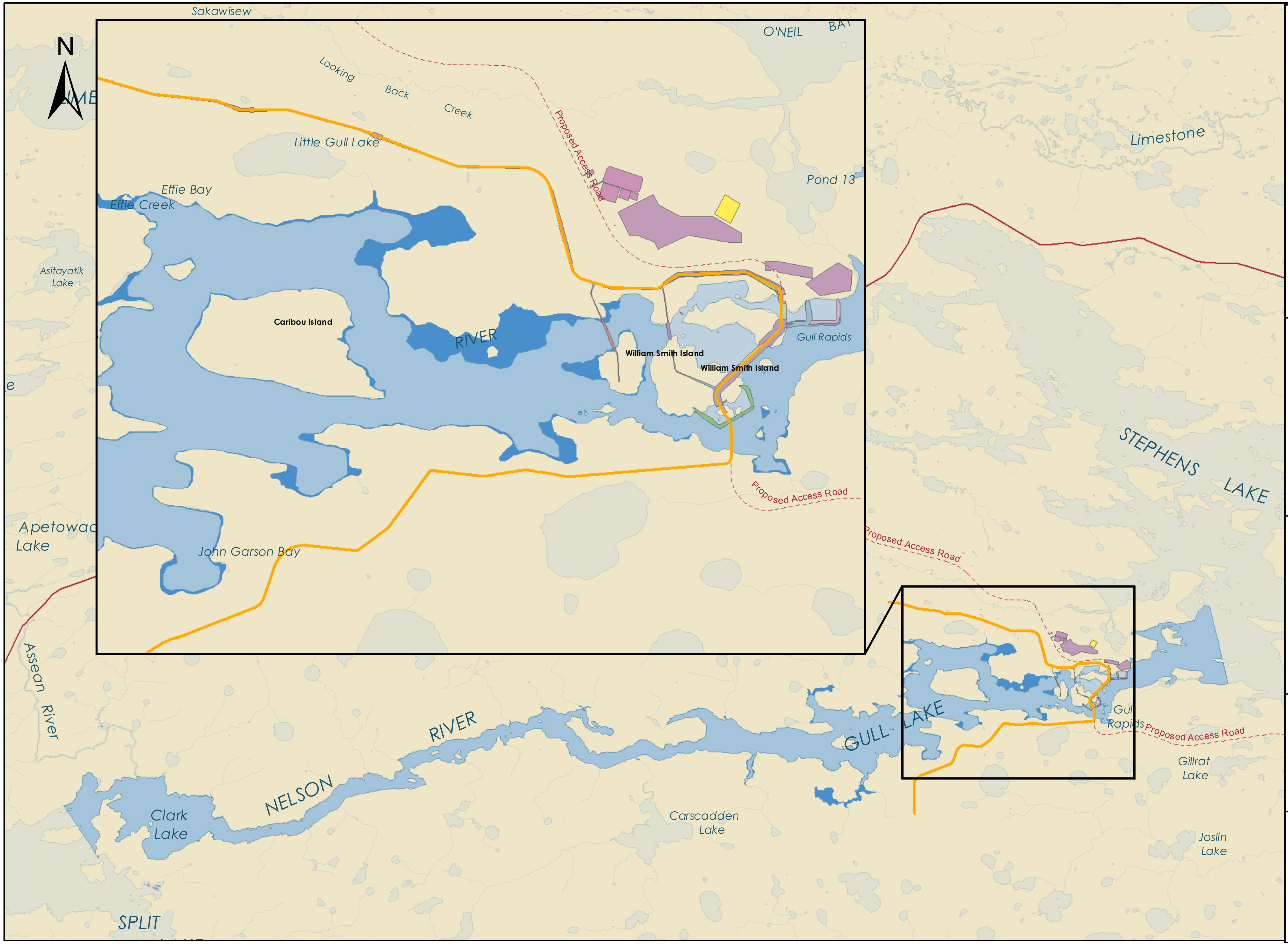


Figure 12 Water Surface Elevation in the Nelson River in Existing Environment and during Stage I Diversion (Q=6358 m^3/s)



Legend

- ▨ Pre-Construction_4855
- ▨ Stage1_4855_Rev1
- ▨ No Change

Projection: NAD 83 Zone 15N
Data Source: Manitoba Hydro
Created By: Michael Kressock
Date: 2009 12 11

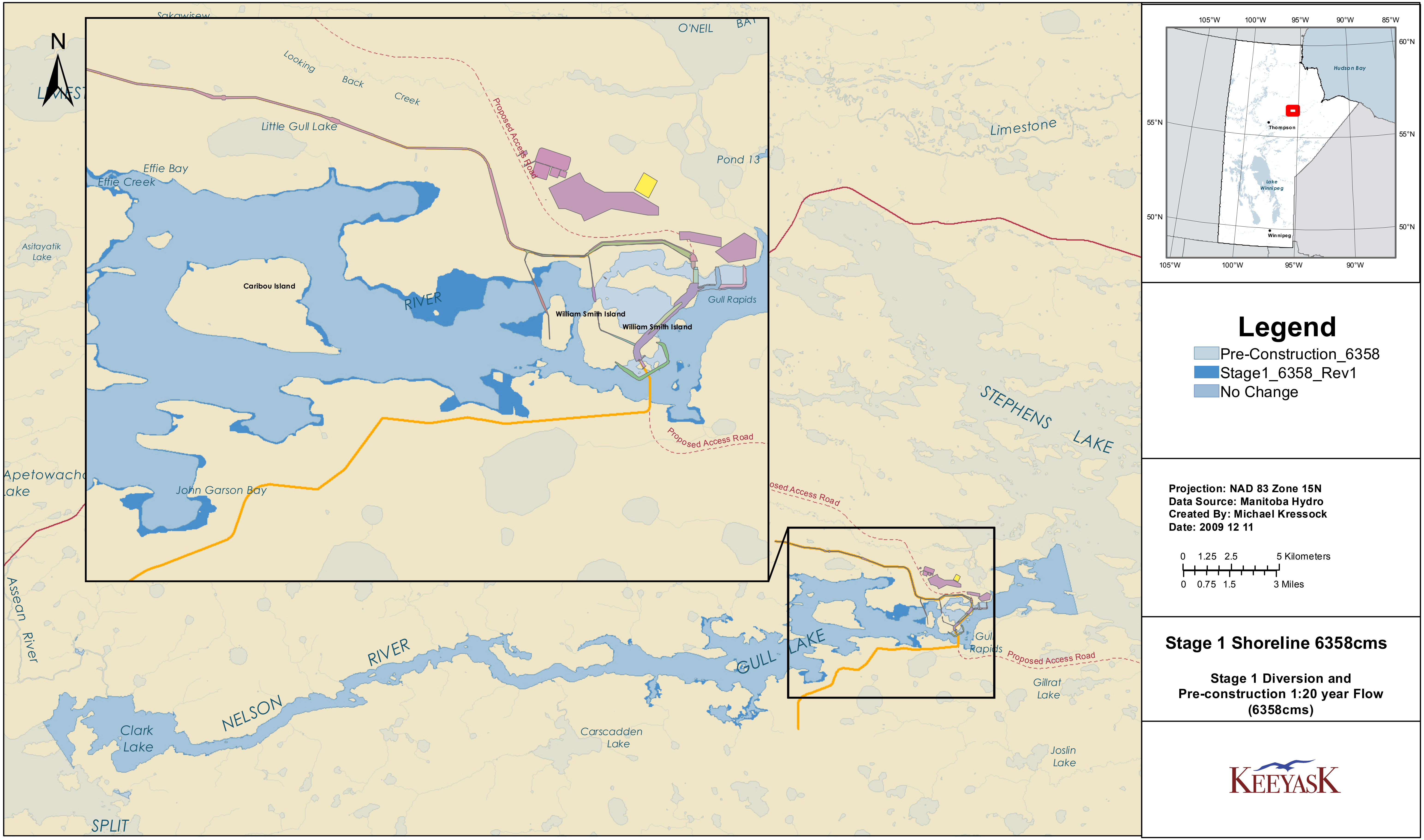
0 1.25 2.5 5 Kilometers
0 0.75 1.5 3 Miles

Stage 1 Shoreline 4855cms

Stage 1 Diversion and
Pre-construction 95% Flow
(4855cms)

KEEYASK

Figure 13



Legend

- Pre-Construction_6358
- Stage1_6358_Rev1
- No Change

Projection: NAD 83 Zone 15N
Data Source: Manitoba Hydro
Created By: Michael Kressock
Date: 2009 12 11

Stage 1 Shoreline 6358cms

Stage 1 Diversion and
Pre-construction 1:20 year Flow
(6358cms)

KEEYASK

Figure 14

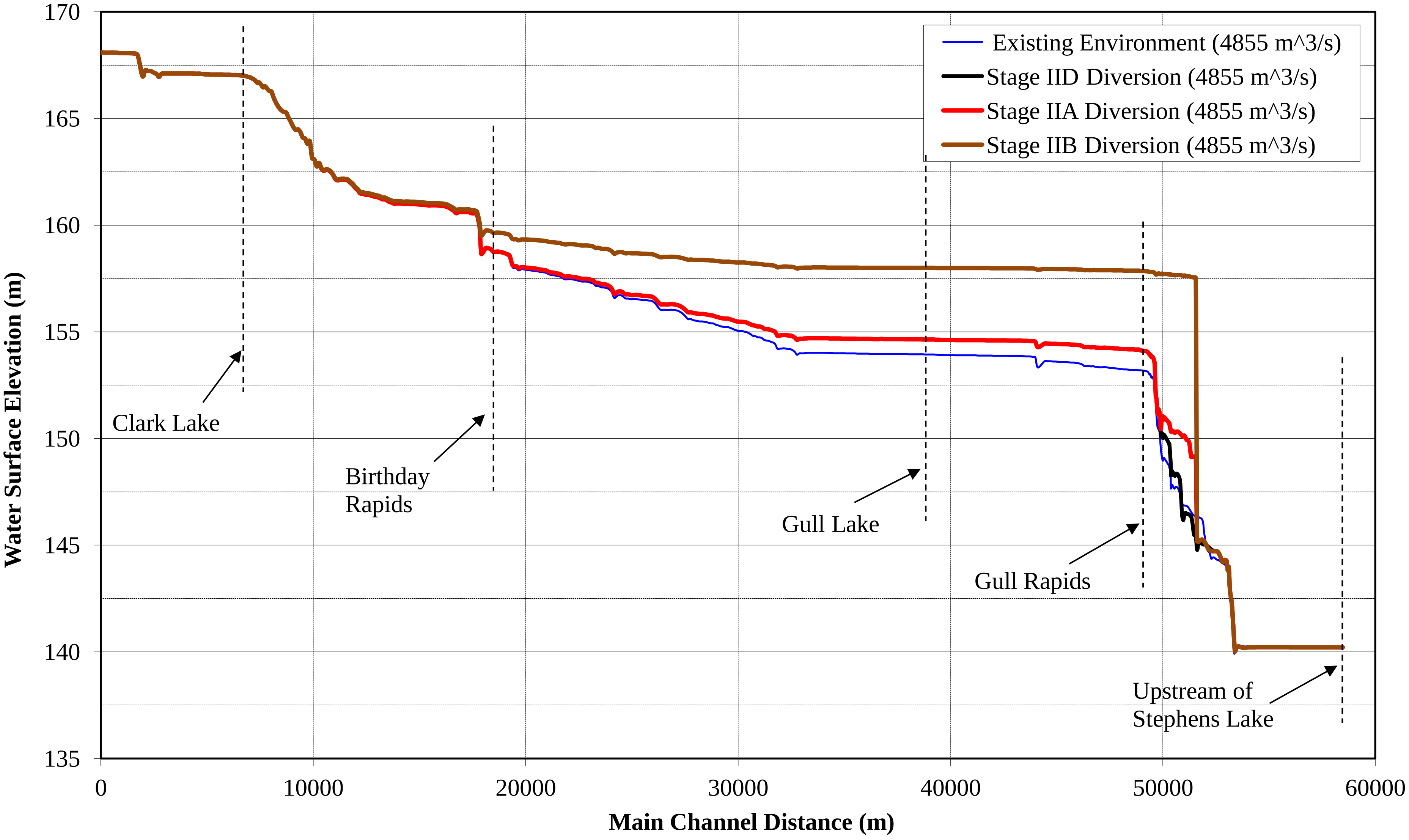


Figure 15 Water Surface Elevation in the Nelson River in Existing Environment and during Stage II Diversion (Q=4855 m^3/s)

