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March 24, 2011
P10008(16). 29

Manitoba Hydro
Hydro Power Planning
15th Floor - 360 Portage Avenue
Winnipeg, Manitoba
R3C 0G8

Attention: M. St. Laurent, P.Eng
Section Head
Keeyask & Burntwood River Planning Section
Hydro Power Planning Department

Dear Mr. St. Laurent:

Keeyask Generating Station
Stage IV Studies
Project Environment Ice Processes & Effect Assessment
Memorandum GN-9.1.7, Rev 0
Manitoba Hydro File 00195-11100-0142_02

Enclosed please find two copies of Revision 0 of the above noted memorandum as well as two sign-off sheets containing the relevant KGS Acres signatures.

Please add a Manitoba Hydro signature to the sign-off sheets and return one copy for our files.

Yours very truly,

N.J. Smith, P.Eng
Project Manager

RMDA:spa
Encl

cc G.P. Schick
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Manitoba Hydro
Hydro Power Planning Department
Power Projects Development Division

Keeyask Generating Station
Stage IV Studies - Axis GR-4

Design Memorandum GN-9.1.7

Rev. 0, March 24, 2011

Project Environment Ice Processes and Effect Assessment

Manitoba Hydro File 00195-11100-0142_02

Prepared by (ANDREW BARYLA) MARCH 24, 2011
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KGS Acres Ltd.
Winnipeg, Manitoba

KEEYASK GENERATION PROJECT

STAGE IV STUDIES - PHYSICAL ENVIRONMENT

PROJECT ENVIRONMENT ICE PROCESSES AND EFFECTS ASSESSMENT

REV 0

DELIVERABLE GN 9.1.7

MANITOBA HYDRO FILE: 00195-11100-00142_02

2011/03/24

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

PREPARED BY:

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EXECUTIVE SUMMARY

The present ice regime on the reach of the Nelson River between Split Lake and Stephens Lake is governed by a complicated interaction between many climatic and hydraulic factors. Construction and operation of the proposed Keeyask Generating Station (G.S.) will change the way that ice develops over this reach. This memorandum summarizes the Post-Project ice regime that would result as a consequence of the Project's construction, and discusses how it is expected to differ from the current ice regime.

Once constructed, the proposed Keeyask G.S. forebay will resemble a lake environment, similar to the conditions found on Stephens Lake, rather than the riverine environment which presently exists. At the onset of winter, the forebay will develop a relatively smooth thermal ice cover, which will extend approximately 25 km upstream of the station. Frazil ice pans and sheets will collect at the upstream edge of this thermal ice cover, which will allow the ice covered surface to advance upstream to Birthday Rapids, through a mechanical thickening process. This will happen more quickly and, on average, three weeks earlier in the winter, resulting in higher water levels in the Birthday Rapids reach than occurs under current conditions. The ice front will continue to stall below the outlet of Clark Lake, as it currently does.

Anchor ice growth and its associated staging at both the Clark Lake outlet and the Split Lake outlet is expected to continue to occur. When compared to the level on Split Lake without the proposed Keeyask G.S., it is estimated that with the proposed Keeyask G.S., the peak winter level on Split Lake may be higher by up to 0.2 m under low flow conditions which occur on average once every 20 years. However, even with this increased staging, the level on Split Lake will remain within the range of winter levels that has been experienced since Churchill River Diversion and Lake Winnipeg Regulation have been in operation.

Downstream of the proposed Keeyask G.S., the short reach of river that leads to Stephens Lake will develop a relatively smooth thermal ice cover, similar to that found on other northern lakes. The proposed Keeyask G.S. will prevent the formation of a hanging ice dam that typically develops at the base of Gull Rapids and into Stephens Lake. An open water area immediately downstream of the Powerhouse will exist throughout the winter, due in part to the turbulence of the water leaving the Powerhouse.

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1 INTRODUCTION

Ice processes have been studied since the mid 1970's along the Nelson River. These studies have included the development of:

- a comprehensive field observation program,
- detailed numerical models, which have been successfully used to simulate the complex ice conditions along the river.

This memorandum summarizes the expected ice regime of the Nelson River between Spilt Lake and Stephens Lake as a result of the construction and operation of the proposed Keeyask Generating Station (G.S.). A discussion of how this new ice regime is expected to differ from the current ice regime is also provided. Information regarding the ice regime of the Nelson River between Split Lake and Stephens Lake for the existing environment, as well as for the future environment without the Project, can be found in Deliverable GN-9.1.6, Existing Environment Ice Processes [Ref 1]. GN-9.1.6 also discusses the long term winter field observation program and the development and calibration of numerical ice models used for this study.

The numerical ice models were developed and calibrated to simulate the formation of the ice cover and its growth throughout the winter. The most recent numerical model developed of the study reach is an ICEDYN hydrodynamic backwater model capable of simulating typical ice formation processes including **ice generation**, deposition, advancement, **shoving** and thickening. The model also has provisions for incorporating additional staging due to **anchor ice**. Using actual daily air temperature and flow data, the model was calibrated to match observed field conditions. Once calibrated, the model was modified to represent the Post-Project condition, and rerun to simulate ice formation under this Post-Project environment. The model was used to assess how the nature of the Post-Project ice cover may vary depending on the severity of the winter air temperatures, varying winter flow magnitudes, and the chosen mode of operation of the Project.

2 MODELING

The study area in the vicinity of the Project is bounded by Split Lake at the upstream end and Stephens Lake at the downstream end. The Project is planned to be developed in the vicinity of Gull Rapids and will create a reservoir and thermal lake ice cover against which the upstream river ice cover can advance. It will also eliminate the downstream passage of ice. As a result, ice modeling over the study area was split at the location of Gull Rapids into an upstream and a downstream model reach. This is the same location that numerical ice models developed to examine the ice regime of the existing and future environment, without the Project had to be split. Thus, the same two ICEDYN models that were developed for that analysis could also be used to simulate the ice regime in the Post-Project environment, with appropriate modifications to the boundary conditions to reflect the conditions to be experienced during operation of the Project. A map showing these modeled reaches, along with the location of key sites along the reach where water levels have been characterized, is provided on Figure 1.

The setup and calibration of these numerical models is discussed in Section 5 of Deliverable GN-9.1.6, Existing Environment Ice Processes [Ref 1].

3 PROJECT ENVIRONMENT BOUNDARY CONDITIONS

3.1 AIR TEMPERATURE

Air temperatures used for this assessment are based on mean daily temperatures recorded at Gillam Airport (Station No. 5061001) by Environment Canada. Data is available for the period from 1971 to 2007. To characterize the **ice processes** under different winter severities, the actual recorded air temperatures for particular winters were chosen to represent a "warm", "average", and "cold" condition. Selection of warm, average, and cold winters was based on a visual inspection of a plot of the cumulative degree days of freezing of all years over the period of record. The winter seasons of 2001/2002, 1988/1989, and 1989/1990 were chosen to represent the warm, average, and cold winters respectively.

3.2 INFLOWS

Inflows to the study area were based on the Project inflow record for a simulated long term period from 1912 to 2006, as provided in Deliverable GN-9.1.1 [Ref 2], Existing and Project Environment Flow Files. The 5^{th}, 50^{th}, and 95^{th} percentile average seasonal inflows (November to March) were used to assess the Project environment ice conditions. These inflows were specified as the upstream flow boundary condition of the upstream model reach.

3.3 STEPHENS LAKE LEVELS

The downstream boundary of the downstream model reach is represented by the level of Stephens Lake. The Stephens Lake levels modeled included the 5^{th}, 50^{th}, and 95^{th} percentile of the recorded daily winter levels from 1977 to 2006, as provided in Deliverable GN-9.1.8, Existing Environment Water Regime - Key Sites [Ref 3]. These percentiles correspond to levels of 139.3 m, 140.4 m, and 141.0 m respectively. The levels were assumed to be constant over the simulation period.

3.4 DATE OF LAKE FREEZE-UP

Under current conditions, freeze-up of Stephens Lake typically occurs by November 1st. It is not expected that this date will be changed as a result of the Project. Upstream of the Project, the date of freeze-up is expected to occur sooner than it currently does as a result of the creation of the forebay. Given the close proximity of the forebay to Stephens Lake and the similar water regime, it has been assumed that under the Project environment the date of forebay freeze-up will also be November 1st. This is the date that the numerical ice formation simulations were set to commence.

3.5 MODE OF OPERATION

Two modes of operation were simulated, one representing a base loaded mode of operation (run-of-river condition), and one representing a peaking mode of operation in which the Project forebay level will vary to allow the Project to discharge the maximum flow through the turbines in accordance with energy demand. For the upstream model reach, the downstream boundary condition is represented by this regulated water level at the Project. For base loaded conditions, this level was kept constant at a Full Supply Level (FSL) of 159.0 m. For the downstream model, the upstream boundary condition is represented by the outflow out of the Project. Under base loaded operations, this outflow is equal to the inflow into the reach (steady-state conditions).

For peaking operations, the forebay level is varied over a one week period such that on-peak power generation is maximized for a given Project inflow within the constraints of the Project operating rules. Forebay levels and associated Powerhouse outflows for peaking operations are provided in Deliverable GN-9.1.12 – Project Environment Water Level and Flow Regime – Effects Assessment [Ref 4]. The outflows were specified as the upstream flow boundary condition for the downstream model reach. Outflow generally varied from the seven unit maximum plant discharge for a 16 hour period down to a minimum plant discharge (which varies based on the magnitude of the inflows) for the remaining eight hours of a day to allow the forebay to recharge.

4 POST-PROJECT ICE REGIME

Under Post-Project conditions, the ice regime over the upstream reach of the Nelson River between the Project and Split Lake will be changed by varying degrees. Immediately downstream of the Project, the volumes of frazil ice that will accumulate will be substantially reduced due to the cutoff of the upstream supply of ice by the Project. Four separate reaches (three upstream of the Project and one downstream) can be defined which represent the varying ice regimes expected over the study area. These reaches are defined as:

- Downstream Reach (between Stephens Lake and the Project).
- Forebay Reach (between the Project and Two Goose Creek).
- Birthday Rapids Reach (between Two Goose Creek and the Outlet of Clark Lake).
- Clark Lake Reach (between the outlet of Clark Lake and Split Lake).

The ice regimes that are expected in these reaches, and how they differ from the conditions that would be expected without the Project, are discussed below. For this discussion, the ice regimes being examined are those for the Project being operated under a base loaded mode of operation. A description of the ice regimes under a peaking mode of operation are discussed in the section on sensitivity (Section 5).

Figures 2 to 4 illustrate expected maximum water surface profiles and ice thicknesses in the upstream model reach with average air temperature conditions for the three different percentile flow conditions that were examined. Corresponding water level hydrographs at various key sites throughout the upstream model reach are also provided on Figures 5 to 7. These hydrographs help to demonstrate the overall timing and the relative amounts of ice staging that can be expected under average winter temperature conditions.

4.1 Downstream Reach

In the reach between the proposed Keeyask G.S. and Stephens Lake, the winter water regime will be changed due to the Project cutting off the upstream supply of frazil ice. As a result, the large ice volumes and water level staging associated with the formation of a hanging dam in this area will no longer occur. It is expected that the ice cover which forms will resemble a thermal ice cover, similar to what currently occurs on Stephens Lake. Water temperatures exiting the Powerhouse will be slightly above 0°C as heat is imparted to the water during the transfer of energy to the turbine rotors (temperatures of approximately 0.02°C have been measured at the Limestone G.S.). As a result, **frazil ice** generation will not begin until the water temperature cools to 0°C (the point where this occurs is referred to as the location of the zero degree isotherm). It is expected that this location will be approximately 800 m downstream of the Powerhouse, but is dependent on the temperature of the water exiting the Powerhouse, the degree of mixing, and the air temperature. This location is only a few hundred meters upstream of Stephens Lake where a thermal lake ice cover forms very quickly due to the low velocities present. Because of the close proximity, formation of an ice cover between the location of the zero degree isotherm and Stephens Lake should also occur very quickly. Normal end of winter ice thicknesses downstream of the zero degree isotherm are expected to be between approximately 0.8 m to 1.2 m. No ice cover is expected in the Tailrace Channel between the Powerhouse and the location of the zero degree isotherm.

During the winter, the resulting water levels at the location of the Powerhouse Tailrace Channel will be much lower than what occurs now, both due to the Tailrace Channel improvements, as well as the elimination of the **hanging ice dam** that typically forms in the area. It is expected that winter water levels in the Powerhouse Tailrace Channel will be in the order of 0.1 m higher than the open water equivalents at maximum Powerhouse discharge. Rating curves showing both the estimated open water and winter water levels in the Tailrace Channel are provided on Figure 8 which illustrates the expected staging.

The ice regime on Stephens Lake is not expected to be materially affected by the Project. However, **pack ice** that typically **shoves** into Stephens Lake at the inlet to the lake is no longer expected to occur due to the cutoff of the upstream ice supply by the Project.

In the spring, the lake ice cover immediately downstream of the Project will simply deteriorate and melt in place, as it currently does on Stephens Lake. Ice in the shore zone areas of Stephens Lake will melt initially as they are generally thinner. Sediment laden runoff from the shore areas may also drain and pool in these areas, decreasing the albedo, and lead to an accelerated deterioration of the ice cover. The retreat of ice along the shorelines may allow some movement of more competent ice sheets by wind events, since the main ice cover will no longer be locked in place. The same breakup process is anticipated each year, with the only variation being the speed with which the cover may deteriorate.

4.2 FOREBAY REACH

In the reach between the proposed Keeyask G.S. and Portage Creek, the water regime will be changed from a riverine environment to a lake environment due to forebay impoundment to el. 159 m. As a result, velocities in this reach will be significantly reduced to the point that an ice cover will form via thermal growth and **juxtaposition**, rather than by a **shoving** and mechanical thickening process which occurs in the existing environment. The forebay ice cover will be able to grow quite rapidly and thus span a large distance in a short amount of time, cutting off the generation of frazil ice over this area. Resulting volumes of ice will be much lower and thus the ice cover in this area will be much thinner than currently experienced. This can be seen by referring to the ice profiles shown on Figures 2 to 4. The forebay ice cover will be very similar to the lake ice cover that forms on Stephens Lake. It is expected that the average thickness of the forebay ice cover will be between approximately 0.8 m to 1.2 m by the end of winter.

In the region between Portage Creek and Two Goose Creek, the velocities will begin to increase as will the slope of the water surface. As a result, ice cover advancement in this area will stall more easily, and large amounts of frazil ice generated in the upstream reaches will not be able to simply juxtapose against the leading edge of the ice cover.

Subsequently, the frazil ice will be drawn under the ice cover. Over time, this process will result in increased head loss, and thus water level staging. The cover will begin to advance again once the water level rise is sufficient to decrease velocities at the leading edge to the point that a **juxtaposed** cover can advance against the in-place ice cover.

During this formation period, the cover will periodically **shove** and thicken mechanically until a stable ice thickness is established which can support the upstream ice cover. The ice cover in the vicinity of this "transitionary zone" between a forebay ice cover to a riverine ice cover will take on more of an **ice jam** appearance, similar to what would be observed currently. The beginning of this region of increased ice thickness is dependent on the flow in the reach. Winters with higher than average flows will result in this **shoving** process beginning closer to Gull Lake due to the higher velocities involved, while under lower flows, this process will tend to occur closer to Two Goose Creek.

During spring breakup, it is expected that water levels will return to their open water equivalents sooner than they presently do. Initially, open water leads will begin to form in the main **pack ice** as warmer water temperatures from inflowing tributaries and increased solar radiation lead to some melting and deterioration of the ice cover. In tandem with this, rising flows will cause stages along the river to increase, which cause the cover to eventually lose its bank resistance against the **shorefast ice**. The leading edge of the cover will then begin to retreat down river as the cover progressively breaks, and reforms. Eventually, the leading edge will retreat to the location of the stronger lake ice, leaving open water in upstream areas. These masses of ice transported from upstream will simply push into the thinner forebay ice cover, breaking it up somewhat, and then remain to float in the forebay until the ice is melted by the sun. It is expected that melting of the forebay ice would be similar to that of Stephens Lake.

Ice jams may occur for a short period of time at the point where the riverine ice cover meets the stronger forebay ice cover. If the strength of the in-place ice cover in this area is still high during an **ice run**, ice transported from upstream may collect at this location, forming an **ice jam**, until water levels stage to the point that the strength of the in-place ice cover can no longer support the accumulated ice. At that point, the **ice jam** would release and an **ice run** would occur that would push this ice mass into the forebay. Water levels in the area would then drop back to a level less than the maximum winter ice level, but possibly still greater than the open water equivalent.

It is difficult to quantify by how much the spring breakup season (i.e. the return to open water levels) will be shortened by. It has been judged that the spring "de-staging" in the Project environment will take place over a period of two months. This would represent a shortening of the de-staging period from the ice regime without the Project by one month. However, the length of this period is highly dependent on flow magnitudes, air temperatures, and ice accumulations over the course of the winter (i.e. ice cover size and thickness).

As described in Section 5 of Deliverable GN-9.1.6, Existing Environment Ice Processes [Ref 1], the ICEDYN model cannot simulate the processes involved during the spring breakup period. Water levels shown on the stage hydrographs (Figures 5 to 7) during this time period were estimated by assuming that over the month of March the amount of water level staging would be decreased by 20%, with the remaining 80% of the total winter staging being eliminated over the month of April. Water levels on these hydrographs were thus shown to return to their open-water equivalents by May 1.

4.3 BIRTHDAY RAPIDS REACH

Ice formation and breakup processes in the reach between Two Goose Creek and the outlet of Clark Lake will be similar to what is currently observed. However, water levels will be higher in this reach due to the establishment of the Project forebay. The higher levels in the forebay will allow the **ice front** to progress further upstream, earlier in the winter. As a result, the leading edge of the cover is expected to advance past Birthday Rapids, approximately three weeks earlier than it would if the Project was not constructed. The leading edge of the cover will eventually stall downstream of Clark Lake, as it does now, and ice generated in the upstream reach will be deposited in a mechanically thickened ice cover located between the downstream forebay lake ice, and the leading edge of the riverine ice. The formation of this ice cover will result in increased head losses and thus higher water levels in this reach than would occur without the Project.

Overall, the **ice front** is still expected to stall downstream of the outlet of Clark Lake, due to the reduction in the incoming upstream ice supply as the cover advances, and the relative steepness of this reach. Overall ice volumes generated in the Post-Project environment are expected to be approximately half of what they are without the Project. As a result, it is expected that the occurrence and amount water level staging associated with spring **ice jams** will be reduced.

4.4 CLARK LAKE REACH

Ice processes in the reach between the outlet of Clark Lake and Split Lake are expected to remain unchanged. The amount of **anchor ice** formation and the resulting staging at both the Clark Lake outlet and the Split Lake outlet is also expected to continue unchanged from what occurs at present. Although water levels are expected to be higher downstream of the Clark Lake outlet, they are not expected to reach the level that would be required to drown out the **anchor ice** affected hydraulic control at the outlet of Clark Lake except, possibly, under low flow conditions which occur on average once every

20 years. Under such low flow conditions, there may be a possibility that, due to the Project, peak winter water levels on Split Lake could be increased by up to 0.2 m above those which would occur without the Project in place.

The mechanism which would cause this to occur would be the generation of enough frazil ice in the reach between Clark Lake and Split Lake that a **hanging ice dam** would be able to form near the foot of the outlet of Clark Lake resulting in sufficient water level staging that would drown out the hydraulic control located at the outlet of Clark Lake.

