Keeyask Generation Project

Physical Environment Monitoring Plan

Physical Environment Monitoring Report

PEMP-2021-01

KEEYASK

Manitoba Conservation and Climate Client File 5550.00
Manitoba Environment Act Licence No. 3107

2020 - 2021

KEEYASK GENERATION PROJECT

PHYSICAL ENVIRONMENT MONITORING PLAN

REPORT #PEMP-2021-01

2020-2021 PHYSICAL ENVIRONMENT MONITORING REPORT: YEAR 7 CONSTRUCTION

Prepared by

Manitoba Hydro

June 2021

This report should be cited as follows:

Manitoba Hydro, 2021. 2020-2021 Physical Environment Monitoring Report: Year 7 Construction. Keeyask Generation Project Physical Environment Monitoring Plan Report #PEMP-2021-01. June 2021.

SUMMARY

Background

The Keeyask Generation Project (the Project) involves the construction and operation of the Keeyask Generating Station (GS) on the Nelson River at the former location of Gull Rapids and managing Gull Lake as a reservoir. To obtain a Manitoba Environment Act licence to construct the GS, and before construction began in July 2014, the Keeyask Hydropower Limited Partnership (KHLP) prepared a plan to monitor the effects of the Project on the physical environment. Monitoring results will help the KHLP, government regulators, members of local First Nation communities, and the general public understand how GS construction and operation affects the physical environment. Monitoring will help determine if the actual effects are consistent with predicted effects reported in the Project's environmental impact statement.

The Keeyask Physical Environment Monitoring Plan (PEMP) discusses planned monitoring during construction and operation of the Project, which includes monitoring of water and ice regimes, shoreline erosion, sedimentation, debris, and emission of greenhouse gases from the future reservoir. This report describes the physical environment monitoring activities and results for the 2020/21 monitoring period.

Water and Ice Regime

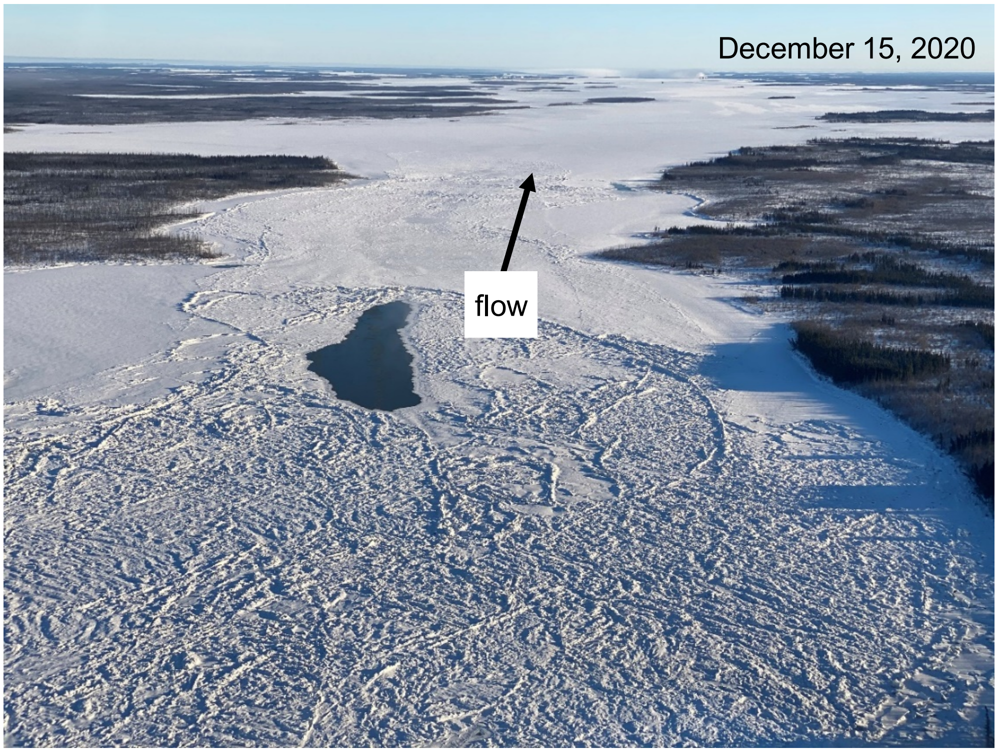
The water and ice monitoring parameters include water levels, water depth, water velocity, and ice cover: velocity and depth monitoring are planned to occur after the reservoir is created. After receiving approval for the Project in the summer of 2014, six automated, continuous water level gauges were installed on the Nelson River between Clark Lake and Gull Rapids to monitor water levels during the construction of the Project.

Nelson River flow in winter from January through April 2020 was near 95th percentile levels. In summer, it varied over a wide range between about 3,300-5,900 m^3/s and was near 95th percentile levels much of the time from mid-May through August. Flows declined through September and October and have generally been in the 50th to 75th percentile range since then.

Water levels on Gull Lake were near 156 m in January and gradually increased to about 156.9 m by Aug. 31 when impoundment of the reservoir began. The reservoir was impounded between Aug. 31 – Sep. 5, 2020 with the level being raised about 0.4 m/day on Gull Lake up to about 158.9 m, just below the reservoir full supply level of 159 m. Prior to impoundment the upstream levels were elevated as usual during winter due to ice effects and varied with flow during the summer. During impoundment, water levels increased between Gull Lake and the gauge site just upstream of Birthday Rapids. Conversely, levels declined at the gauge site just downstream of Clark Lake and on Split and Clark lakes during impoundment as river flows were declining, indicating there was no effect of impoundment at these locations.

A water level increase was observed in early February 2021 that caused the water level downstream of Clark and on Split Lake and Clark Lake to increase for a number of days. Based

on conditions observed previously in winter during construction, it appears a key factor leading to the water level increase was the occurrence of several days of snow fall in conjunction with the drop in temperature. The event is not considered entirely typical of events observed before and during construction. Manitoba Hydro will continue to monitor water levels and ice along with our Partners and further assess the conditions that resulted in the water level increase and whether similar events are observed in future years.



Ice formation at entrance to Gull Lake

Ice monitoring is done using satellite imagery and photographs taken along the length of the study area during monthly field trips. With impoundment completed in September 2020, winter 2020/21 was the first winter season during construction when the ice cover was not initiated by the construction ice-boom. It also represents the first year of ice formation under water level conditions that will be typical of the Keeyask GS during operation. Ice cover development was initiated in the first week of November as in the previous 3 years and by the third week of December the ice front had progressed to its maximum extent upstream of Birthday Rapids. By late March 2021 there were signs of open water leads forming upstream of Birthday Rapids and early April saw melting conditions. By the end of April an open channel was visible downstream of Birthday Rapids and by mid May the channel had opened up to the entrance of Gull Lake.

Sedimentation

Sedimentation monitoring includes studying how sediment is carried (sediment transport) in the water and where it is deposited. It involves collecting water samples to measure the amount of sediment suspended in the water (done in a laboratory), using electronic devices that continuously measure turbidity (i.e., the murkiness of the water) over time and by taking readings with a hand-held meter when visiting monitoring sites. Sediment traps are used to collect sediment from the water over time to monitor the potential for sediment to settle out (deposit) near areas of potentially important sturgeon habitat.

Between Clark Lake and the Kettle GS, continuous turbidity probes were installed at five locations in summer and three locations in winter. In addition, water samples were obtained on roughly a monthly basis at 10 different locations, in this stretch of the river. At some of the 10 locations, samples were taken from across the width of the river. In total there were 25 different sampling sites.

Results from the 2019-20 winter monitoring show similar results to the past four winters with a reduction in turbidity levels in Stephens Lake from pre-construction conditions. The EIS included the prediction that the Project would “significantly reduce erosion potential” downstream of the Project after construction, which would result in lower turbidity downstream. Changes were not anticipated during the construction period as some increases in water level due to ice were still expected to cause erosion at the entrance to Stephens Lake.

Collecting Water Samples for Sedimentation Monitoring

Throughout the study reach (Clark Lake to Stephens Lake) the average summer turbidity in 2020 was similar to 2018 and lower than the long term average as measured by the incoming turbidity at Clark Lake. There were no discernable changes resulting from the Project observed including during and after reservoir impoundment. The 2020 average summer suspended sediment load was similar to 2017 when similar flow conditions were observed. In 2020 the average annual TSS and turbidity across all sites was lower than the average since the pre-construction and during construction periods. This reflects lower TSS and turbidity entering the project area from upstream.

Continuous turbidity monitoring equipment – setting up a turbidity sensor

Debris

Impoundment of the Keeyask reservoir over a week in August/September raised Gull Lake about 2 m to 158.9 m elevation, just below the full supply level of 159 m, which resulted in flooding of terrestrial areas around Gull Lake as expected. During impoundment large quantities of large woody debris were observed to be mobilized in the waterway and rafted along various shoreline areas. The quantities of debris present are greater than had been anticipated in the Keeyask EIS, likely due to mechanical clearing not scraping down to ground level as anticipated for the EIS assessment and resulting in fallen trees not being gathered and disposed via burning. The presence of larger quantities of woody debris than anticipated may result in greater management effort being required through the Waterways Management Program.

Reservoir Greenhouse Gas

The purpose of Keeyask reservoir greenhouse gas monitoring program is to enable the comparison of greenhouse gas (GHG) emissions before and after reservoir creation.

Reservoir GHG monitoring was conducted prior to construction of the Project from 2009 to 2013 and during construction in 2014, 2019 and 2020. The 2020 monitoring program had to be scaled back from what was done in 2019 due to travel restrictions in response to the Covid-19 pandemic. As a result, the 2020 program did not include installing land-based portable towers and sensors that are designed to measure carbon dioxide (CO_2) and methane (CH_4) emissions and only one underwater sensor could be deployed from a raft in the Nelson River during the summer. Water samples were collected 5 times between March and September at 8 sites and were analysed for GHGs and related water quality parameters.

Throughout the 2020 monitoring period concentrations of CO_2 and CH_4 were higher in the Nelson River water than in the atmosphere above. This is typical of many fresh waterbodies and consistent with baseline Nelson River conditions. Since the Nelson River is carrying higher concentrations of CO_2 and CH_4 than in the atmosphere, there is the potential for these gases to move from the water column into the air.

A comprehensive reservoir GHG monitoring program is planned for 2021. The pre-construction and construction period GHG monitoring results will be compiled and the plan is to report the entire pre-flooding information in next year's monitoring report. This will enable the comparison of pre and post flood GHG measurements to determine the impact of impoundment.

STUDY TEAM

Field Team and Support

Andrew Benger

Darrel Brunet

Keith Dobson

Leslie Flett

Leslie Gbeve

Paiten Harapiak

Leslie Klaassen

Joseph Langan

Jarod Morrison

Greg Petryk

Justin Pollick

Data Analysis, Report Preparation, and Report Review

Wil DeWit

Bob Gill

Danielle Kerr

Jennifer Lidgett

Tim Papakyriakou

Russell Schmidt

Ashley Soloway

Marc Totte

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF MAPS

LIST OF PHOTOS

LIST OF APPENDICES

1.0 INTRODUCTION

Construction of the Keeyask Generation Project (the Project), a 695 megawatt hydroelectric generating station (GS) and associated facilities, began in July 2014. The Project is located at Gull Rapids on the lower Nelson River in northern Manitoba where Gull Lake flows into Stephens Lake, 35 km upstream of the existing Kettle GS.

The *Keeyask Generation Project: Response to EIS Guidelines* (EIS), completed in June 2012, provides a summary of predicted effects and planned mitigation for the Project (KHLP 2012a). Technical supporting information for the physical environment and a summary of proposed monitoring and follow-up programs are provided in the *Keeyask Generation Project Environmental Impact Statement: Physical Environment Supporting Volume* (PESV; KHLP 2012b). As part of the licensing process for the Project, the Keeyask Physical Environment Monitoring Plan (PEMP) was developed detailing the monitoring activities for various components of the physical environment. The PEMP was finalized in 2015 following regulatory review and approval (KHLP 2015a).

This report generally describes the physical environment monitoring performed from April 2020 to March 2021, the seventh year of construction monitoring. During this period the reservoir was impounded to the full supply level and the first generating unit went into service. When information is not available the information will be reported in the following year's monitoring report.

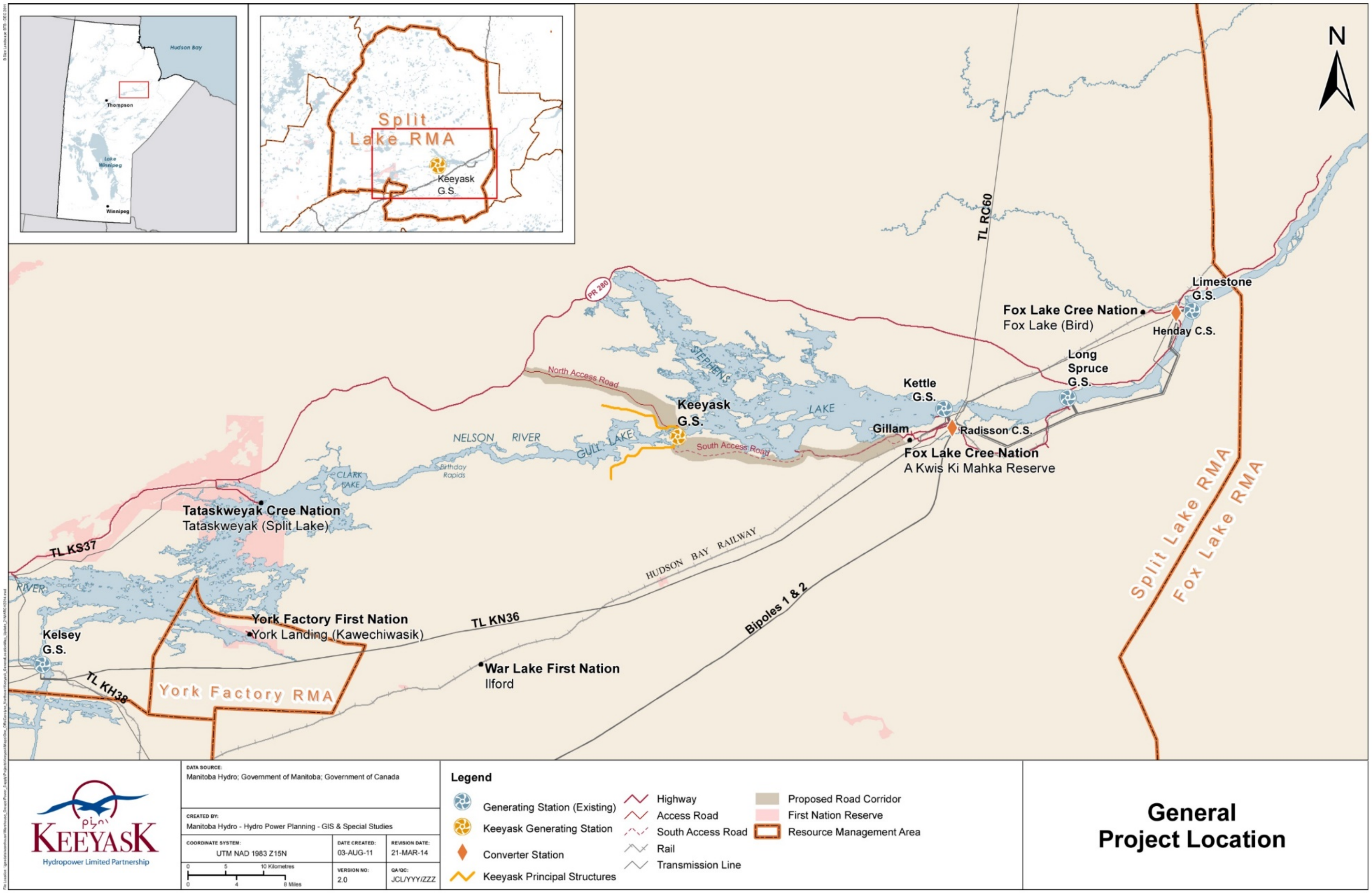
The physical environment is defined as the physical and chemical make-up of an ecosystem and describes the area where things live and includes the air, water and land within the ecosystem. Monitoring and follow-up activities focus on effects to key components of the physical environment to:

- Determine if EIS predictions of Project effects on the physical environment are correct and to identify unanticipated effects.
- Support other monitoring programs (e.g., aquatic and terrestrial) that will monitor Project effects and determine the effectiveness of mitigation and offsetting measures.

The environmental components that are monitored under the PEMP include the following:

- surface water (level/depth) and ice-regimes,
- shoreline erosion and reservoir expansion,
- sedimentation (related to water quality, sediment transport and deposition),
- greenhouse gas,
- woody debris,
- surface water temperature and dissolved oxygen (related to water quality and aquatic habitat), and
- total dissolved gas pressure.

In 2020/21, physical environment monitoring included surface water and ice regime, sedimentation, dissolved oxygen, greenhouse gases, and woody debris monitoring. Monitoring for surface water temperature and dissolved oxygen occurred in the 2020/21 winter and the results will be provided in next years report. Shoreline erosion and reservoir expansion, and total dissolved gas pressure will begin after the reservoir is impounded. The PEMP provides a schedule of the physical environment monitoring activities planned during the construction and operation periods of the Project. The study area generally extends from Clark Lake into Stephens Lake near the Kettle Generating Station as shown on Map 1 (detailed site maps are provided in Appendix 1).



Map 1: **General Project location and study area**

2.0 SURFACE WATER AND ICE REGIMES

The water regime and ice parameters include water levels, water depth, river and lake-bottom elevation, water velocity, and ice cover. The largest changes to water and ice regimes are expected to occur once the reservoir has been impounded and include increases in water levels, reduction of velocities and development of a smoother ice cover. During the construction period, water levels are expected to increase from the construction of cofferdams used to isolate construction areas and an ice cover is expected to develop earlier from the installation of an ice boom.

The objectives of the water and ice regime monitoring include:

- determining water level regime and verifying expected changes in water levels resulting from the Project;
- confirming that there are no unanticipated Project effects on Split Lake water levels;
- determining water depth/bottom elevation and velocity information to support monitoring being performed under the Aquatic Effects Monitoring Plan (AEMP; KHLP 2015b);
- measuring ice conditions to support understanding of winter water levels, which may be affected by ice processes; and
- confirming that future ice conditions during operation are consistent with predicted effects reported in the EIS.

2.1 NELSON RIVER FLOW CONDITIONS

River discharge (flow) is reported as the outflow from Split Lake which is not affected by the Keeyask Project. Small streams that flow into the monitoring area between Clark Lake and Gull Rapids typically contribute less than 3% of the total flow (KHLP 2012b) and are not included in the total flow. River flows are directly correlated to water levels under open water conditions (i.e. high flow volumes result in high water levels). In winter, the levels are also influenced by ice conditions so the relationship between flow and water level is not consistent between summer and winter months. Split Lake outflows are calculated by Manitoba Hydro based on routing flows from upstream through the lake. The historical daily flow records have been analyzed to characterize flow conditions since September 1, 1977 and represent regulated flow conditions since Lake Winnipeg Regulation and Churchill River Diversion began operating. Average seasonal flows are summarized in Table 1; the summer flows are taken as May through October and winter flows from November through April.

The flow in winter from January through April 2020 was near 95th percentile levels (Figure 1). In summer, it varied over a wide range between about 3,300-5,900 m^3/s and was near 95th percentile levels much of the time from mid-May through August. Flows declined through September and October and have generally been in the median to 75th percentile range since then.

Table 1: Split Lake seasonal discharges since start of Keeyask construction

Year /Season	Minimum (m^3/s)	Mean (m^3/s)	Maximum (m^3/s)
2014 Summer	3438	5245	5907
2014/15 Winter	3340	3865	5057
2015 Summer	3277	3694	4282
2015/16 Winter	3198	3745	4050
2016 Summer	3194	4034	4748
2016/17 Winter	3583	4366	5007
2017 Summer	3082	4838	6594
2017/18 Winter	2880	3396	4093
2018 Summer	2508	3060	3608
2018/19 Winter	2817	3227	3735
2019 Summer	2614	3259	3665
2019/20 Winter	3135	4051	4390
2020 Summer	3350	4913	5944
2020/21 Winter	3008	3516	4111

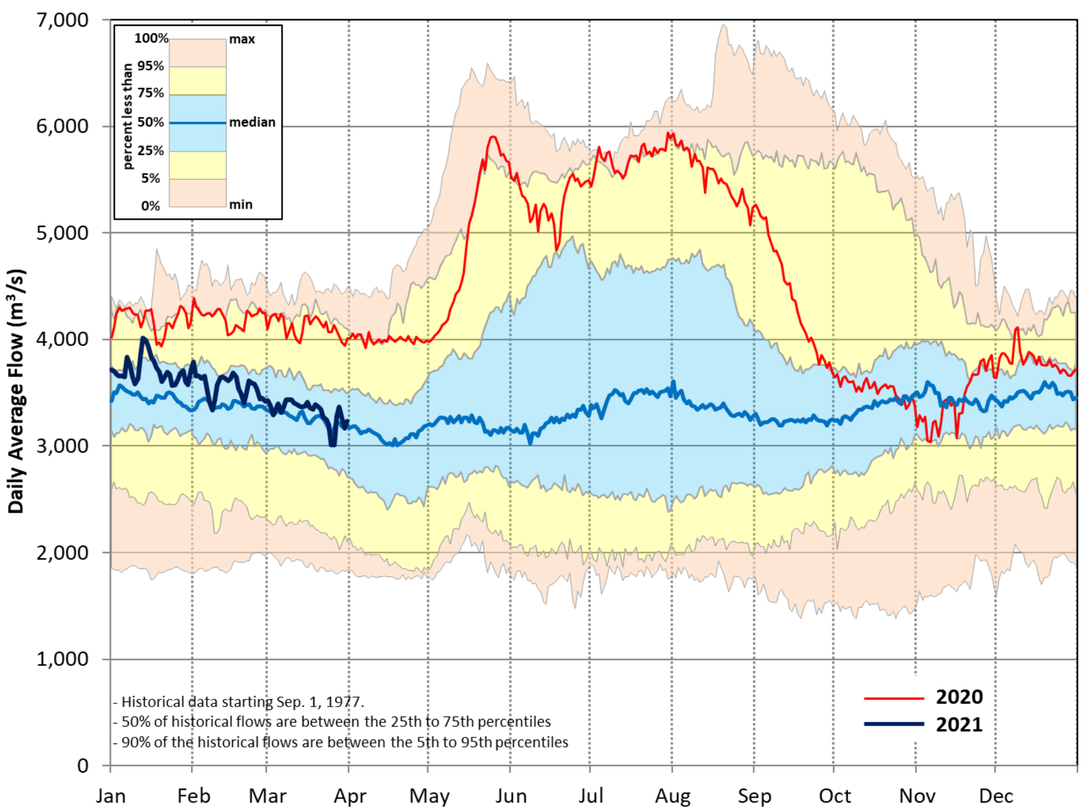


Figure 1: Split Lake 2020/2021 daily average outflow and historical statistics

2.2 OBSERVED WATER LEVELS – RESERVOIR IMPOUNDMENT

Water levels are monitored at six sites from Clark Lake to Gull Rapids (Table 2, Map 2). A typical water level gauge is shown in Photo 1. The two Clark Lake sites have been monitored regularly since 2003, while the Gull Lake gauge was installed at the start of construction in mid July 2014. The other three sites were installed after construction started, once the necessary permits and heritage surveys were complete, which were applied for and done after the Environment Act licence was received in early July 2014. The original gauge at the upstream end of Gull Lake (05UF749) was wrecked by ice and was discontinued in May 2016. The gauge was relocated about 3 km upstream to the mouth of Portage Creek and began operation in September 2016 (site 05UF587). In addition to data from the PEMP gauges, data is reported from the existing gauge on Split Lake at the community of Split Lake.