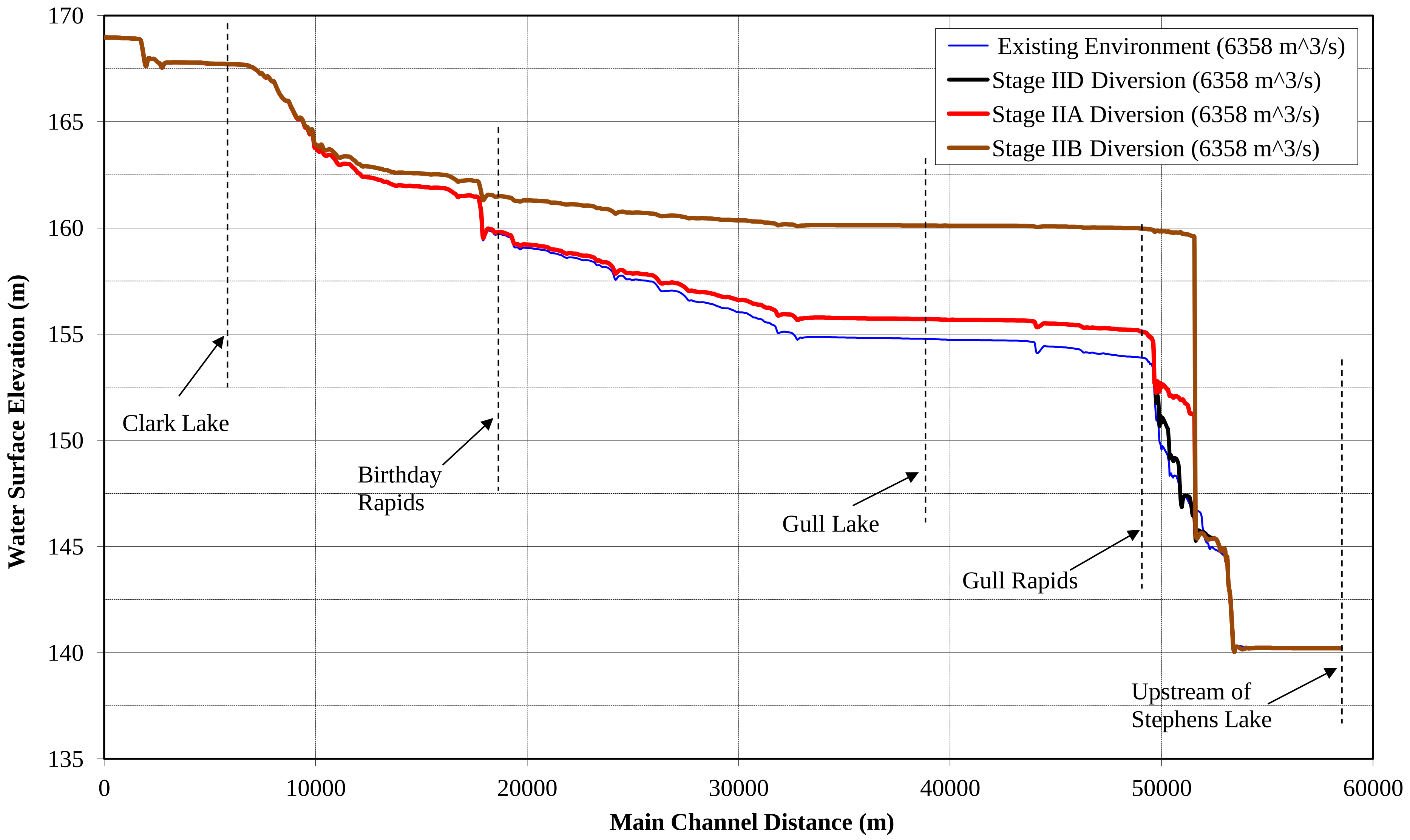
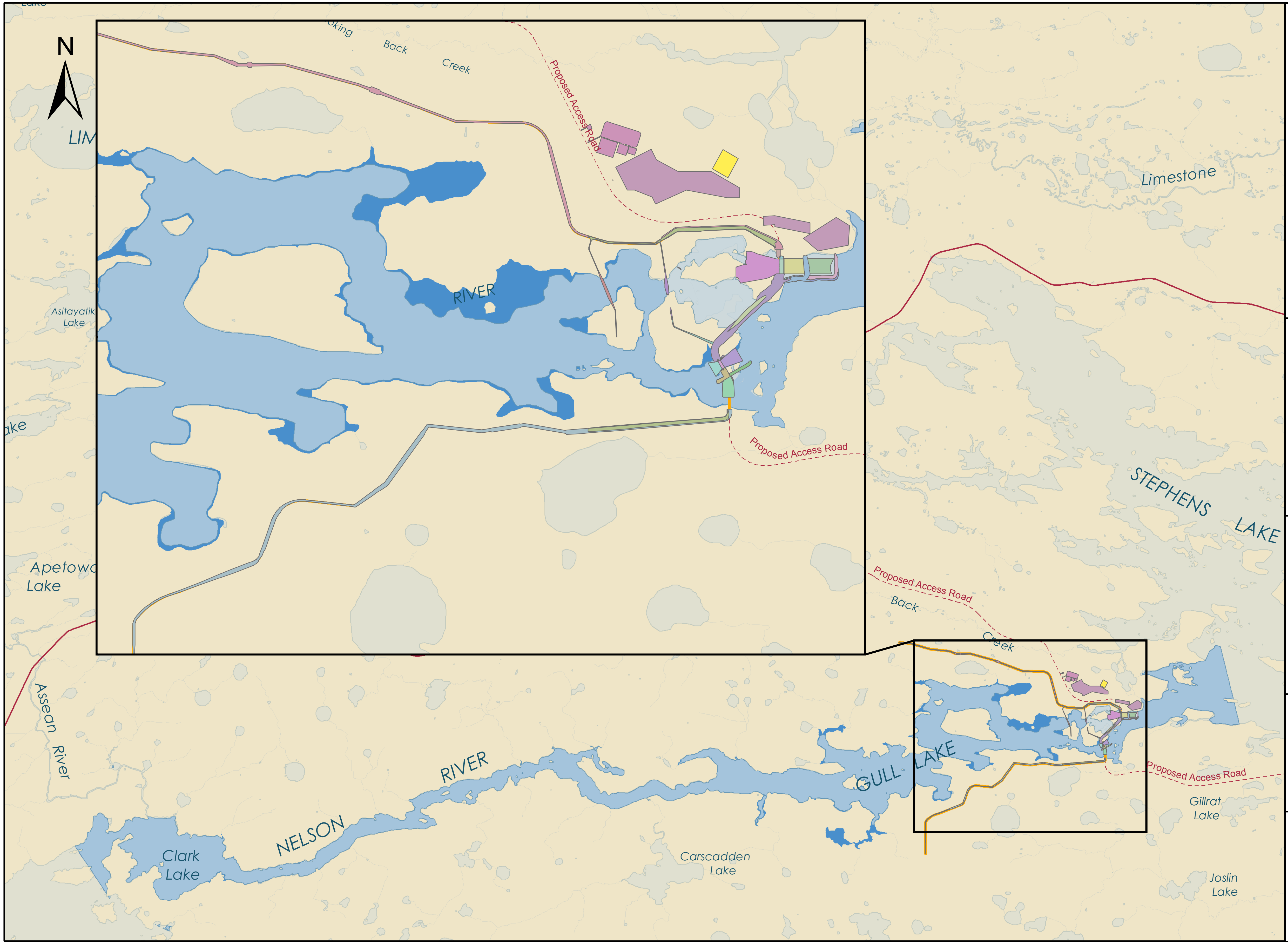


Figure 16 Water Surface Elevation in the Nelson River in Existing Environment and during Stage II Diversion (Q=6358 m^3/s)



Legend

- ▨ Existing Environment
- ▨ Stage IID
- ▨ No Change

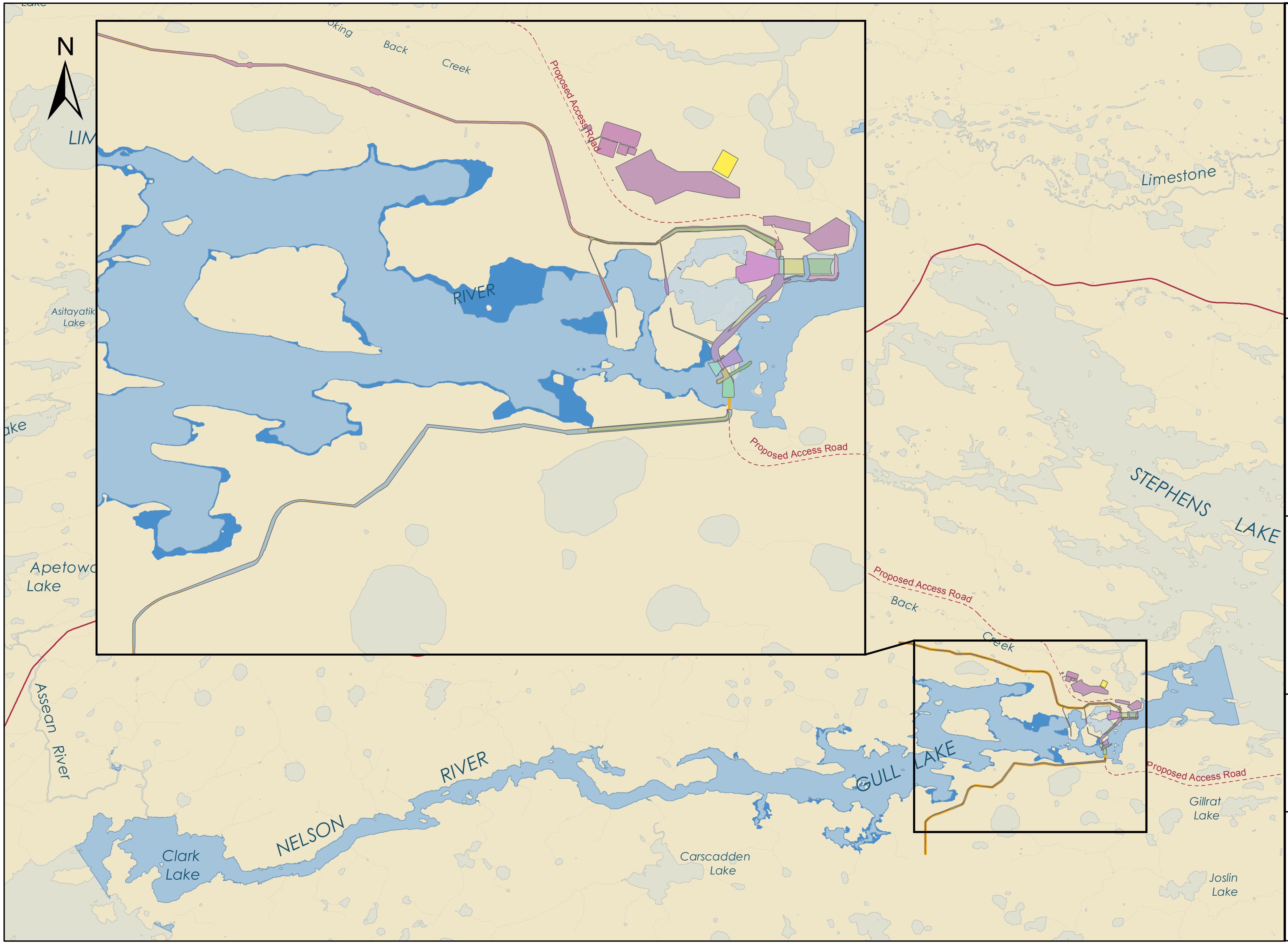
Projection: NAD 83 Zone 15N
Data Source: Manitoba Hydro

0 1.25 2.5 5 Kilometers
0 1 2 4 Miles

Flooded Area During Stage IID Diversion - 95% flow (4855m^3/s)