Such a scenario is expected to occur only under low flow conditions. Under greater flows, the restricted conveyance of the hydraulic control at the outlet of Clark Lake results in a larger drop in water levels, preventing ice-induced backwater effects from drowning out the control. Under low flow conditions, the drop in water level is smaller and thus could result in ice-induced backwater effects partially drowning out the control. The formation of **anchor ice** at this location further increases the water level drop however, and thus increases the likelihood that the hydraulic control will be maintained under low flow conditions.

In addition, the velocities associated with higher flows would prevent the **ice front** from advancing upstream of Birthday Rapids until later in the winter. As a result, by the time the **ice front** begins to get close to the Clark Lake outlet under these higher flows, the winter ice formation period will have ended and further generation of **frazil ice** in the upstream reach would be limited. This would reduce the staging associated with the **hanging ice dam** at the foot of the Clark Lake outlet. This is evident in the Post-Project environment water surface profiles shown in Figures 2 to 4. Under higher flow magnitudes, the larger ice volumes are seen to accumulate at locations further downstream in order to maintain the stability of the ice cover. On the other hand, under low flow conditions, the hydrodynamic drag and thrust on the cover is lower, resulting in reduced ice accumulations at these downstream locations and a “transferring” of the ice volumes to locations further upstream.

Numerical modeling of low flow conditions (5^{th} percentile) was undertaken to determine if sufficient downstream staging would be able to drown out the hydraulic control at the outlet of Clark Lake. As discussed in Section 5 of Deliverable GN-9.1.6, Existing Environment Ice Processes [Ref 1], the numerical ice model was calibrated and verified against field measurements gathered over a number of past winters, including the 2003/2004 winter which was the lowest winter flow season on record. The numerical modeling results indicate that under such low flow conditions there will not be any additional staging of winter water levels on Spilt Lake above those which would occur without the Project in place.

While this finding is reflected in the modeled water levels presented herein, it is noted that it is contingent both on the formation of sufficient **border ice** on Clark Lake to limit **frazil ice** production, as well as the formation of sufficient **anchor ice** at the outlet of Clark Lake. The impact of having less **border ice** form on Clark Lake, or having no **anchor ice** form at its outlet was also assessed. The results of these sensitivity tests indicate that should there be smaller accumulations of border ice or anchor ice, there may be a possibility that peak Split Lake winter water levels could be increased by up to 0.2 m under low flow conditions due to the Project. Should this occur, resulting winter water levels would still be well within the range of winter levels experienced in the existing environment on Split Lake since Churchill River Diversion and Lake Winnipeg Regulation have been in operation.

5 SENSITIVITY ANALYSES

5.1 AIR TEMPERATURE

The numerical modeling of Post-Project conditions has been based on an assumption that temperatures in the area would follow long term averages. However, the impact on ice processes (and associated staging in this area) of experiencing a warmer or colder winter was also examined. These sensitivity analyses indicated that overall, ice regime and the maximum amount of winter staging experienced would remain the same. What is affected is the timing at which the peak winter stage is reached.

Upstream of the Project, a colder than average winter had the effect of advancing the timing of the peak staging by approximately three weeks, while a warmer than average winter delayed the peak by approximately one week. Although a colder than average winter has the ability to generate more **frazil ice** and thus could be thought to result in additional staging, this is not predicted to occur, since the ice cover over the entire reach would form sooner, thus cutting off the additional generation of **frazil ice**. This can be seen by examining Figures 9 to 11 which show the variation in water level staging at Two Goose Creek, Birthday Rapids, and downstream of Clark Lake for the cold, average, and warm temperature sequences. In these figures, the inflow was held constant at the 50th percentile magnitude.

Downstream of the Project, the ice cover will be formed by thermal growth. The thickness of this ice cover is directly proportional to the number of degrees days of freezing over the winter and its onset will also be affected by the severity of the winter in the initial months. Warmer weather during the beginning of winter would delay the onset of the ice cover until air temperatures drop to below 0^{o}C for a few days in a row. Ice cover thicknesses are expected to reach between approximately 0.8 m to 1.2 m over the winter, depending on its severity and snow cover thickness. Differences in the thickness of the ice cover of this magnitude are not expected to appreciably alter the winter Powerhouse Tailrace rating curves presented in Figure 8.

5.2 STEPHENS LAKE LEVEL

The level of Stephens Lake has historically varied over a 3.7 m range. For the analysis undertaken, Stephens Lake water levels corresponding to the 5th, 50th, and 95th winter percentiles were considered. It was assumed that the 5th percentile Stephens Lake level would occur during the 5th percentile inflow, the 50th percentile Stephens Lake level would occur during the 50th percentile flow, and so on. It is recognized that these two variables are likely more independent than this. However, because the low level of Stephens Lake is still high enough that the water regime will support thermal lake ice formation and growth, there will be little effect on the ice regime and amount of water level staging due to ice in the downstream reach if a low Stephens Lake level were to occur during high outflows. This is illustrated in Figure 8 which shows a rating curve of the open water and ice affected water levels in the Powerhouse Tailrace for the three Stephens Lake levels considered.

5.3 MODE OF OPERATION

The operation of the Project in a peaking mode rather than a base loaded mode would result in daily water level fluctuations both upstream and downstream of the Project. The magnitude of the fluctuations is dependent on the inflows to the reach. Figures 12 to 14 show representative water level hydrographs at various key sites throughout the upstream model reach under peaking operations for average winter temperature conditions.

Figures 15 and 16 illustrate the predicted average and maximum daily fluctuation in water levels as a function of distance upstream of Gull Rapids respectively, for the 5th, 50th, and 95th percentile inflows under peaking operations. Also provided are the average and maximum daily fluctuations which were predicted to occur under base-loaded conditions. Since there is no fluctuation of the forebay under base loaded conditions, those fluctuations represent changes in water levels due to ice cover formation and advancement. The difference between these two curves can be interpreted as the incremental water level fluctuation due to peaking operations.

Upstream of the Project, the magnitude of forebay water level fluctuations observed at locations up to Portage Creek are almost equivalent to the fluctuations observed at the Project site. At locations further upstream, the daily fluctuation would still be observed (albeit over a smaller range) but they begin to disappear as the ice cover develops, and the river’s hydraulics gradient steepens significantly, thus dampening out downstream effects. During higher inflows, the operation of the Project under a peaking mode would require a steady drop in forebay level over the week (little to no daily cycling).

Under the higher inflow scenarios, water level variations were predicted to occur all the way back to a point just downstream of the Clark Lake outlet. The weekly fluctuation in water levels was predicted to cease after a stable ice cover forms over the full reach. Again this is due to establishment of a sufficiently steep hydraulic gradient that dampens out downstream effects.

Overall the operation of the Project in either a base loaded or peaking mode should not substantively change the overall rate of ice cover formation and water level staging over a winter, or the peak water levels attained. As can be seen in examining Figures 5 to 6 and Figures 12 to 14, while the daily fluctuations of the forebay would result in fluctuations in the water levels at upstream locations, the actual degree of water level staging over a winter period would remain about the same. In essence, the water levels experienced under peaking operations can be thought of as having the daily fluctuation (adjusted for head loss over the reach) superimposed on top of the stage hydrographs resulting from base loaded operation. Figure 17 illustrates this by showing a comparison between the modeled stage hydrographs downstream of Birthday Rapids for base loaded and peaking operations.

Fluctuations of the forebay water level due to peaking operations in the winter will result in some hinging of the ice in the forebay along the shoreline. As a result, there may be areas along the shoreline where cracks that form fill with water and subsequently create slush ice conditions.

Downstream of the proposed Keeyask G.S., water level fluctuations will be dependent on the outflows from the Powerhouse. The largest fluctuations would be observed during lower flow periods when the forebay is being replenished by cycling the units between all seven units being on, during on-peak hours, down to one unit being on during off-peak hours. Because the ice cover that is created downstream of the Project would be a thinner thermal type, significant water level staging in the reach should not occur. Operation of the plant in either a base loaded or peaking mode is not expected to affect the development of this cover. A comparison of predicted water levels expected in the Tailrace Channel over a weekly period for both peaking and base loaded operation under the 5^{th}, 50^{th}, and 95^{th} percentile flows and Stephens Lake water levels is provided on Figures 18 to 20.

6 CHARACTERIZATION OF PROJECT ENVIRONMENT WATER LEVELS

Water levels over the winter period at the key locations throughout the study reach have been characterized by running the ICEDYN model over the full range of flows that make up the Project inflow record. Model results were extracted and processed into duration curves to demonstrate the range and frequency of water levels that are anticipated to be experienced in the Post-Project environment under base loaded operating conditions and average winter temperatures.

Figures 21 to 31 show these duration curves at the key sites, along with the corresponding duration curves of water levels expected to occur if the Project were not constructed. A summary of the 5th, 50th and 95th percentile water levels for the Post-Project environment and the future environment without the Project at the key sites is provided in Tables 1 and 2 respectively.

Note that modeled water levels at the Keeyask Tailrace site for the future environment without the Project scenario reflect typical **ice bridging** dates on Gull Lake. Water levels at this location can be higher than indicated in years when the bridging of Gull Lake is delayed or does not occur.

TABLE 1

Range of Winter Post-Project Environment Water Levels at Key Sites

Site	5th Percentile	50th Percentile	95th Percentile
Stephens Lake	139.3 m	140.4 m	141.0 m
Keeyask Tailrace(1)	139.4 m	140.5 m	141.1 m
U/S Gull Rapids	159.0 m	159.0 m	159.0 m
Gull Lake	159.0 m	159.0 m	159.1 m
Portage Creek	159.1 m	159.2 m	160.0 m
Two Goose Creek	159.3 m	160.5 m	162.1 m
D/S Birthday Rapids	159.9 m	162.1 m	163.8 m
U/S Birthday Rapids	160.2 m	162.6 m	164.0 m
D/S Clark Lake Outlet	163.6 m	164.8 m	165.4 m
Clark Lake	166.3 m	167.0 m	167.4 m
Split Lake	166.7 m	167.4 m	167.9 m

Note:
(1) Water levels reflect corresponding Stephens Lake level and Nelson River flow percentiles.

TABLE 2

Range of Winter Future Environment Without the Project
Water Levels at Key Sites

Site	5th Percentile	50th Percentile	95th Percentile
Stephens Lake	139.3 m	140.4 m	141.0 m
Keeyask Tailrace(1)	141.1 m	142.9 m	143.7 m
U/S Gull Rapids	152.6 m	153.4 m	154.1 m
Gull Lake	152.9 m	153.8 m	154.7 m
Portage Creek	153.9 m	156.0 m	158.6 m
Two Goose Creek	155.5 m	158.6 m	160.8 m
D/S Birthday Rapids	157.2 m	160.5 m	162.5 m
U/S Birthday Rapids	159.1 m	161.2 m	162.9 m
D/S Clark Lake Outlet	163.5 m	164.0 m	164.3 m
Clark Lake	166.3 m	167.0 m	167.4 m
Split Lake	166.7 m	167.4 m	167.9 m

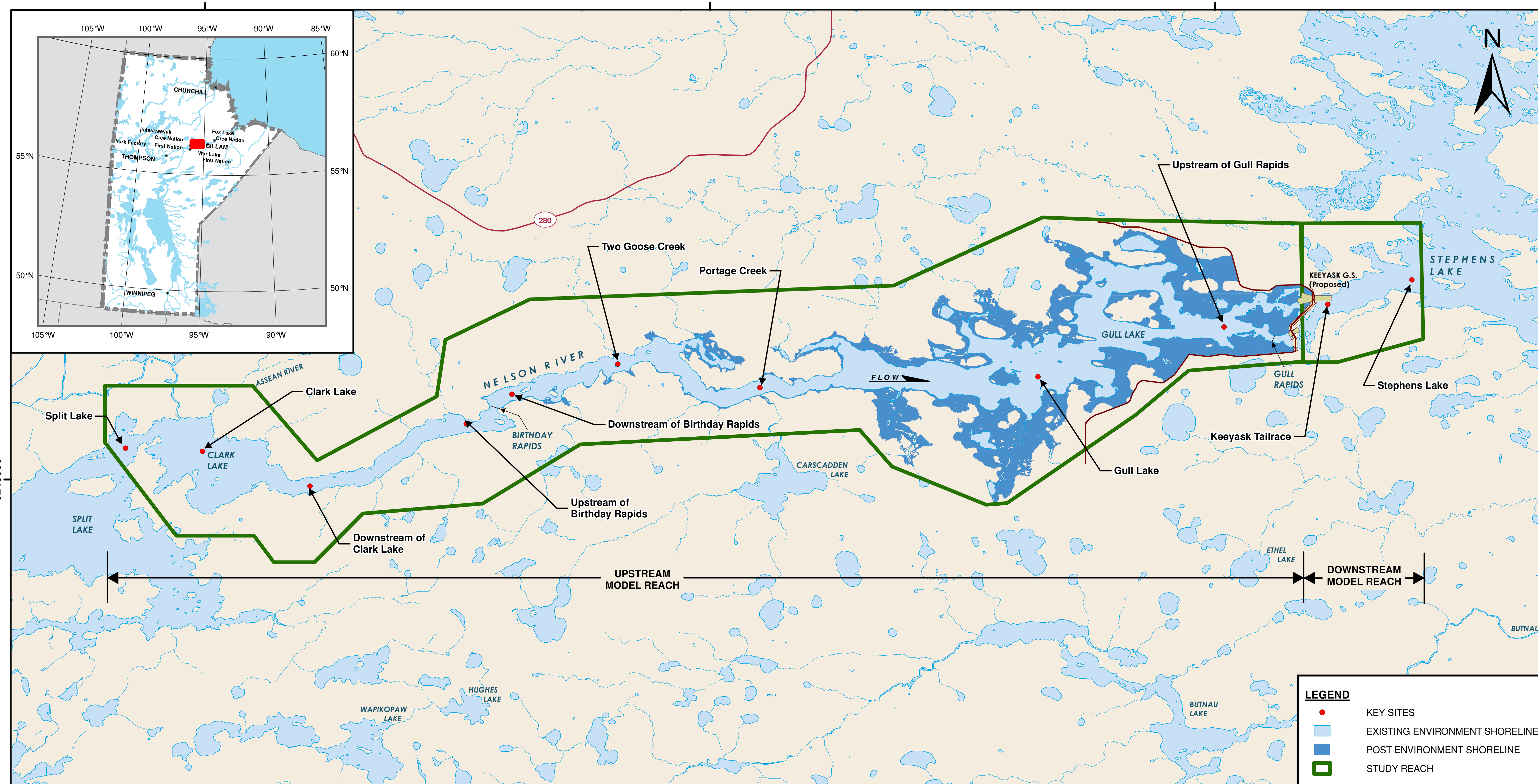
Note:
(1) Water levels reflect corresponding Stephens Lake level and Nelson River flow percentiles.

REFERENCES

REFERENCES

1. KGS ACRES Ltd, Memorandum GN-9.1.6 “Keeyask Generation Project – Stage IV Studies – Physical Environment – Existing Environment Ice Processes” Draft 2, Manitoba Hydro File 00195-11100-0141_01, May 2009.
2. Manitoba Hydro, Memorandum GN-9.1.1 “Keeyask Generation Project – Stage IV Studies – Physical Environment – Existing and Project Environment Flow Files” Draft 1, Manitoba Hydro File 00195-11100-0136_00, January 2008.
3. Manitoba Hydro, Memorandum GN-9.1.8 “Keeyask Generation Project – Stage IV Studies – Physical Environment – Existing Environment Water Regime – Key Sites” Draft 1, Manitoba Hydro File 00195-11100-0143_00, April 2008.
4. Manitoba Hydro, Memorandum GN-9.1.12 “Keeyask Generation Project – Stage IV Studies – Physical Environment – Project Environment – Water Level and Flow Regime At Key Sites – Effects Assessment” Draft 1, Manitoba Hydro File 00195-11100-0147_00, April 2008.

FIGURES



KEEYASK

0 1,500 3,000 6,000 Meters

0 7,500 15,000 30,000 Feet

Projection: Universal Transverse Mercator Zone 15N, NAD 83

Data Source: Baseline lakes, rivers, roads, railway and transmission line, taken from NTDB maps 64A1, 64A8, 54D3, 54D4, 54D5 and 54D6, 2005. Her Majesty the Queen in right of Canada. All rights reserved.
Proposed Keeyask Generating station structures provided by KGS Acres 2004
Post environment shoreline provided by Manitoba Hydro 2007

Mapping grade for general reference only.

Key Sites Along Study Reach

Figure 1

Created By:
KGS ACRES

Date Created:
March 13, 2008

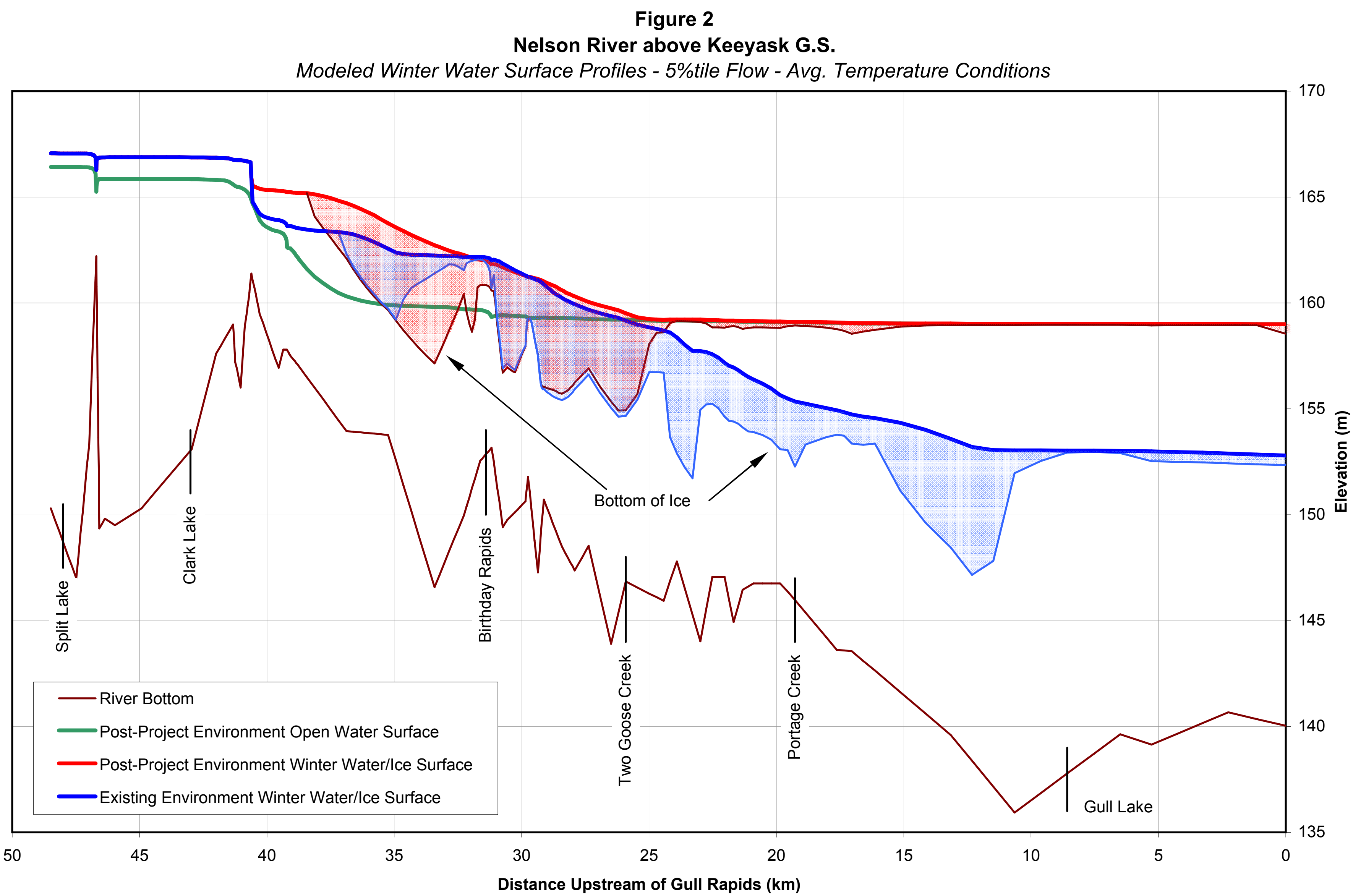


Figure 2
Nelson River above Keeyask G.S.
Modeled Winter Water Surface Profiles - 5%tile Flow - Avg. Temperature Conditions
Split Lake
Clark Lake
Birthday Rapids
Two Goose Creek
Portage Creek
Gull Lake
Bottom of Ice
River Bottom
Post-Project Environment Open Water Surface
Post-Project Environment Winter Water/Ice Surface
Existing Environment Winter Water/Ice Surface
Elevation (m)
Distance Upstream of Gull Rapids (km)
170
165
160
155
150
145
140
135
50
45
40
35
30
25
20
15
10
5
0