A significant milestone for the Keeyask Project was achieved in 2020 with the completion of water-up in early 2020 and impoundment at the start of September. Water-up was the process of flooding the de-watered work area upstream of the central dam and powerhouse and removing the remaining upstream cofferdams and the north channel rock groin. This work area had been isolated from the river and dewatered at the start of the project in 2014. Water-up was achieved by cutting a channel through a section of cofferdam and then, on February 26, partially closing the spillway gates to raise water levels until it flowed through the channel into the dewatered work area (Photo 2). Water levels were adjusted up and down to facilitate removal of cofferdams and the north channel rock groin until the work was completed by April 20. During this period the levels fluctuated between about 156-156.5 m (Figure 2). When the work was completed, the water level had been increased by about 0.3-0.4 m at the Gull Lake gauge relative to levels for the same flow conditions immediately prior to water-up. Upstream water levels were not affected during water-up. Until impoundment began on August 31st, Gull Lake was held steady between about 156.5-156.8 m while upstream levels varied with flow.

Reservoir impoundment began at about 6 pm on August 31, 2020, when spillway gates were lowered to reduce flow through the structure, causing upstream water levels to rise as water began to be stored in the upstream reservoir on Gull Lake. The water level was raised 2 m over a period of 5 days, or an average of 0.4 m per day, from about 6 pm on Aug. 31, when Gull Lake was at 156.9 m, until about 5 pm on Sep. 5 when it reached 158.9 m and impoundment was considered complete (Figure 3). The spillway has subsequently been operated to hold the level on Gull Lake near 158.8 m, although there have been fluctuations above and below that level.

During impoundment, water levels also rose at the monitoring sites located 3 km upstream of Gull Lake and immediately downstream and upstream of Birthday Rapids (Figure 4). As expected, the water level increases diminished in the upstream direction, rising about 1.6 m 3 km upstream of Gull Lake and by 0.84 m downstream and 0.19 m upstream of Birthday Rapids. Further upstream, impoundment did not affect levels at the site below Clark Lake or on Clark and Split lakes, where levels dropped about 0.13 m, 0.16 m and 0.18 m respectively from Aug. 1 - Sep. 5, 2020.

Manitoba Hydro obtained photographs and video imagery that demonstrate changes from prior to or at the beginning of impoundment to conditions after impoundment was completed as shown for the locations: north dyke at Little Gull Lake (Photo 3); a location on the south dyke(Photo 4); Caribou Island (Photo 5); Birthday Rapids (Photo 6); and Two Goose Creek (Photo 7). Changes in water surface area due to impoundment are also demonstrated in a comparison of sentinel 2 satellite imagery from before impoundment in 2019 and 2020 and after impoundment in September 2020 (Figure 5). The extent of flooding between the pre-construction shoreline and the expected post-Project shorelines in the vicinity of Gull Lake is indicated in Figure 6. This figure shows that the flooded extents around Gull Lake closely match the expected initial shoreline at 159 m elevation contour (identified from the digital elevation model derived from LIDAR and photogrammetry derived elevation data) without any notable areas of unanticipated flooding.

Table 2: List of water level monitoring sites

Site ID	Name	Record	Notes
05UF766	Clark Lake	Oct. 2003 - present	4 km above outlet
05UF759	downstream of Clark Lake	Dec. 2003 - present	1.9 km below outlet
05UF770	upstream of Birthday Rapids	Oct. 2014 - present	1.1 km above rapids
05UF771	downstream of Birthday Rapids	Oct. 2014 - present	2.1 km below rapids
05UF749	upstream of Gull Lake	Oct. 2014 - May 2016	0.26 km above lake
05UF587	upstream of Gull Lake	Sep. 2016 - present	3.0 km above lake
05UF596	Gull Lake	Jul. 2014 - present	7 km above Gull Rapids
05UF701	Split Lake at Split Lake Community	Oct. 1997 - present	existing site

Photo 1: Water level gauging station in winter

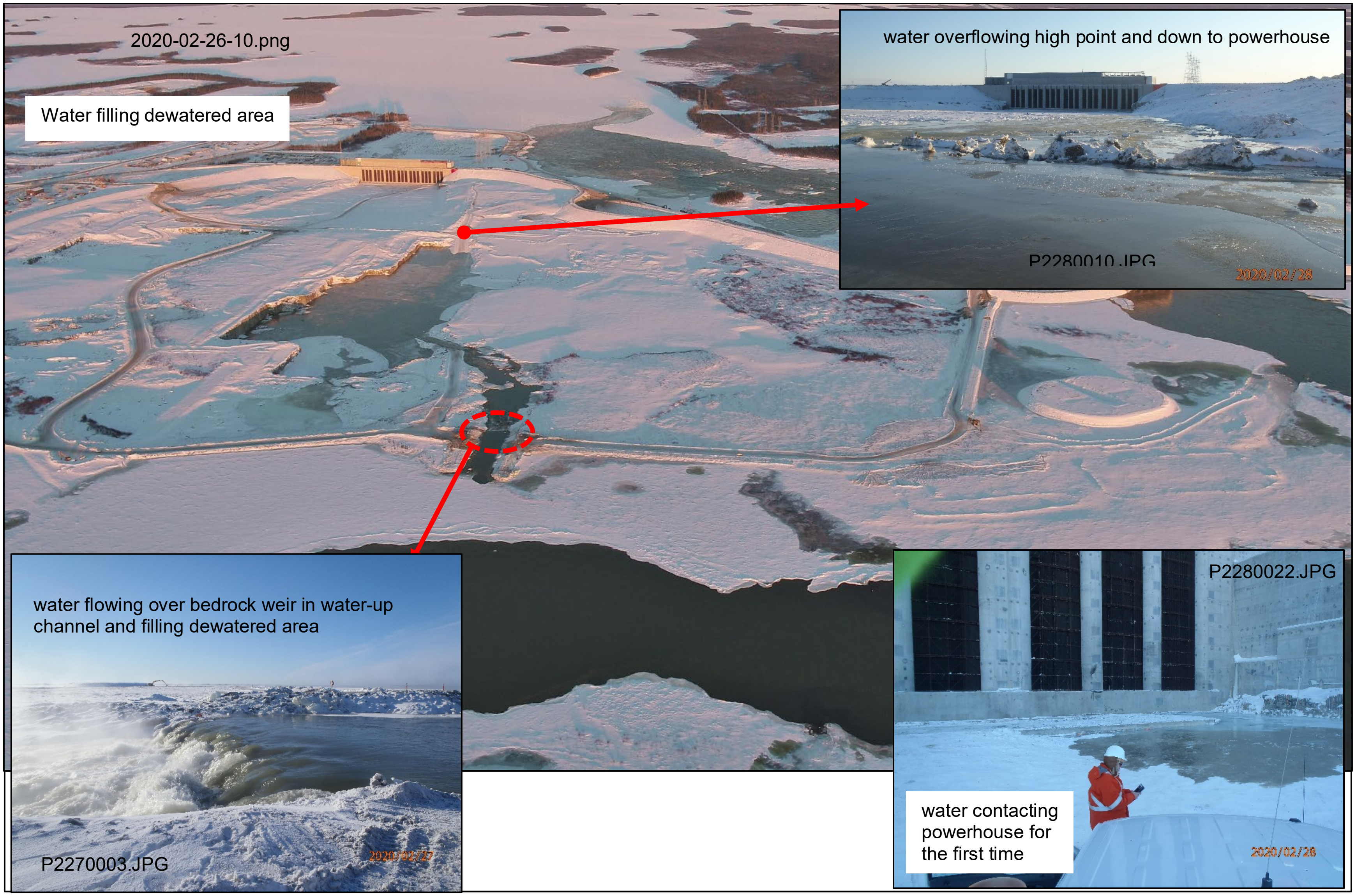
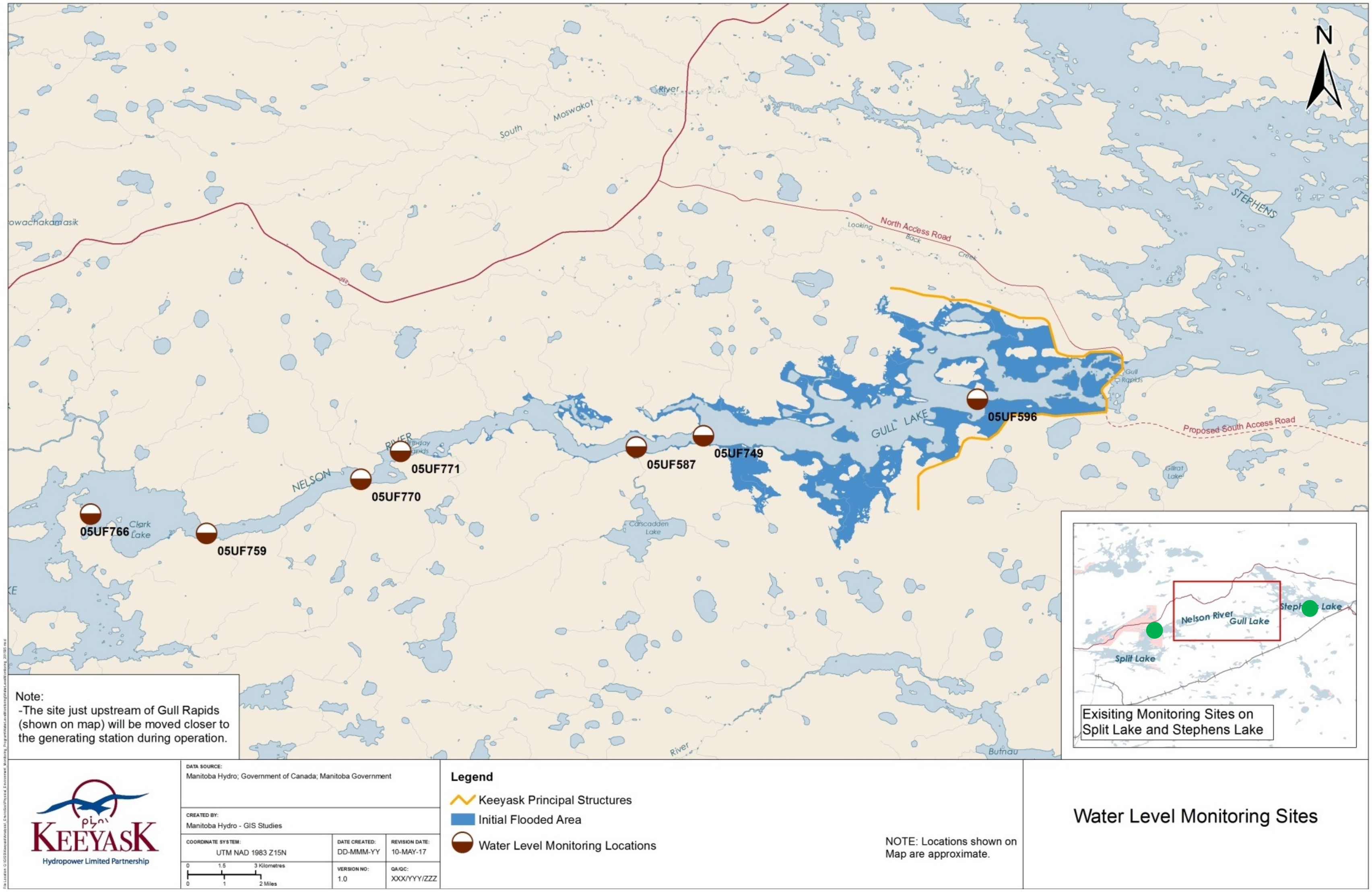