KEEYASK
Hydropower Limited Partnership

Figure 17



Legend

- ▨ Existing Environment
- ▨ Stage IID
- ▨ No Change

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

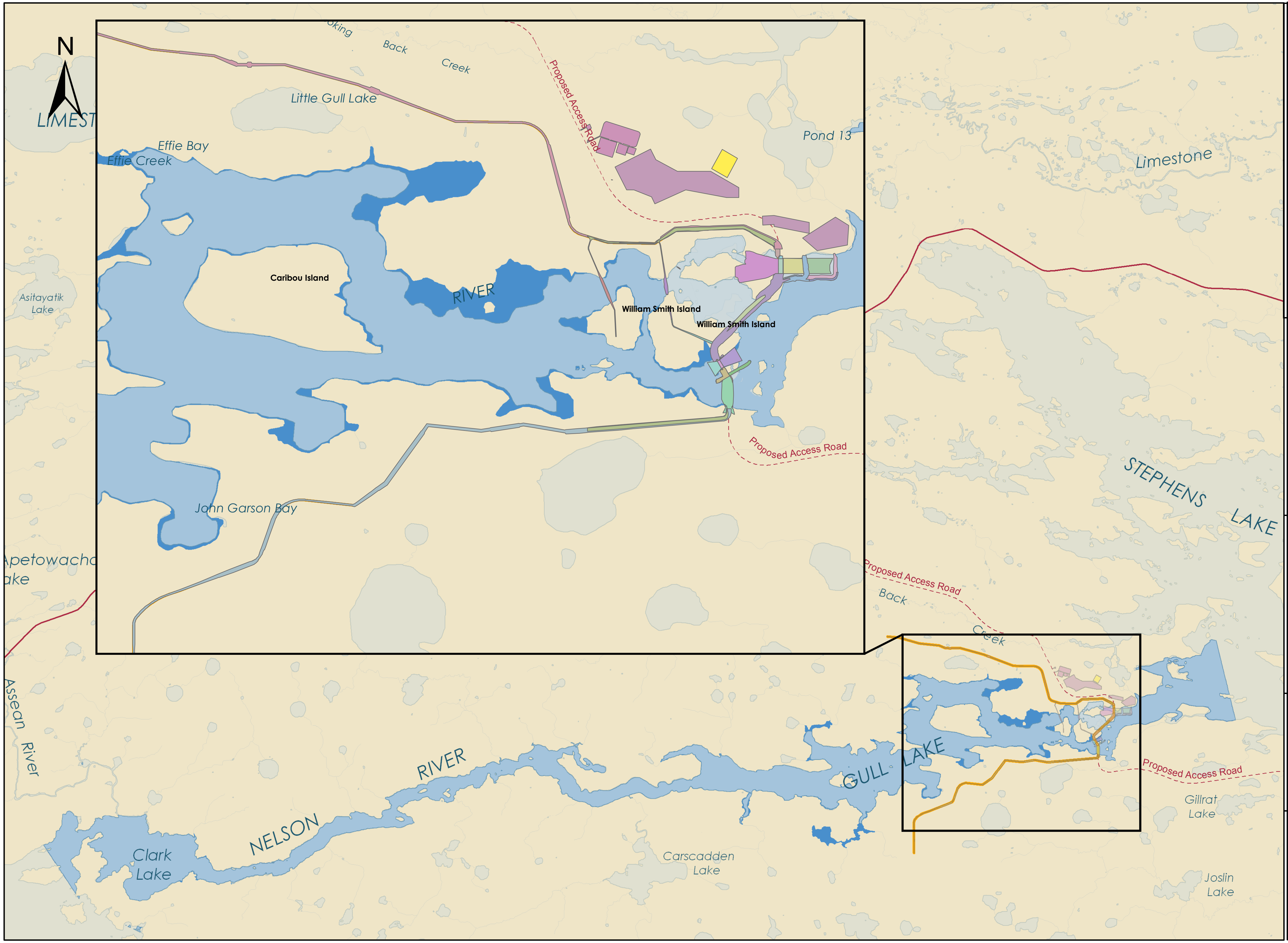
0 1.25 2.5 5 Kilometers
0 1 2 4 Miles

Flooded Area During Stage IID

Diversion - 1:20 year Flood Flow (6358m^3/s)

KEEYASK
Hydropower Limited Partnership

Figure 18



Legend

▭ Existing Environment
■ Stage IIA
■ No Change

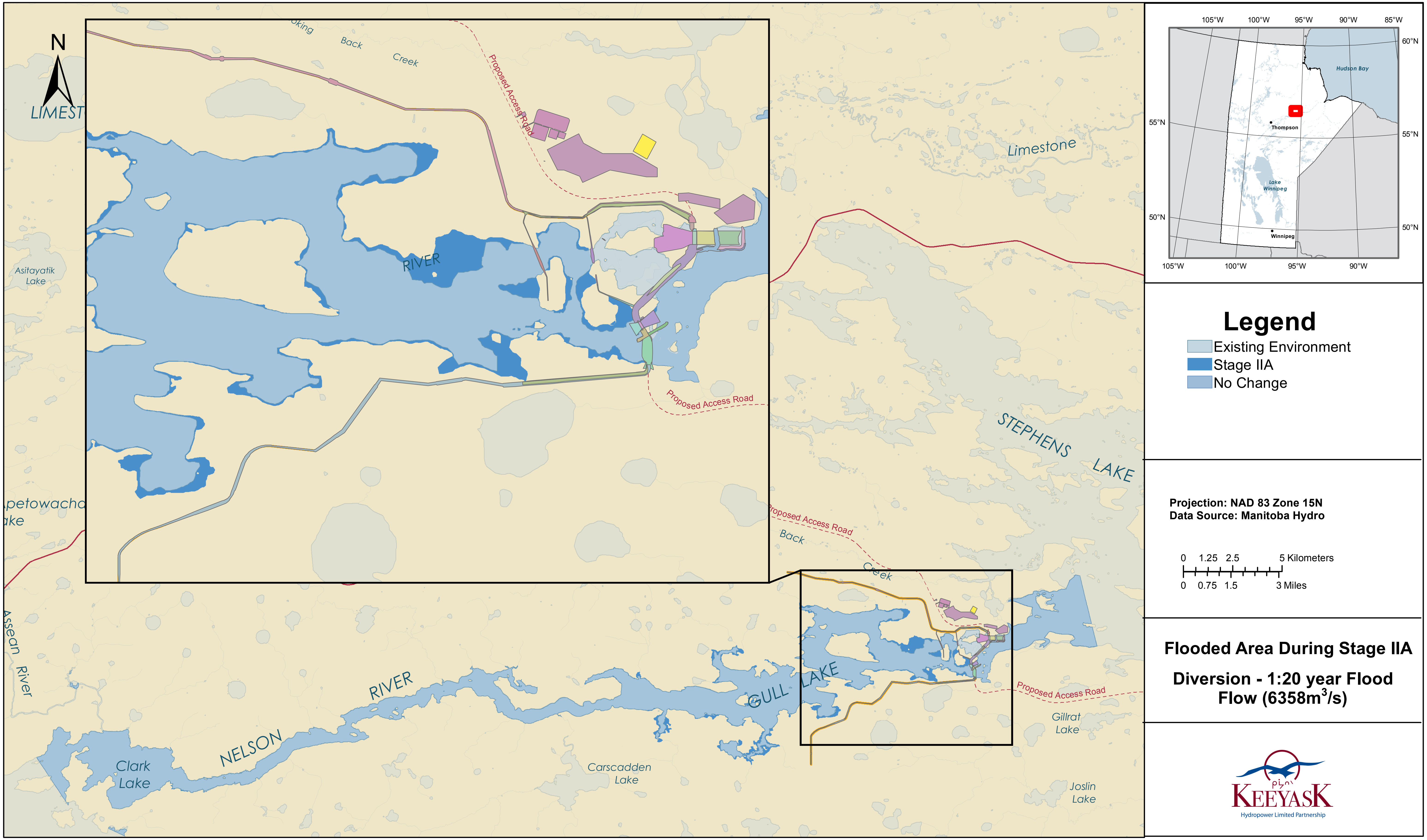
Projection: NAD 83 Zone 15N
Data Source: Manitoba Hydro

0 1.25 2.5 5 Kilometers
0 0.75 1.5 3 Miles

Flooded Area during Stage IIA Diversion - 95% Flow (4855m^{3}s)

KEEYASK
Hydropower Limited Partnership

Figure 19



Legend

▨ Existing Environment
▨ Stage IIA
▨ No Change

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

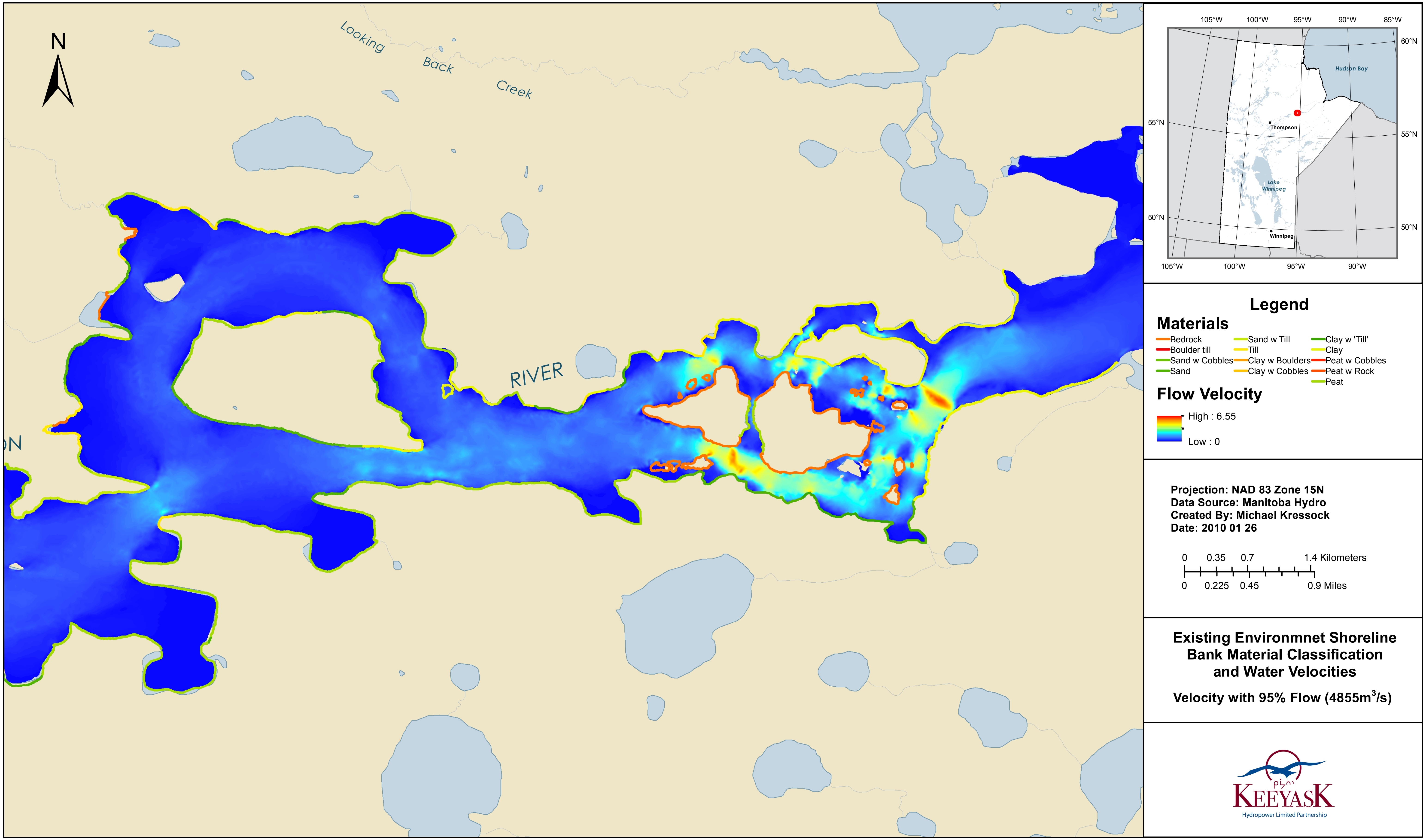
0 1.25 2.5 5 Kilometers
0 0.75 1.5 3 Miles

Flooded Area During Stage IIA

Diversion - 1:20 year Flood Flow (6358m^3/s)

KEEYASK
Hydropower Limited Partnership

Figure 20



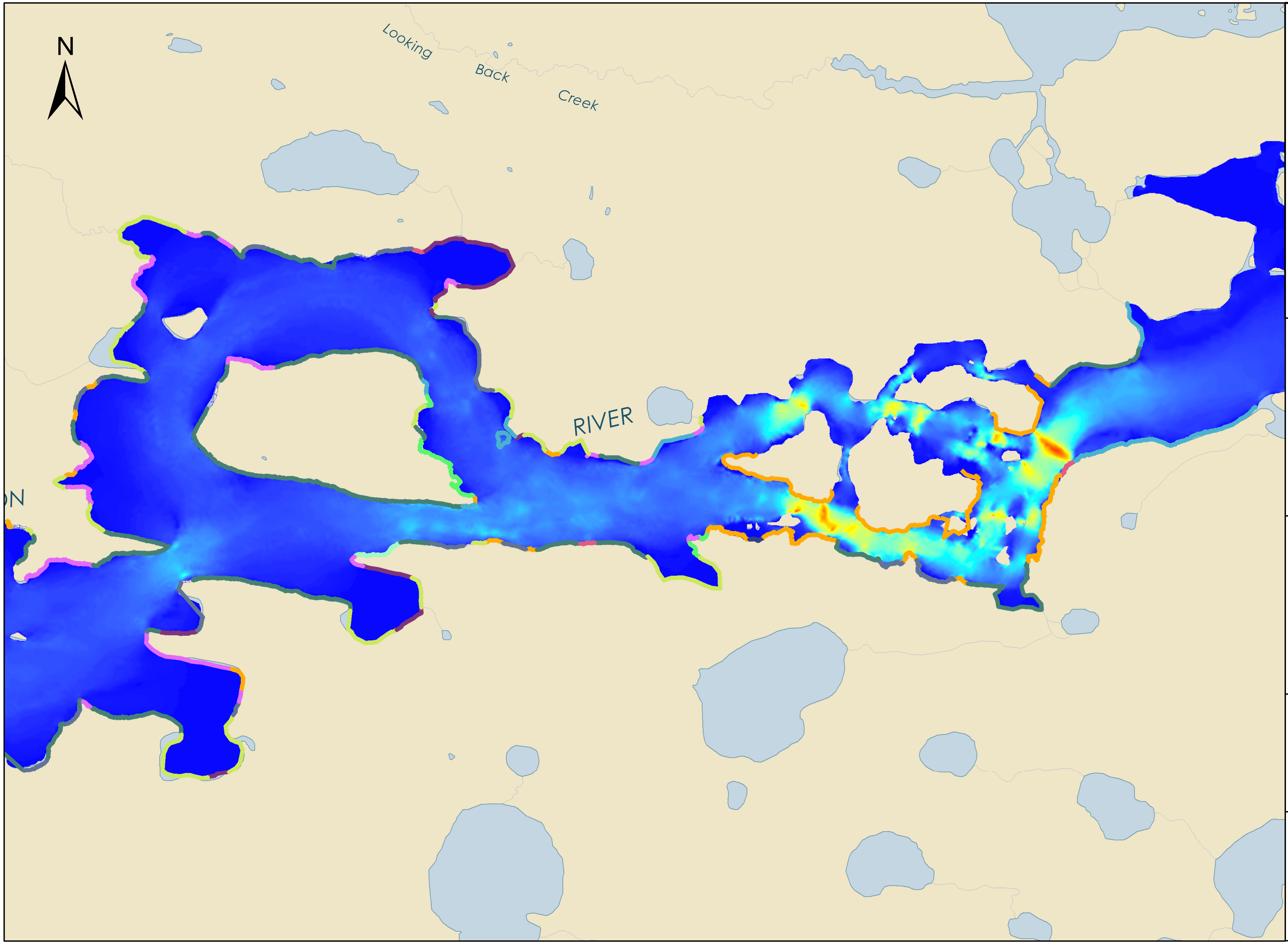
Projection: NAD 83 Zone 15N
Data Source: Manitoba Hydro
Created By: Michael Kressock
Date: 2010 01 26