Figure 3
Nelson River above Keeyask G.S.
Modeled Winter Water Surface Profiles - 50%tile Flow - Avg. Temperature Conditions

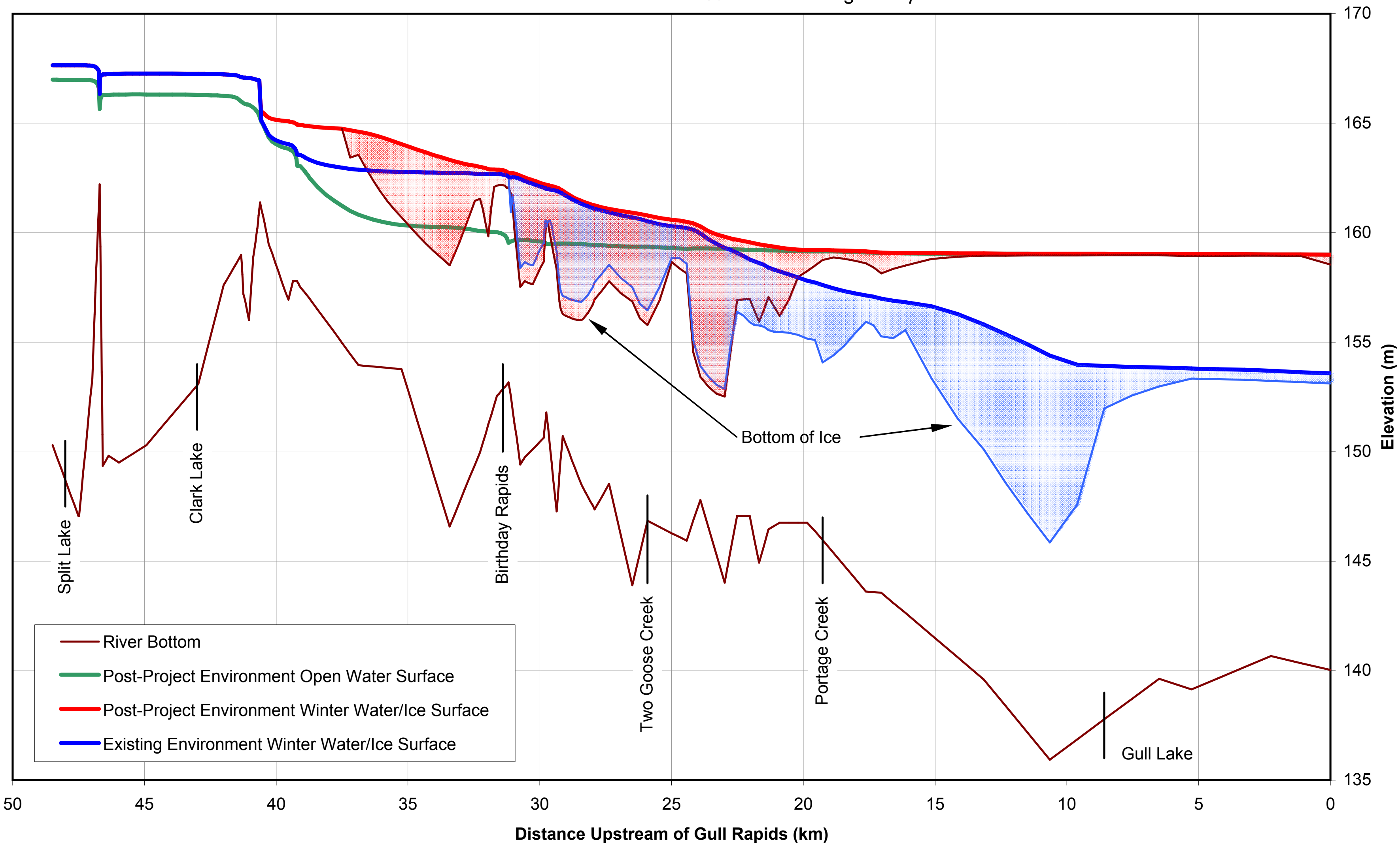


Figure 4
Nelson River above Keeyask G.S.
Modeled Winter Water Surface Profiles - 95%tile Flow - Avg. Temperature Conditions

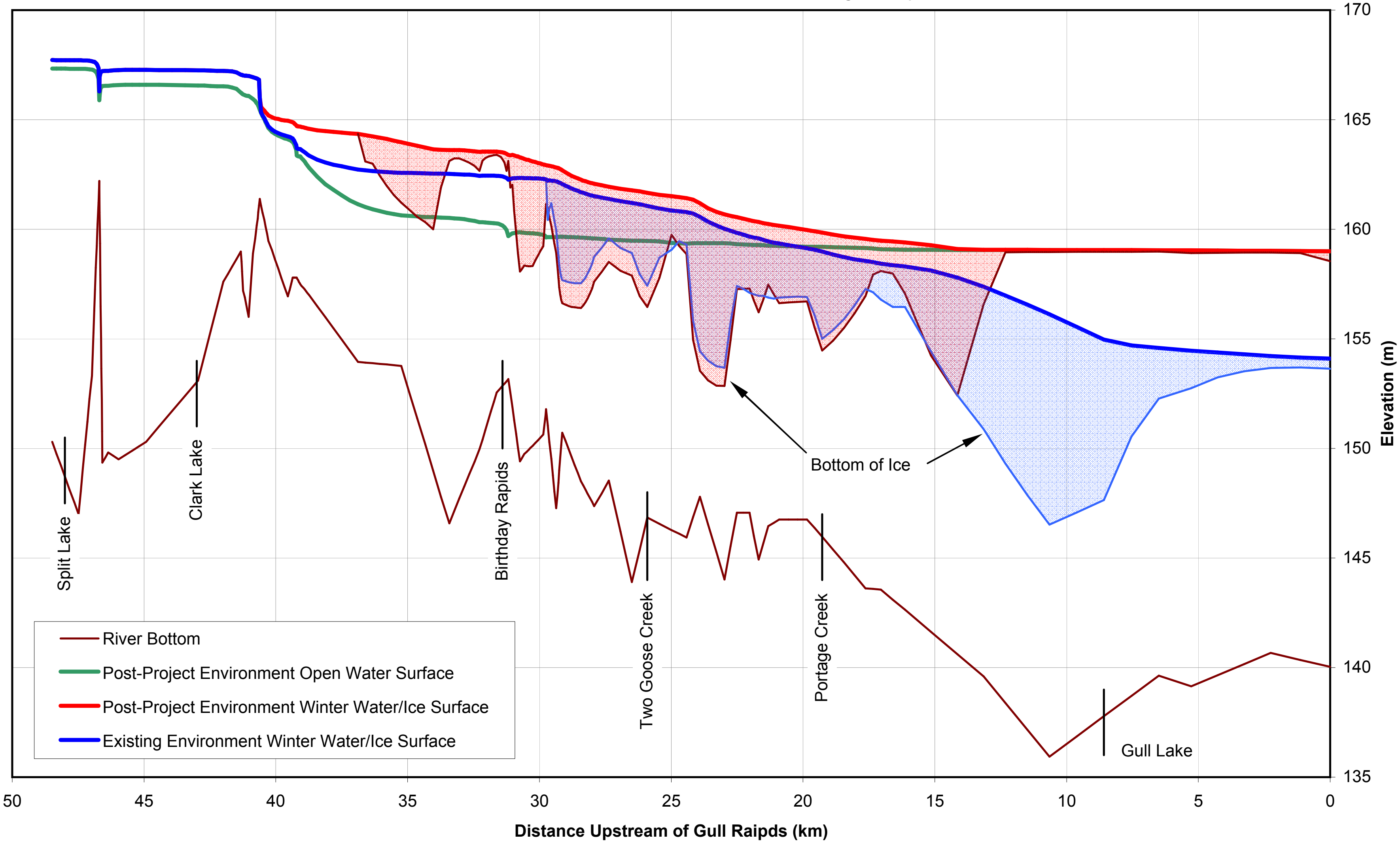
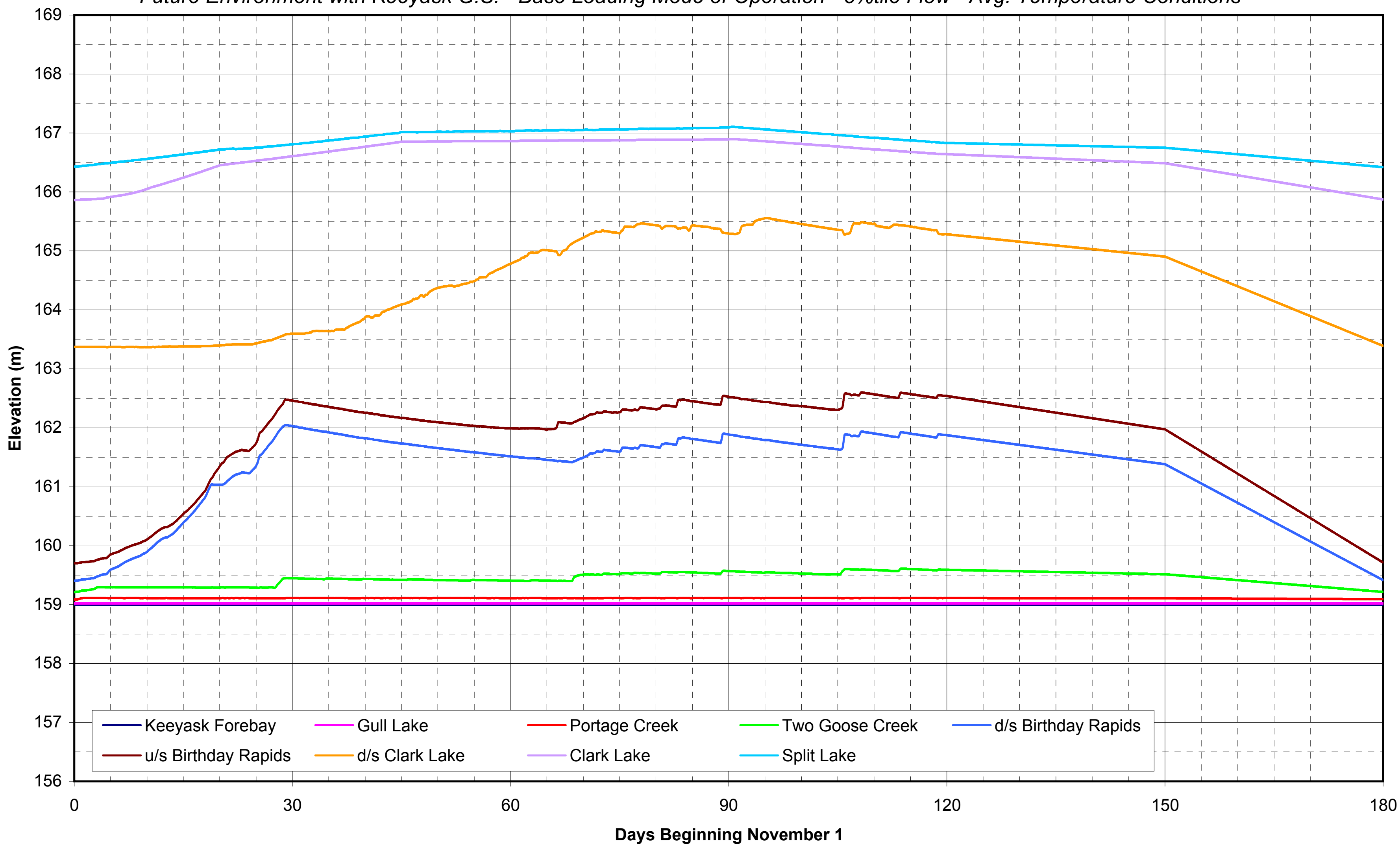


Figure 5

Nelson River above Keeyask G.S. - Modeled Winter Stage Hydrographs

Future Environment with Keeyask G.S. - Base Loading Mode of Operation - 5%tile Flow - Avg. Temperature Conditions



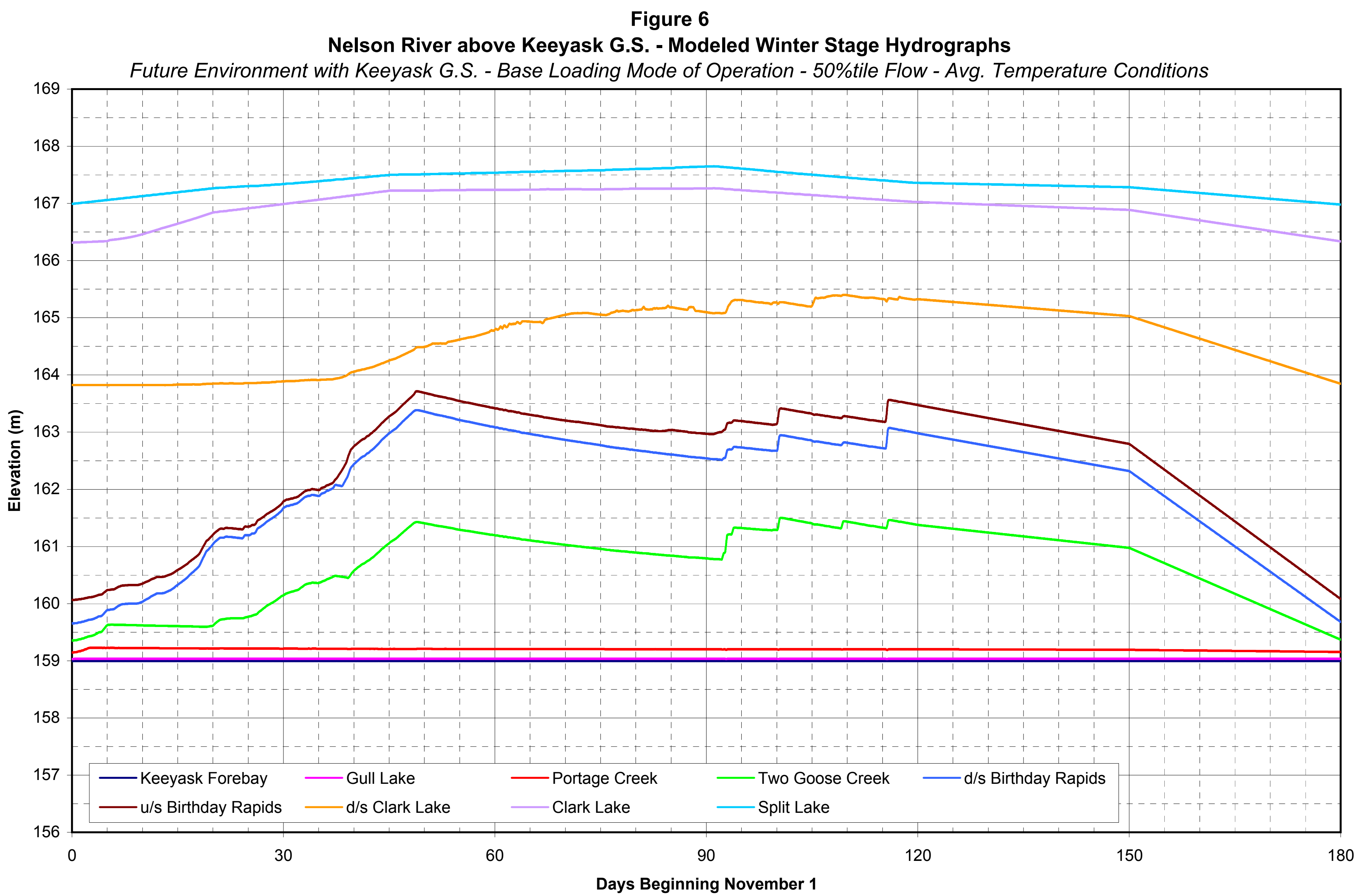


Figure 6
Nelson River above Keeyask G.S. - Modeled Winter Stage Hydrographs
Future Environment with Keeyask G.S. - Base Loading Mode of Operation - 50%tile Flow - Avg. Temperature Conditions
Elevation (m)
Days Beginning November 1
169
168
167
166
165
164
163
162
161
160
159
158
157
156
0
30
60
90
120
150
180
Keeyask Forebay
Gull Lake
Portage Creek
Two Goose Creek
d/s Birthday Rapids
u/s Birthday Rapids
d/s Clark Lake
Clark Lake
Split Lake

Figure 7
Nelson River above Keeyask G.S. - Modeled Winter Stage Hydrographs
Future Environment with Keeyask G.S. - Base Loading Mode of Operation - 95%tile Flow - Avg. Temperature Conditions