Photo 2: Photos from water-up in February 2020



Map 2: **PEMP water level monitoring sites**

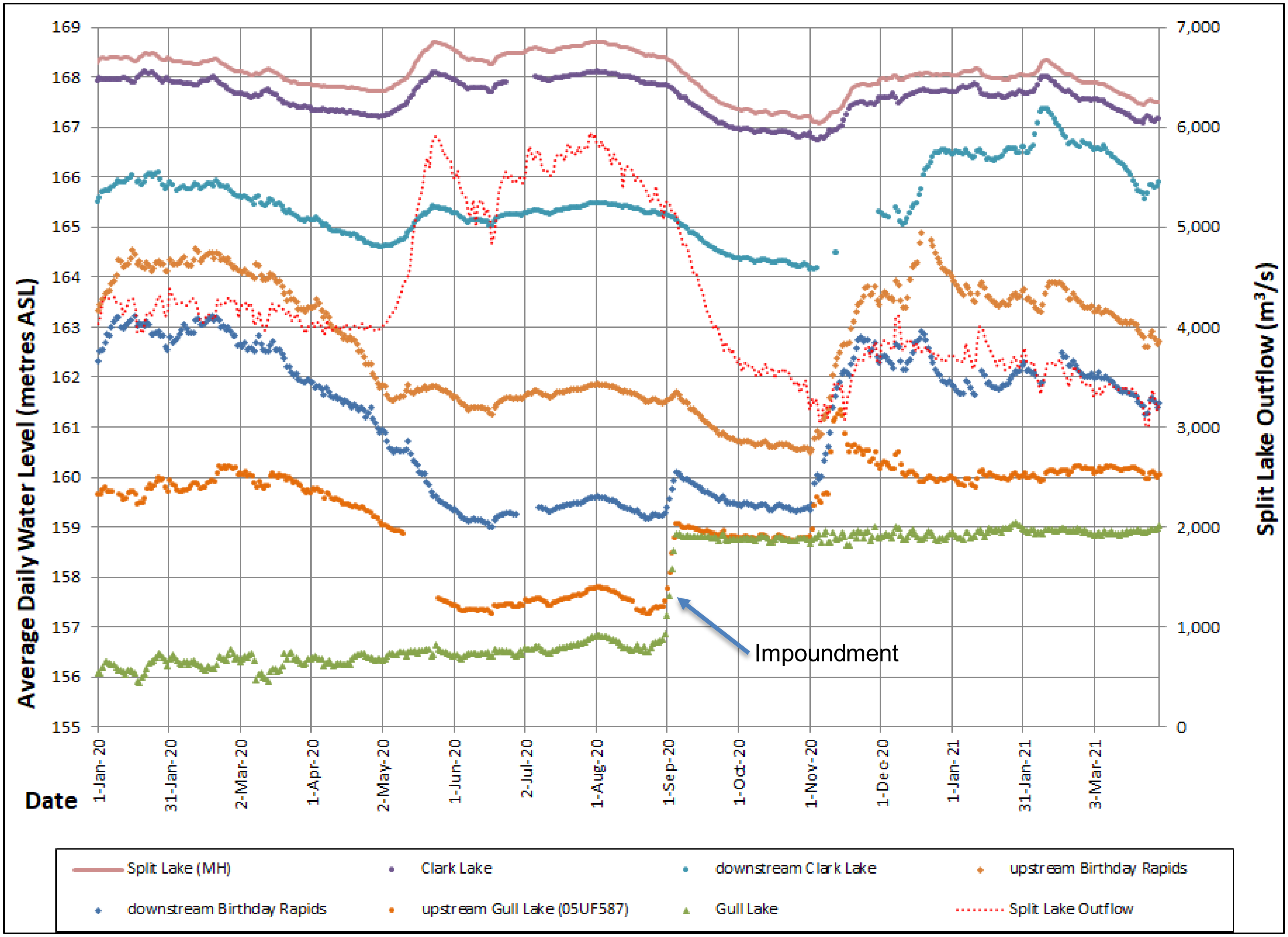


Figure 2: Observed water levels at PEMP monitoring sites in 2020/2021

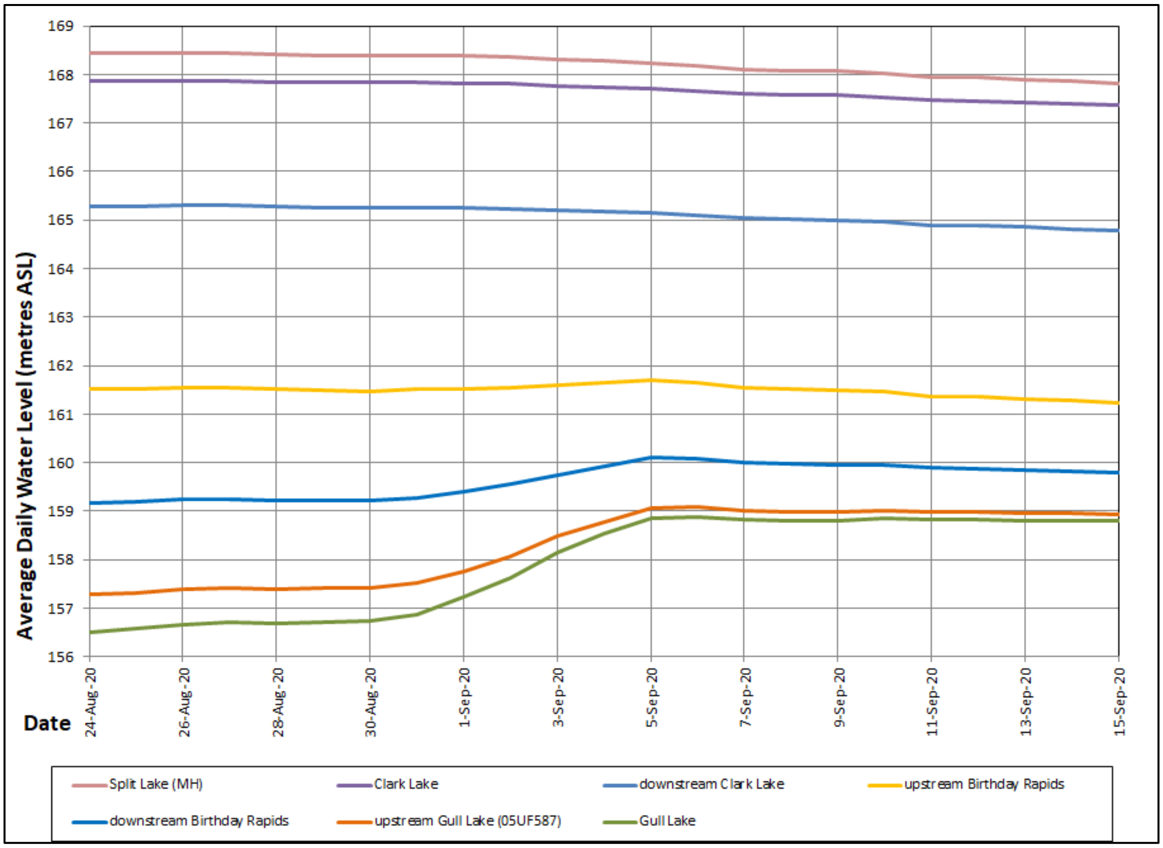


Figure 3: Water levels during impoundment of the Keeyask reservoir

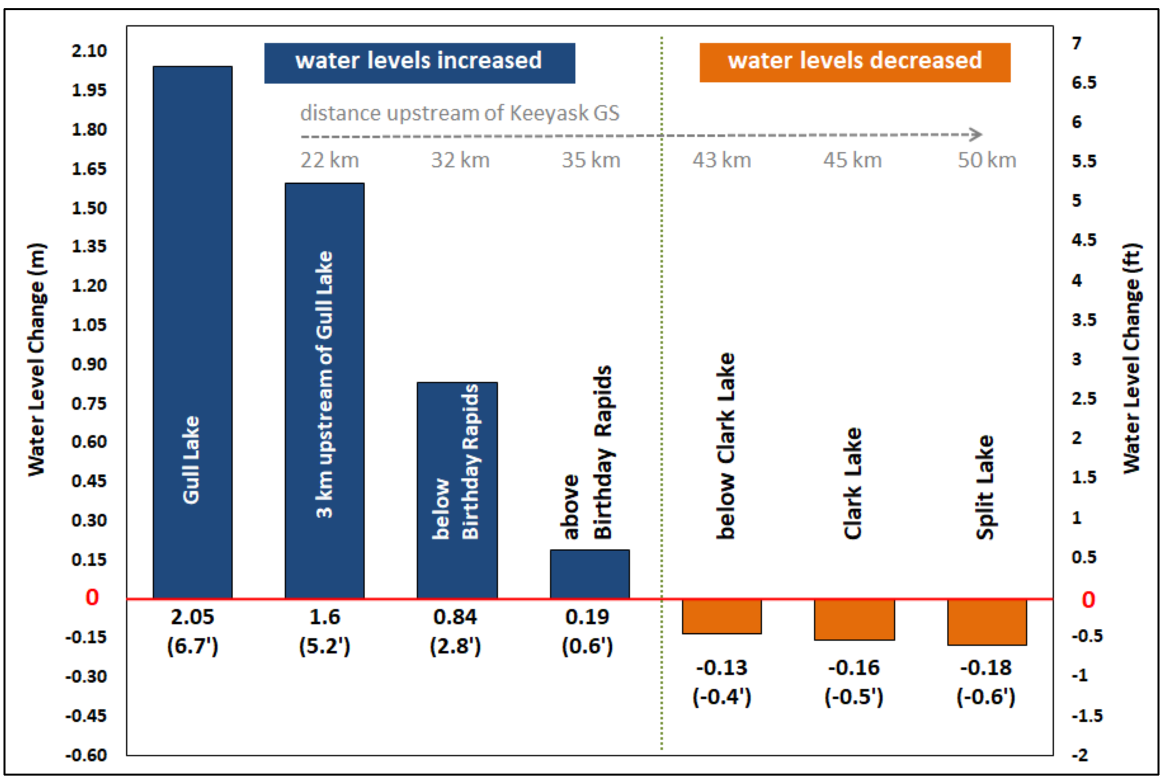


Figure 4: Water level changes during impoundment of the Keeyask reservoir

Photo 3: Pre- & post-impoundment images – north dyke at Little Gull Lake

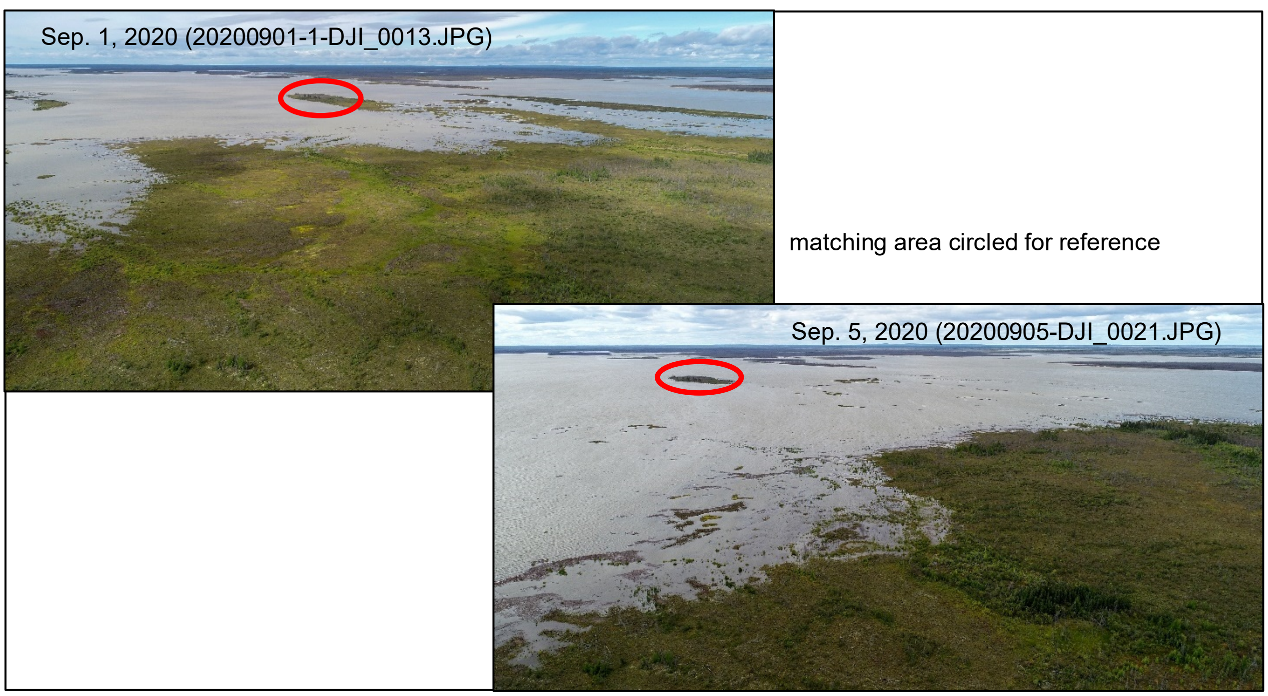


Photo 4: Pre- & post-impoundment images – south dyke

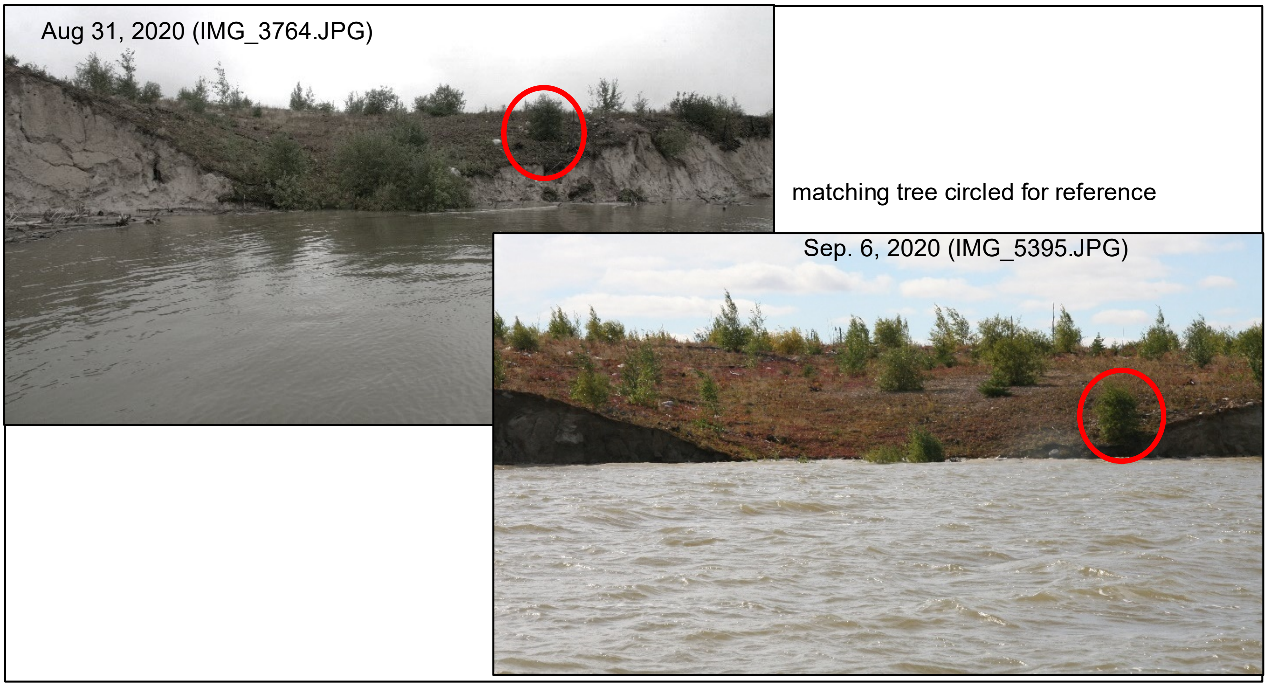


Photo 5: Pre- & post-impoundment images – Caribou Island NE shoreline

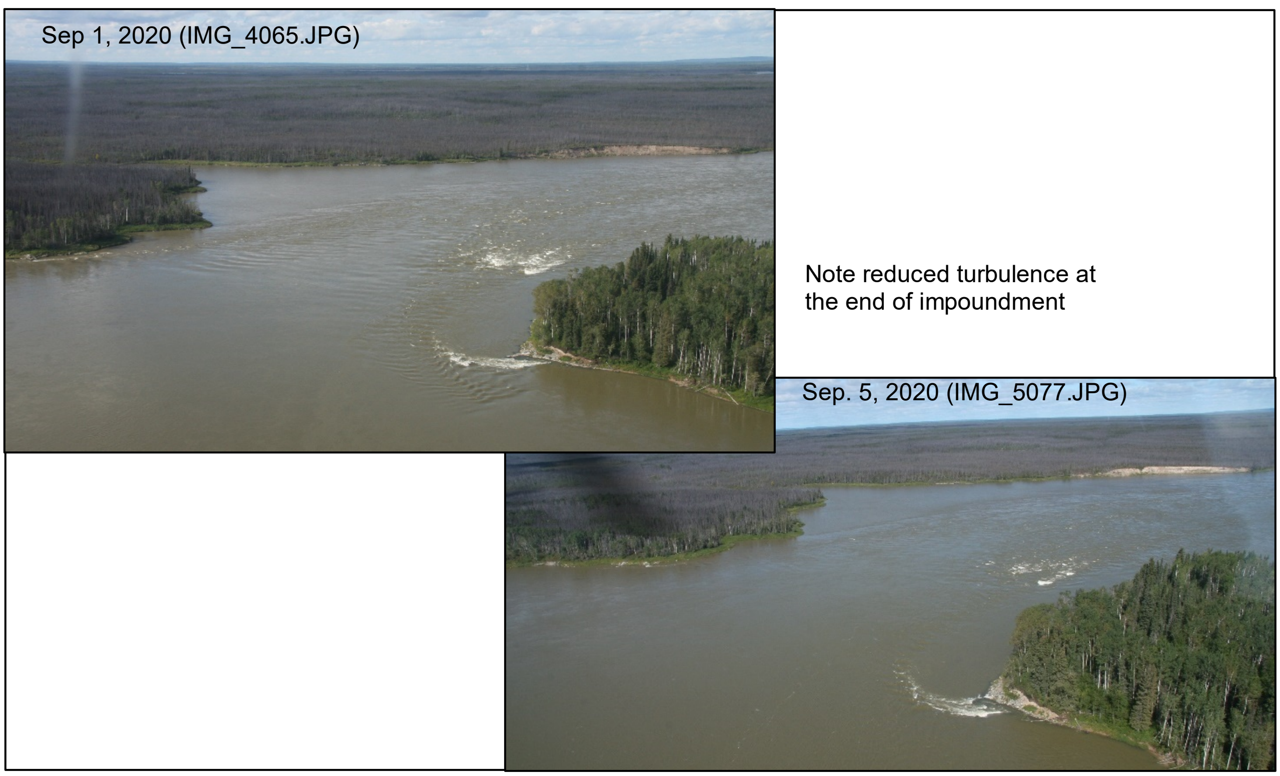


Photo 6: Pre- & post-impoundment images – Birthday Rapids

Photo 7: Pre- & post-impoundment images – mouth of Two Goose Creek

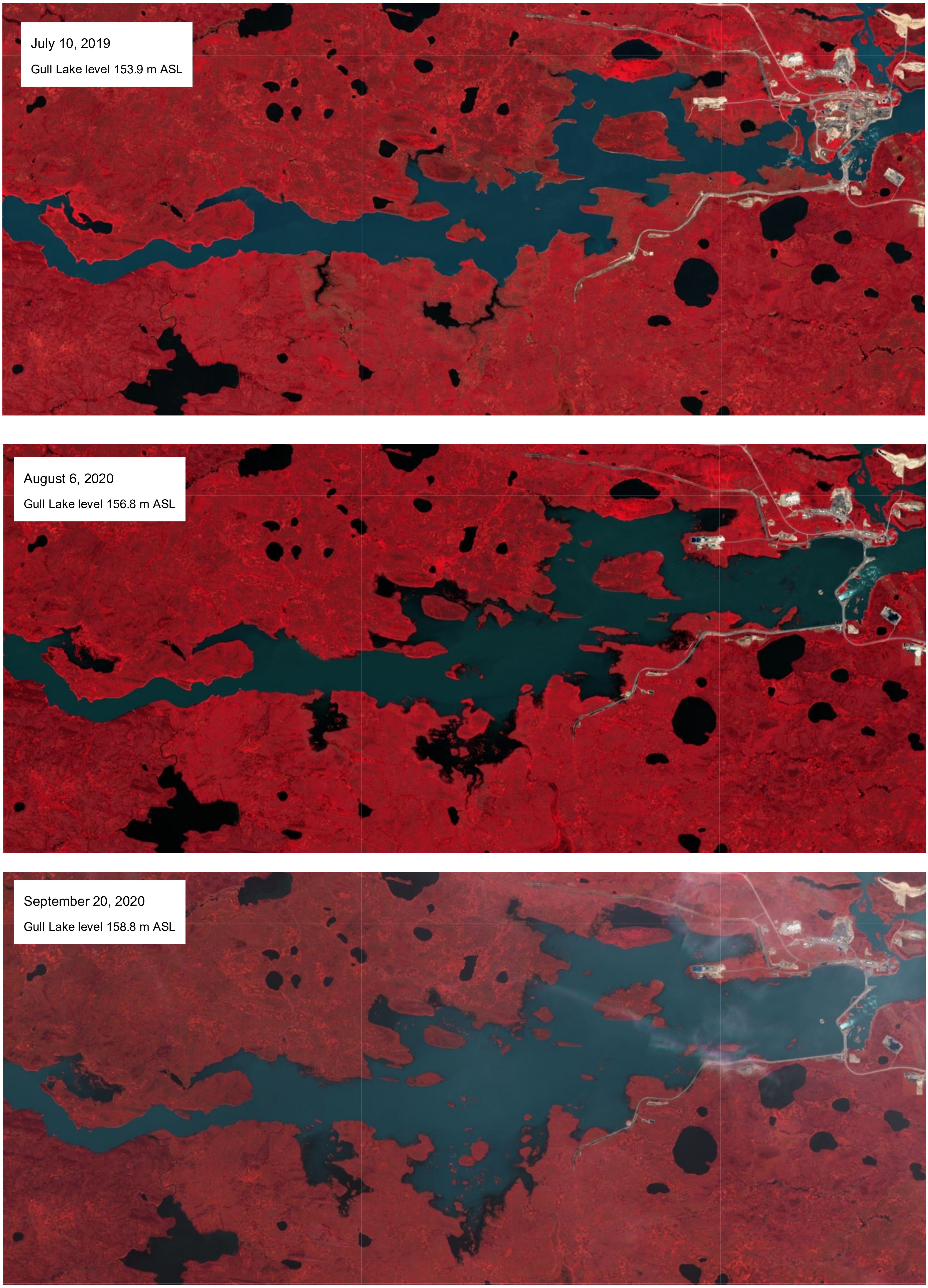


Figure 5: Sentinel 2 satellite false colour imagery showing change in pre / post-impoundment Gull Lake water surface area

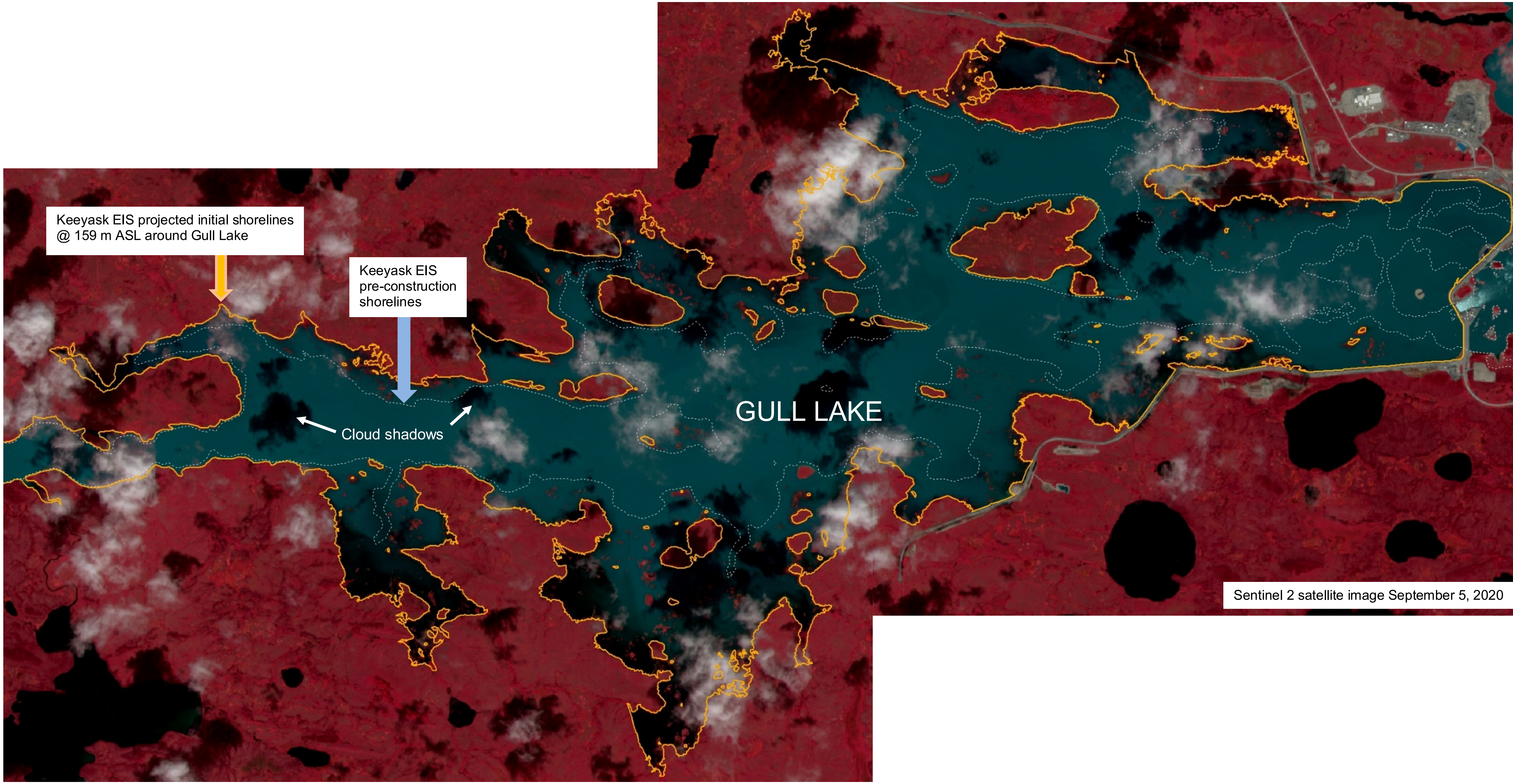


Figure 6: Comparison of Keeyask EIS pre-construction and expected post-impoundment shorelines on post-impoundment satellite false colour image

2.3 CLARK LAKE AND SPLIT LAKE WATER LEVELS

Split Lake water level data from the Split Lake Community gauging station (Site ID: 05UF701) were obtained and plotted along with the levels for the site on Clark Lake and immediately downstream (Figure 7). The levels on these two lakes show the same pattern of variation, differing by about 0.3-0.5 m with an average difference of approximately 0.4 m. During open water periods, both sites show a clear correlation to variations in flow.

In winter, ice effects typically increase water levels on Split and Clark lakes by about 0.6 m on average above open water levels (KHLP 2012b) and this is approximately the increase observed in winter 2020/21. A water level increase was observed starting on February 5 that caused the water level downstream of Clark Lake to increase about 0.75 m while flow remained steady. After February 8th the levels stabilized before beginning to decline on the 10th (Figure 7). On Split Lake and Clark Lake the levels increased about 0.3 m from February 6 to 10 before starting to decline.

Based on conditions observed previously in winter during construction, it appears a key factor leading to the water level increase was the occurrence of several days of snow fall in conjunction with the drop in temperature. The event occurred post-impoundment and is not considered entirely typical of events observed before and during construction. Manitoba Hydro will continue to monitor water levels and ice along with our Partners and further assess the conditions that resulted in the water level increase and whether similar events are observed in future years.

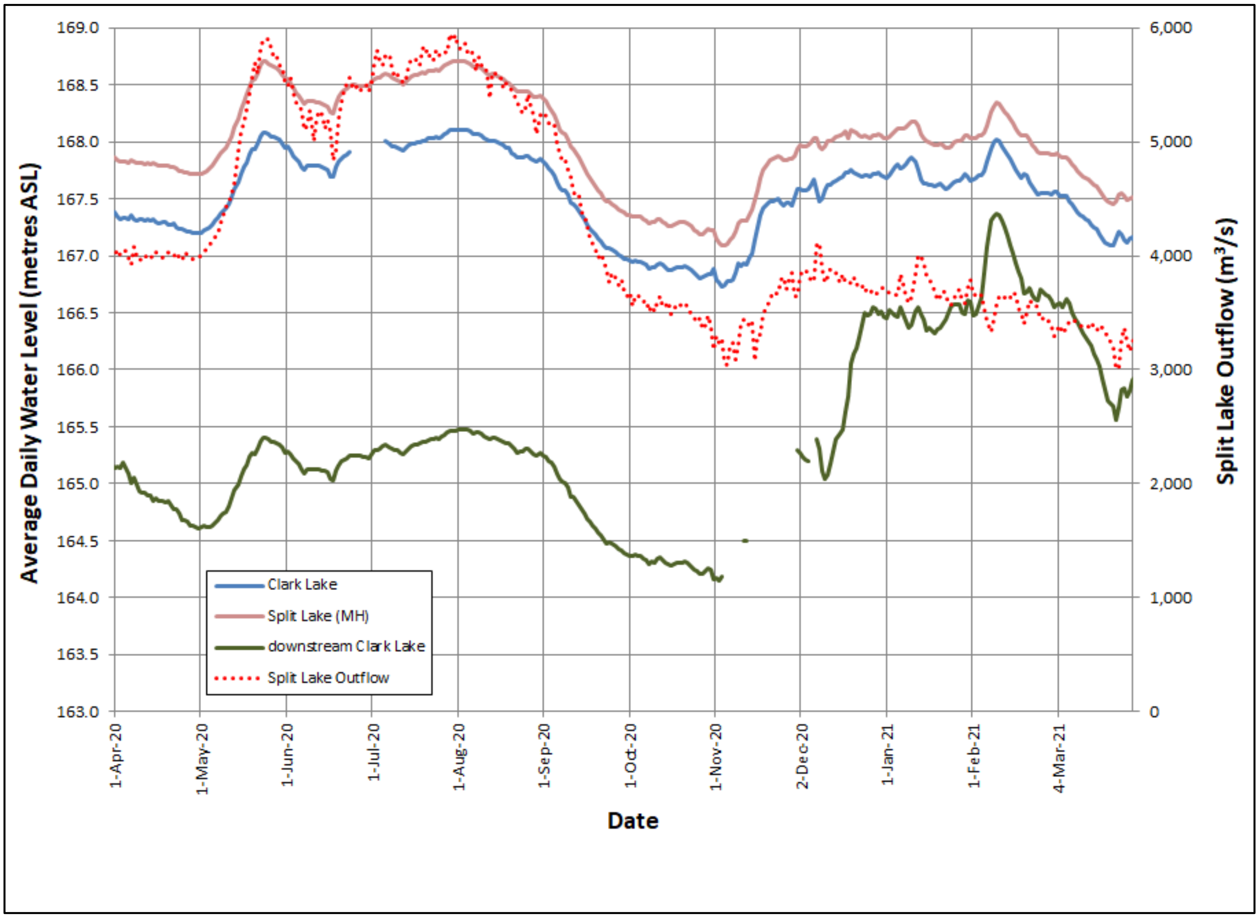


Figure 7: Observed water levels at Clark Lake and Split Lake in 2020/2021

2.4 ICE REGIME

The PESV (KHLP 2012b, Section 4) discusses ice processes and the pre-Project ice regime in the vicinity of the Project. In the pre-Project environment, a complete ice cover formed most years (approximately 2 out of 3 years) on Gull Lake and the Nelson River up to Birthday Rapids, although the timing and extent varied with flow and climate conditions. A combination of higher flow and/or warmer conditions could prevent an ice bridge from forming in some years so that open water persisted in the central channel from the exit of Split Lake to the entrance of Stephens Lake. In contrast, with early cold temperatures and lower flows the ice front cover could advance upstream of Birthday Rapids. In years when bridging occurred, the date when it formed ranged from as early as November at lower flows to as late as January at higher flows.

The approximate dates for freeze up and breakup on Gull Lake since the start of construction are shown in Table 3. The 2020/21 winter saw the initiation of an ice cover in the first week of November, the same as the previous three years. With impoundment being completed before the onset of ice cover it was the first winter that ice established without the aid of the construction ice-boom. Photos (Photo 8) of the ice in front of the Keeyask Generating Station (GS) and at the entrance to Gull Lake show the smooth conditions near the GS and rough ice conditions at the entrance to the lake where the frazil ice accumulates.