Existing Environmnet Shoreline Bank Material Classification and Water Velocities

Velocity with 95% Flow (4855m^3/s)

KEEYASK
Hydropower Limited Partnership

Figure 21



Legend

Materials

- Bedrock
- Boulders
- Clay
- Clay with Boulders
- Clay with Cobbles
- Clay with Gravel
- Clay with Rock
- Clay with Till
- Cobbles
- Gravel
- Peat
- Peat with Cobbles
- Peat with Cobbles & Boulders
- Sand
- Sand with Cobbles

Flow Velocity

High : 6.55

Low : 0

Projection: NAD 83 Zone 15N
Data Source: Manitoba Hydro
Created By: Michael Kressock
Date: 2010 01 26

0 0.35 0.7 1.4 Kilometers

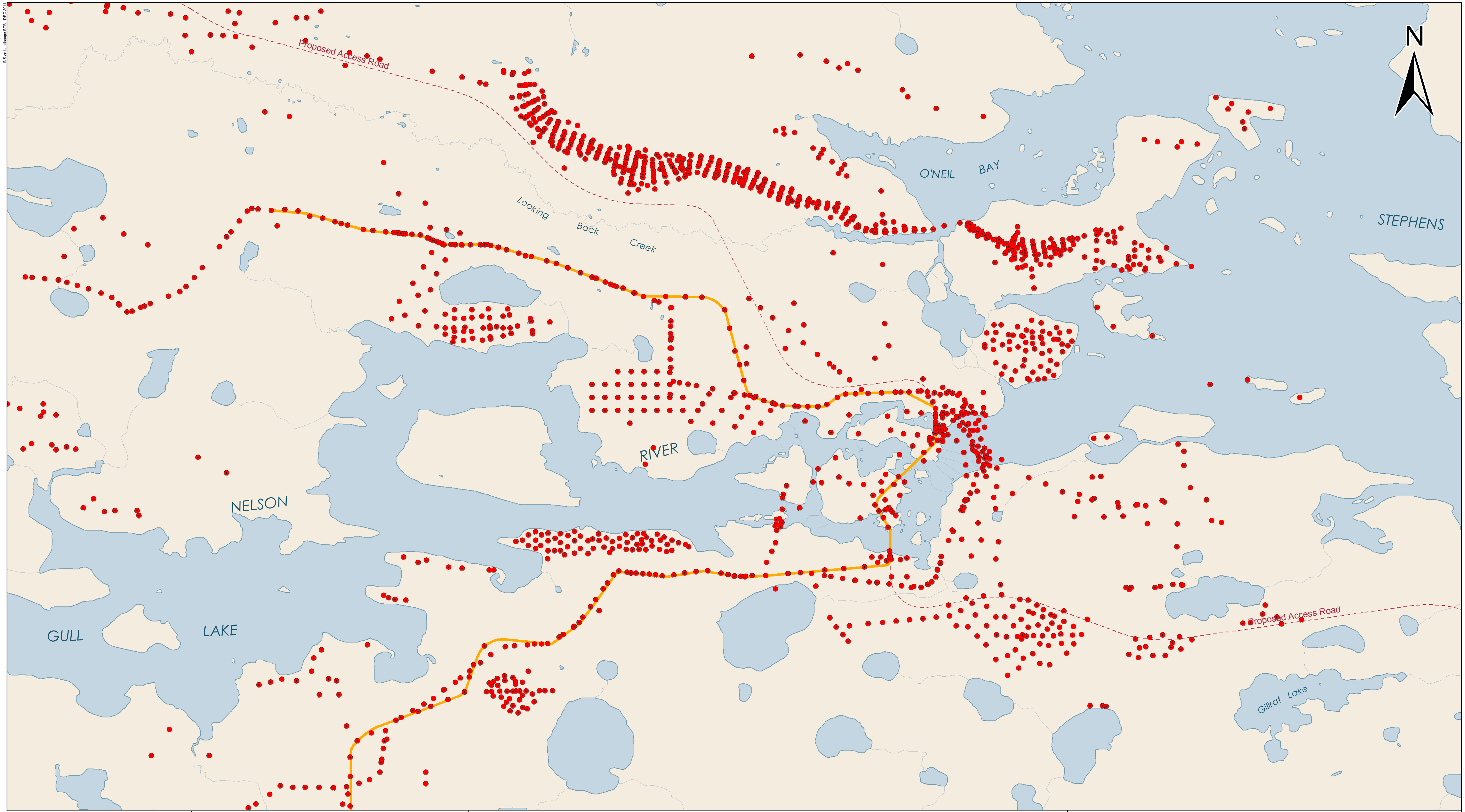
0 0.225 0.45 0.9 Miles

Existing Environmnet Shoreline Beach Material Classification and Water Velocities

Velocity with 95% Flow (4855m^3/s)

KEEYASK
Hydropower Limited Partnership

Figure 22



KEEYASK
Hydropower Limited Partnership

DATA SOURCE:
Manitoba Hydro

CREATED BY:
Hydro Power Planning

COORDINATE SYSTEM:
UTM NAD 1983 Z15N

DATE CREATED:
06-AUG-09

REVISION DATE:
25-FEB-13

0 0.6 1.2 Kilometres
0 0.55 1.1 Miles

VERSION NO:
1.0

QA/QC:
25-FEB-13

Legend

- ● Borehole Locations
- Keeyask Principal Infrastructure Axis

Keeyask Project
Temporary Borehole Locations

Figure 23

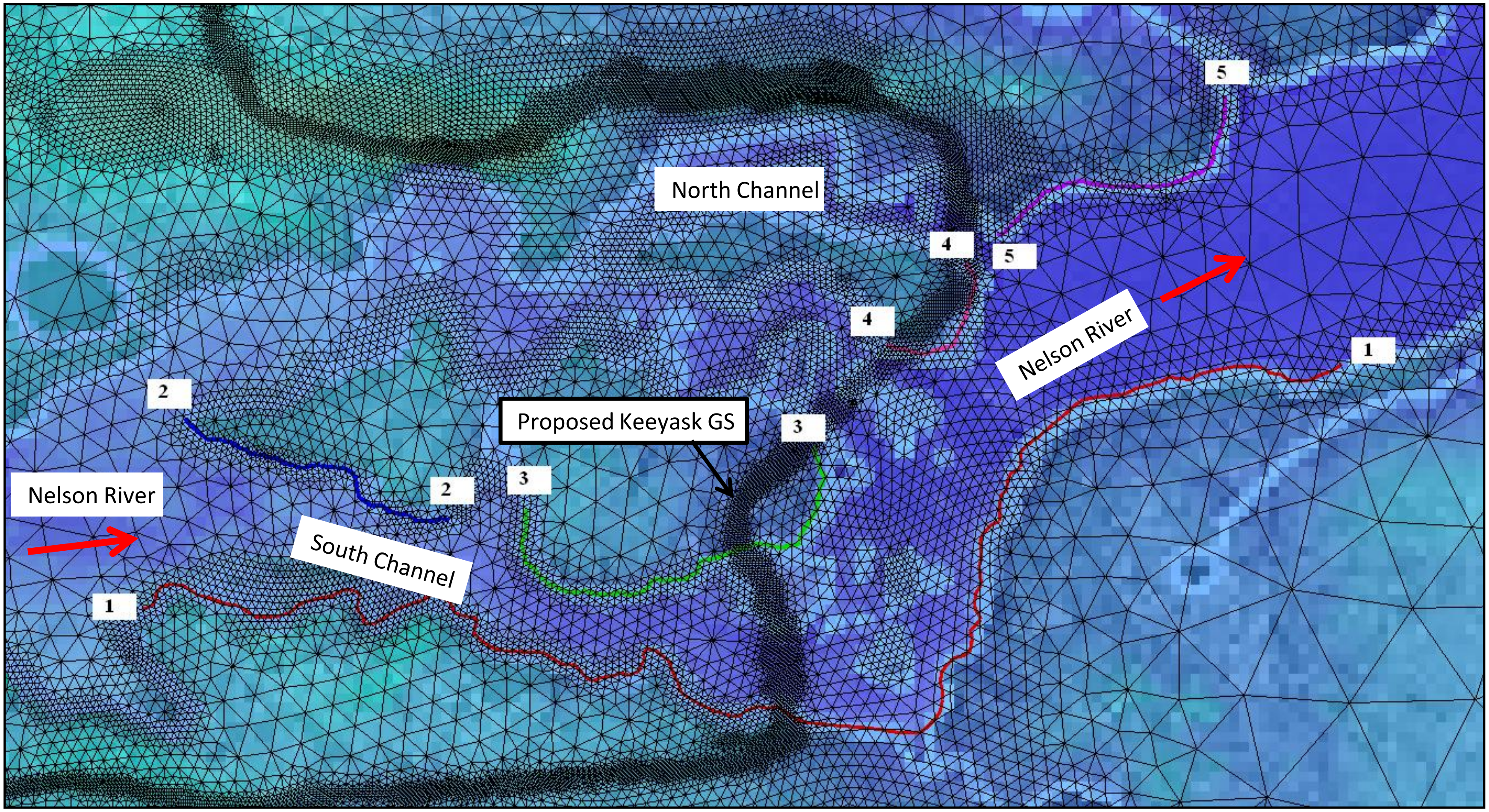


Figure 24 Location of longitudinal profiles in the groundwater model to estimate the thickness of the overburden in the study area

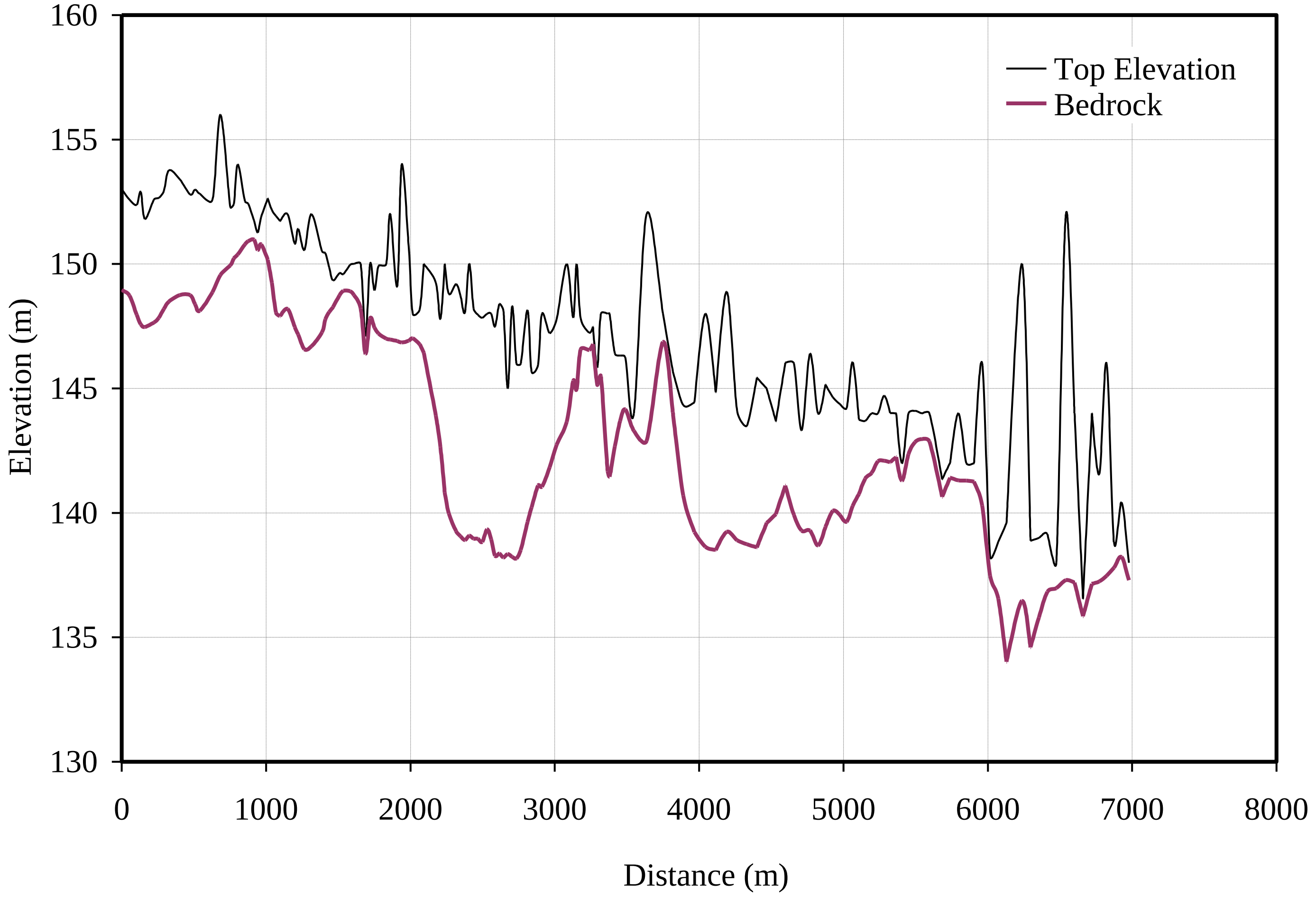


Figure 25 Cross-sectional profile of bedrock and ground surface elevation at location 1-1 (see Figure 24 for location of this profile).