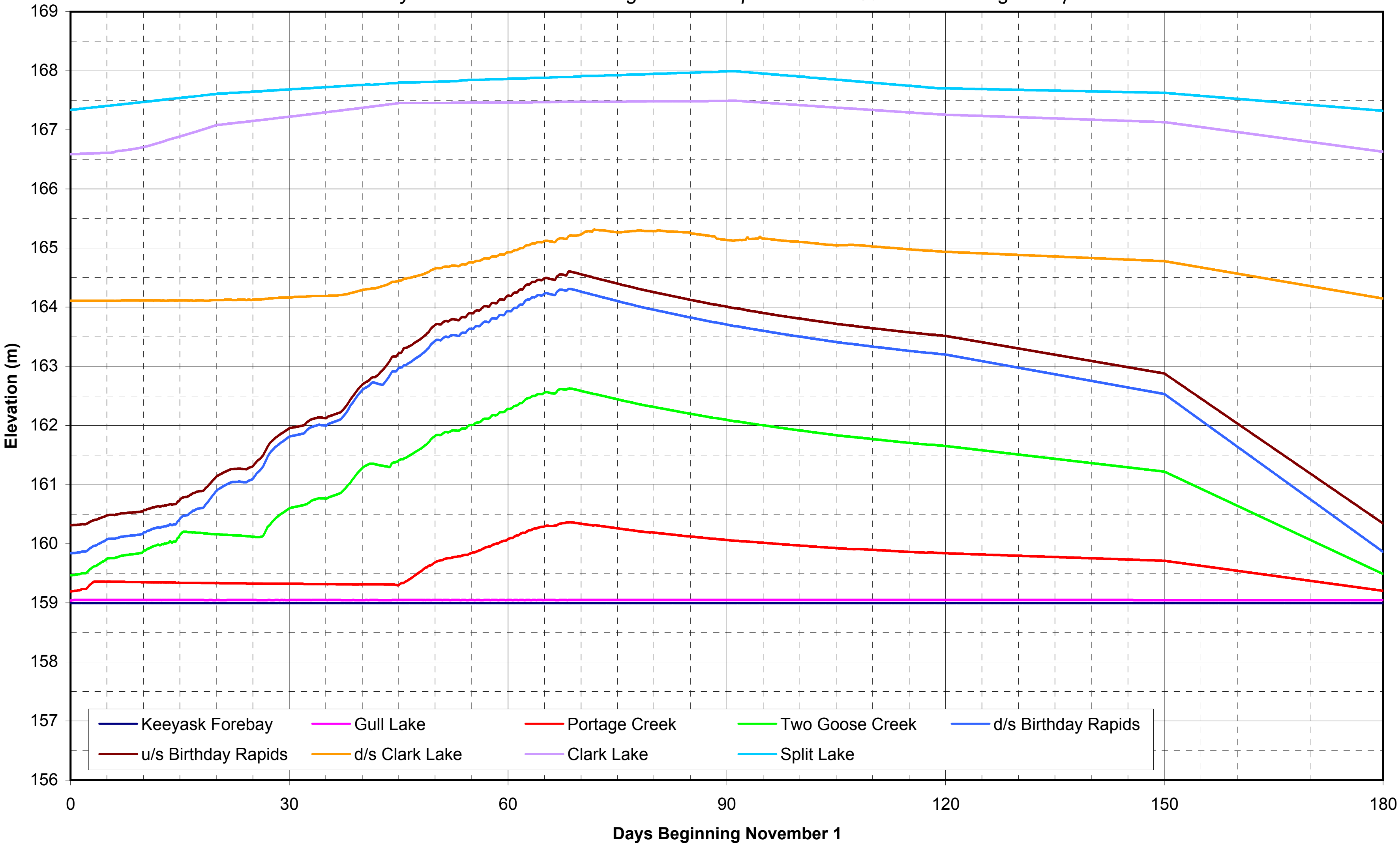


Figure 8
Keeyask G.S. Tailrace Channel
Predicted Open Water and Winter Rating Curves

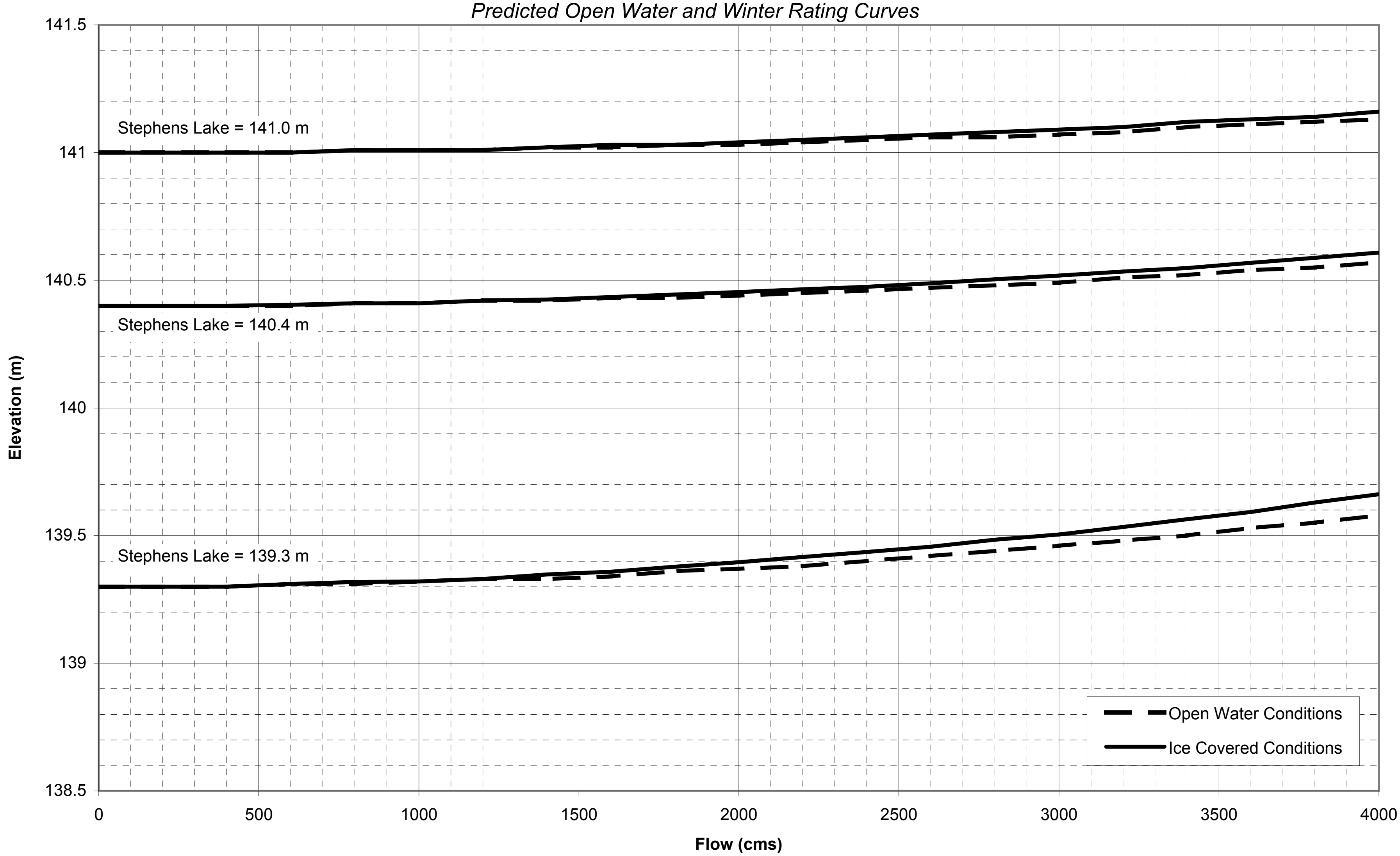
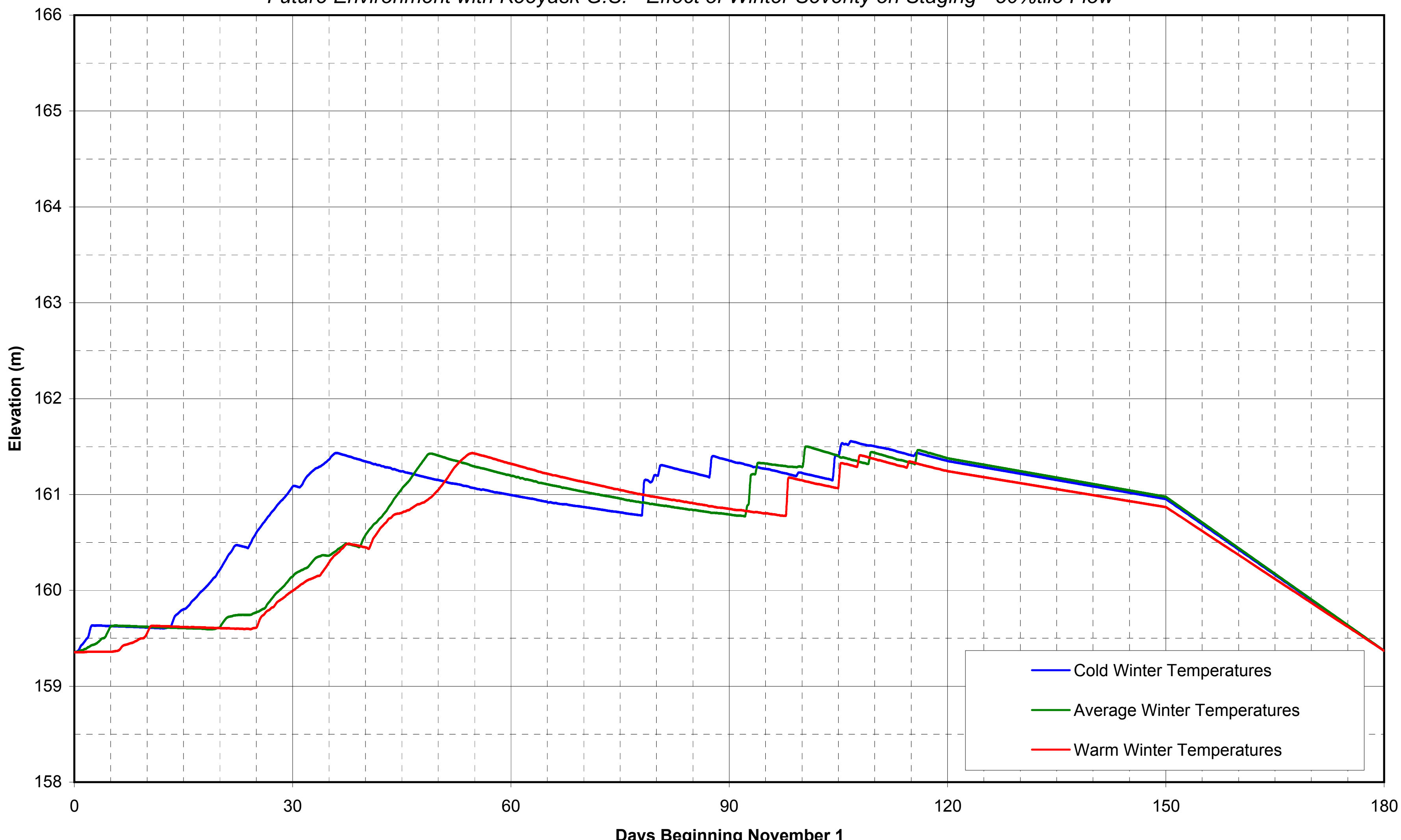
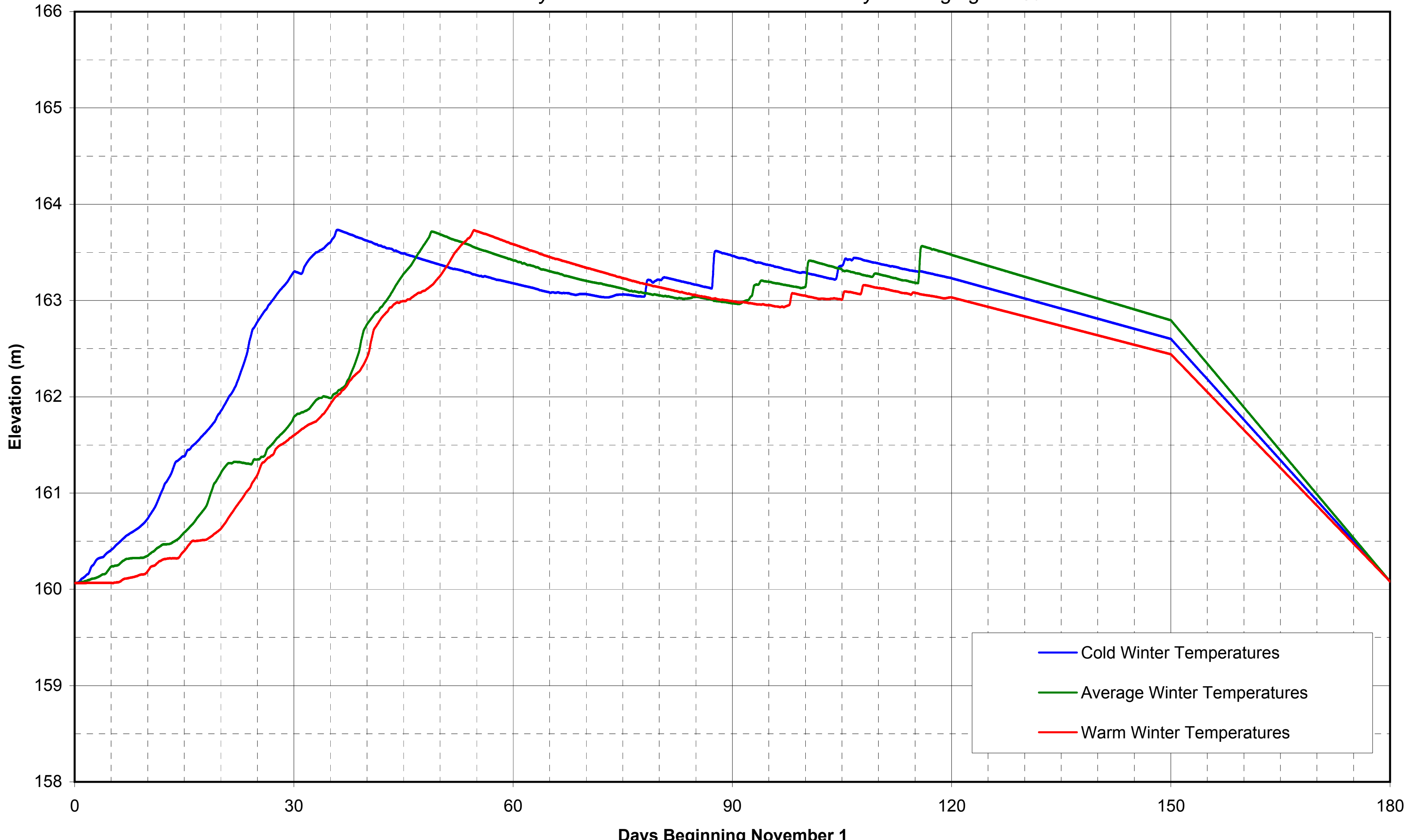


Figure 9
Nelson River at Two Goose Creek - Modeled Winter Stage Hydrographs
Future Environment with Keeyask G.S. - Effect of Winter Severity on Staging - 50%tile Flow



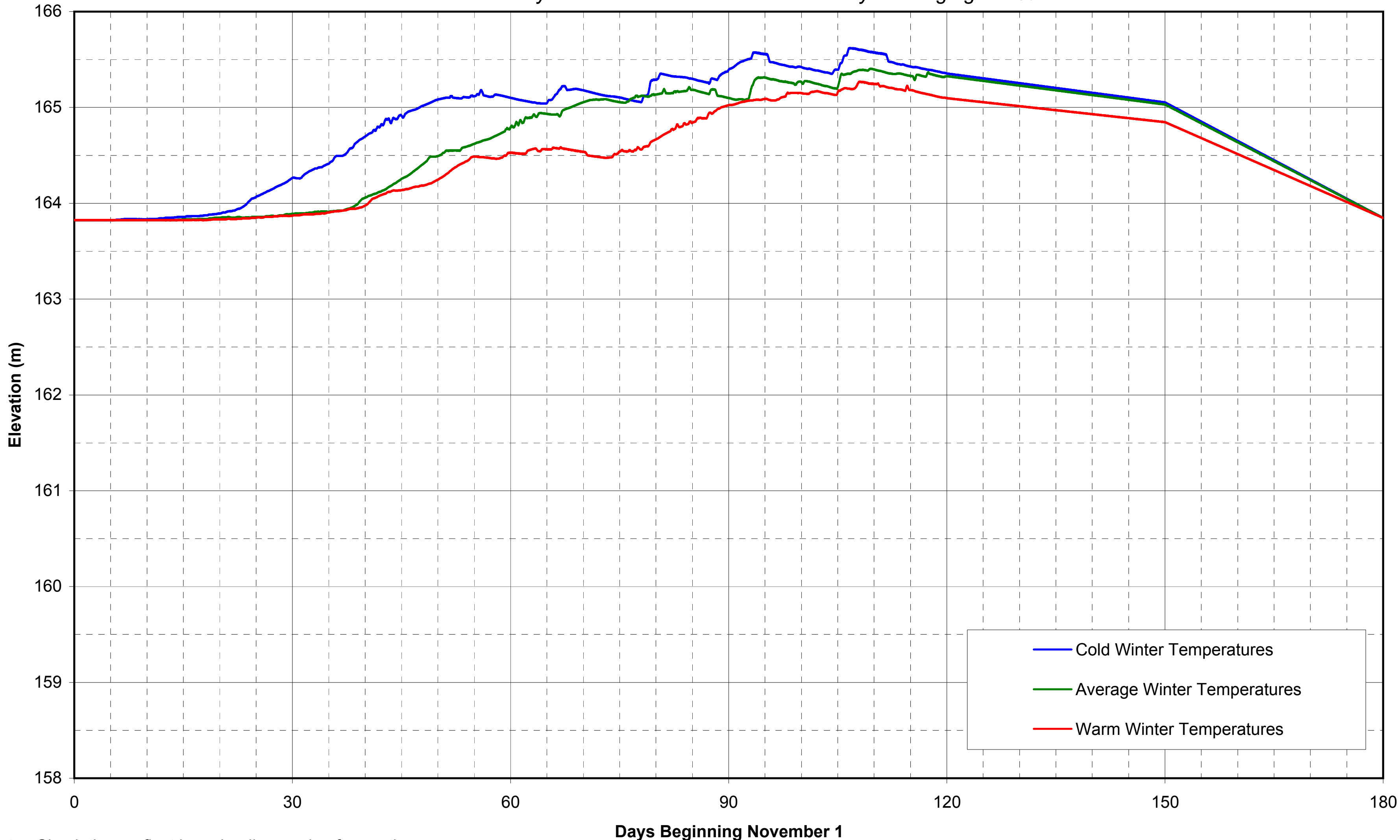
Note: Simulations reflect base loading mode of operation.

Figure 10
Nelson River above Birthday Rapids - Modeled Winter Stage Hydrographs
Future Environment with Keeyask G.S. - Effect of Winter Severity on Staging - 50%tile Flow



Note: Simulations reflect base loading mode of operation.