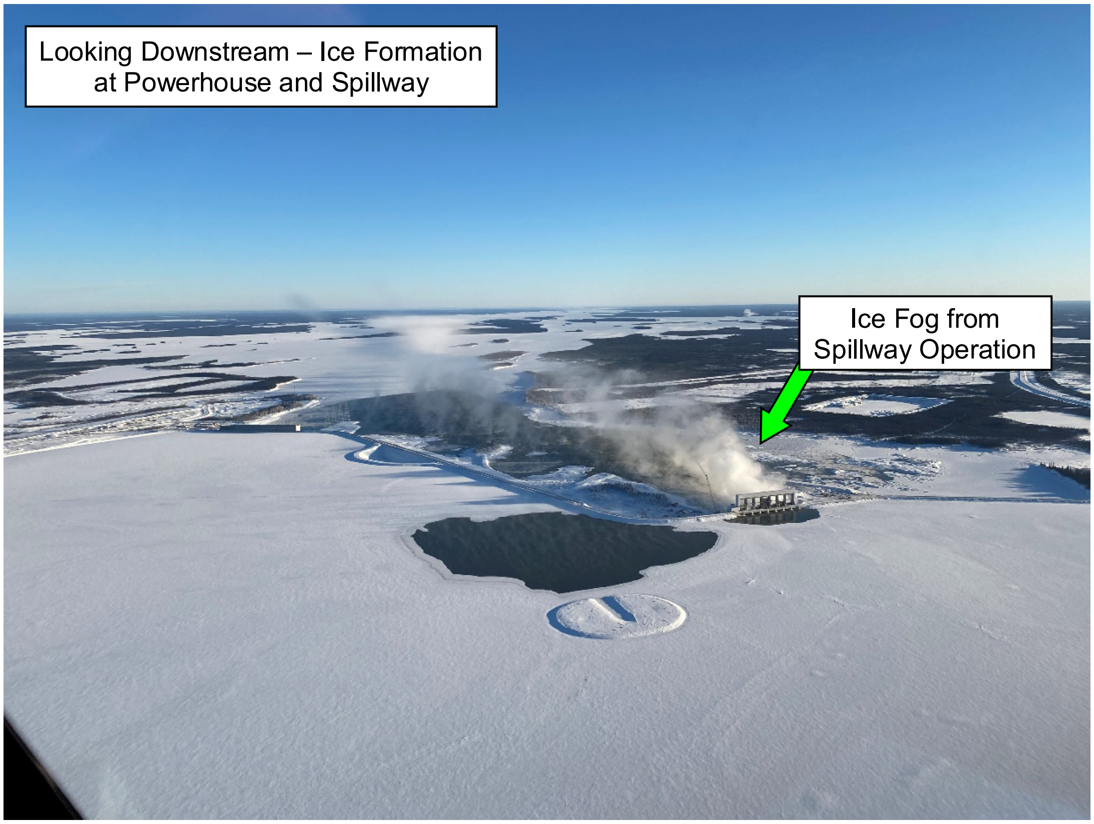
With an ice cover established on Gull Lake the ice advanced up the river as frazil ice accumulated at the leading edge (Figure 8). By the third week in December the ice front had progressed through Birthday Rapids and the maximum ice cover was reached (Photo 9). Ice continued to build up at the ice front as observed through continued water level increases after the maximum cover was reached.

By late March there were signs of open water leads forming upstream of Birthday Rapids and early April saw melting conditions (Figure 9). By the end of April an open channel was visible downstream of Birthday Rapids and by mid May the channel had opened up to the entrance of Gull Lake.

Table 3: Ice dates and cover advancement / break-up

Year	Initial Freeze-up on Gull Lake	Ice Cover Advancement	Gull Lake Ice Break-up
2014/15	Jan 23, 2015 Nov 9, 2014*	foot of Birthday Rapids	May 13-15, 2015
2015/16	Nov 20, 2015	about 4 km upstream of Birthday Rapids	May 4-9, 2016
2016/17	Nov 19, 2016	about 6 km upstream of Birthday Rapids	May 22-24, 2017
2017/18	Nov 4, 2017	about 6 km upstream of Birthday Rapids	May 19-20, 2018
2018/19	Nov 4-6, 2018	about 6 km upstream of Birthday Rapids	May 13-15 2019
2019/20	Nov 5, 2019	Birthday Rapids	May 21-25, 2020
2020/21	Nov 2-3, 2020	About 6km upstream of Birthday Rapids	May 22-23, 2021

*Ice formation start date before ice boom failed



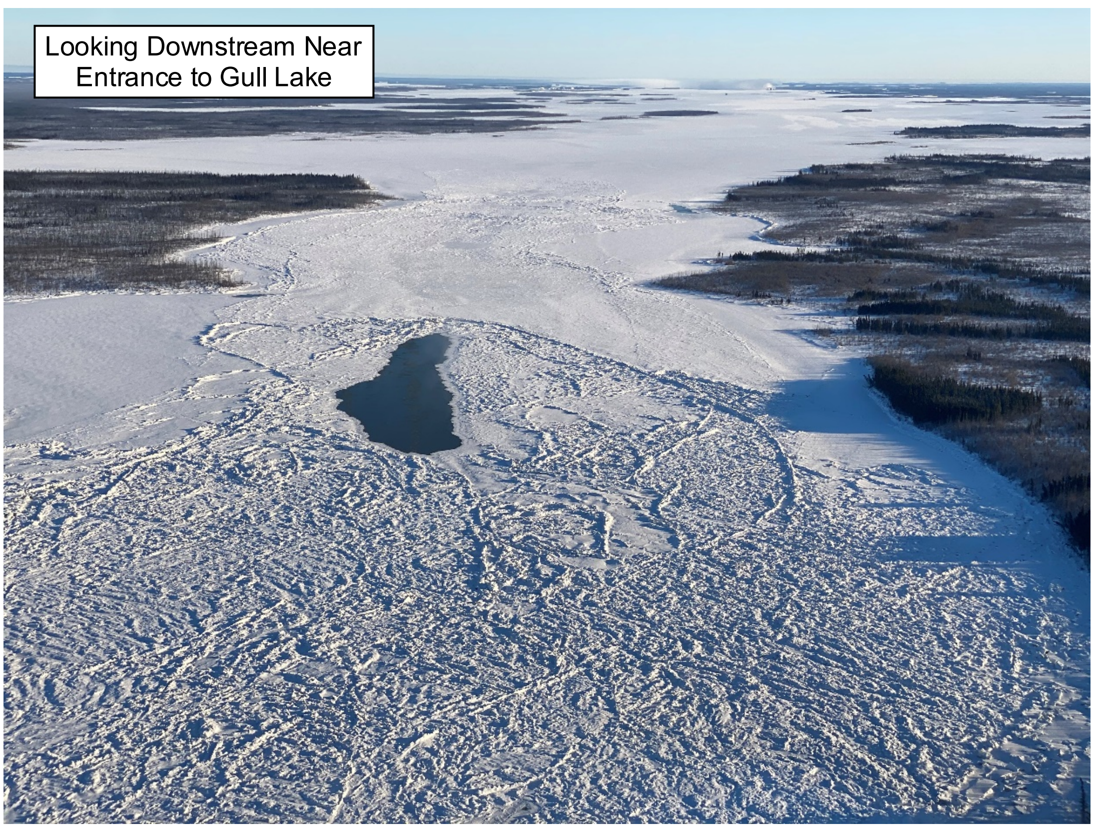


Photo 8: Ice formation on reservoir, December 15, 2020

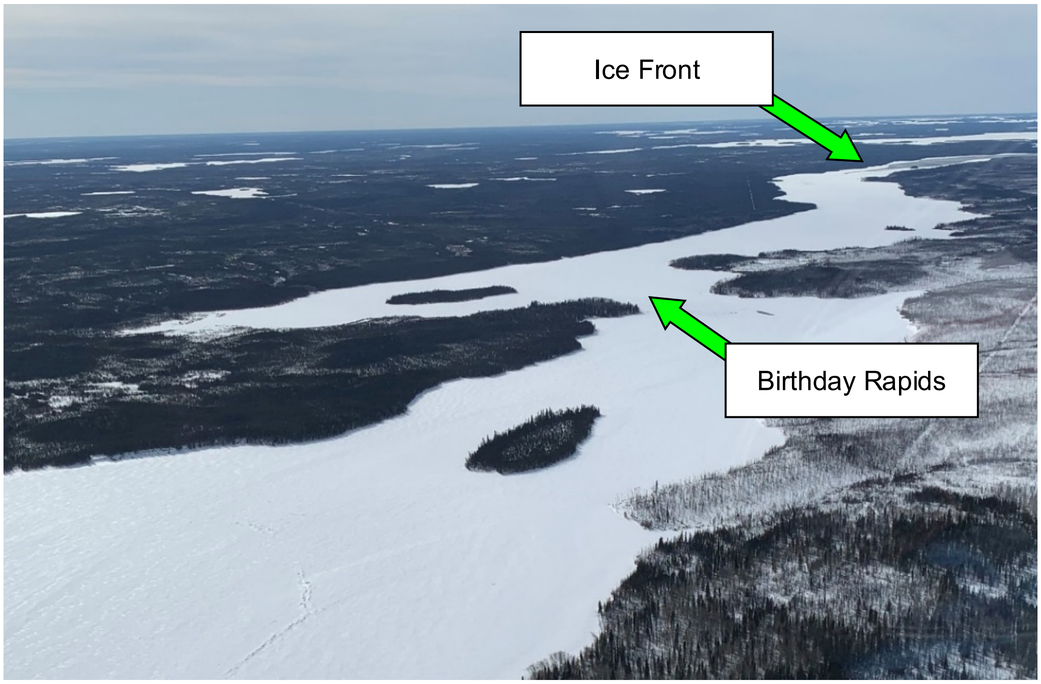
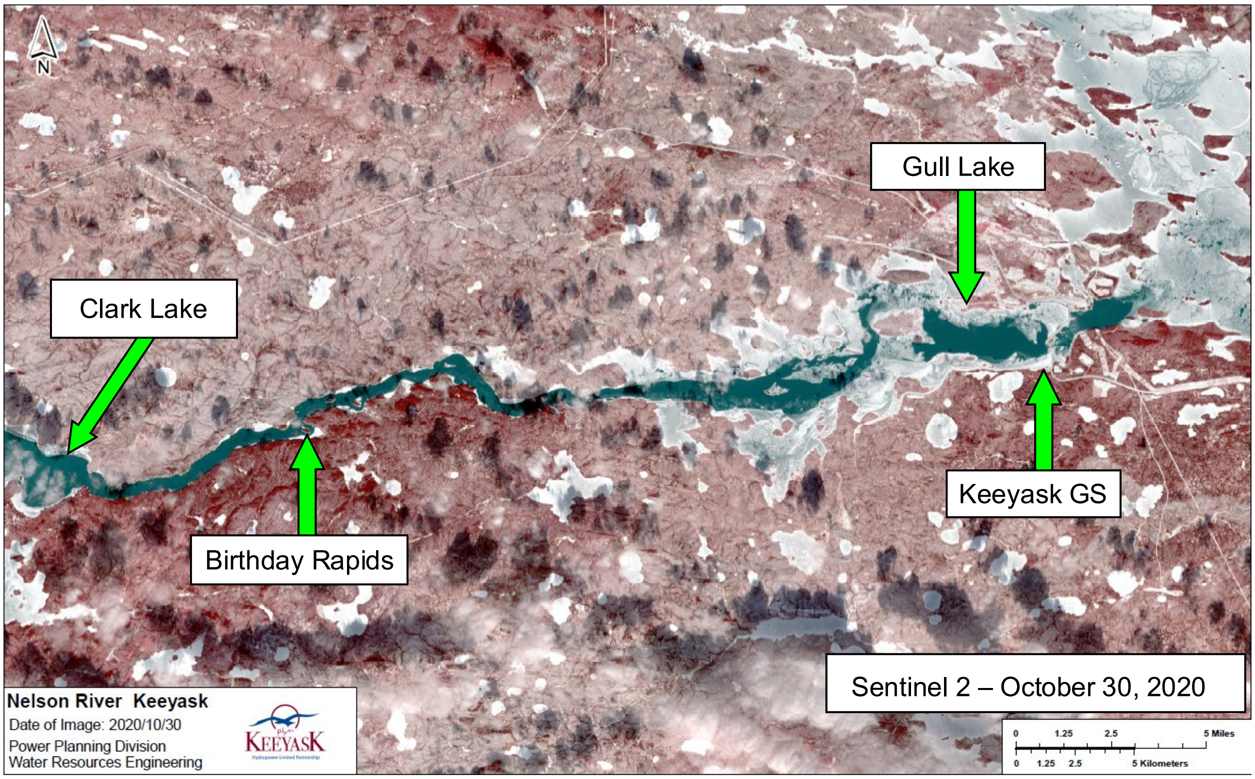
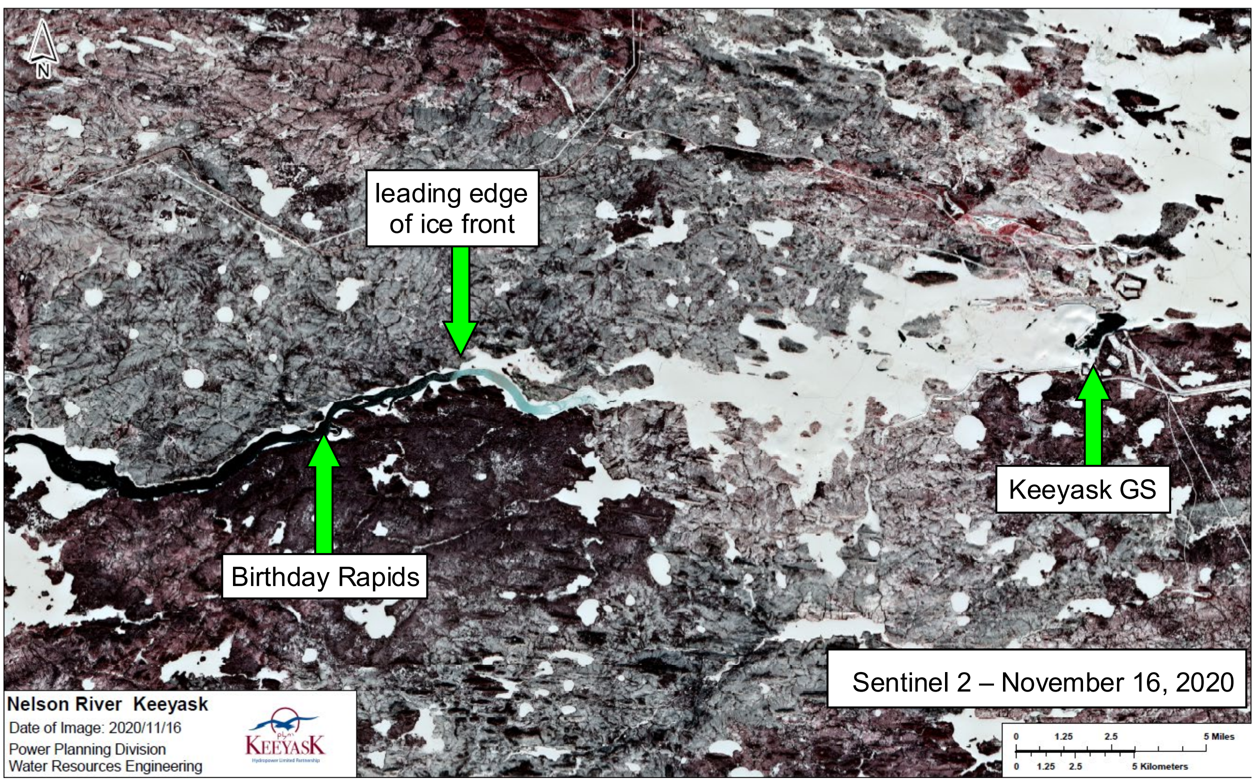


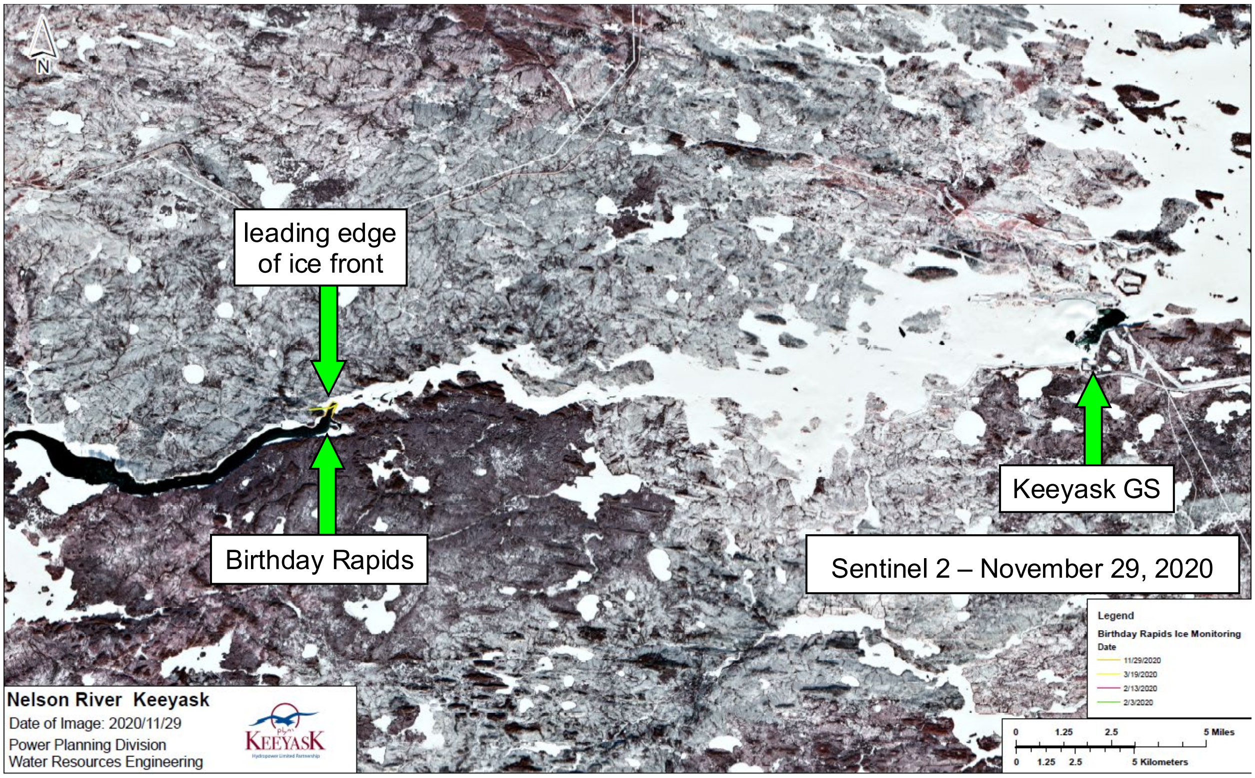
Photo 9: Ice front about 6 km upstream of Birthday Rapids, March 15, 2021



Gull Lake
Clark Lake
Keeyask GS
Birthday Rapids
Sentinel 2 – October 30, 2020
Nelson River Keeyask
Date of Image: 2020/10/30
Power Planning Division
Water Resources Engineering
0 1.25 2.5 5 Miles
0 1.25 2.5 5 Kilometers



leading edge
of ice front
Keeyask GS
Birthday Rapids
Sentinel 2 – November 16, 2020
Nelson River Keeyask
Date of Image: 2020/11/16
Power Planning Division
Water Resources Engineering
0 1.25 2.5 5 Miles
0 1.25 2.5 5 Kilometers