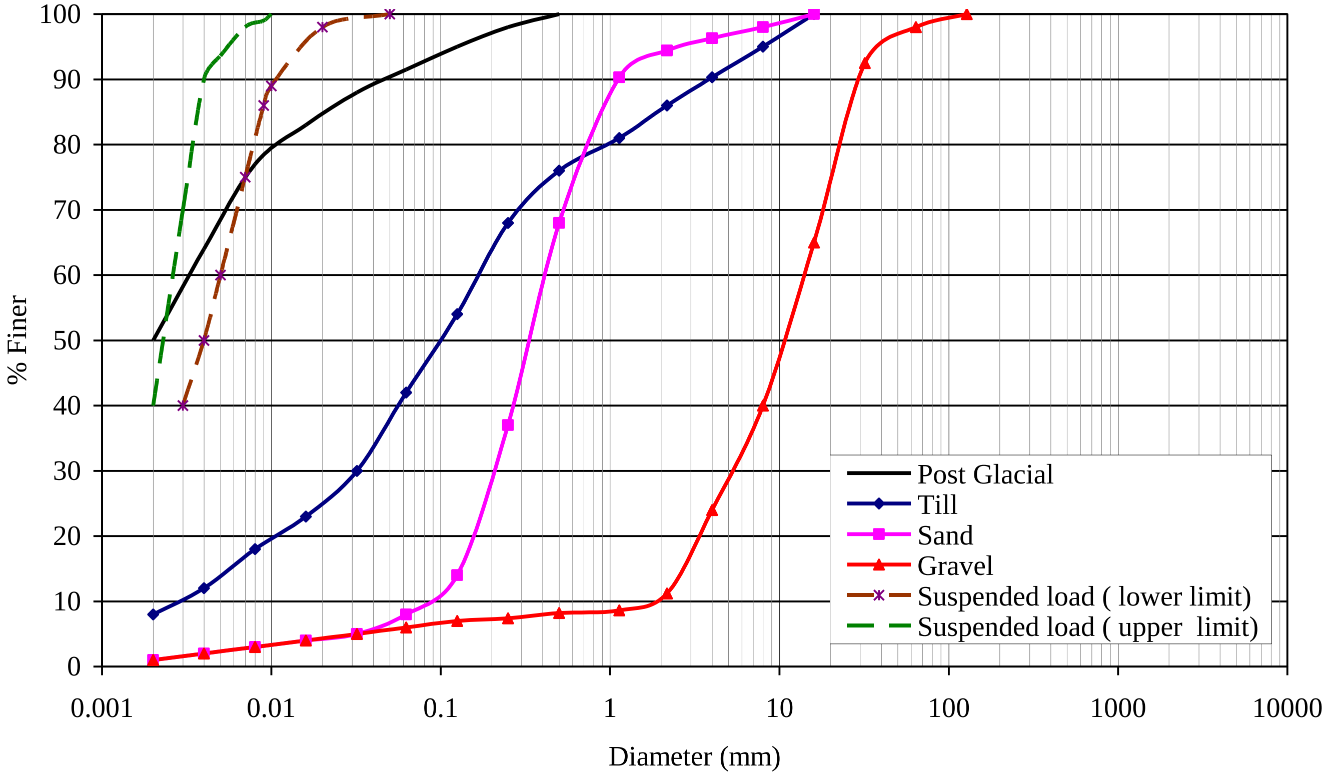


Figure 26 Gradation curves of shoreline materials and suspended load in the study reach of the Nelson River.

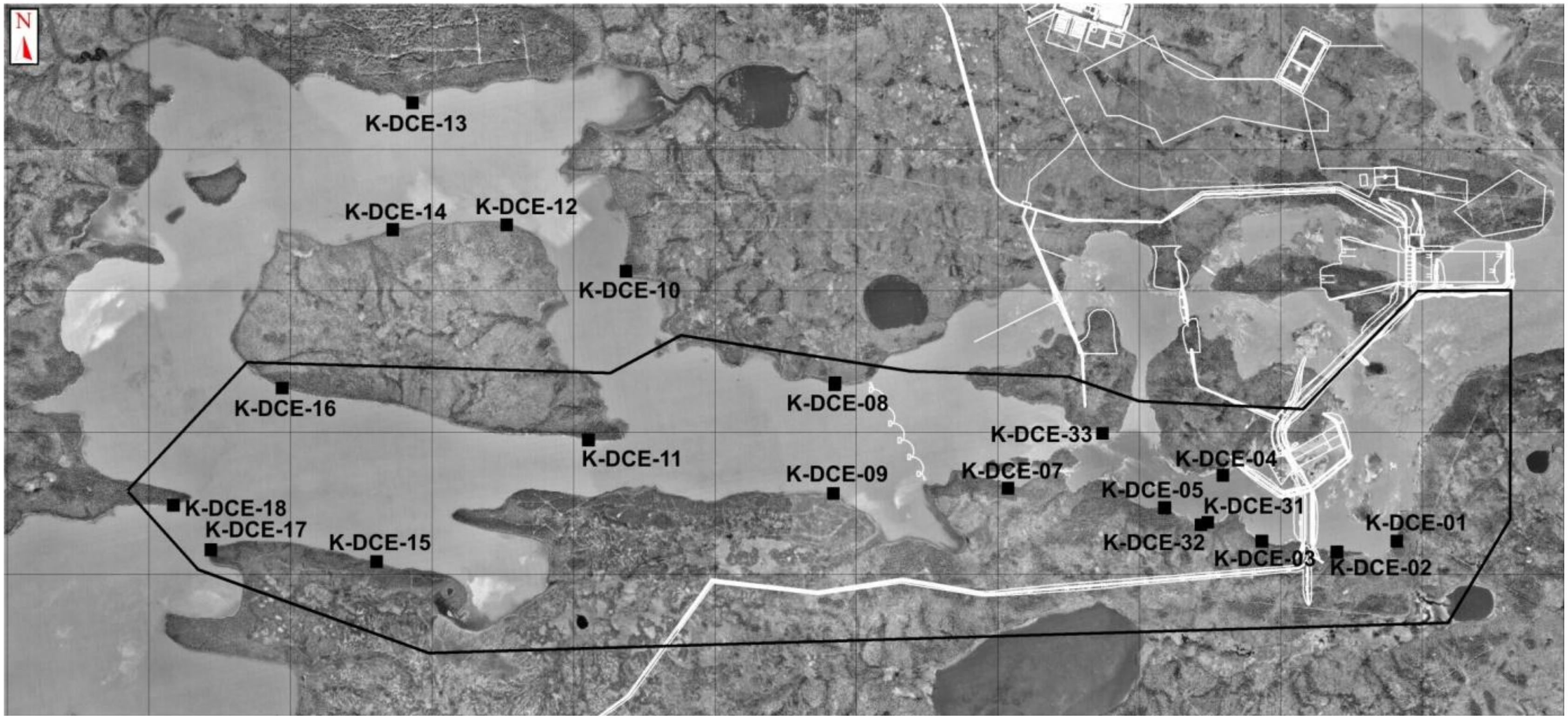


Figure 27 Location of shoreline soil gradation sample sites (summer 2009 program).

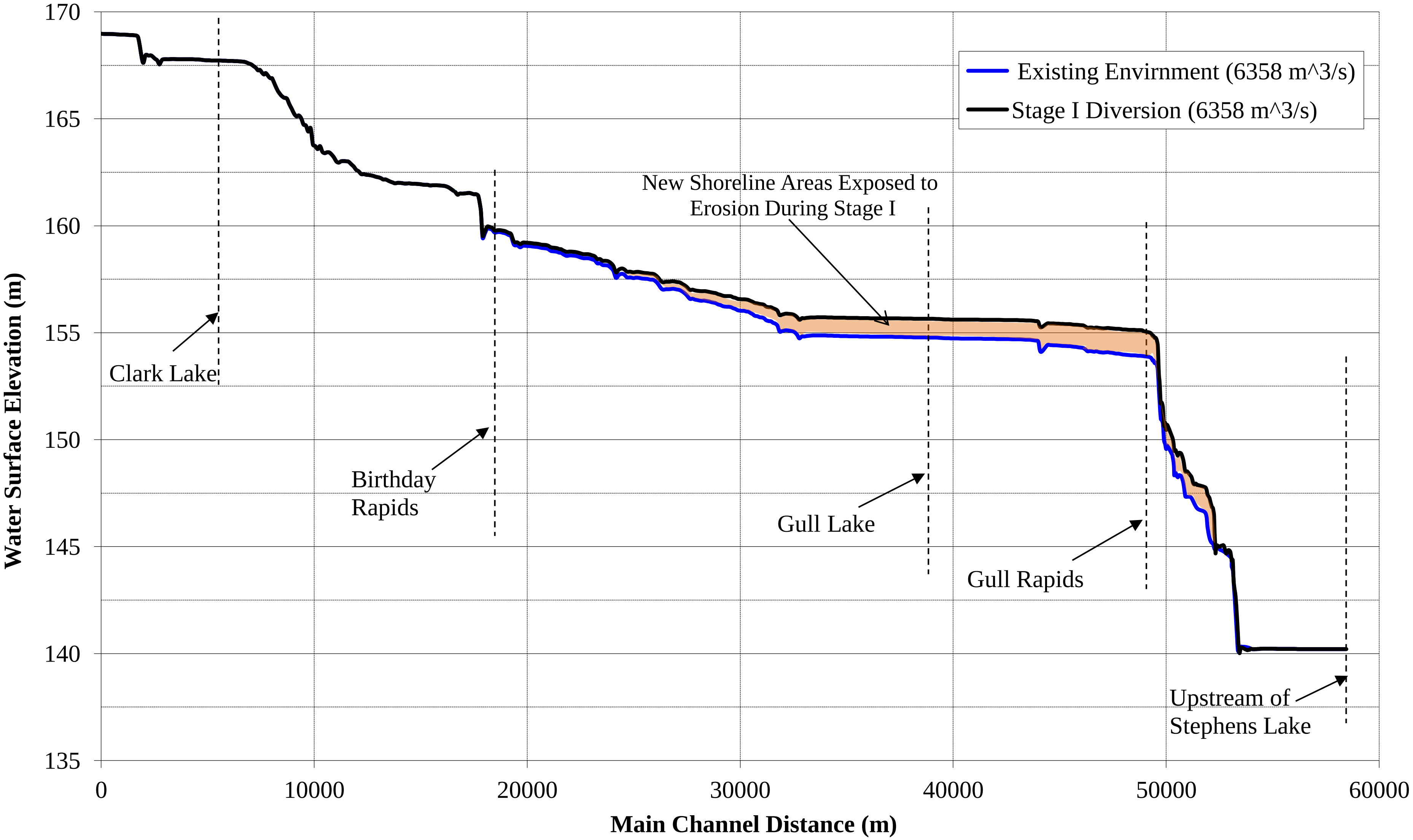


Figure 28 Increase in water surface elevation in the Nelson River and new shoreline areas exposed to erosion during Stage I Diversion (1:20 years flood flow)