Figure 11
Nelson River below Clark Lake - Modeled Winter Stage Hydrographs
Future Environment with Keeyask G.S. - Effect of Winter Severity on Staging - 50%tile Flow

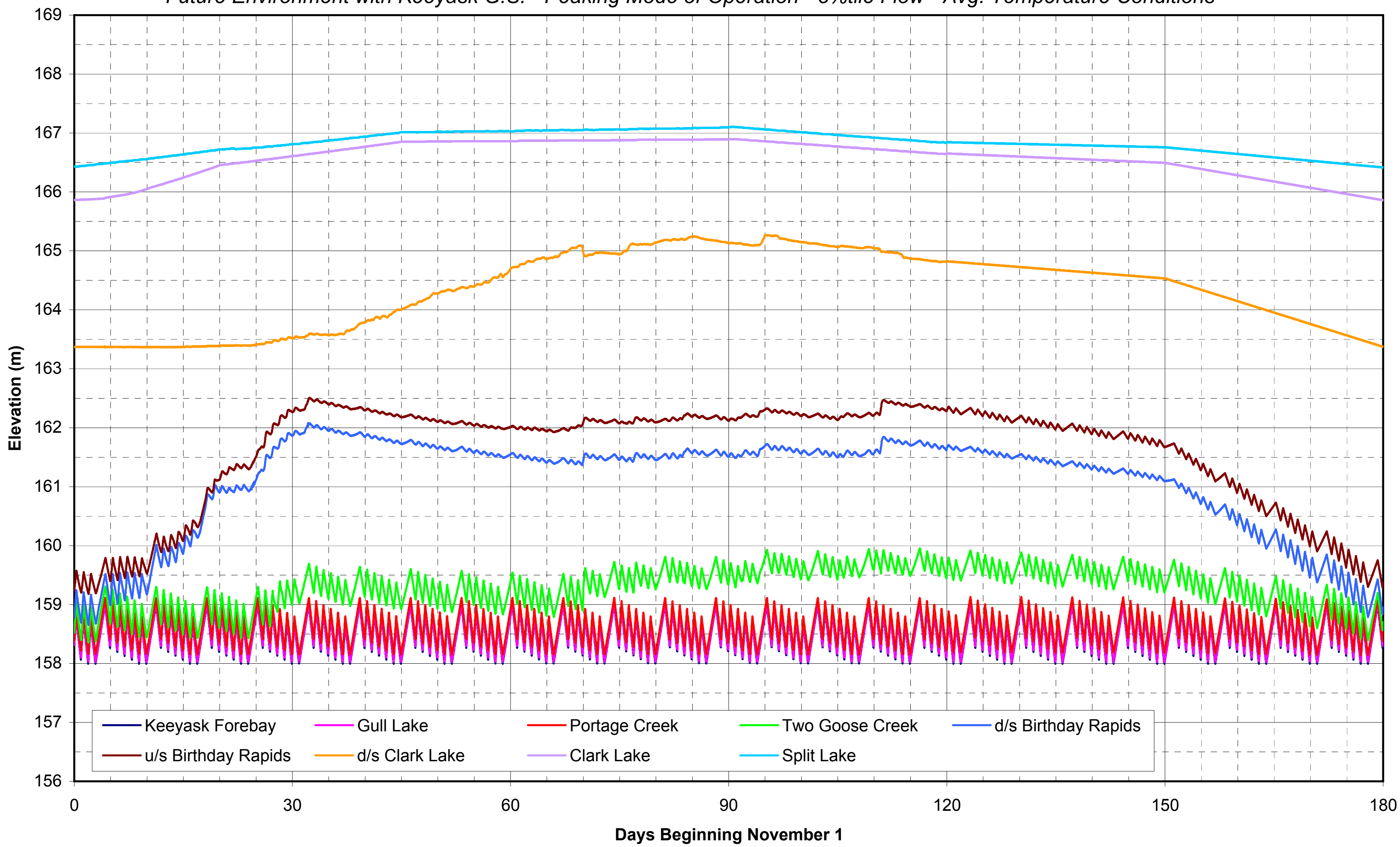


Note: Simulations reflect base loading mode of operation.

Figure 12

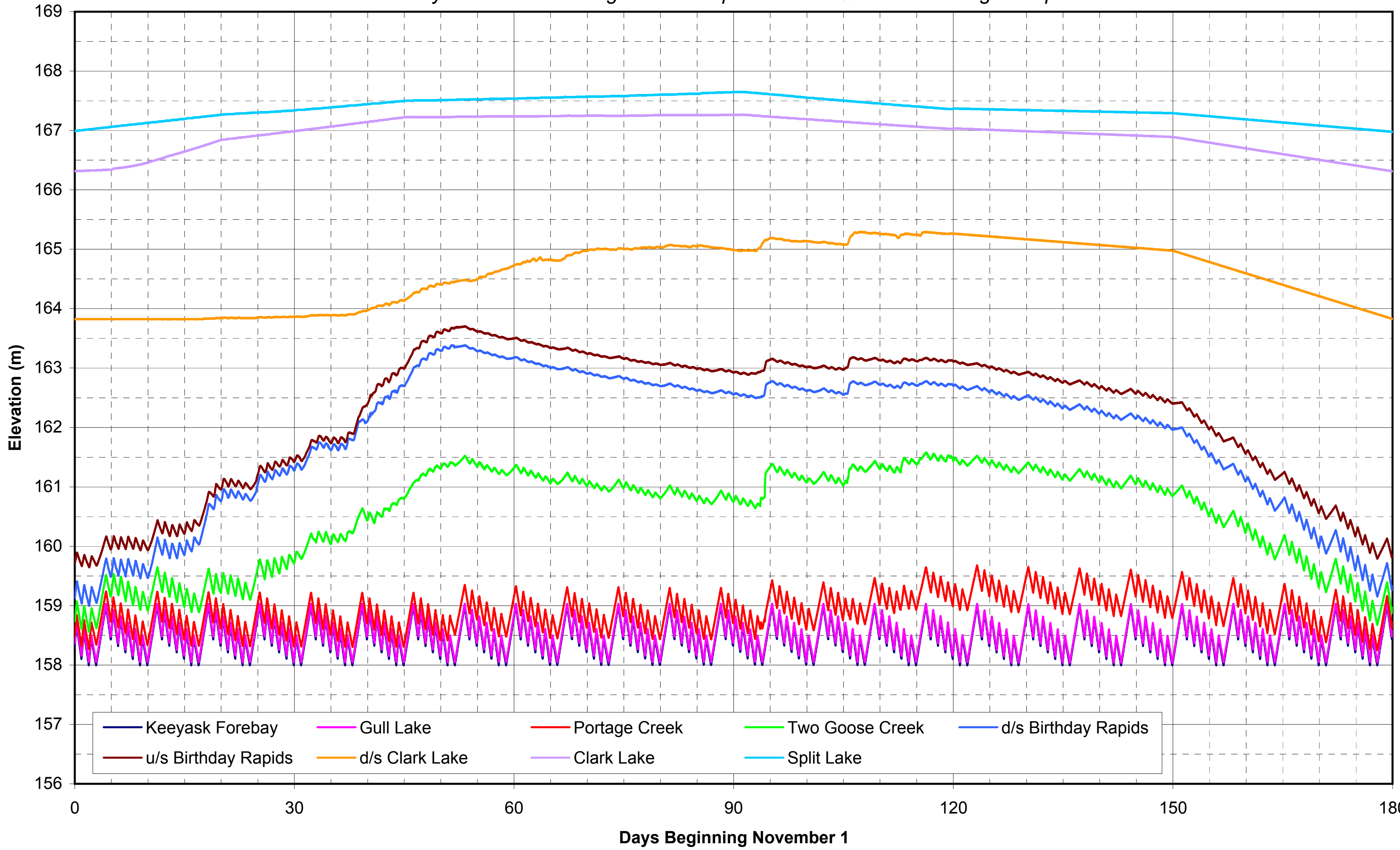
Nelson River above Keeyask G.S. - Modeled Winter Stage Hydrographs

Future Environment with Keeyask G.S. - Peaking Mode of Operation - 5%tile Flow - Avg. Temperature Conditions



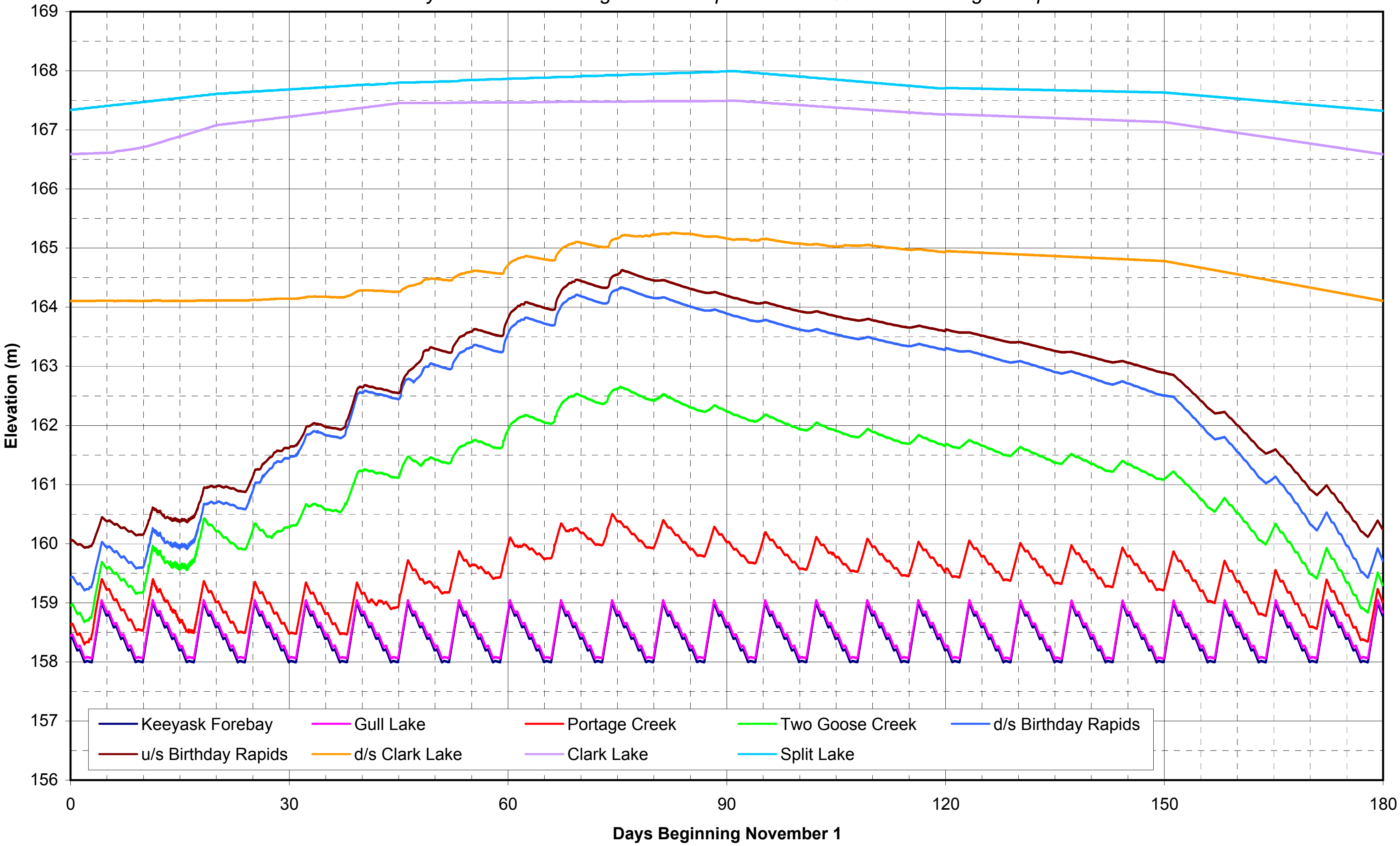
Note: Keeyask Forebay, Gull Lake, and Portage Creek water levels are almost identical and therefore indistinguishable on this plot

Figure 13
Nelson River above Keeyask G.S. - Modeled Winter Stage Hydrographs
Future Environment with Keeyask G.S. - Peaking Mode of Operation - 50%tile Flow - Avg. Temperature Conditions



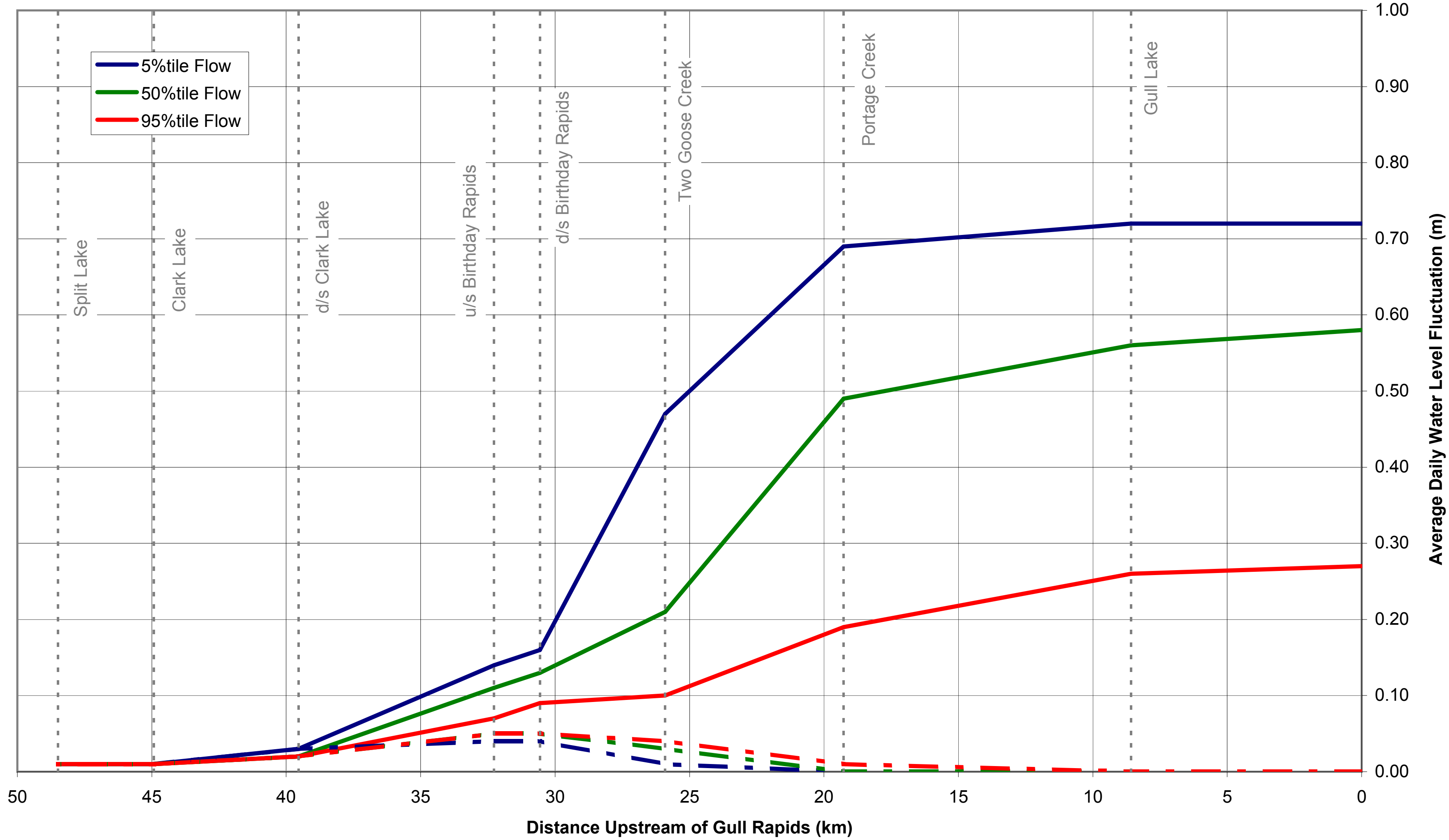
Note: Keeyask Forebay, Gull Lake, and Portage Creek water levels are almost identical and therefore indistinguishable on this plot

Figure 14
Nelson River above Keeyask G.S. - Modeled Winter Stage Hydrographs
Future Environment with Keeyask G.S. - Peaking Mode of Operation - 95%tile Flow - Avg. Temperature Conditions



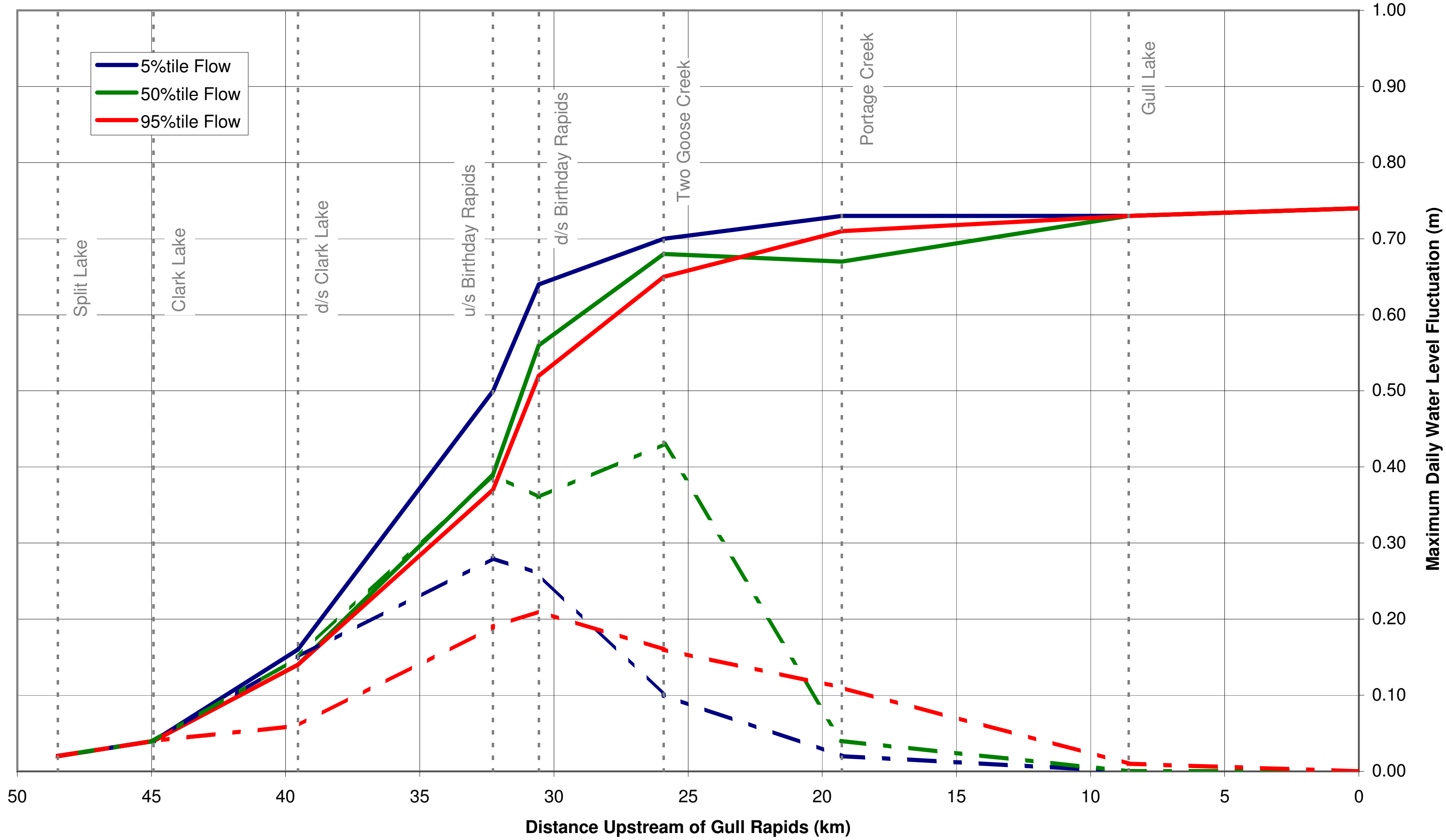
Note: Keeyask Forebay and Gull Lake water levels are almost identical and therefore indistinguishable on this plot

Figure 15
Nelson River above Keeyask G.S. - Modeled Average Daily Winter Water Level Fluctuations
Comparison Between Base Loaded and Peaking Mode of Operation Over Winter Period



Solid lines represent peaking mode of operation, dashed lines represent base loaded mode of operation

Figure 16
Nelson River above Keeyask G.S. - Modeled Maximum Daily Winter Water Level Fluctuations
Comparison Between Base Loaded and Peaking Mode of Operation Over Winter Period



Solid lines represent peaking mode of operation, dashed lines represent base loaded mode of operation

Figure 17

Nelson River at Two Goose Creek - Modeled Winter Stage Hydrographs

Comparison Between Base Loaded and Peaking Mode of Operation - 50%tile Flow - Avg. Temperature Conditions