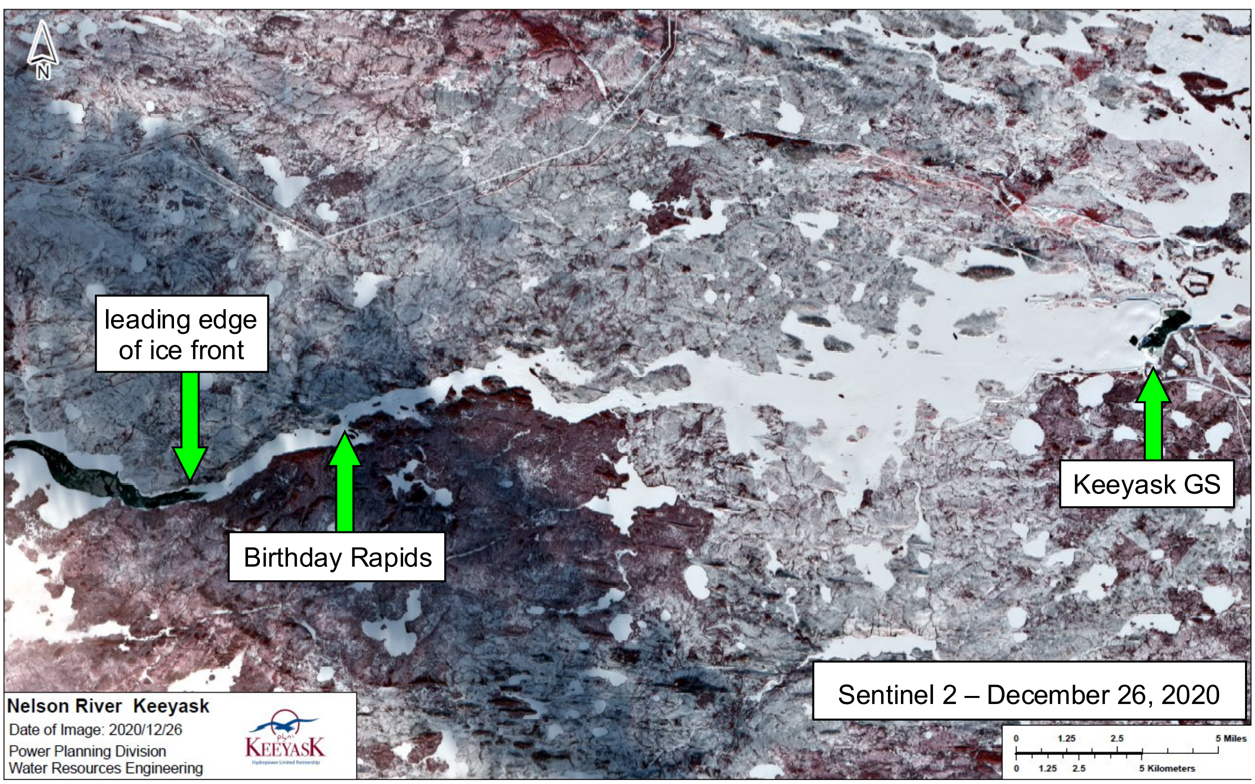
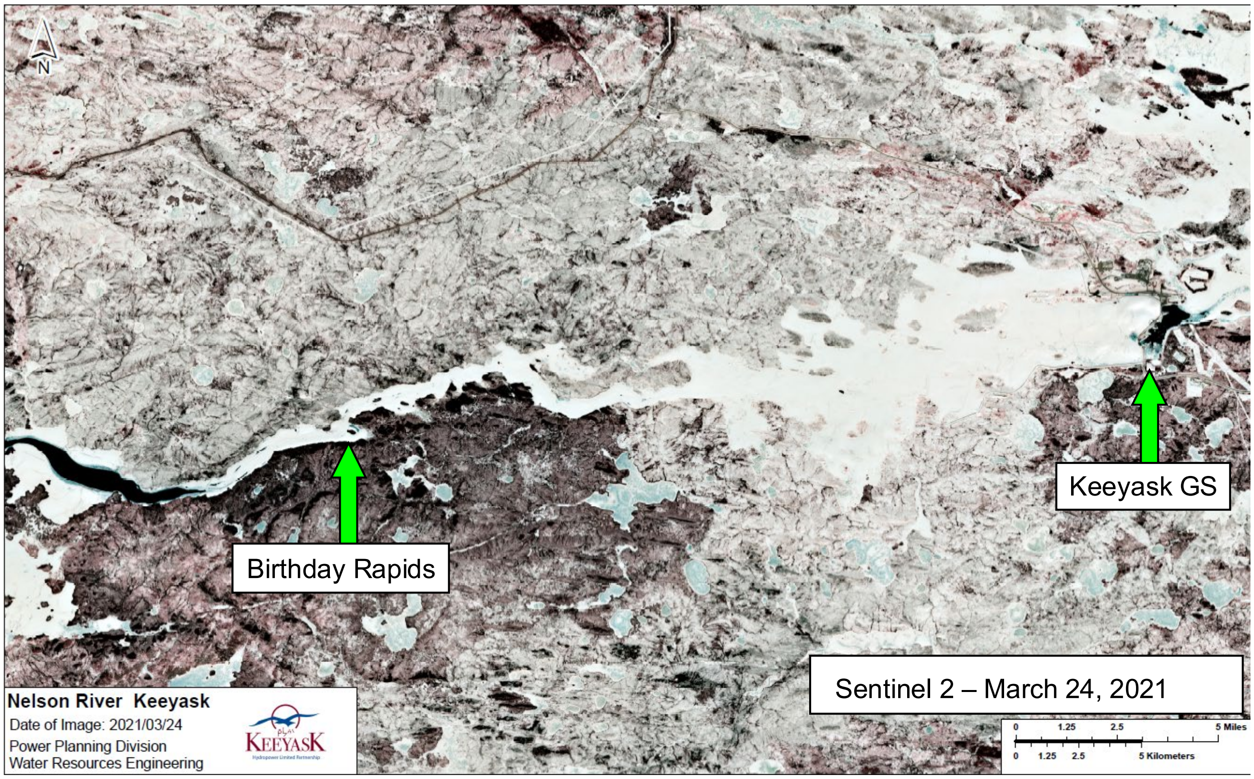
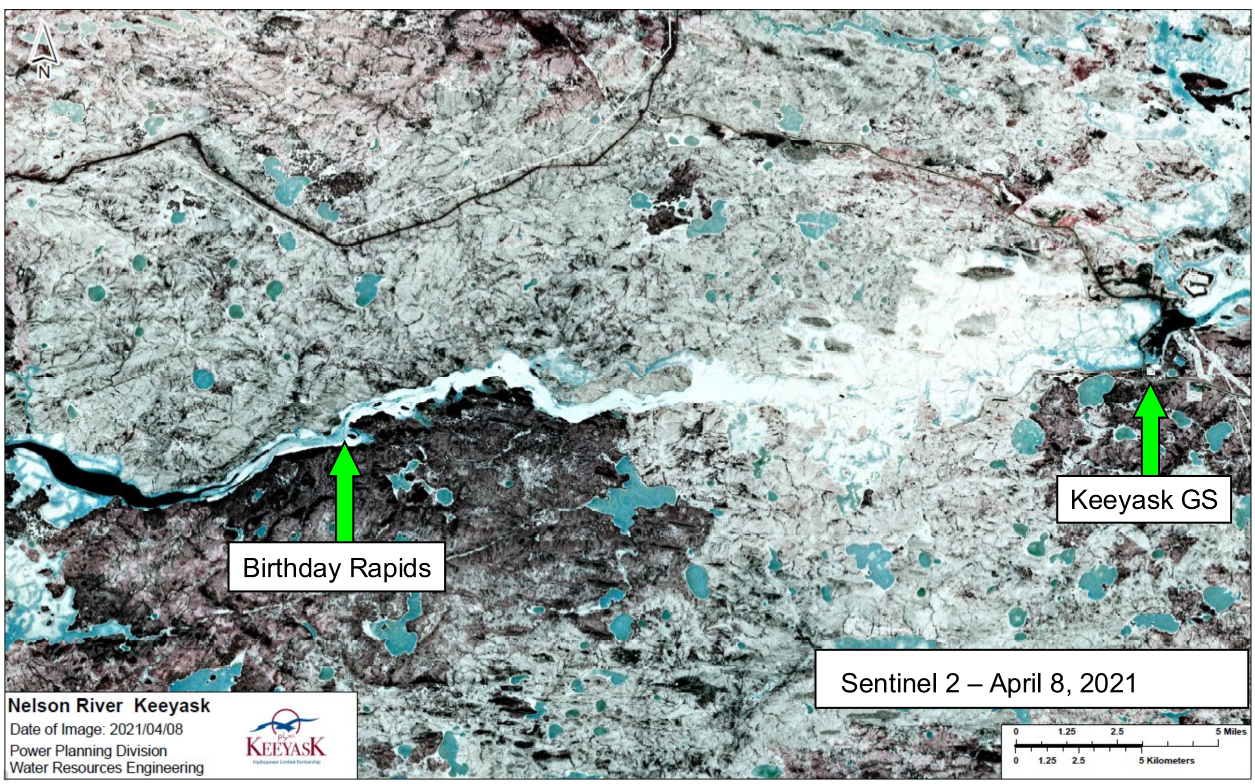
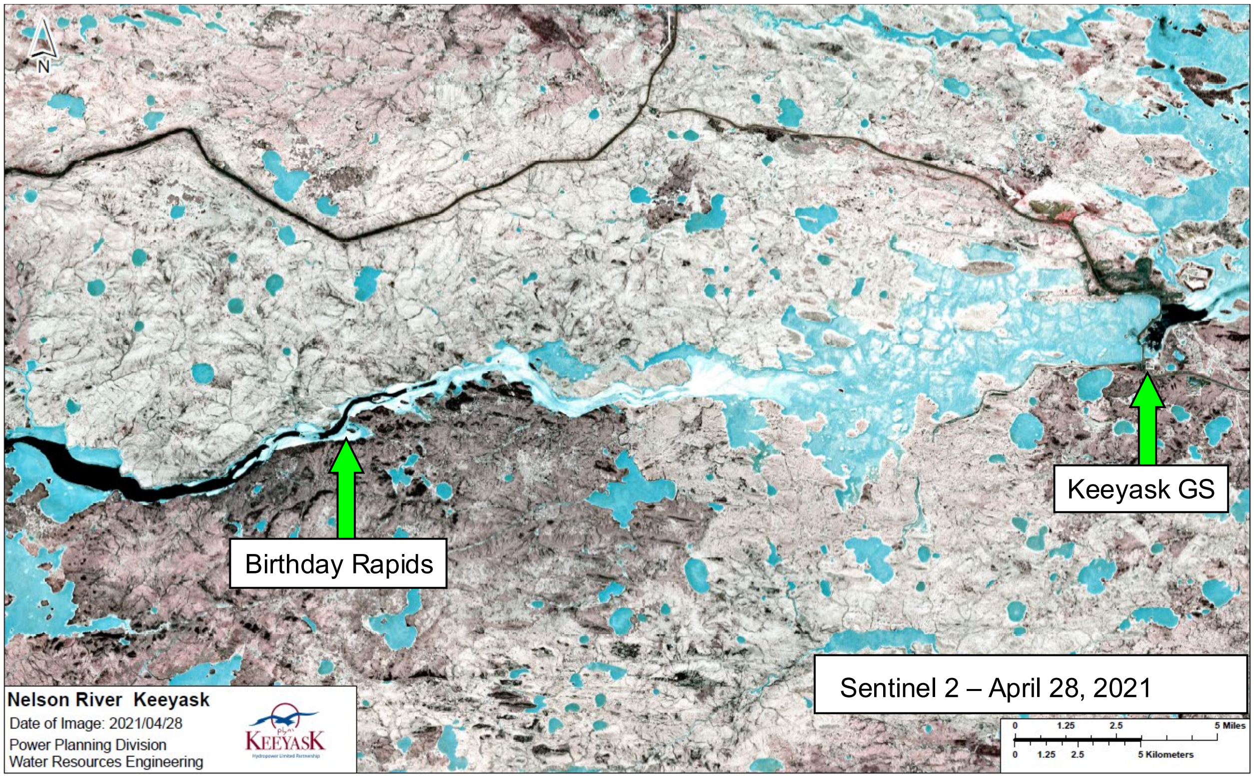
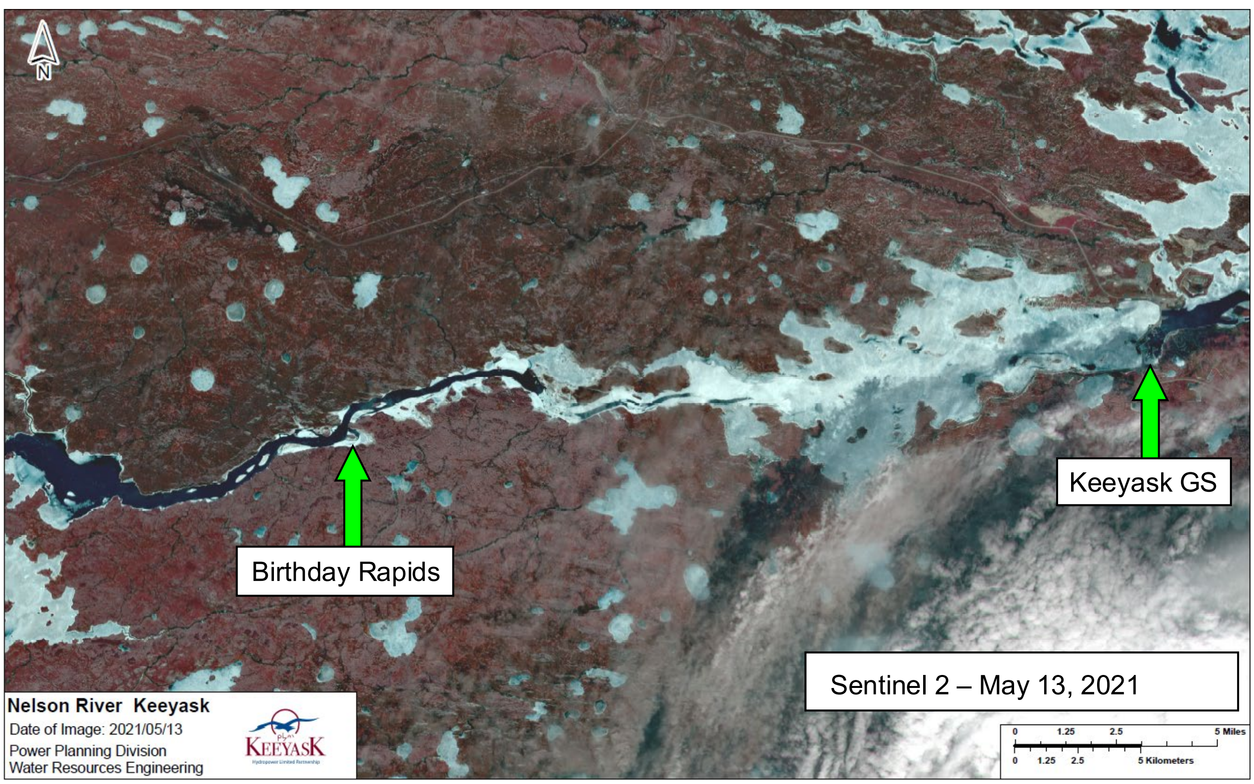


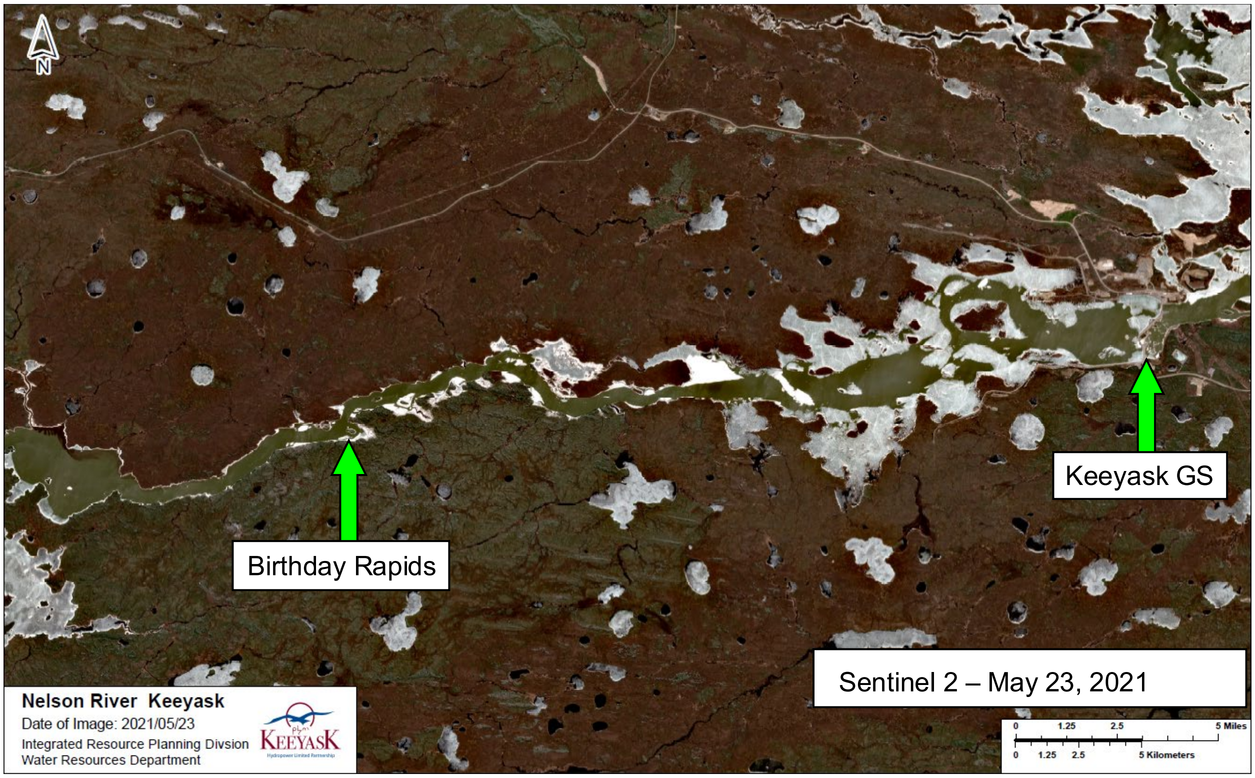
Figure 8: Ice cover development observations from satellite images


Birthday Rapids
Keeyask GS
Sentinel 2 – March 24, 2021
Nelson River Keeyask
Date of Image: 2021/03/24
Power Planning Division
Water Resources Engineering
KEEYASK
0 1.25 2.5 5 Miles
0 1.25 2.5 5 Kilometers


Birthday Rapids
Keeyask GS
Sentinel 2 – April 8, 2021
Nelson River Keeyask
Date of Image: 2021/04/08
Power Planning Division
Water Resources Engineering
KEEYASK
0 1.25 2.5 5 Miles
0 1.25 2.5 5 Kilometers


Birthday Rapids
Keeyask GS
Sentinel 2 – April 28, 2021
Nelson River Keeyask
Date of Image: 2021/04/28
Power Planning Division
Water Resources Engineering
KEEYASK
0 1.25 2.5 5 Miles
0 1.25 2.5 5 Kilometers


Birthday Rapids
Keeyask GS
Sentinel 2 – May 13, 2021
Nelson River Keeyask
Date of Image: 2021/05/13
Power Planning Division
Water Resources Engineering
KEEYASK
0 1.25 2.5 5 Miles
0 1.25 2.5 5 Kilometers



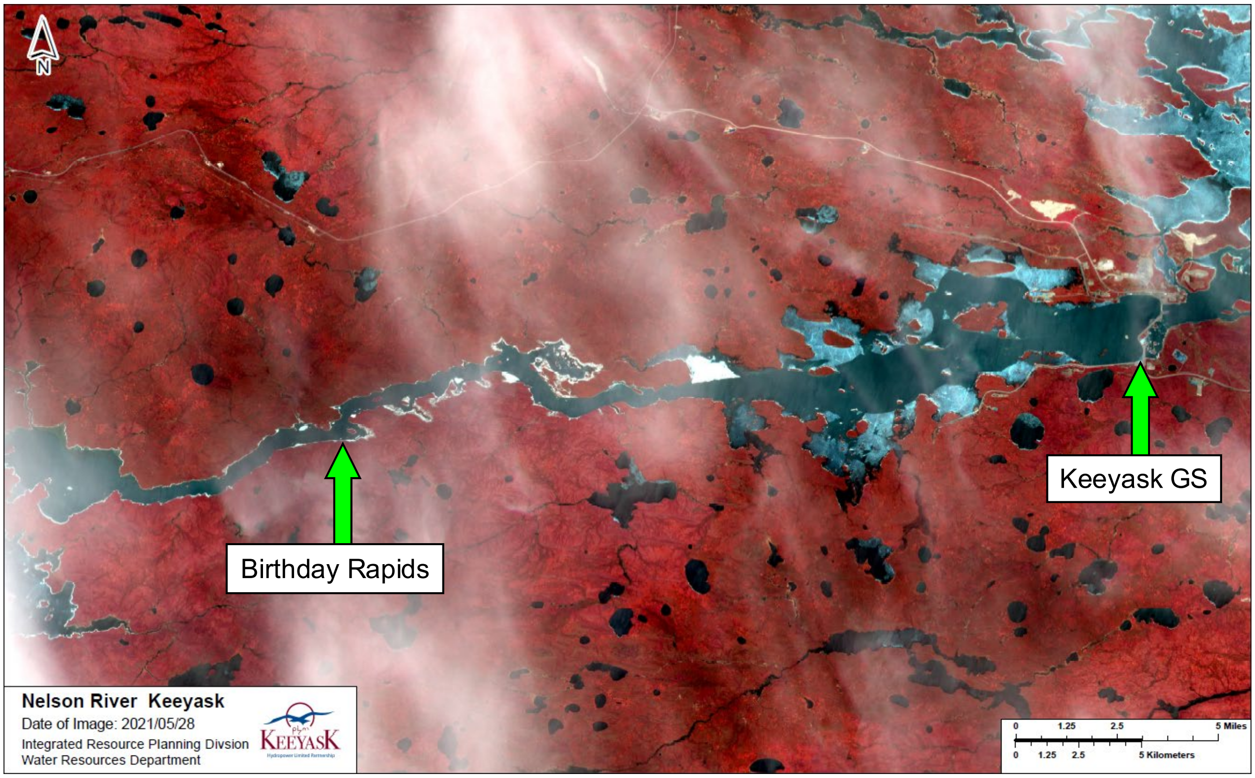


Figure 9: Receding ice cover observations from satellite images

3.0 SHORELINE EROSION

Shoreline erosion monitoring during construction consists of mapping the shoreline position (edge of peat for peat shorelines, top-of-bluff for mineral banks) prior to full impoundment of the reservoir. In 2014 a high-resolution satellite imagery was collected at the start of the construction period. In 2019 another similar satellite image was collected to represent the conditions prior to impoundment that occurred in 2020. The shorelines at the start and end of construction will be compared to see if any substantive shoreline erosion occurred during construction. Images collected after impoundment will be used to determine the actual extent of flooding and reservoir expansion over time.

4.0 SEDIMENTATION

Sedimentation monitoring includes monitoring the transport and deposition of sediment; the objectives of the sedimentation monitoring include:

- confirming sediment transport and deposition predictions; and
- supporting water quality and aquatic habitat monitoring components of the AEMP (KHLP 2015b).

The largest overall effects of the Project on sedimentation are predicted to occur after impoundment of the reservoir with the highest total sediment loading predicted to occur in the first year after impoundment. During the construction period prior to reservoir impoundment the PEMP sedimentation monitoring is generally done to collect data that will support conclusions of the effects of the Project on sediment transport and deposition after impoundment. Sediment monitoring under the *Sediment Management Plan for In-stream Construction* (SMP) (KHLP 2014) is designed to specifically monitor sediment releases due to in-stream construction activities. A separate annual report discusses the results of monitoring performed in the implementation of the SMP (Manitoba Hydro 2021).

Sediment transport monitoring is done through the collection of discrete water samples, continuous turbidity monitoring and sediment traps at locations shown in Map 3 (detailed site maps are provided in Appendix 1). Discrete sampling involves the collection of water samples and in-situ measurements by field personnel at certain times (e.g., monthly) while continuous turbidity monitoring involves the installation of automated equipment that remains in place to take readings much more frequently. The continuous turbidity sites are periodically visited for maintenance checks; typically completed while discrete monitoring is performed. Sediment loading is estimated from the continuous turbidity data.

4.1 WINTER 2019-2020

In each annual report the winter sedimentation data is reported from the previous winter (i.e. one year delay) to allow time after the end of the field season for all data to be reviewed and analyzed before reporting. This report presents the 2019-20 winter sedimentation data.

4.1.1 CONTINUOUS AND DISCRETE TSS AND TURBIDITY

Winter monitoring in 2019-20 was conducted at three sites (Table 4), upstream of the Project area in Clark Lake, Gull Lake and downstream of the Project in Stephens Lake. Each year the equipment is installed after suitable ice conditions develop at the sites and removed before ice break up. In 2019-20 the loggers were left in place late into May, about 4 or 5 weeks longer than other years in anticipation of a possible spring impoundment which did not ultimately occur. The data collected at each of the monitoring sites was reviewed to identify and remove poor quality data from factors such ice, dead batteries, and equipment malfunction. The continuous data (Figure 10 & Figure 11) were also compared with the discrete readings (Figure 12) obtained on each maintenance site visit and adjustments made for any sensor drift.