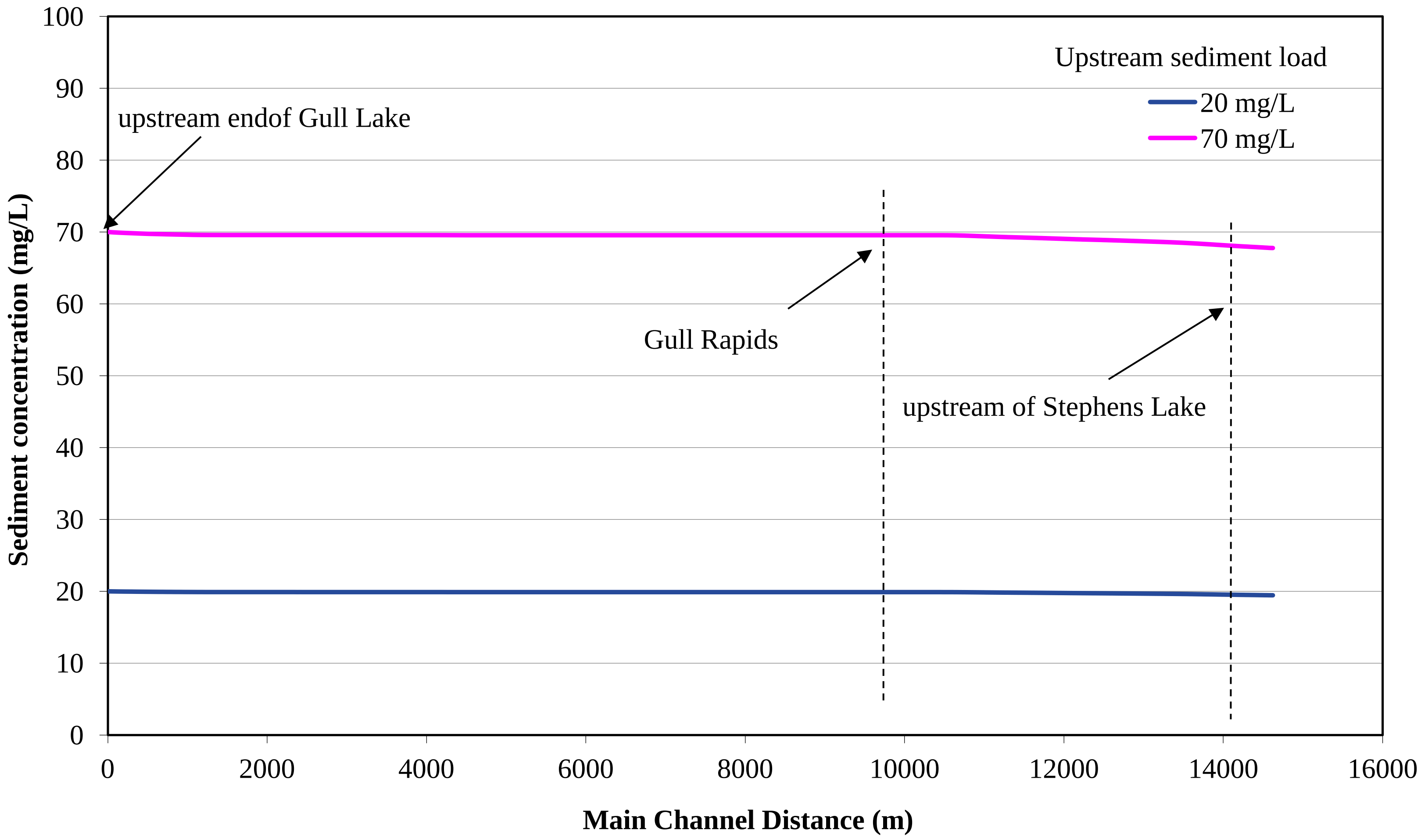


Figure 29 Sediment concentration along the study reach assuming normal and extreme suspended sediment loads from upstream.

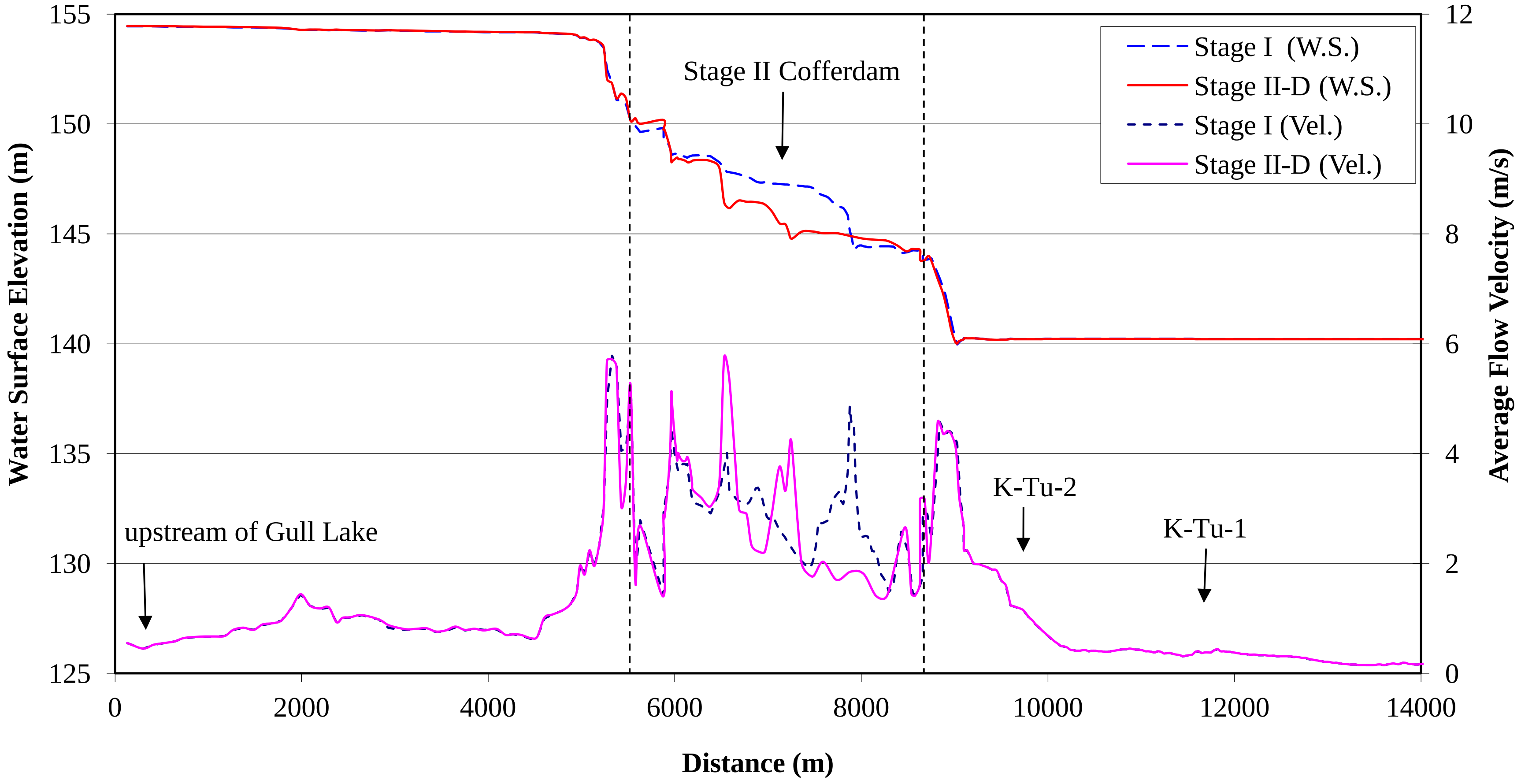


Figure 30 Water surface elevation and average flow velocity of the Nelson River in the study reach during Stage I and Stage IID Diversion (Q=4855 m3/s).

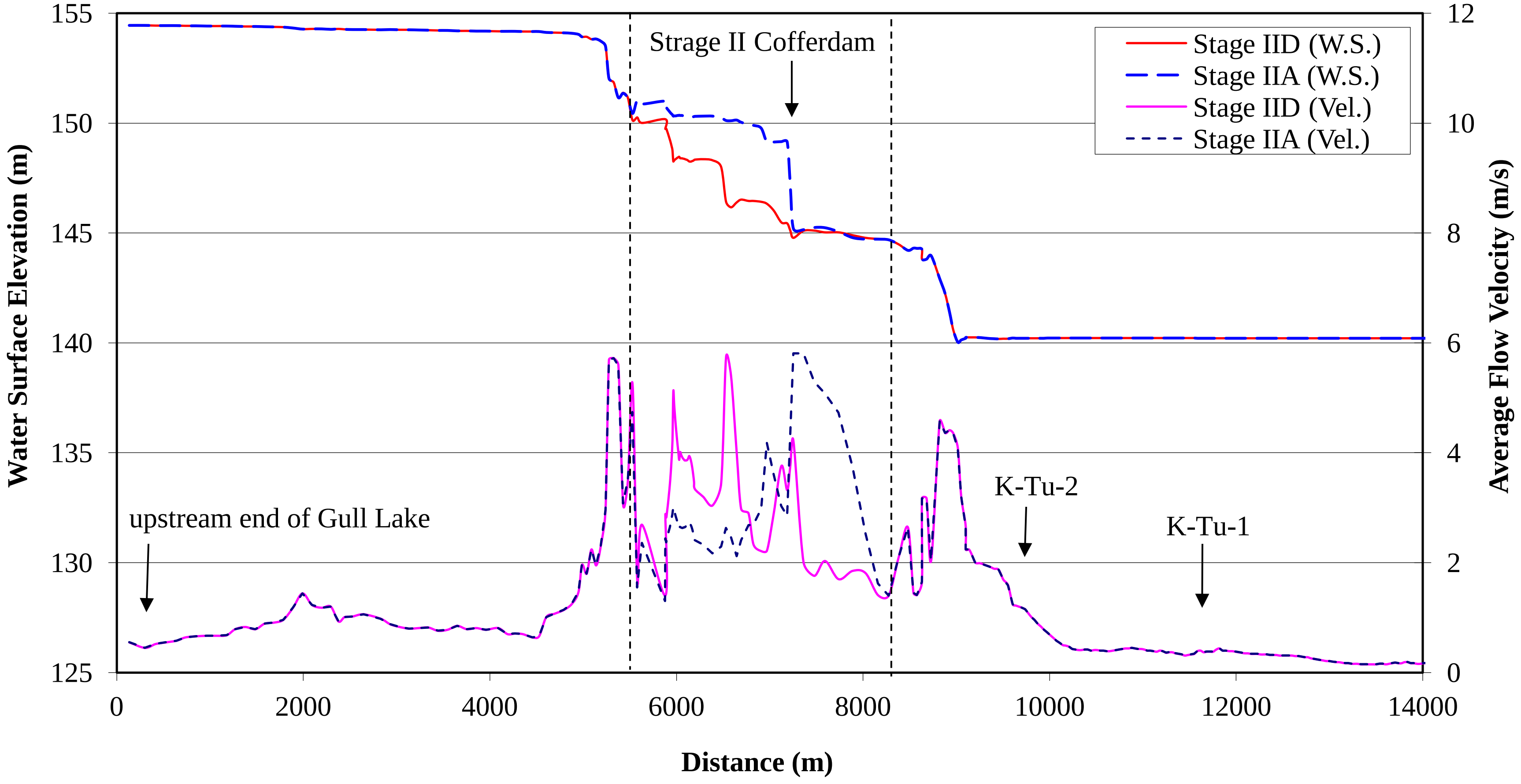


Figure 31 Water surface elevation and average flow velocity of the Nelson River in the study reach during Stage IID and Stage IIA Diversions (Q=4855 m3/s).

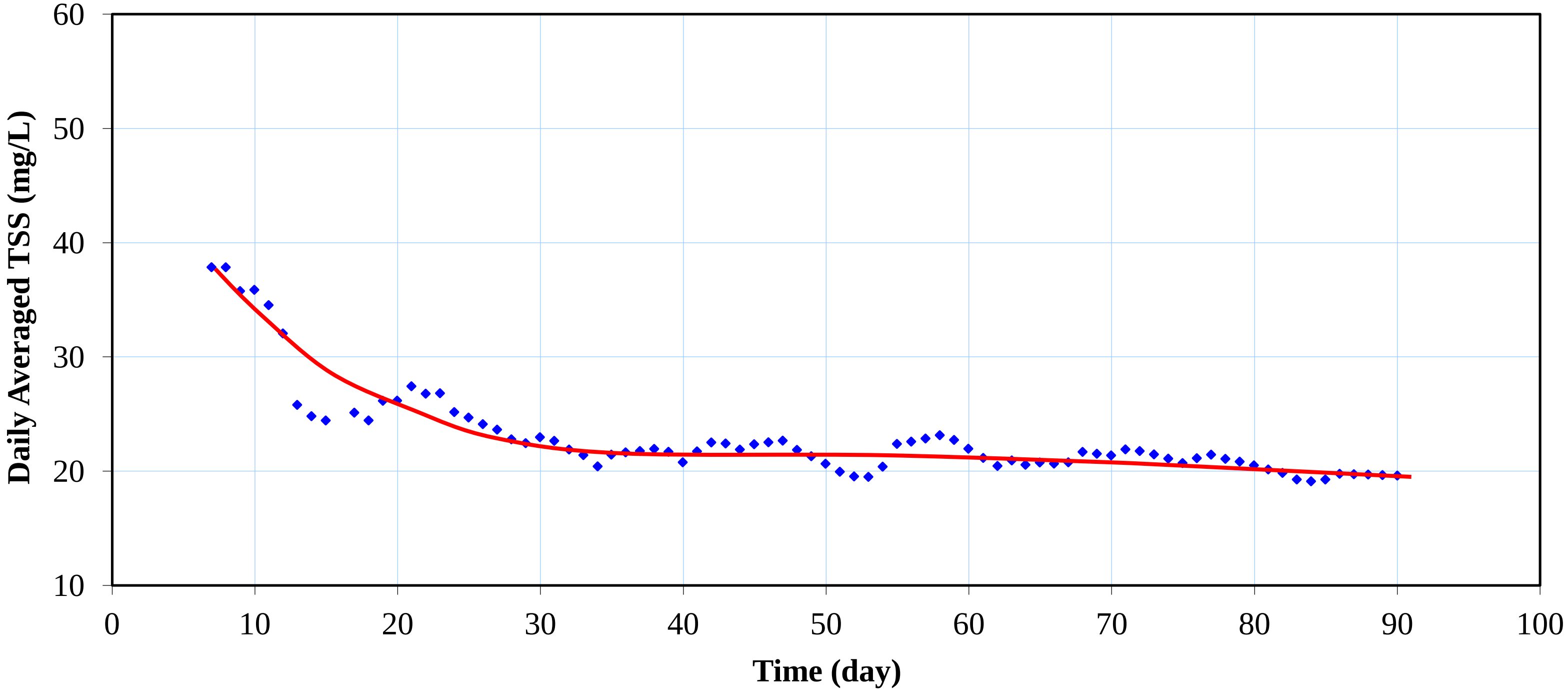


Figure 32 TSS Concentration at site K-Tu-2 during Stage IIA Diversion
Yang Transport Equation (Q=6358 m^3/s).