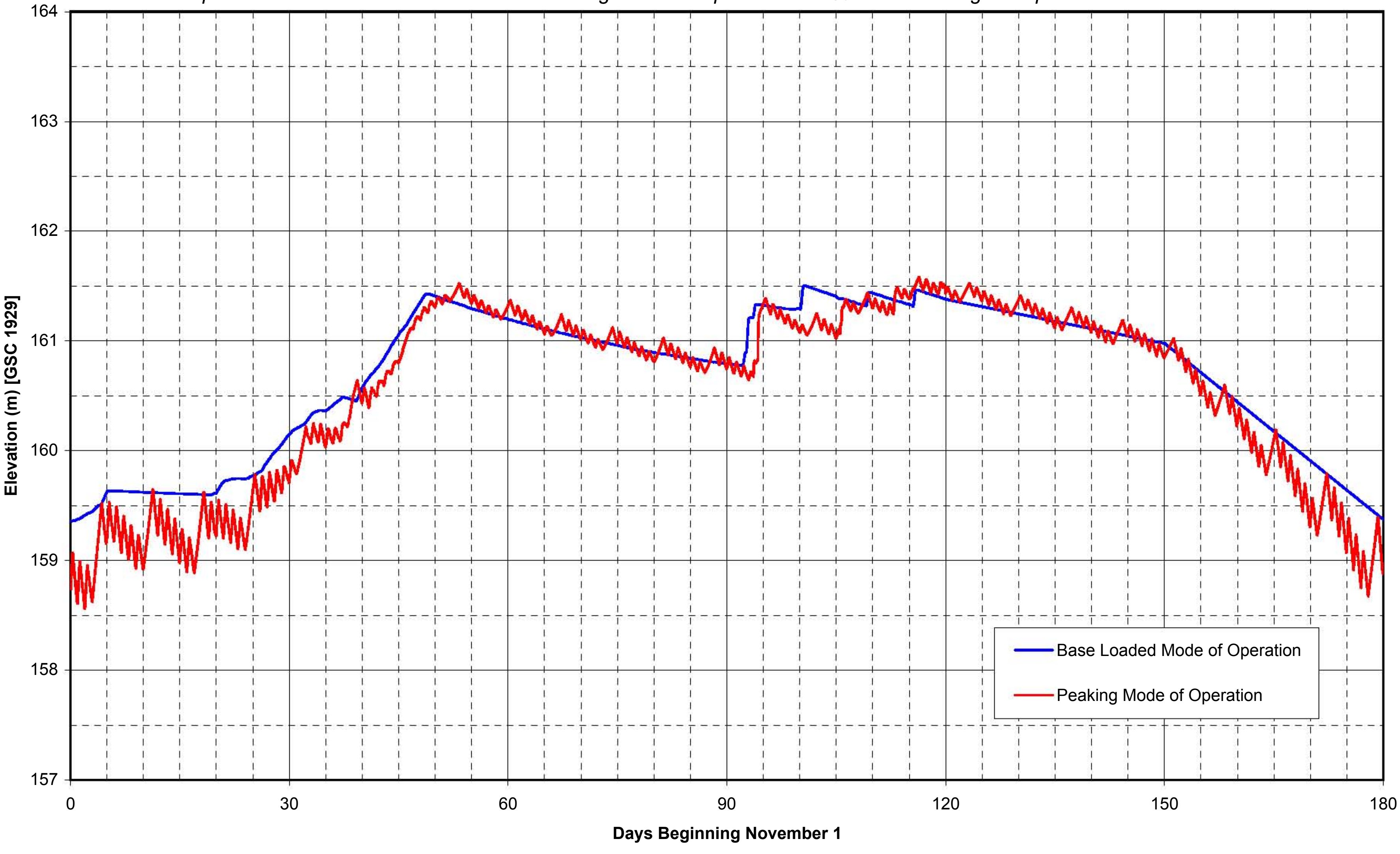


Figure 18
Keeyask G.S. Tailrace - Modeled Winter Stage Hydrographs
Future Environment with Keeyask G.S. - 5%tile Flow - Avg. Temperature Conditions

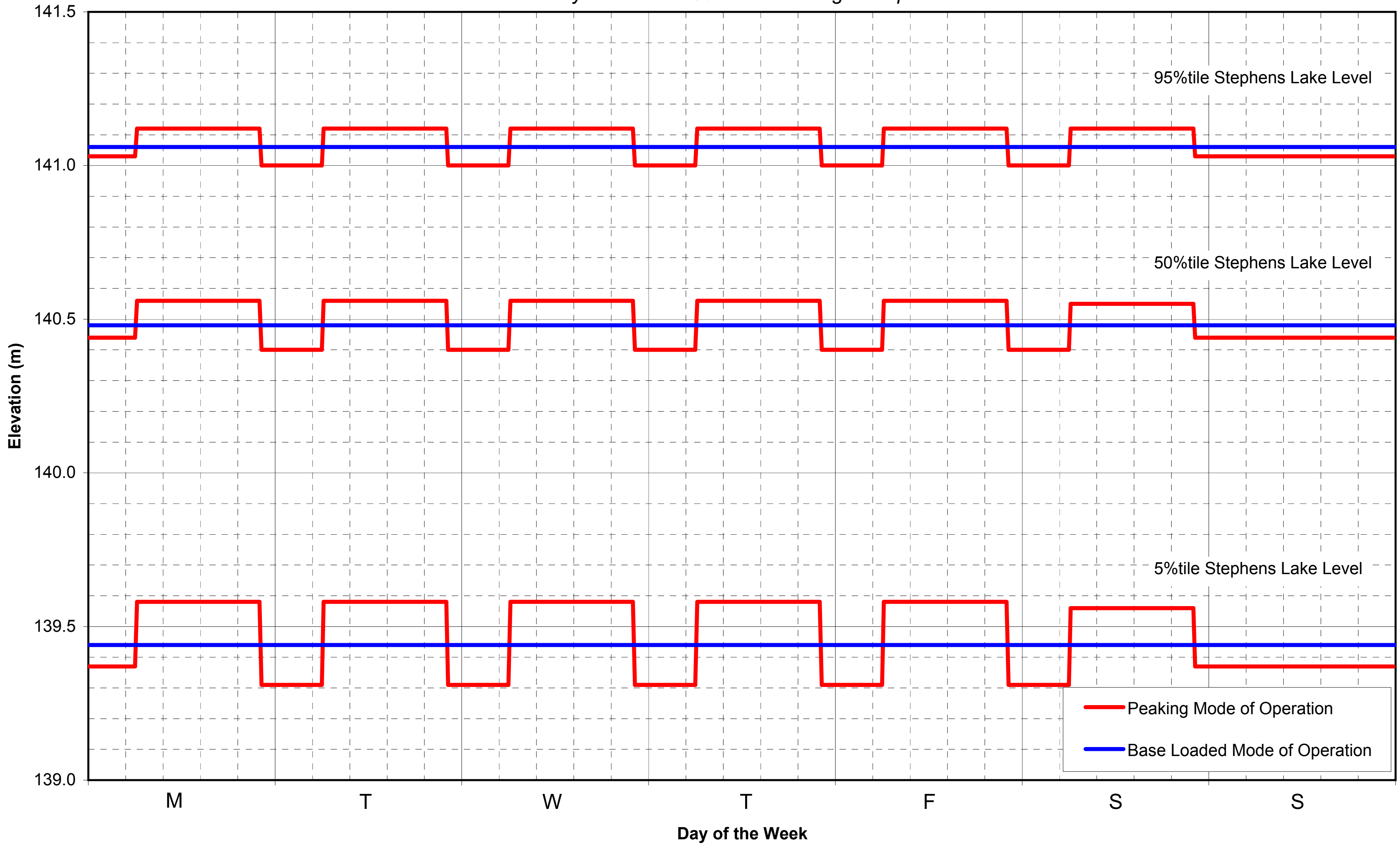


Figure 19
Keeyask G.S. Tailrace - Modeled Winter Stage Hydrographs
Future Environment with Keeyask G.S. - 50%tile Flow - Avg. Temperature Conditions

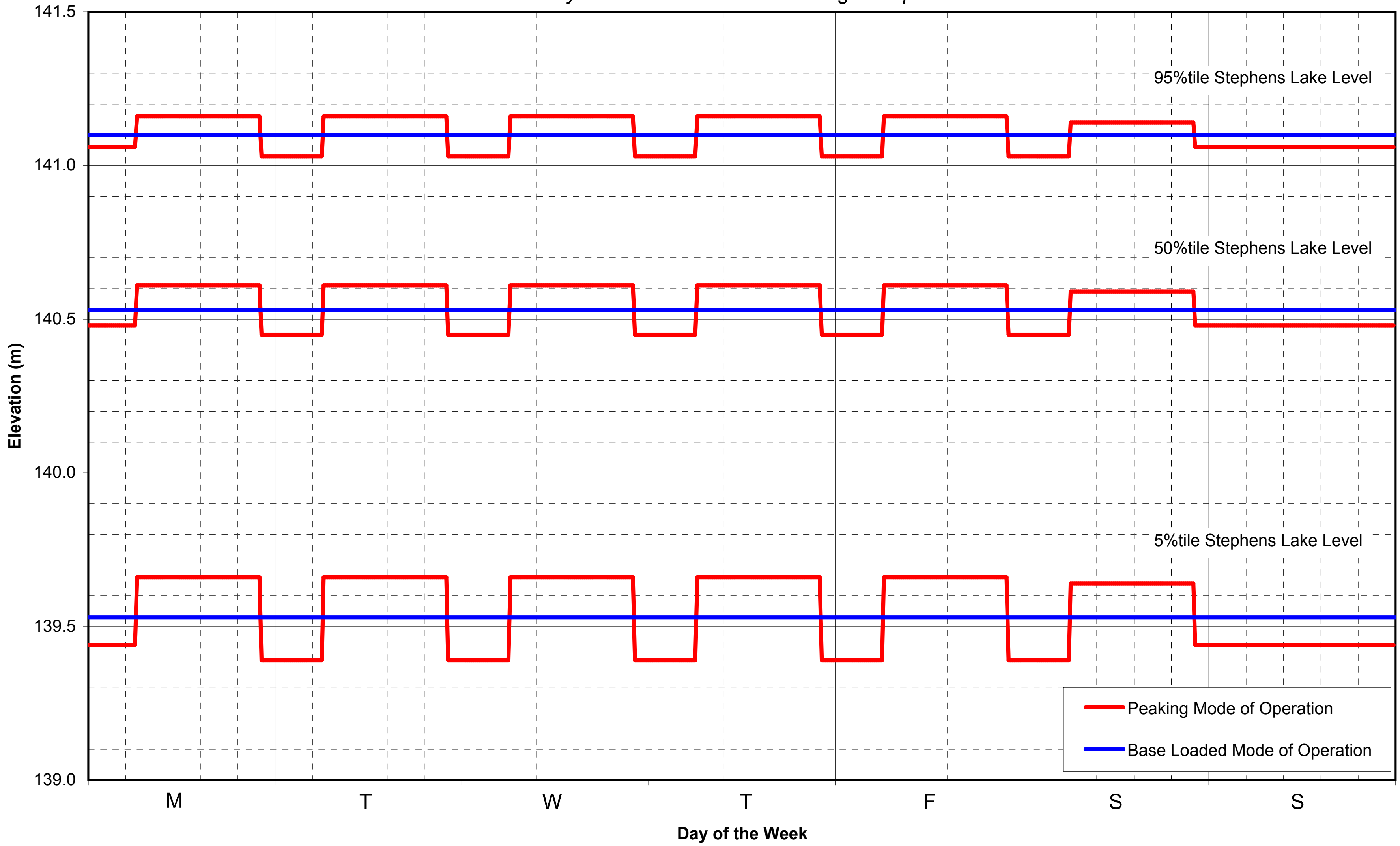


Figure 20
Keeyask G.S. Tailrace - Modeled Winter Stage Hydrographs
Future Environment with Keeyask G.S. - 95%tile Flow - Avg. Temperature Conditions

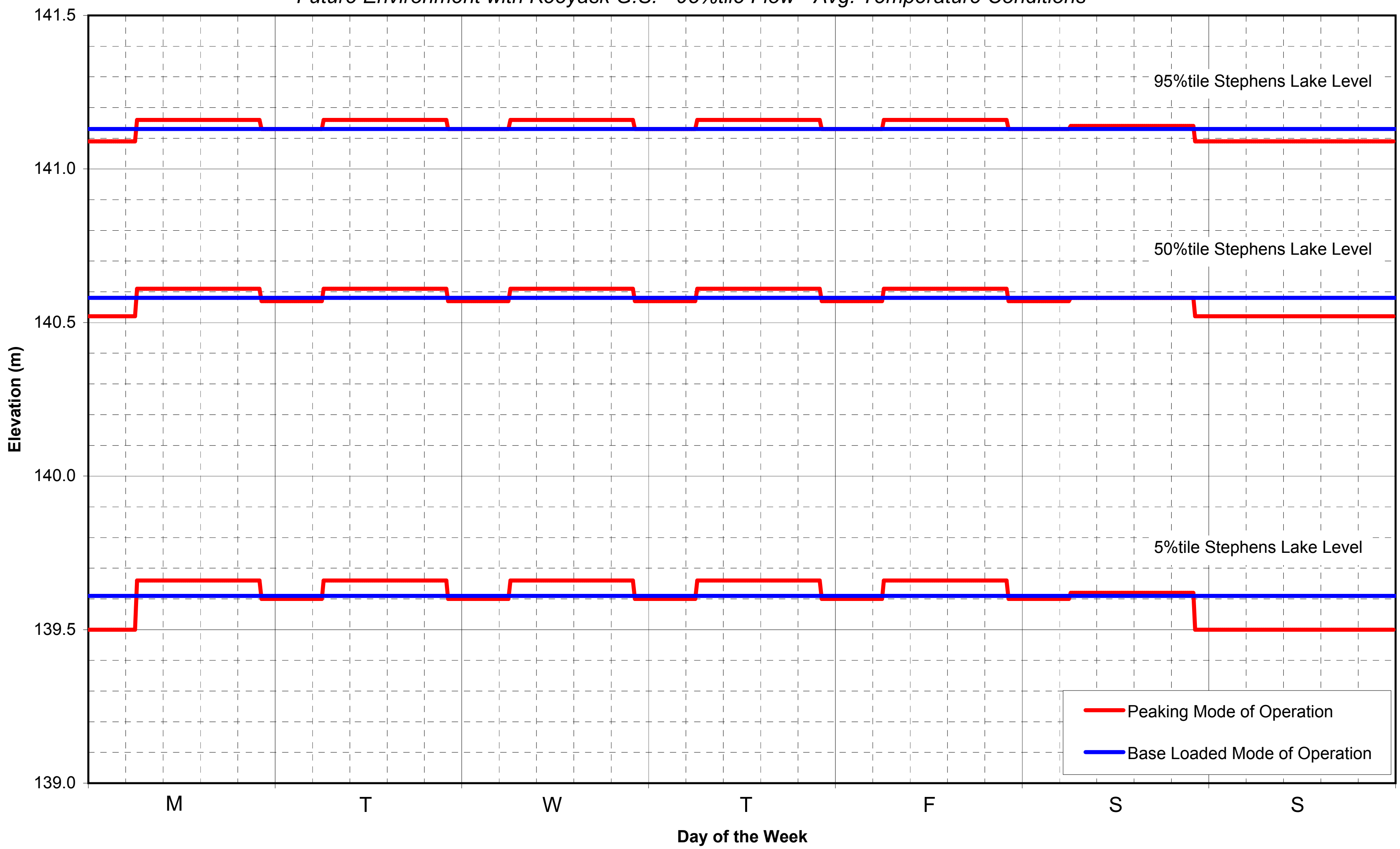
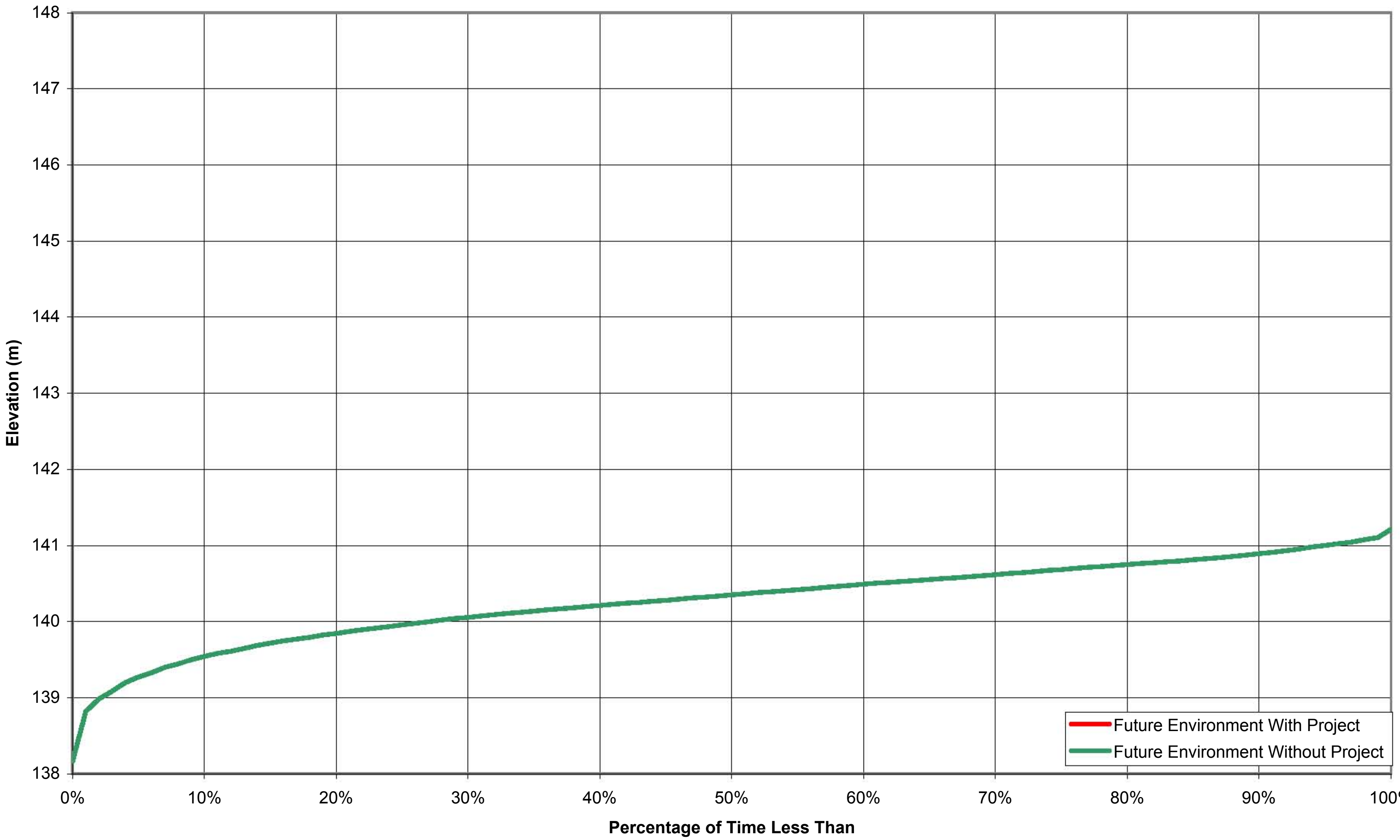
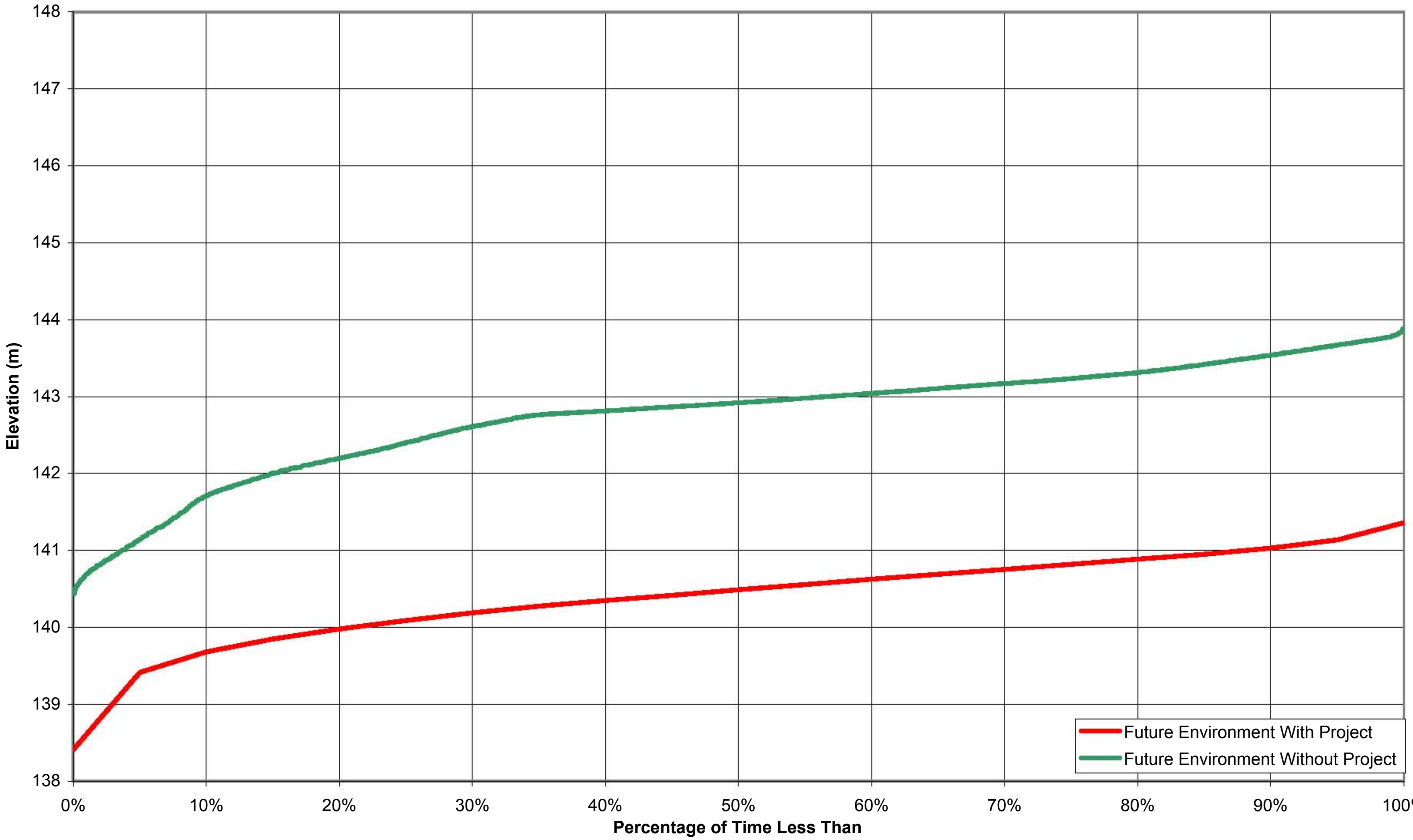