Turbidity levels dropped slightly over the course of the winter, with highest levels observed in late January followed by a decreasing trend over the winter; this pattern is commonly seen in winter. With the monitoring extending into late May 2020, an increase in turbidity was observed over the last two weeks as ice melting and breakup had started, which is expected.

Table 4: 2019-2020 winter monitoring locations

Site ID	Dates
K-Tu-06 (Clark Lake)	16-Jan-2020 to 25-May-2020
SMP-01 (Gull Lake)	13-Jan-2020 to 19-May-2020
SMP-02 (Stephens Lake)	18-Jan-2020 to 25-May-2020

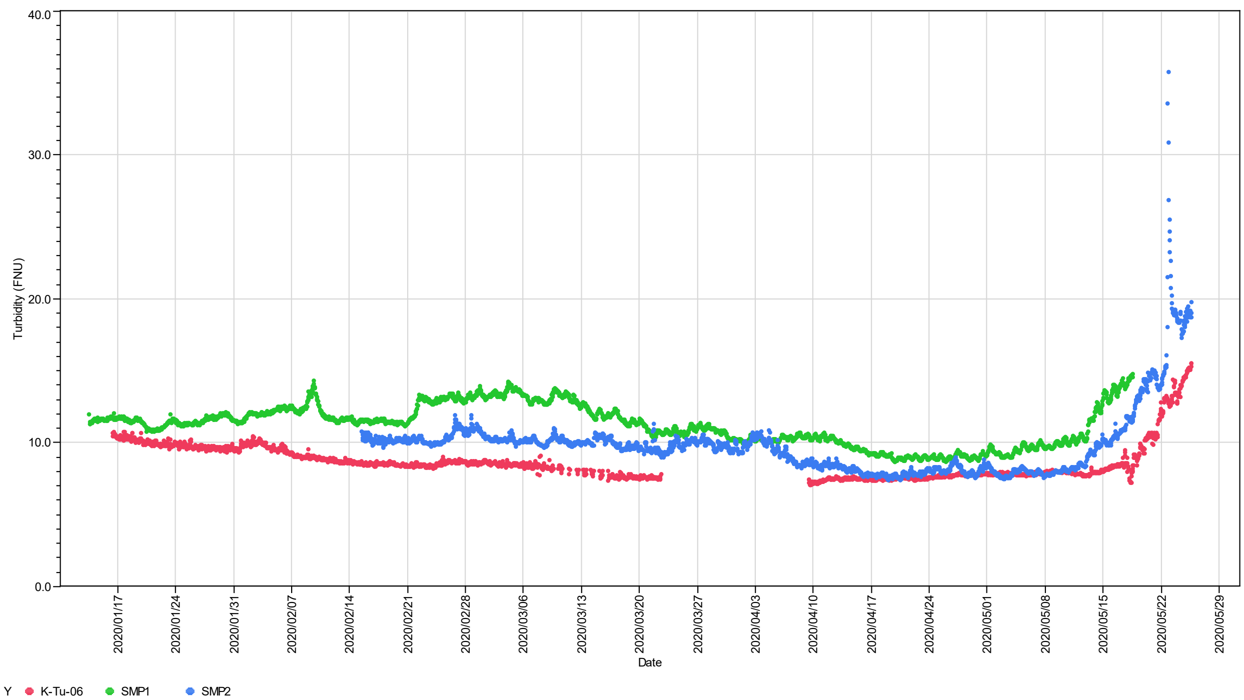


Figure 10: 2019-2020 winter continuous turbidity

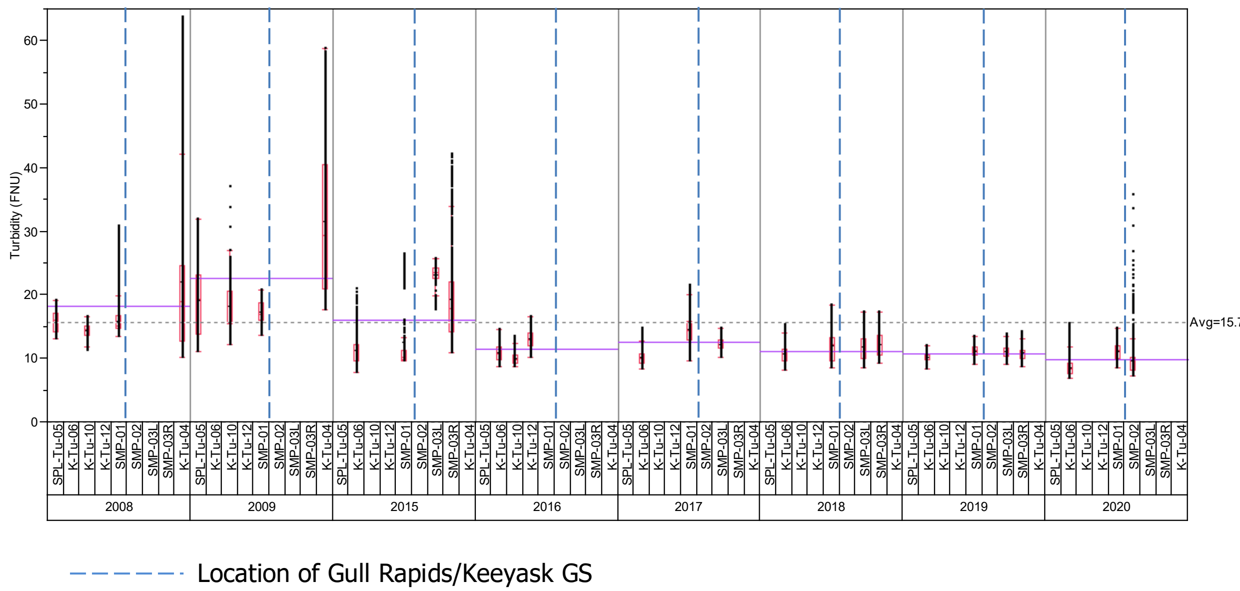


Figure 11: Summary of winter continuous turbidity

Results from the 2019-20 winter monitoring show similar results to the past four winters with a reduction in turbidity levels in Stephens Lake from pre-construction conditions. The EIS included the prediction that the Project will "significantly reduce erosion potential" downstream of the Project after construction which would result in lower turbidity downstream. Changes were not anticipated during the construction period as some increases in water level due to ice were still expected to cause erosion at the entrance to Stephens Lake. The earlier than expected reduction is likely due to the upstream ice boom creating a more stable upstream ice cover and reduction in the Stephens Lake ice dam and the cofferdams reducing the potential erosion of shorelines.

Discrete TSS and Turbidity (Figure 12) data show consistent results with the continuous data. With the ice boom working to produce a stable ice cover upstream of the Project the downstream TSS and turbidity has dropped.

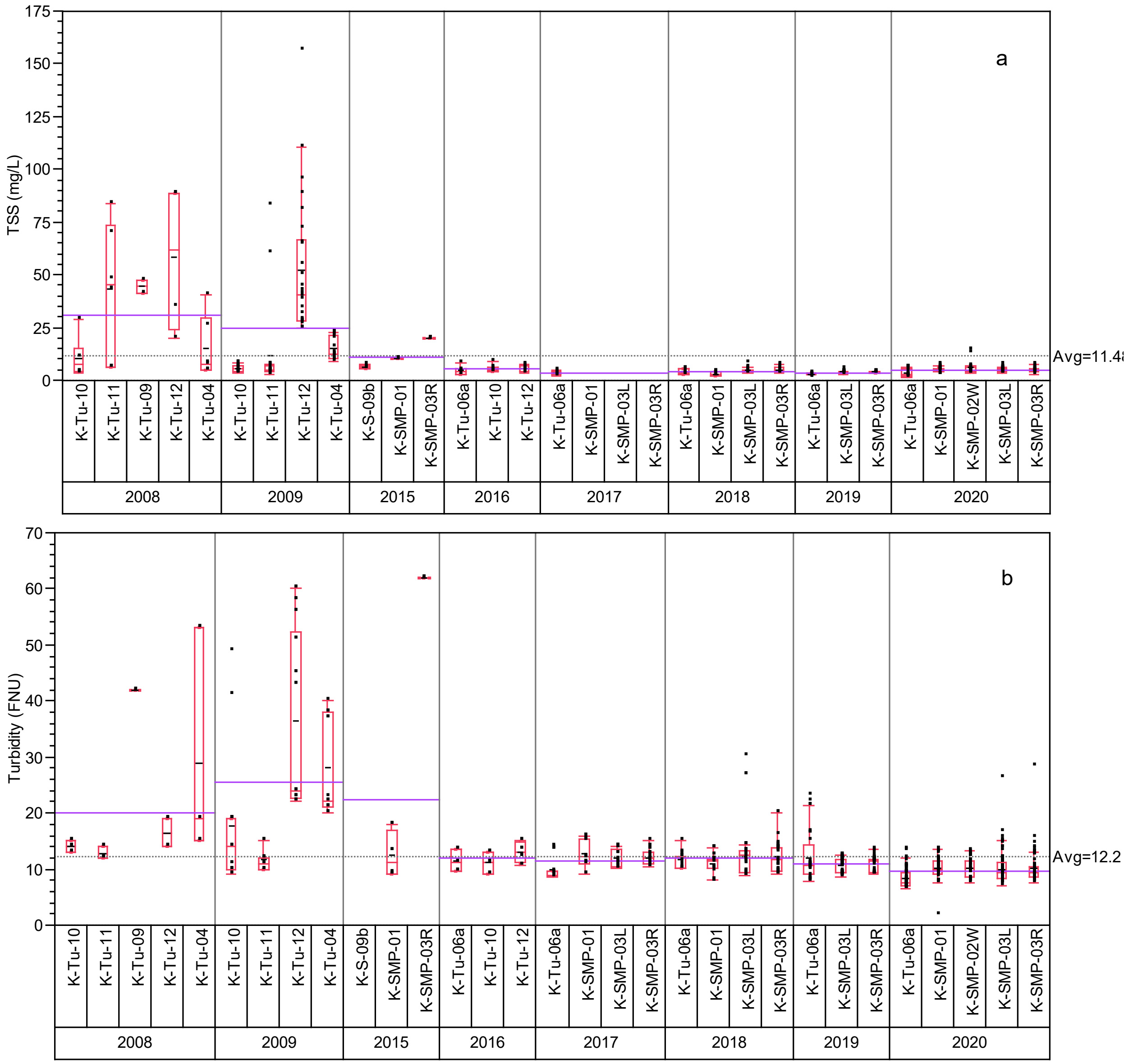


Figure 12: Summary of winter discrete TSS (a) and turbidity (b)

4.1.2 ESTIMATED SUSPENDED SEDIMENT LOAD

The winter suspended sediment loads (Figure 13) are estimated based on the average daily turbidity and discharge. Turbidity was converted to TSS concentrations using a Turbidity-TSS relationship developed for the In stream Sediment Monitoring Plan (KHLP 2014).

The estimated sediment load upstream of the area where the Project is expected to have effects (measured at SPL-Tu-05 on Split Lake and K-Tu-06 Clark Lake) indicates that the winter average was higher during the two pre-construction years than the winters monitored since construction started.

As noted above, a downstream reduction in turbidity has resulted in a reduced sediment load entering Stephens Lake from the pre-construction period and in 2014-15 when the ice boom failed. It is estimated that approximately 80,000 tonnes were eroded between the Gull Lake site (K-Tu-03) and Stephens Lake site (K-Tu-04) over a 2 ½ week period in 2007-2008 when the higher turbidity was observed.

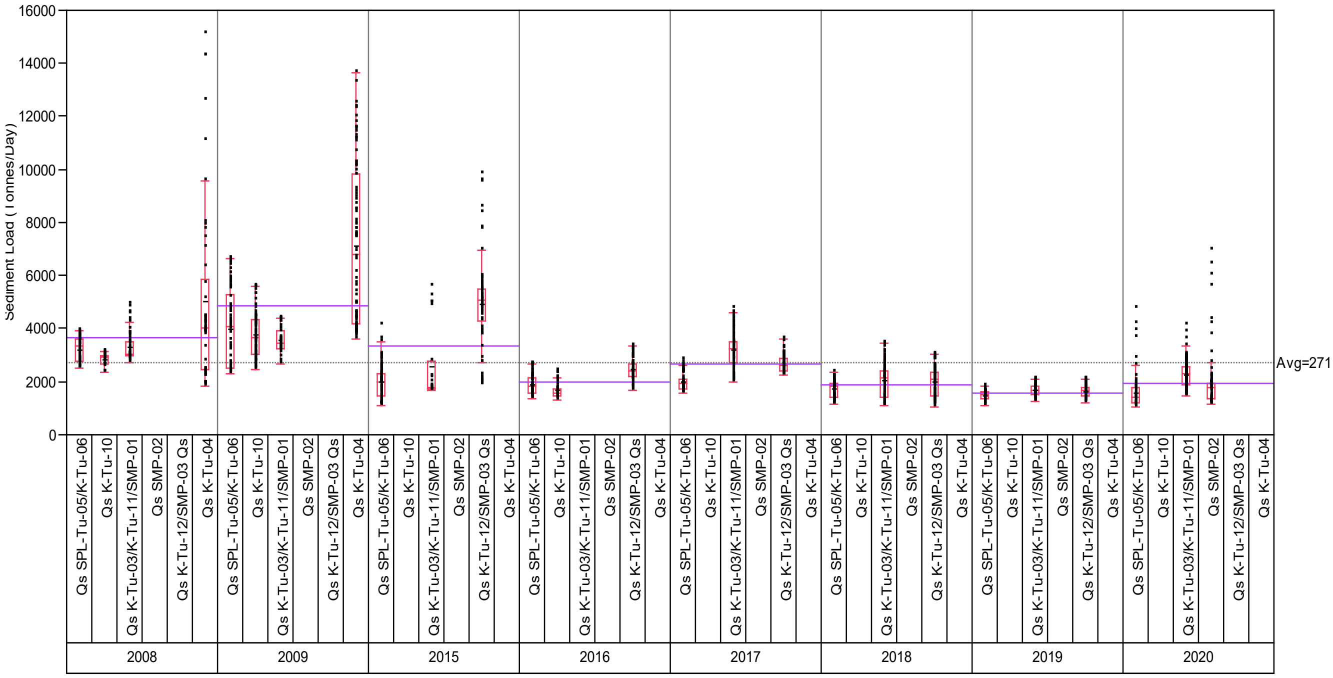


Figure 13: Summary of winter daily suspended sediment load

4.2 SUMMER 2020

The summer monitoring period extends from the time ice has melted and equipment can be safely placed in the water (typically in June) until equipment can be safely removed before winter conditions and freeze up starts (typically late September/October).

4.2.1 CONTINUOUS TURBIDITY

The five continuous turbidity sites monitored in summer 2020 and the dates for which records are available are shown in Table 5 (location maps in Appendix 1).

The continuous turbidity monitoring stations consist of either a catamaran equipped for satellite data transmission (Photo 10) or a stand-alone buoy system requiring manual downloading of data. Both systems are equipped with an YSI multi-parameter sonde (6600 or EXO2 series) suspended two metres below the surface of the water.

Table 5: 2019 Summer monitoring locations

Site ID / Location	Dates
K-Tu-06 (Clark Lake)	2020/06/30 to 2020/09/22
*K-Tu-05 (Nelson River)	2020/06/25 to 2020/09/19
K-Tu-03 / SMP-01 (Gull Lake)	2020/06/26 to 2020/10/02
K-Tu-02 / SMP-02 (Stephens Lake Entrance)	2020/06/13 to 2020/09/26
K-Tu-04 (Stephens Lake)	2020/06/26 to 2020/09/17

*K-Tu-05 relocated to K-Tu-13 in 2017 and 2018

The data collected at each of the monitoring sites was reviewed to identify and remove poor quality data that may result due to factors such as algae growth and vegetation on probes, dead batteries, and equipment malfunction. The continuous data (Figure 14 & Figure 15) were also compared with the discrete readings (Figure 16) obtained on each maintenance site visit and adjustments made for any sensor drift. For the PEMP report, the turbidity recorded at SMP-02L (left side of Stephens Lake entrance channel) and SMP-02R (right side of entrance channel) were averaged to represent the average turbidity entering Stephens Lake.

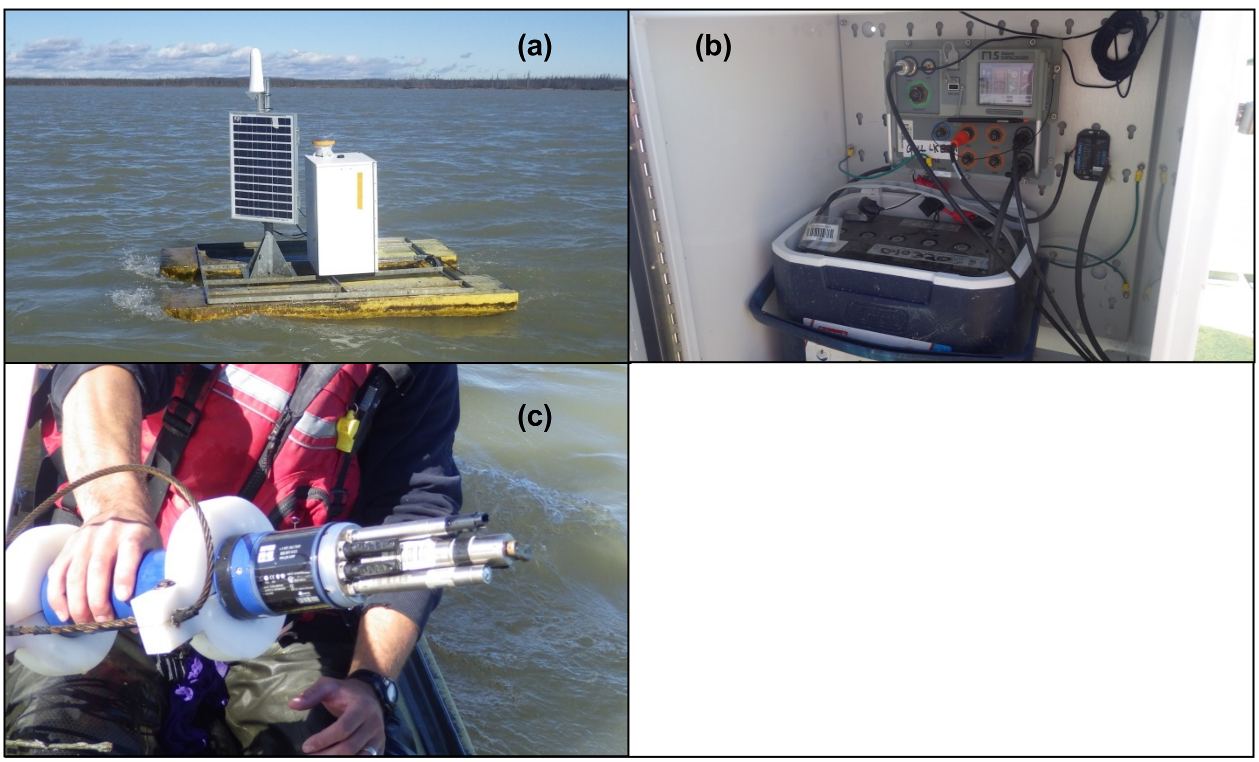


Photo 10: Continuous turbidity monitoring site: (a) catamaran with solar panel, transmitter and electronics cabinet, (b) electronics in cabinet, (c) probe with turbidity sensor installed

The turbidity at each of the sites follows a similar pattern (Figure 14) throughout the monitoring period with the site near the Kettle GS (K-Tu-04) being slightly lower until mid-August. Turbidity increased through June while remaining relatively steady in July and August with some variations as turbidity responds to wind/storm events. The wind speed shown in Figure 14 is taken from the Environment Canada Station at Gillam.

The average summer turbidity (Figure 15) was very similar to 2017 and 2018. Differences between the sites are similar to observations seen in other years and no discernable changes resulting from the Project, including impoundment, were observed when comparing upstream Clark Lake turbidity with downstream observations.