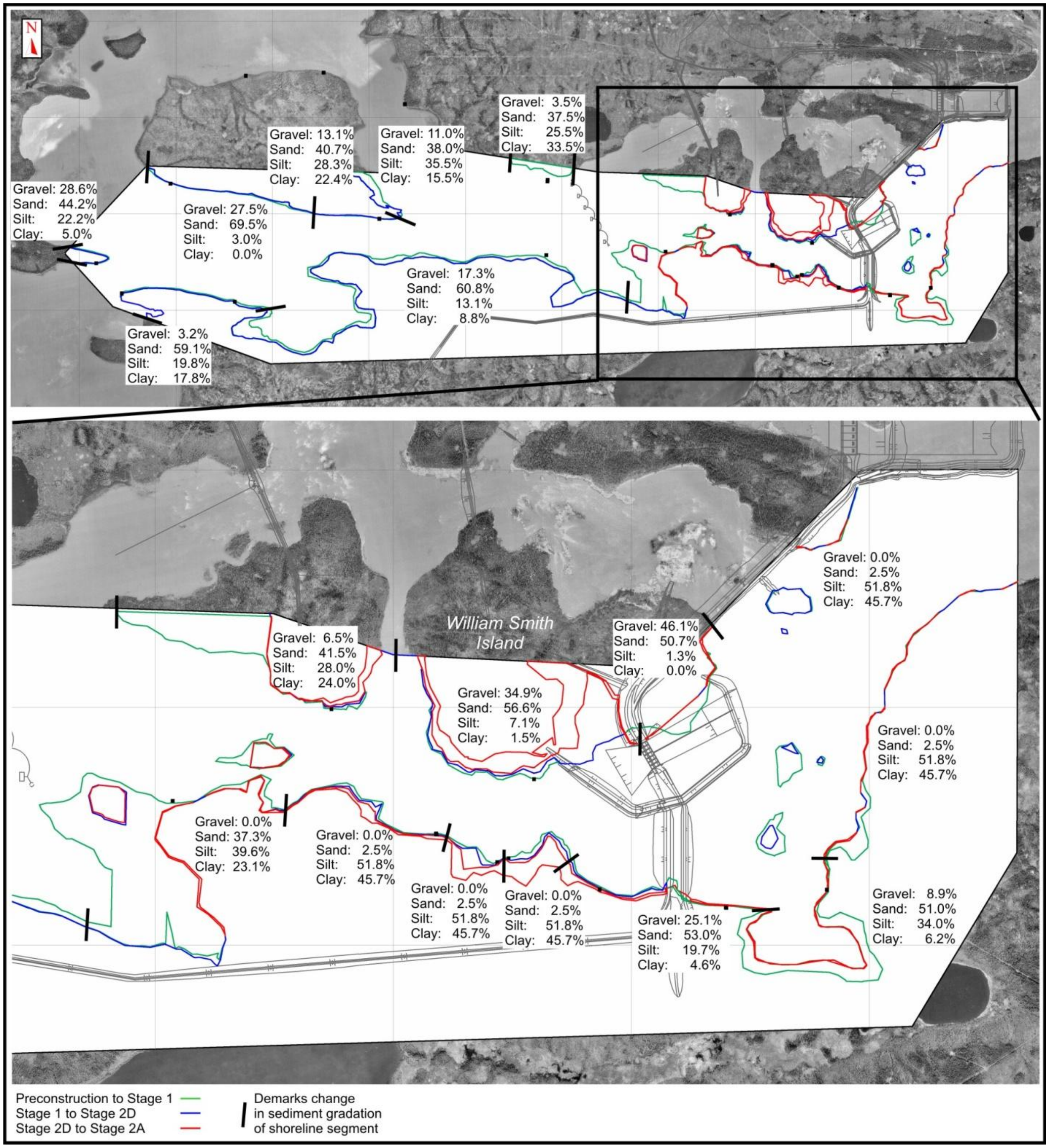


Figure 33 Nelson River south channel shoreline classification using soil samples from the flooded area during construction of the Keeyask GS [Ref 23]

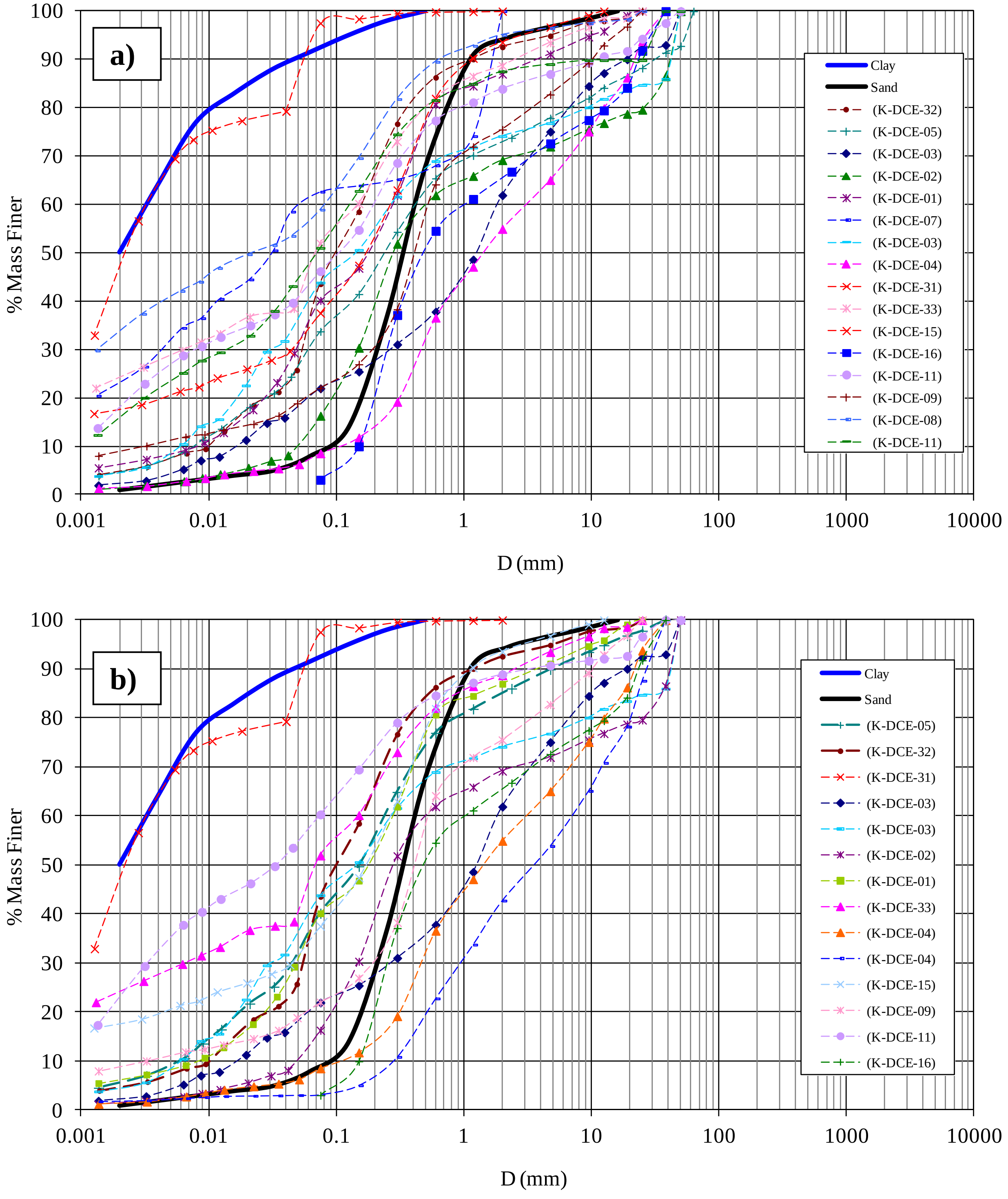


Figure 34 Keeyask shoreline material gradation curves for flooded area between; a) Existing Environment to Stage I, b) Stage I to IIA (for location of sampling sites see Figure 33; Solid lines= theoretical gradations based on visual soil classification, dash lines= actual gradations obtained from shoreline sampling in 2009).

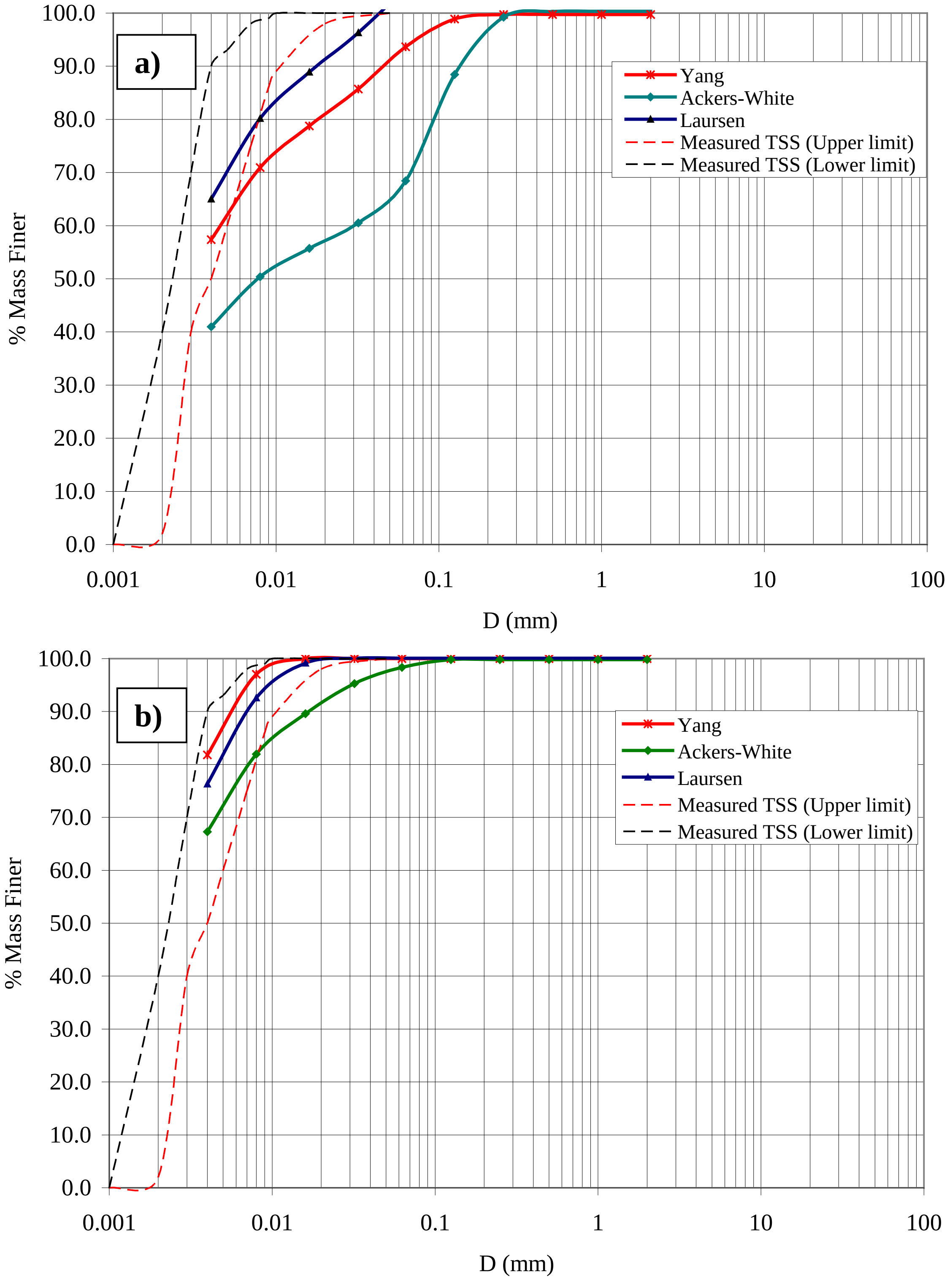


Figure 35 Gradation curves of sediment load carried by the Nelson River during Stage I Diversion (Q=6358 m^3/s) at a) K-Tu-2 b) K-Tu-1 (Dash lines: measured TSS in Existing Environment; solid lines; Estimated TSS for during Construction)