Figure 21
Nelson River at Stephens Lake - Winter Stage Duration Curves



Note: Water levels both with and without the Project are the same and therefore indistinguishable on this plot

Figure 22
Nelson River at Keeyask G.S. Tailrace - Modeled Winter Stage Duration Curves



Note: 1. Water levels without the Project may be higher in years when bridging of Gull Lake is delayed

2. Percentile level of Stephens Lake assumed to correspond to flow percentile under consideration (ie. 50th percentile level occurs with 50th percentile flow)

Figure 23
Nelson River above Gull Rapids - Modeled Winter Stage Duration Curves

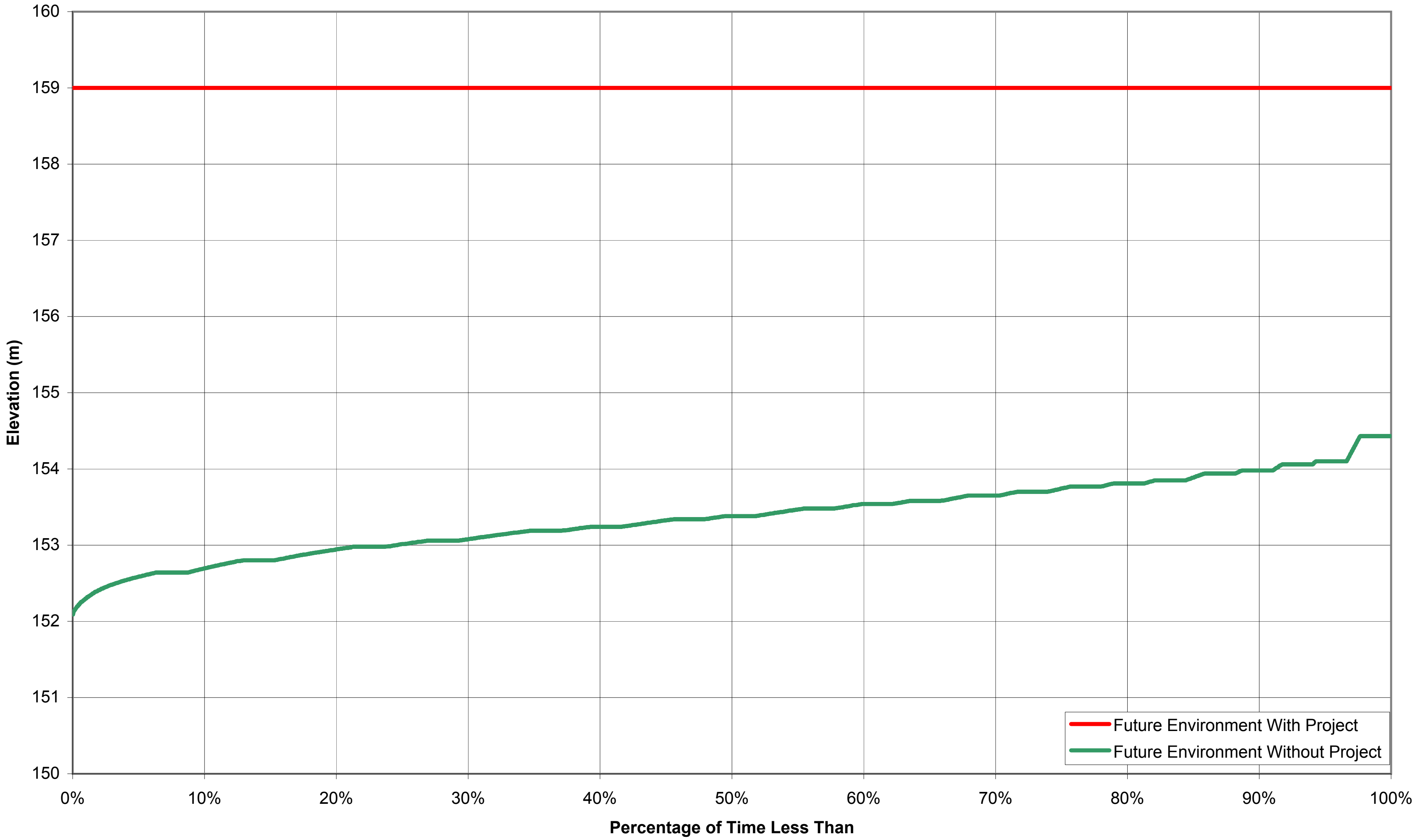


Figure 24
Nelson River at Gull Lake - Modeled Winter Stage Duration Curves

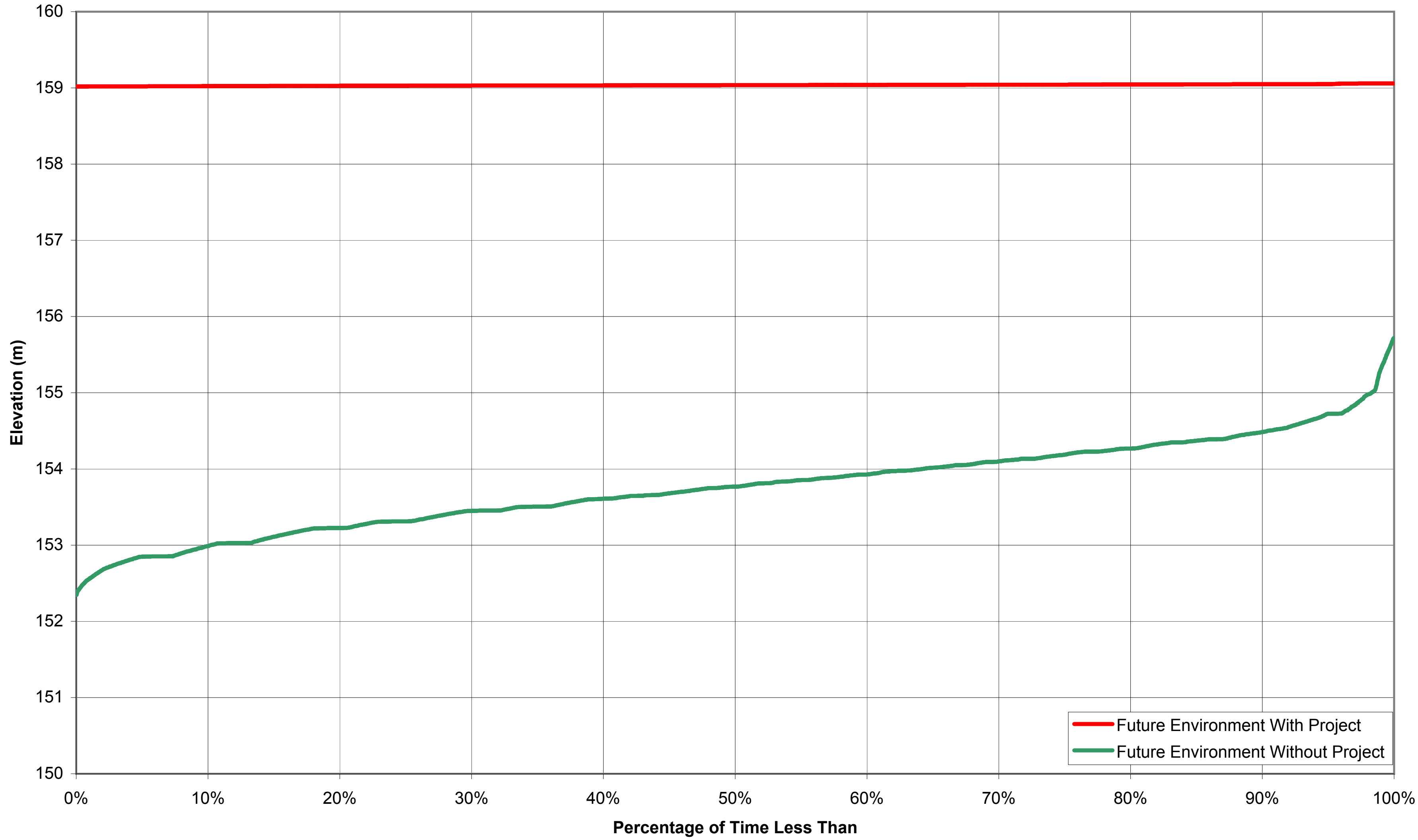


Figure 25
Nelson River at Portage Creek - Modeled Winter Stage Duration Curves

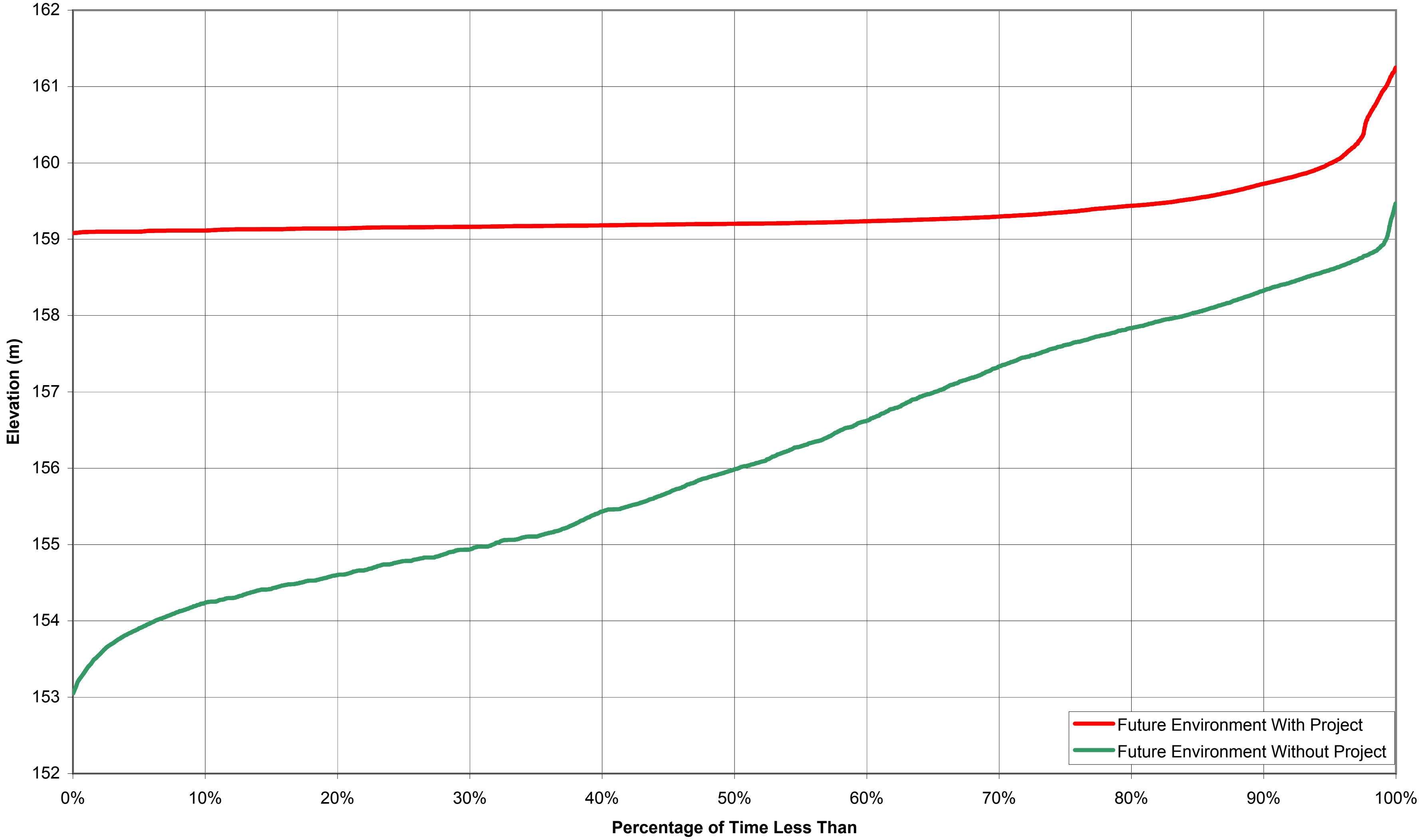


Figure 26
Nelson River at Two Goose Creek - Modeled Winter Stage Duration Curves

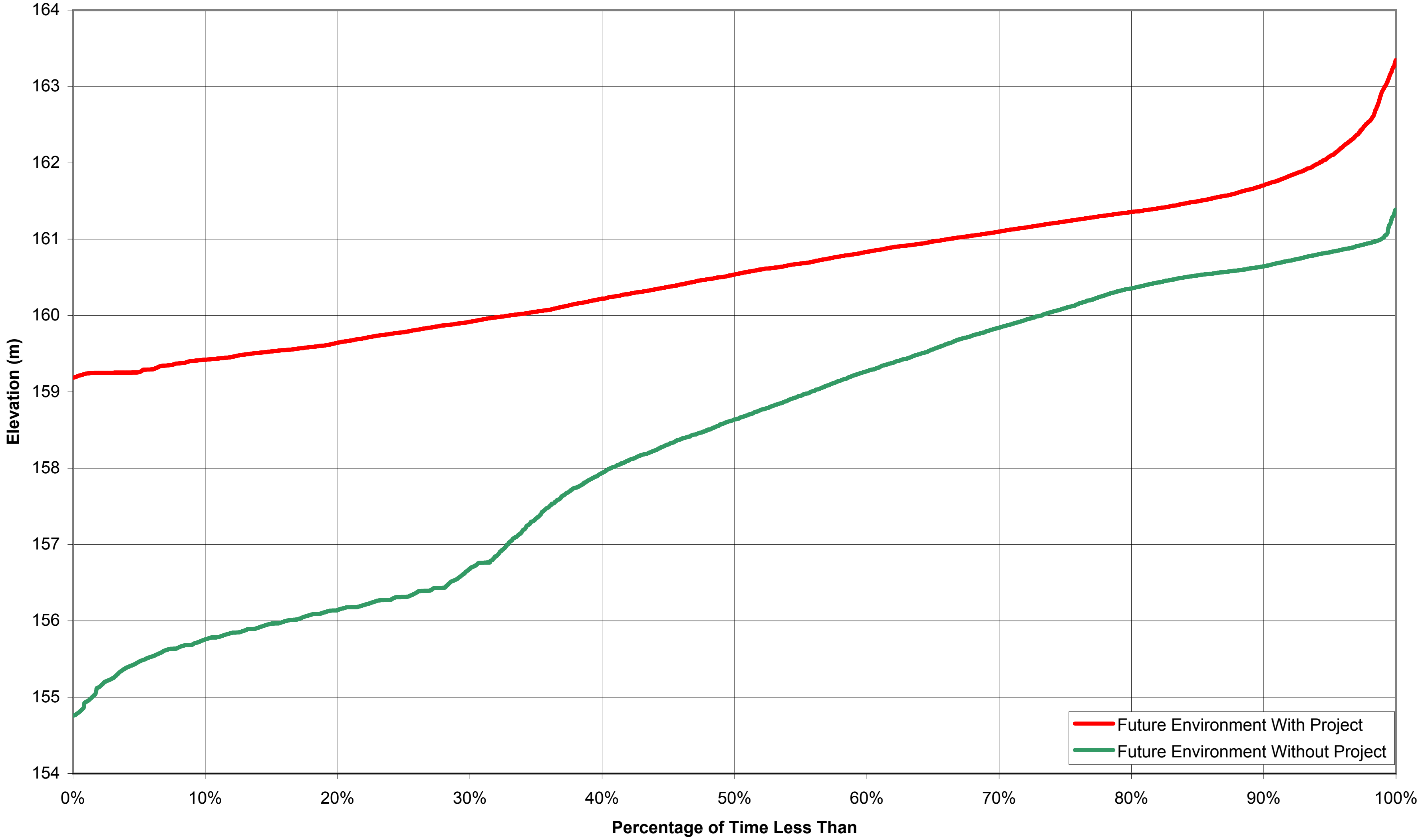


Figure 27
Nelson River below Birthday Rapids - Modeled Winter Stage Duration Curves