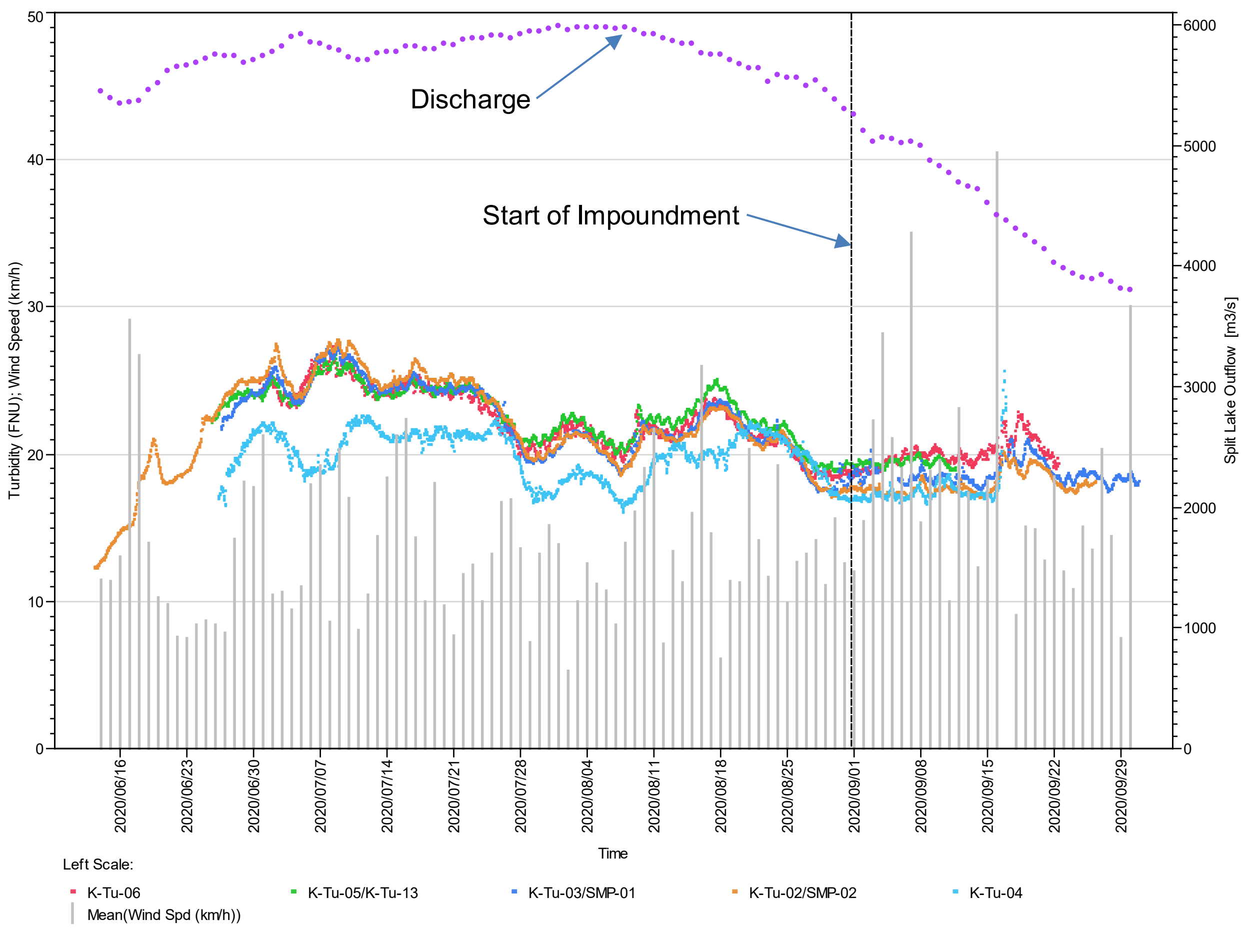


Figure 14: 2020 Summer continuous turbidity, daily discharge, 24-hr wind speed

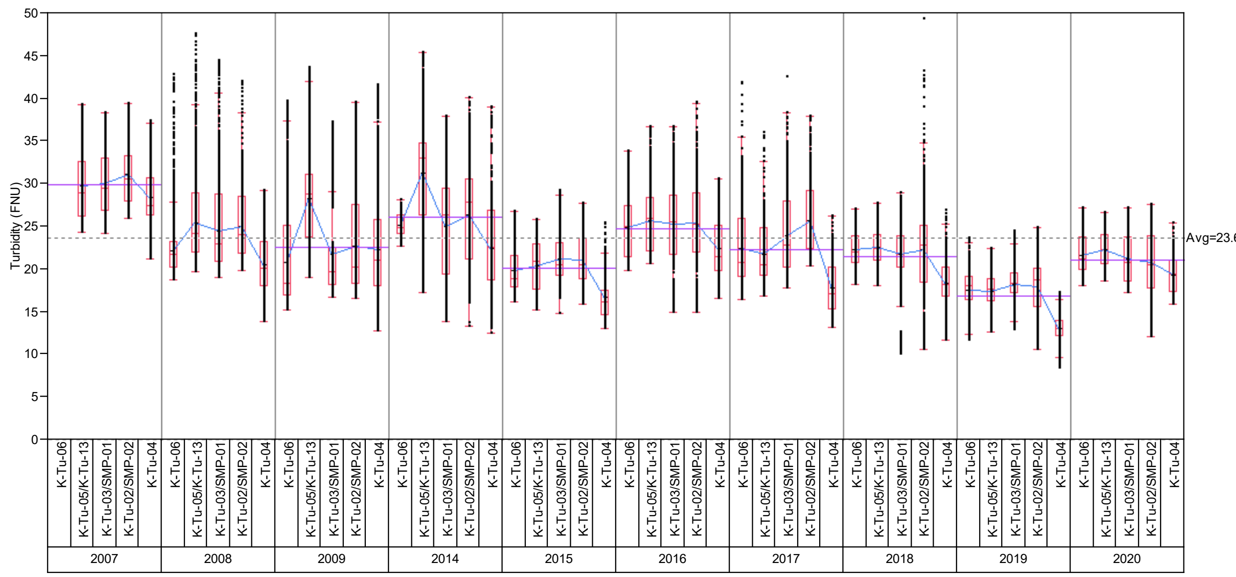


Figure 15: Summary of annual summer continuous turbidity

4.2.2 DISCRETE TOTAL SUSPENDED SEDIMENT AND TURBIDITY

During the summer period, discrete water samples were taken for total suspended sediment (TSS) testing and in-situ turbidity (Tu) readings at both the discrete monitoring sites and at the continuous turbidity sites (see maps in Appendix A). Discrete sampling was performed four times at each site; typically coinciding with the scheduled monthly maintenance visits at the continuous turbidity sites between June and September. The discrete readings are used to verify the continuous readings, confirm readings throughout the entire depth of the site and correlate turbidity and TSS.

The 2020 TSS results (Figure 16) generally ranged between 5 and 18 mg/L. Figure 17 and Figure 18 shows the site, year and overall average of summer turbidity and TSS data collected during the pre-construction and construction periods to date under the sedimentation monitoring program. In 2020 the average annual TSS and turbidity across all sites was lower than the average since the pre-construction and during construction periods. This reflects lower TSS and turbidity entering the project area from upstream.

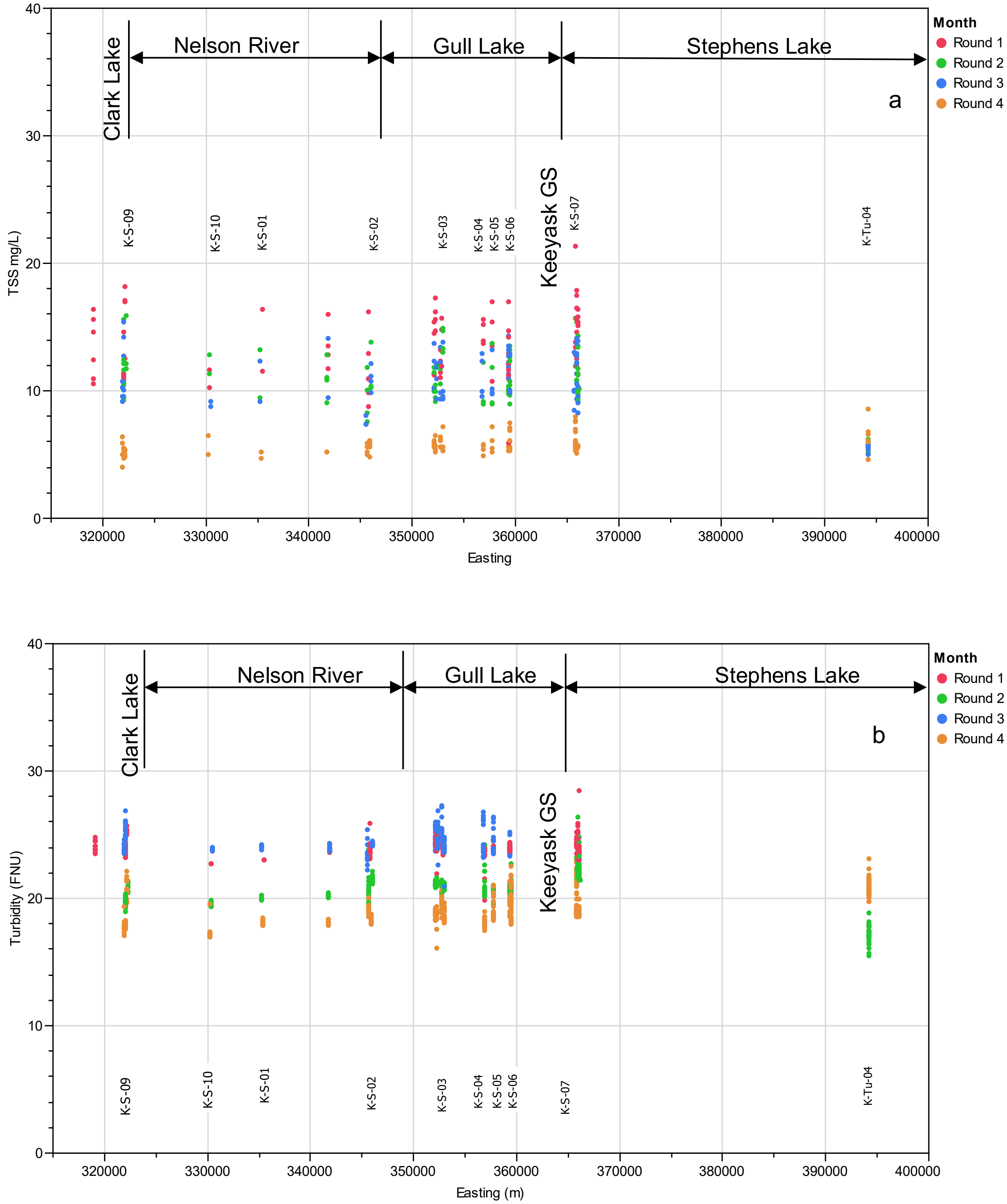


Figure 16: 2020 summer discrete TSS (a) and turbidity (b)

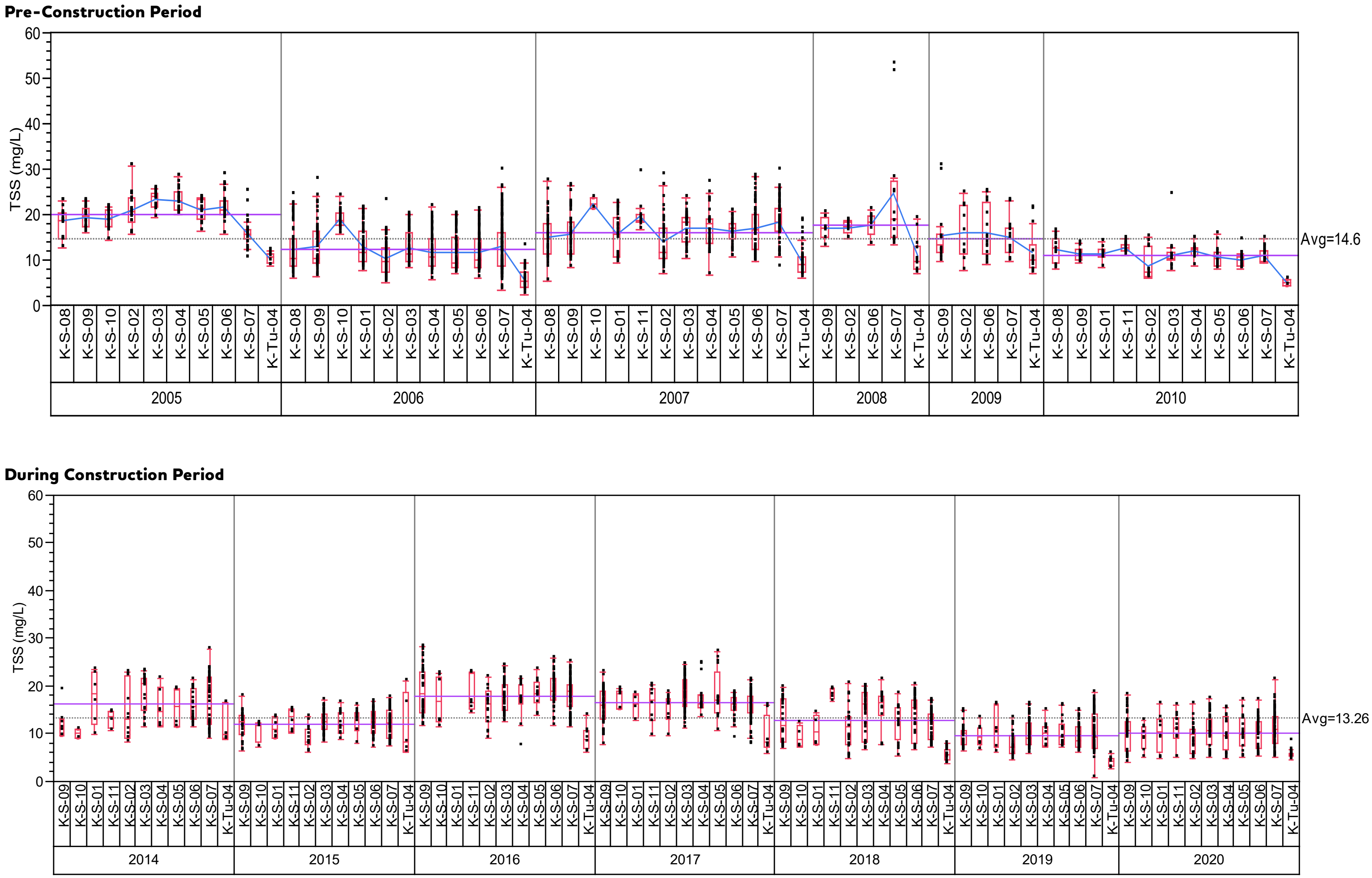


Figure 17: Summary of annual summer discrete TSS

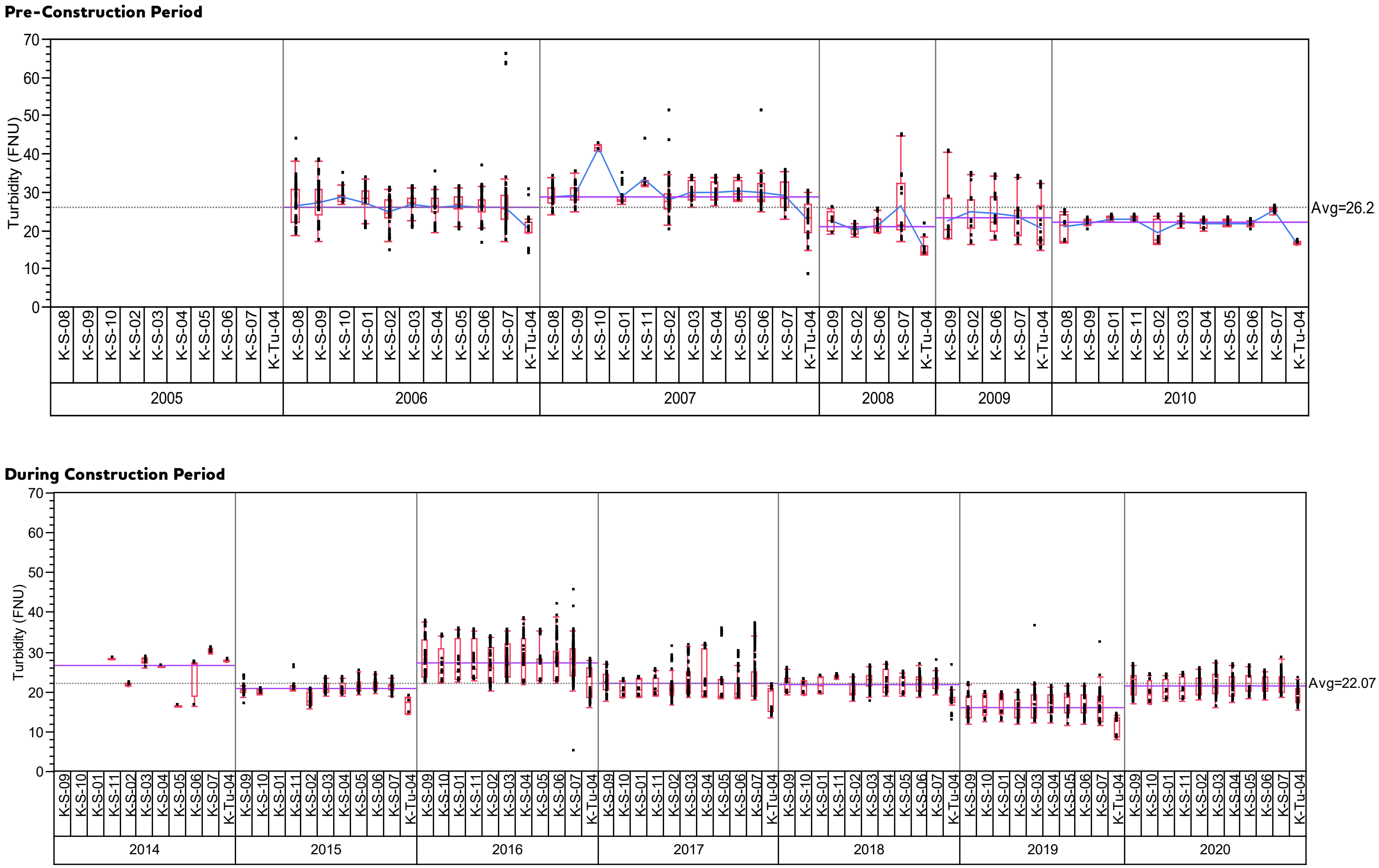


Figure 18: Summary of annual summer discrete turbidity

4.2.3 ESTIMATED SUSPENDED SEDIMENT LOAD

The summer suspended sediment loads (Figure 19) are estimated based on the average daily turbidity and Keeyask inflow discharge. Turbidity was converted to TSS concentrations using a Turbidity-TSS relationships developed for each summer (annual equation) and using the relationship developed for the Instream Sediment Monitoring Program (SMP; KHLP 2014).

The 2020 average summer suspended sediment load was similar to 2017. This may be due to similarly high average Split Lake outflows (June-September) of about 4,900 m^3/s and 5,200 m^3/s 2017 and 2020 respectively. As seen in other years, there was a drop in suspended sediment load through Stephens Lake (K-Tu-02 to K-Tu-04).

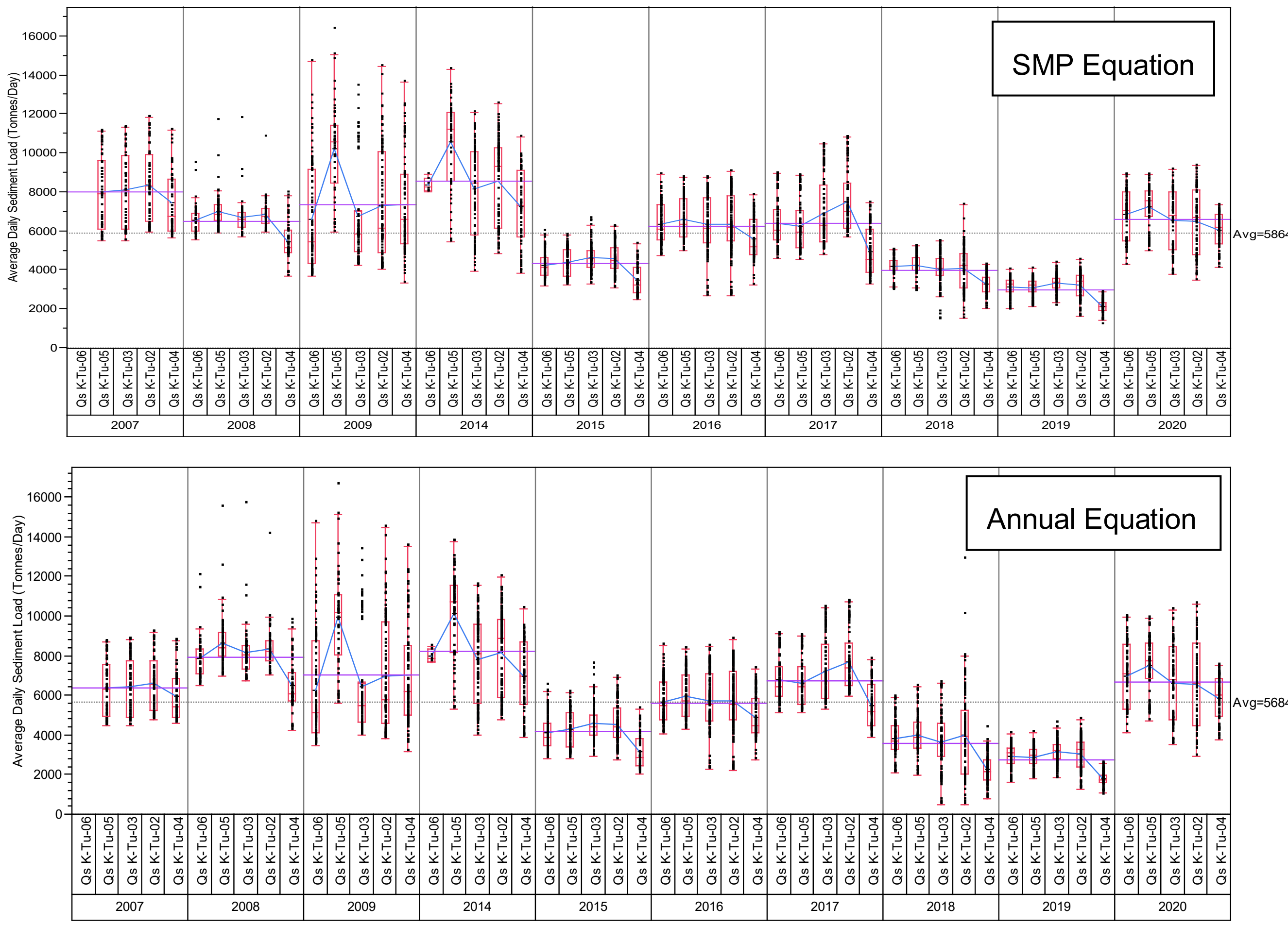


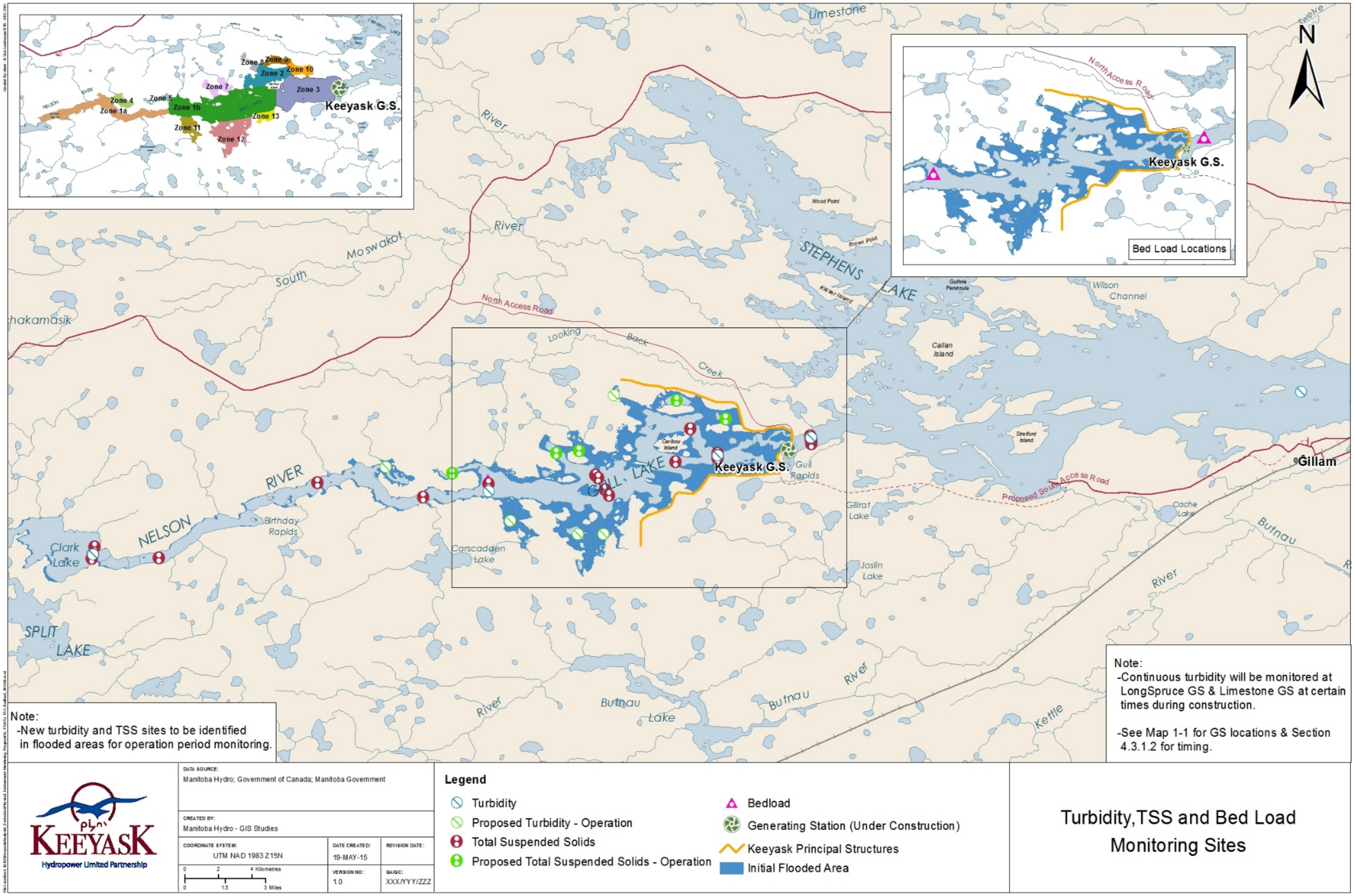
Figure 19: Summary of summer daily sediment load

4.2.4 DEPOSITION

Sediment traps with two vertical tubes (Photo 11) were installed in Stephens Lake to monitor the sediment accumulation rate over the 2019/20 winter and the 2020 summer periods. One tube is a settling trap that is open at the top and the second tube is a flow through trap that has holes in the side to allow water and sediment to flow into it.