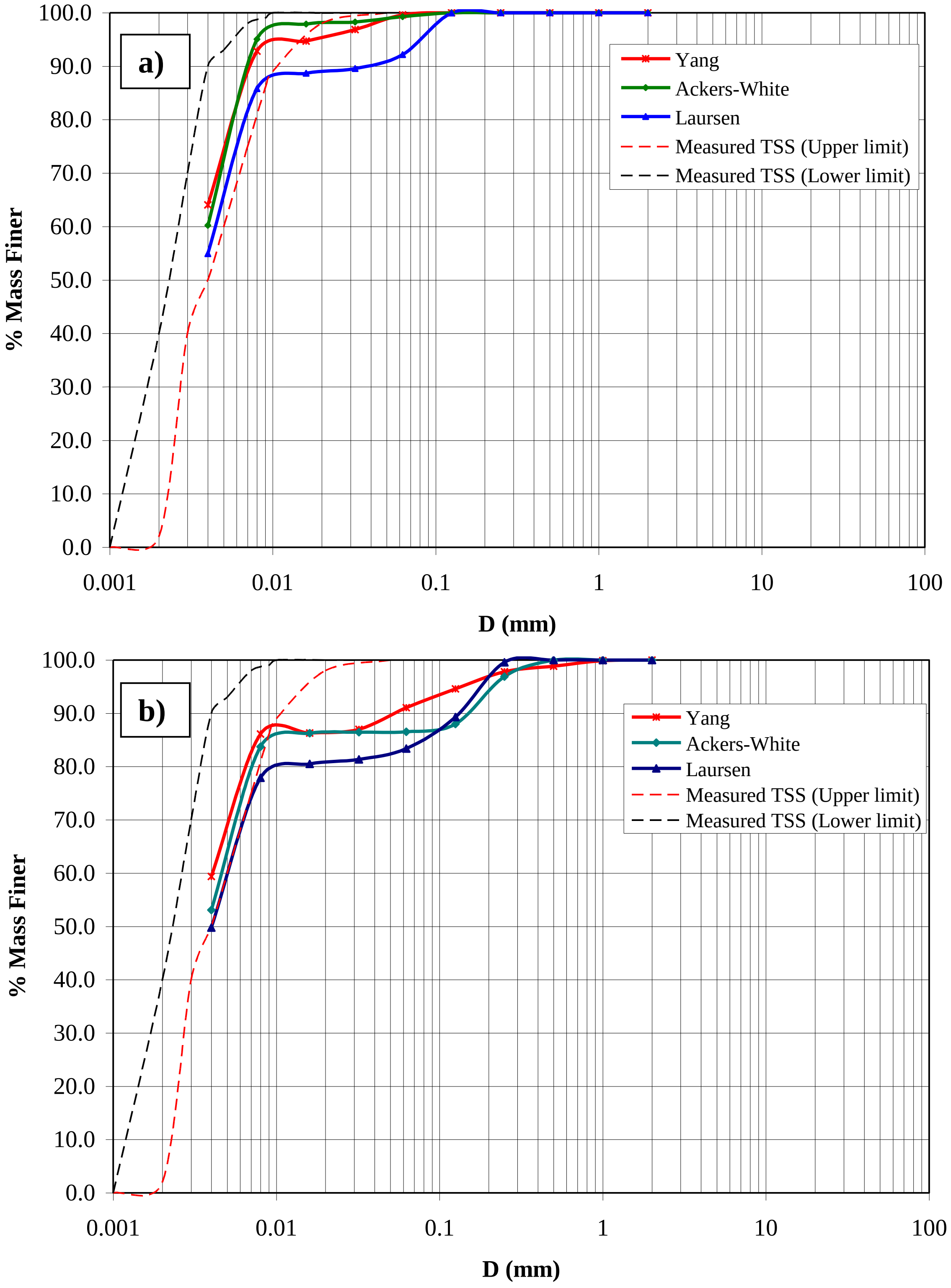
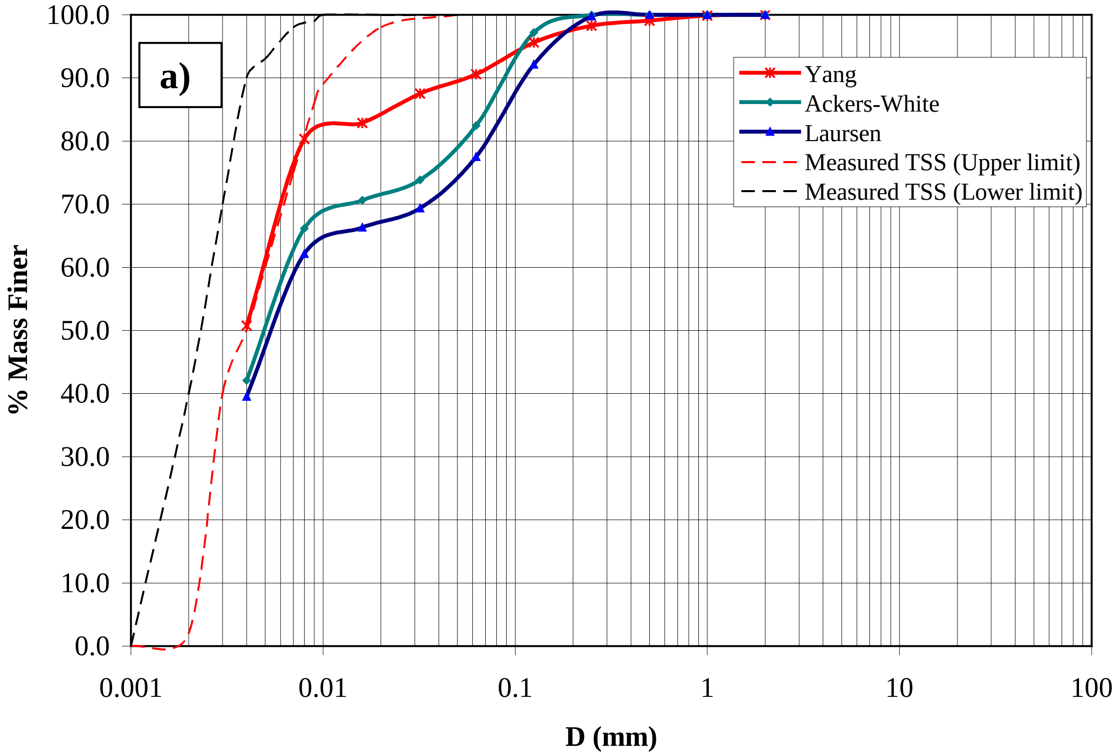


Figure 36 Gradation curves of sediment load carried by the Nelson River during Stage IID Diversion (Q=6358 m^3/s) at a) K-Tu-2 b) K-Tu-1 (Dash lines: measured TSS in Existing Environment; solid lines; Estimated TSS for during Construction)



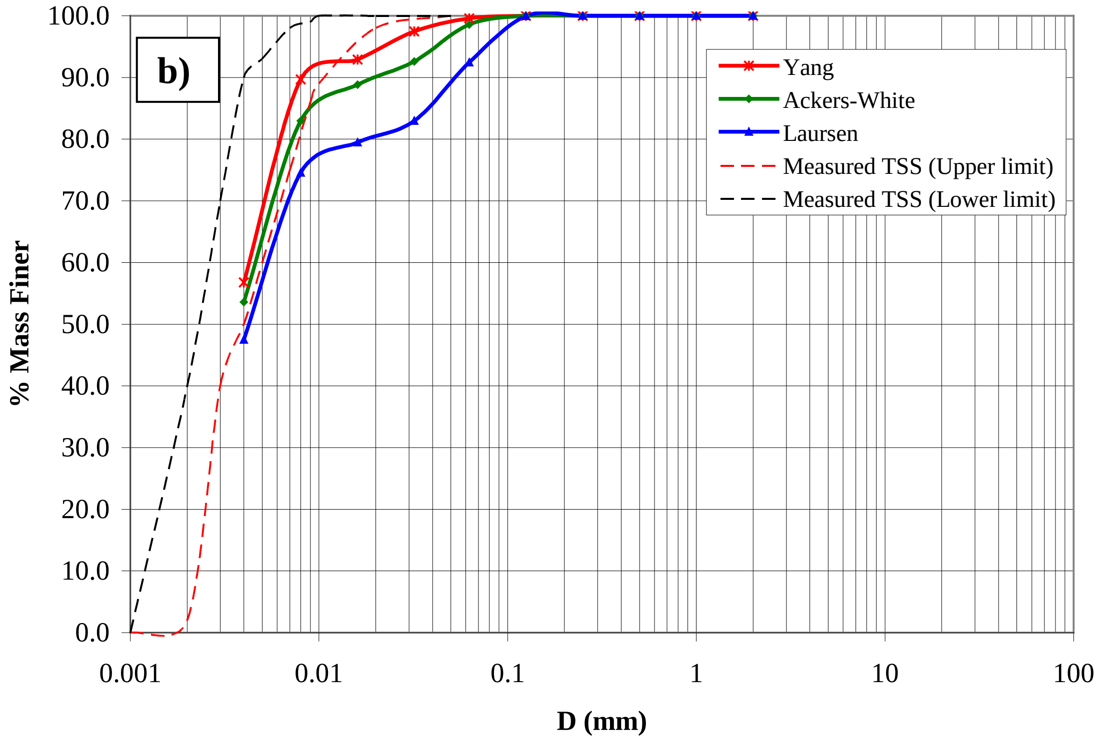


Figure 37 Gradation curves of sediment load carried by the Nelson River during Stage IIA Diversion (Q=6358 m^3/s) at a) K-Tu-2 b) K-Tu-1 (Dash lines: measured TSS in Existing Environment; solid lines; Estimated TSS for during Construction)

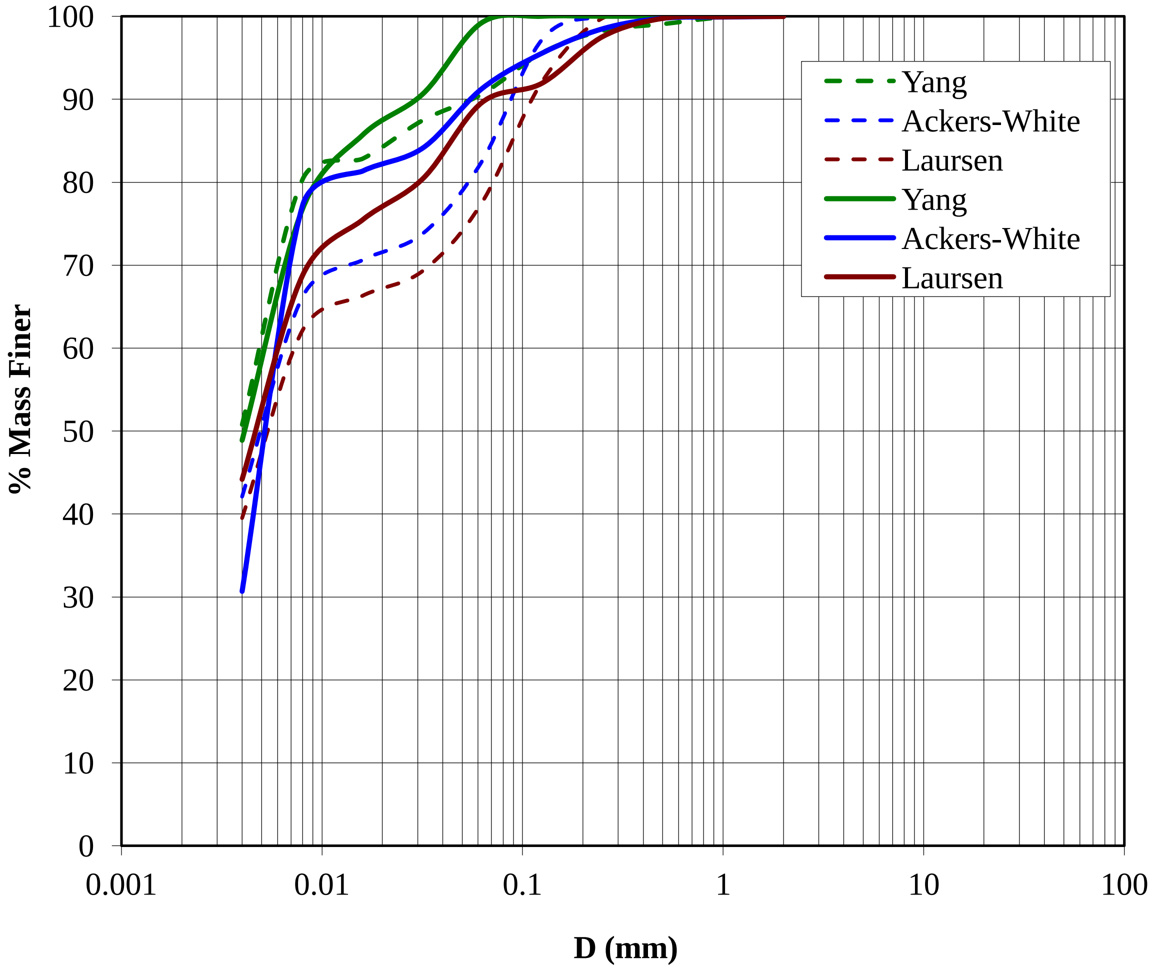


Figure 38 Gradation curves of sediment load during Stage IIA Diversion at station K-Tu-2 (Dash lines: applying visual shoreline classification; Solid lines: applying actual shoreline gradation curves).