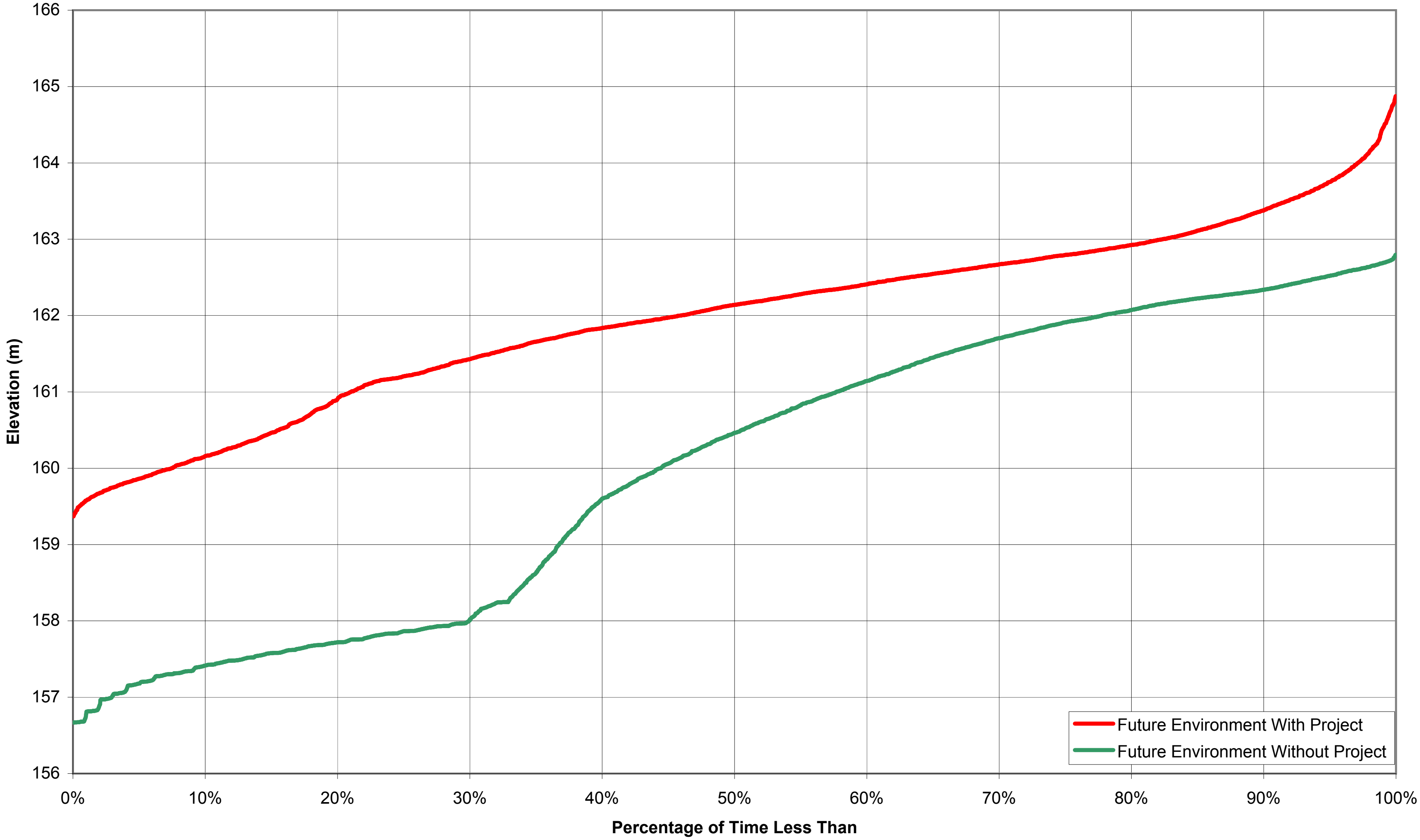


Figure 28
Nelson River above Birthday Rapids - Modeled Winter Stage Duration Curves

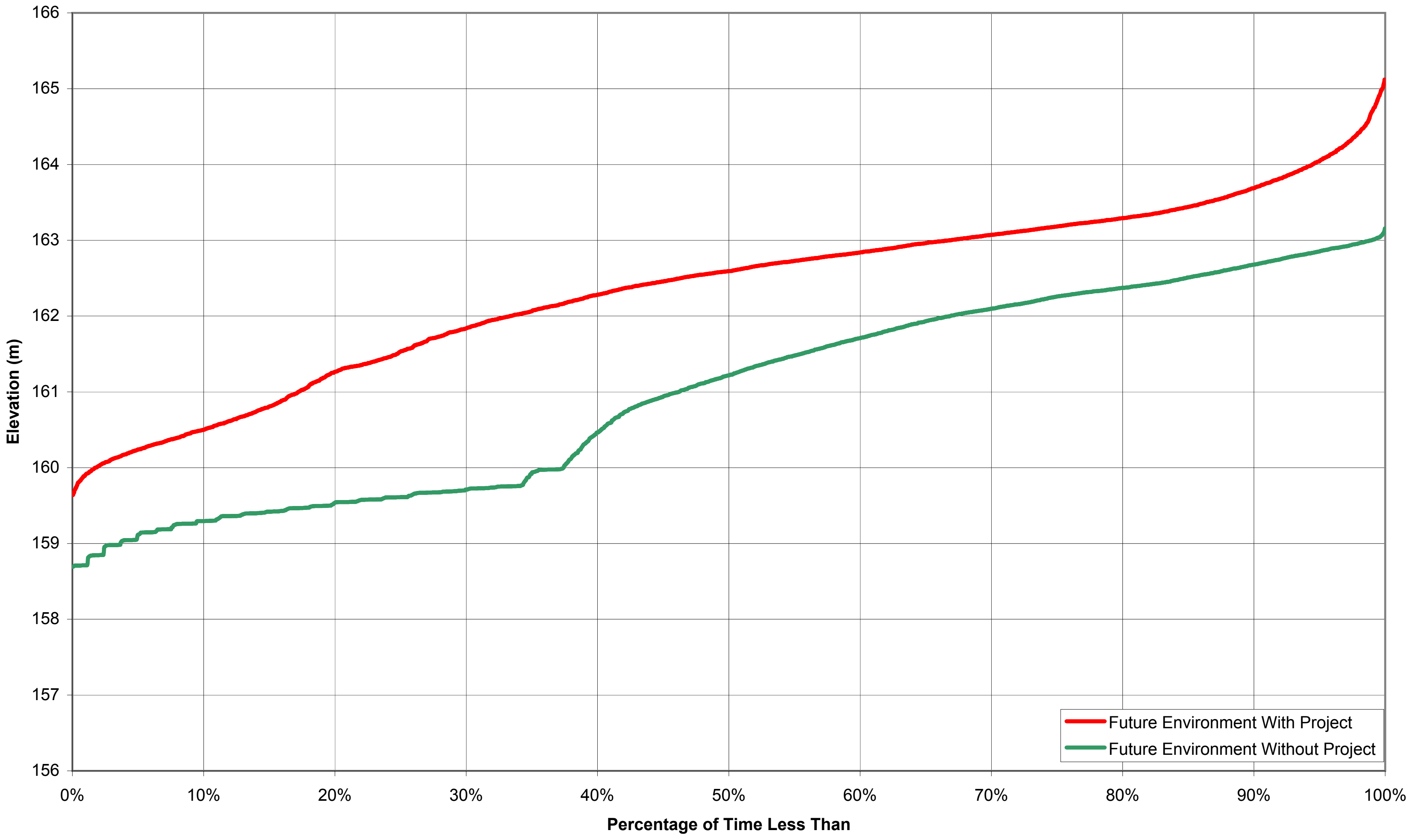


Figure 29
Nelson River below Clark Lake - Modeled Winter Stage Duration Curves

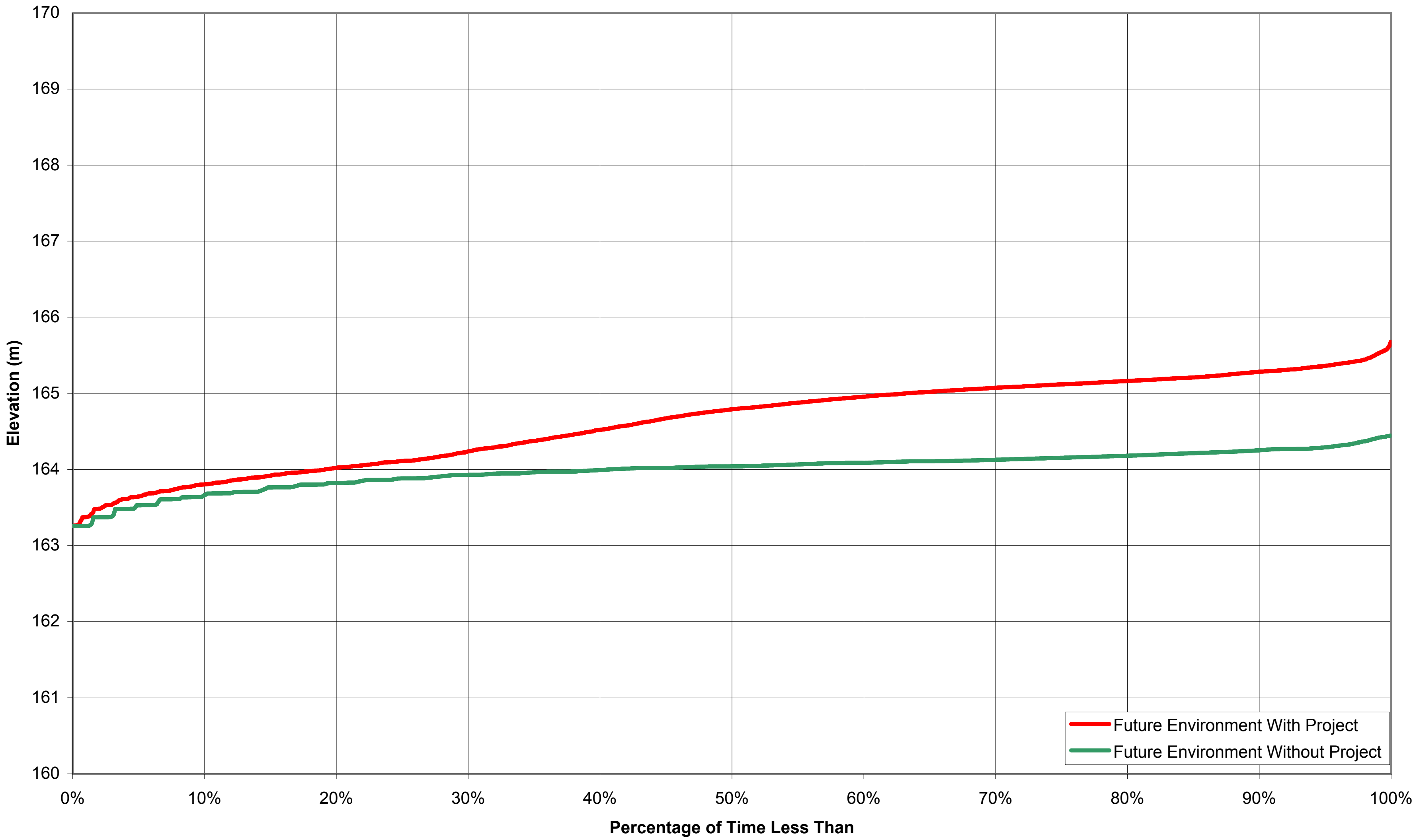
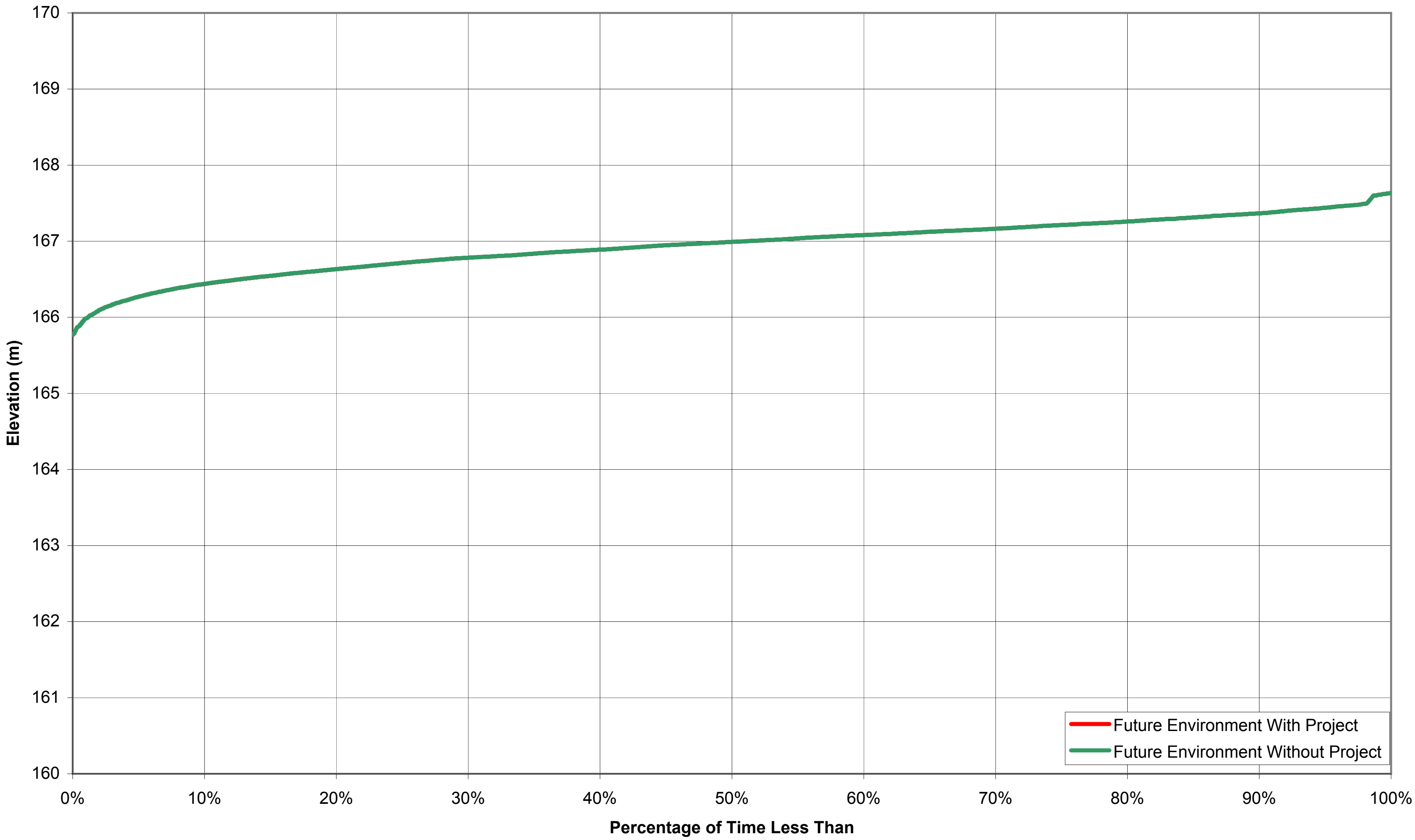
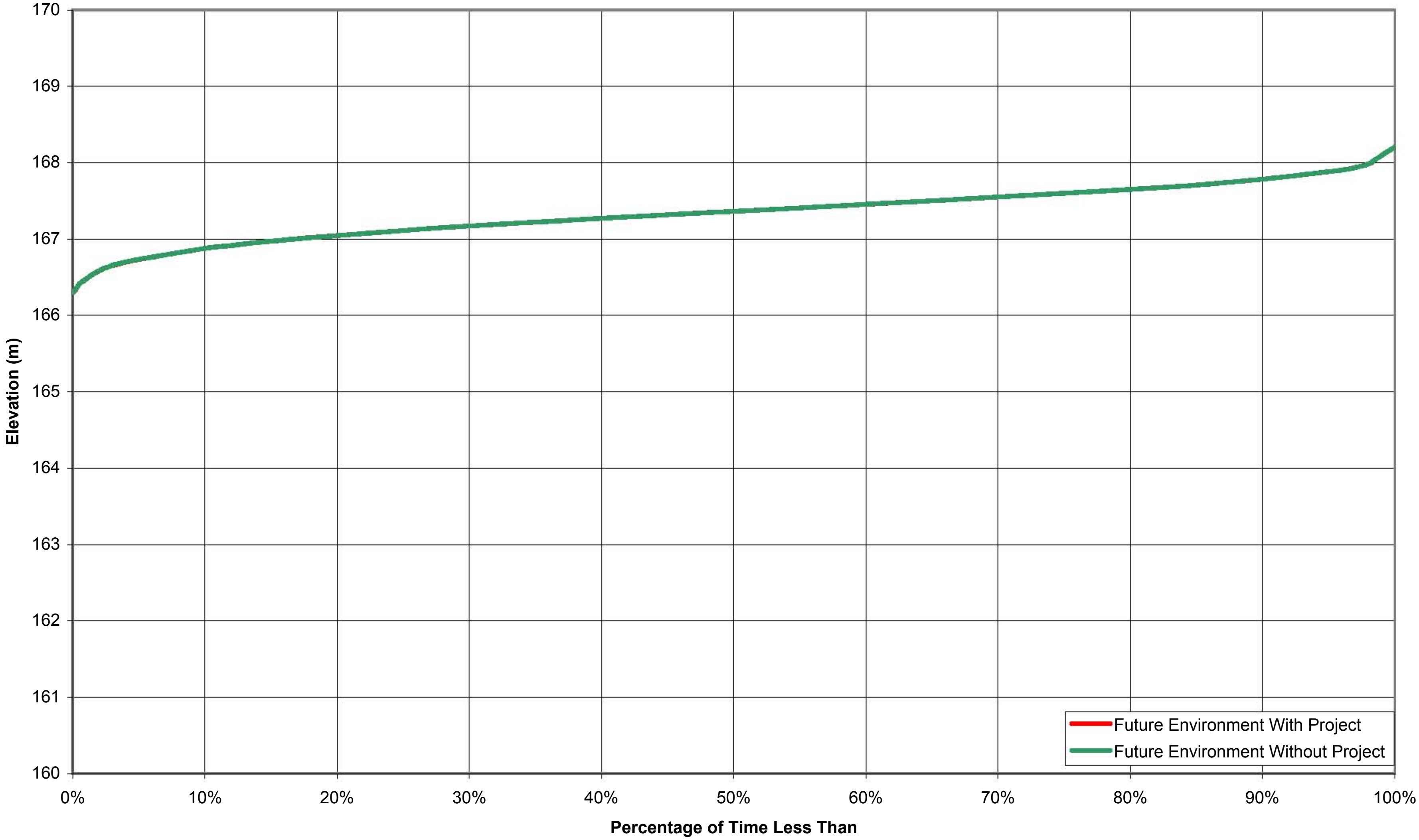


Figure 30
Nelson River at Clark Lake - Modeled Winter Stage Duration Curves



Note: Water levels both with and without the Project are the same and therefore indistinguishable on this plot

Figure 31
Nelson River at Split Lake - Modeled Winter Stage Duration Curves



Note: Water levels both with and without the Project are the same and therefore indistinguishable on this plot

APPENDIX A - ABBREVIATIONS

ABBREVIATIONS

˚C ....degrees Celsius

D/S ....Downstream

FSL.............................full supply level

ft ....feet

ft^3/s ....cubic feet per second

G.S. ....generating station

km ....kilometer

m ....metre

m^3..cubic metre

m^3/s or cms.................cubic metres per second

U/S ....Upstream