Laboratory results from the sediment trap monitoring were not available at the time of writing this report. Results will be reviewed and reported in the next annual monitoring report.

Photo 11: Sediment traps - 2 tube design



Map 3: Turbidity, total suspended solids and bed load monitoring sites

5.0 ORGANIC CARBON

Organic carbon in the water is not expected to be affected by construction prior to impoundment of the reservoir. However, it is being measured during the construction period to provide baseline information. When the reservoir is filled, it will flood organic material such as peat and vegetation that may add organic carbon to the water in both dissolved and particulate forms.

Discrete water samples were obtained at up to 4 sites once a month from January to April 2020, and up to 12 sites from June to September. These water samples were tested to measure the concentrations of Dissolved Organic Carbon (DOC) and Total Organic Carbon (TOC). These results are used to calculate the amount of Particulate Organic Carbon (POC), since POC is equal to TOC minus DOC.

For purposes of the organic carbon analysis, results for samples at the continuous turbidity monitoring sites K-Tu-06 and K-Tu-05 were respectively pooled with the results for the discrete monitoring sites K-S-09 and K-S-02 because the respective sites are in the same location (see maps Appendix 1). Multiple samples were typically collected at each monitoring site on each day of sampling and at some sites more than one location was sampled (e.g., 3 locations across river width at K-S-09a, K-S-09b, K-S-09c). The results from the multiple samples collected each day of sampling have been summarized by averaging the organic carbon concentrations obtained at each site for each sampling day (Figure 20).

There are cases where the laboratory result for TOC was less than the result for DOC, which produces a negative value for POC when deducting DOC from TOC. Where this occurs, only the DOC is plotted and is assumed to represent the TOC for the site (i.e., assumes no POC). Although DOC cannot technically be greater than TOC, this occurs in the test results because both parameters have a measurement accuracy of approximately +/-1 mg/l. Within the monitoring area TOC and DOC are typically nearly equal so the DOC test result can end up larger than the TOC value within the range of testing accuracy.

From all the results, the site averaged TOC typically ranged from about 8-9 mg/l in summer and in January-February while March and April were between 7-8 mg/l (Figure 20). The organic carbon present was predominantly comprised of DOC as site averaged POC was 0.5 mg/l or less in those cases where TOC was greater than DOC. In each month the site average TOC concentrations were typically within 1 mg/L of each other across the sites and the ranged over about 3 mg/l from 7-10 mg/l through the year. There is no apparent pattern in TOC concentration from upstream to downstream, either increasing, decreasing or otherwise. The TOC concentrations measured in summer 2020 are of a similar magnitude and overall range as in previous years of monitoring during construction. The observations are consistent with those reported in the Keeyask EIS for the pre-construction period (KHLP 2012c, Appendix 2H) and, as before, show organic carbon is present primarily in dissolved form.

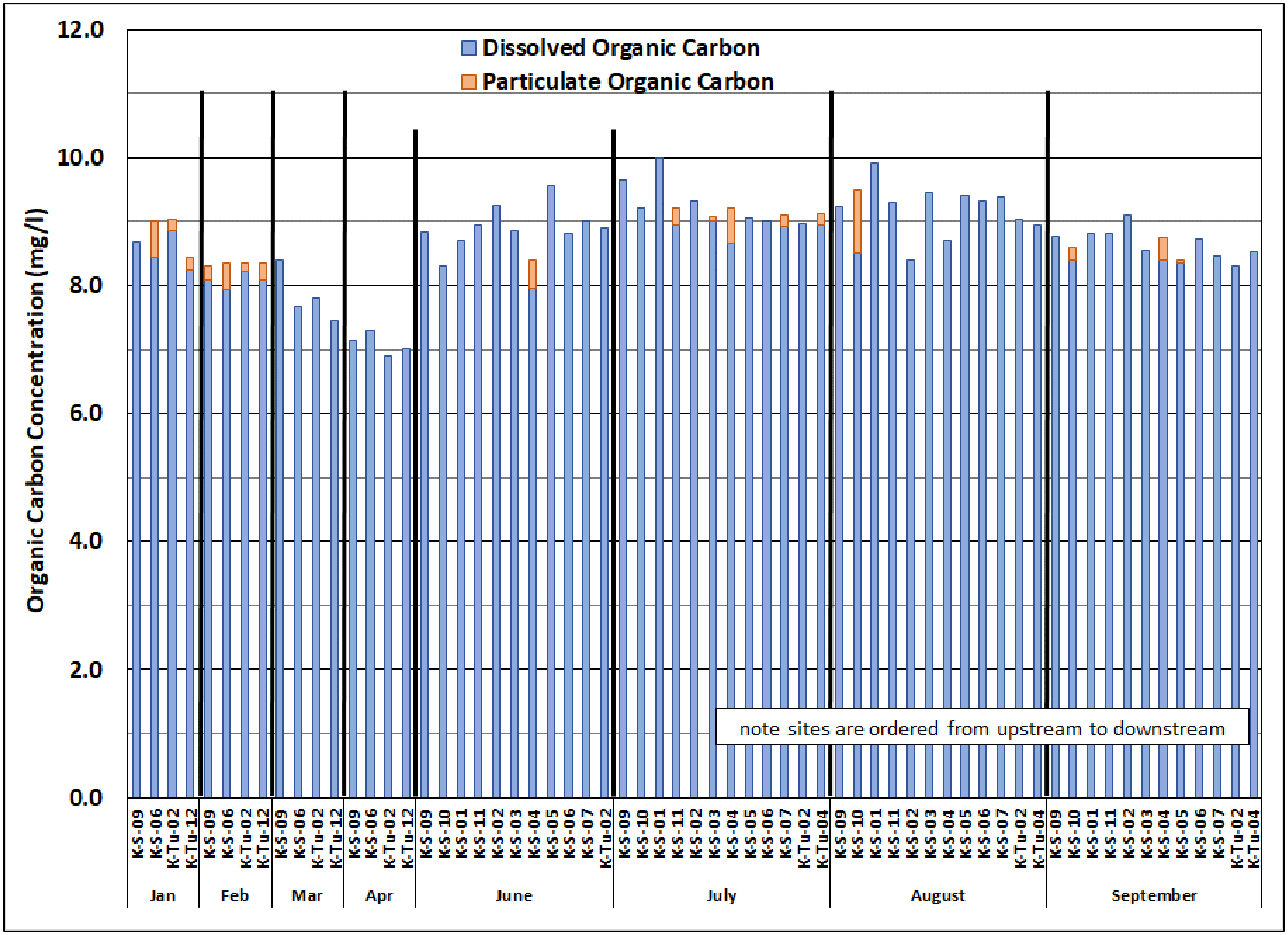


Figure 20: Summary of particulate, dissolved and total organic carbon in 2020

6.0 DISSOLVED OXYGEN

The in-situ monitoring included measuring the water temperature and dissolved oxygen (DO) concentration at TSS and turbidity monitoring sites. Based on the water temperature, the DO saturation concentration can be calculated using a standard formula (USEPA 1985). Saturation concentration is the equilibrium DO concentration that the water will preferentially attain for a given water temperature. Water at low temperatures can hold more DO and thus has a higher saturation concentration than water at high temperatures. The degree of saturation, or percent saturation, is calculated as the actual DO concentration in the water divided by the saturation concentration. When the actual DO concentration equals the saturation concentration it is referred to as being “saturated”, whereas water with a DO greater than the saturation level is “super saturated”. The amount of oxygen dissolved in the water will attempt to balance out at the saturation concentration (i.e., 100% saturation) by exchanging oxygen with the atmosphere.

At each monitoring site, one or more locations were sampled across the river width (e.g., two locations sampled across river width at site K-S-03) and, depending on sampling being done, multiple DO readings may have been obtained through the water depth. Results were reviewed and found that there was little variation between locations and depth at the monitoring sites. For this reason, the results were summarized by calculating the average DO concentration at each sampling site in each month of monitoring from June-September so that averaged conditions could be compared between the monitoring sites. The summary results show that DO concentrations was lowest in July and August and higher in June and September (Figure 21a), as would be expected because water temperatures are higher in July and August. Concentrations upstream of the Keeyask GS were lower than downstream concentrations in the same months. The downstream concentrations are higher due to turbulent flow through the spillway that causes air to be entrained in the flow, which results in additional oxygen being dissolved into the water.

Upstream of the Keeyask GS, the DO concentrations generally range between 95%-100% of the saturation concentration ((Figure 21b). Immediately downstream of the GS at site K-S-07 the DO is supersaturated, with the degree of saturation as high as 110% (i.e., 10% over saturation concentrations). The degree of supersaturation decreases moving downstream, being a few percent lower about 8 km downstream at K-Tu-12 and almost back to saturation 30 km downstream at K-Tu-04. Pre-construction monitoring found that DO concentrations were typically at or near saturation concentration in the Project area. During construction, prior to reservoir impoundment, the Project was not expected to affect DO (KHLP 2012b, Section 9) and, as observed in previous years, the monitoring results from summer 2020 confirmed this.

Dissolved Oxygen sampling has included sampling either partially or completely through the depth of the water column at monitoring sites. The monitoring results do not indicate any degree of DO stratification, with high DO at the surface and low DO at depth, at any of the monitoring sites (Figure 22 to Figure 24). The relatively uniform DO concentrations through the depth are indicative of well mixed conditions, as previously observed and expected as discussed in the Keeyask EIS (KHLP 2012b).

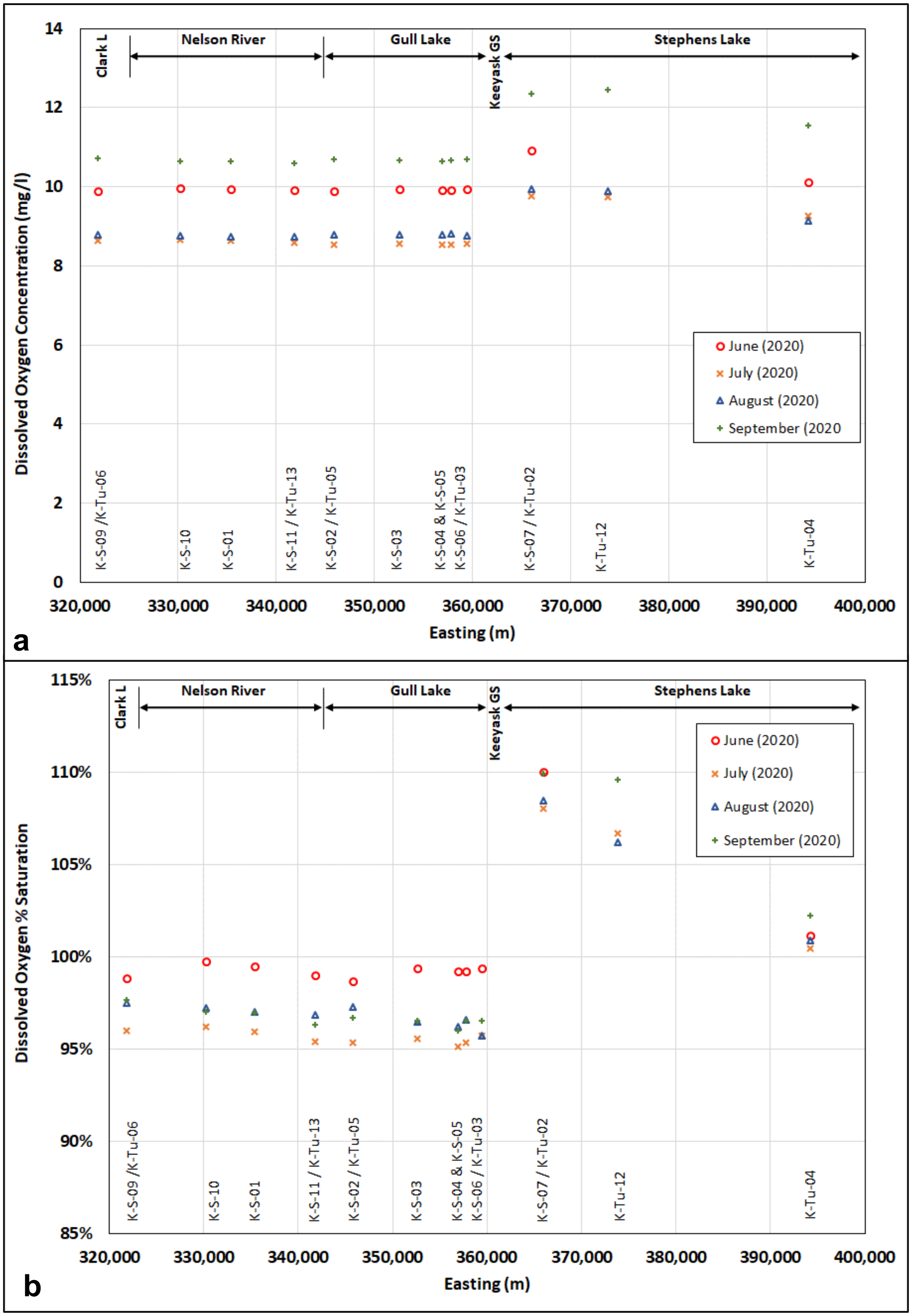


Figure 21: 2020 discrete DO monitoring results: (a) dissolved oxygen concentration (b) degree of saturation

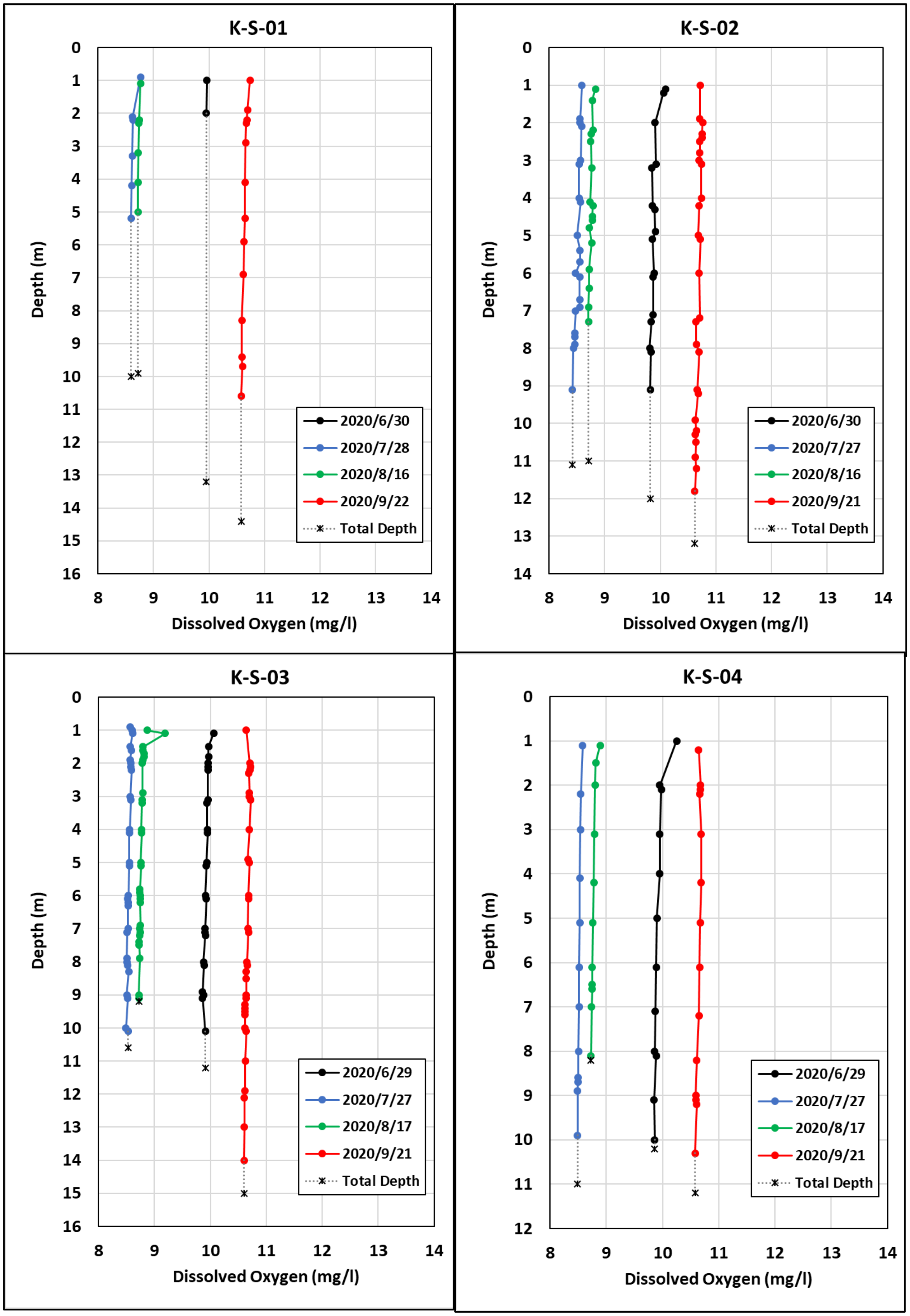


Figure 22: DO depth profiles at sites K-S-01, K-S-02, K-S-03, K-S-04

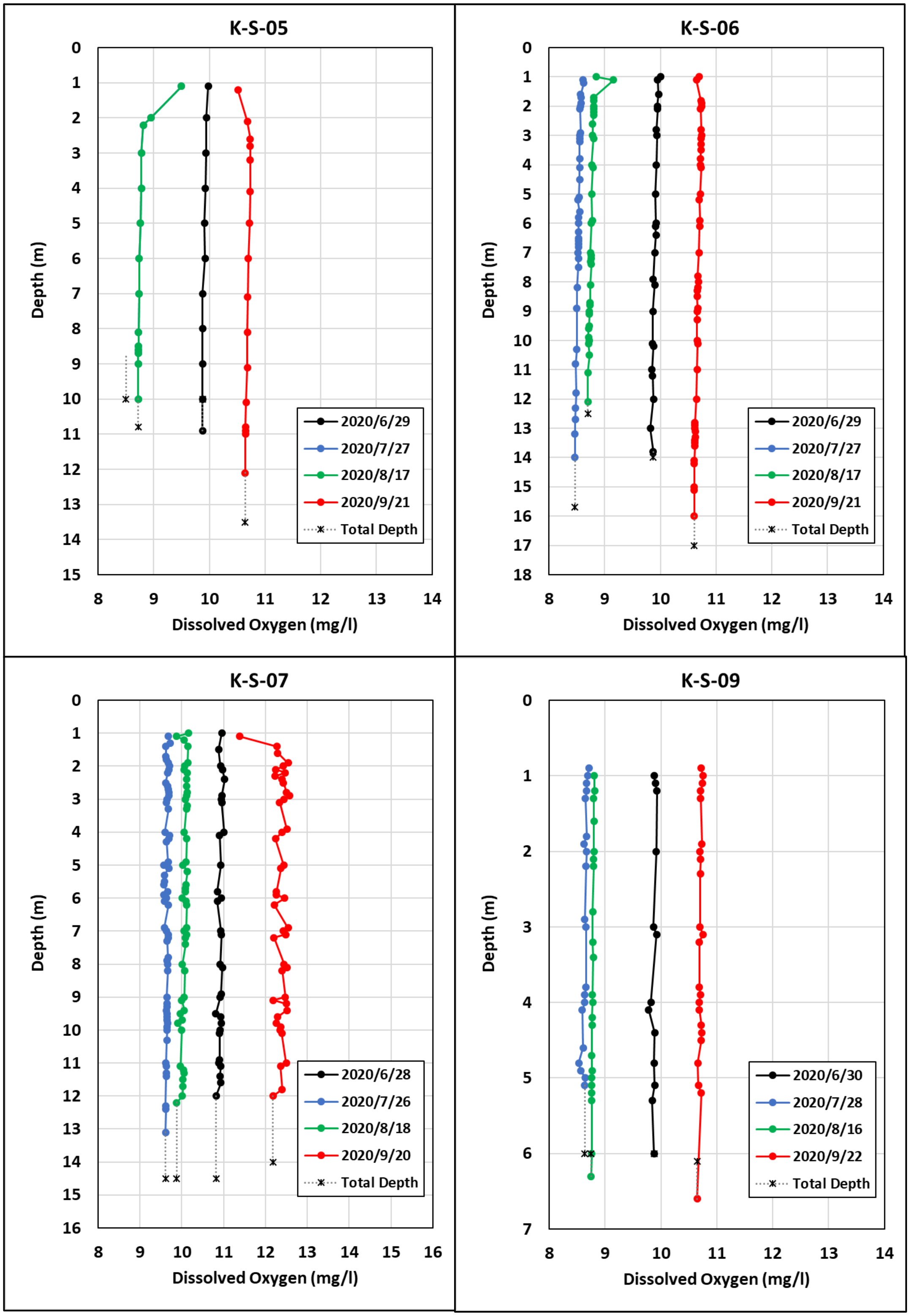


Figure 23: DO depth profiles at sites K-S-05, K-S-06, K-S-07, K-S-09

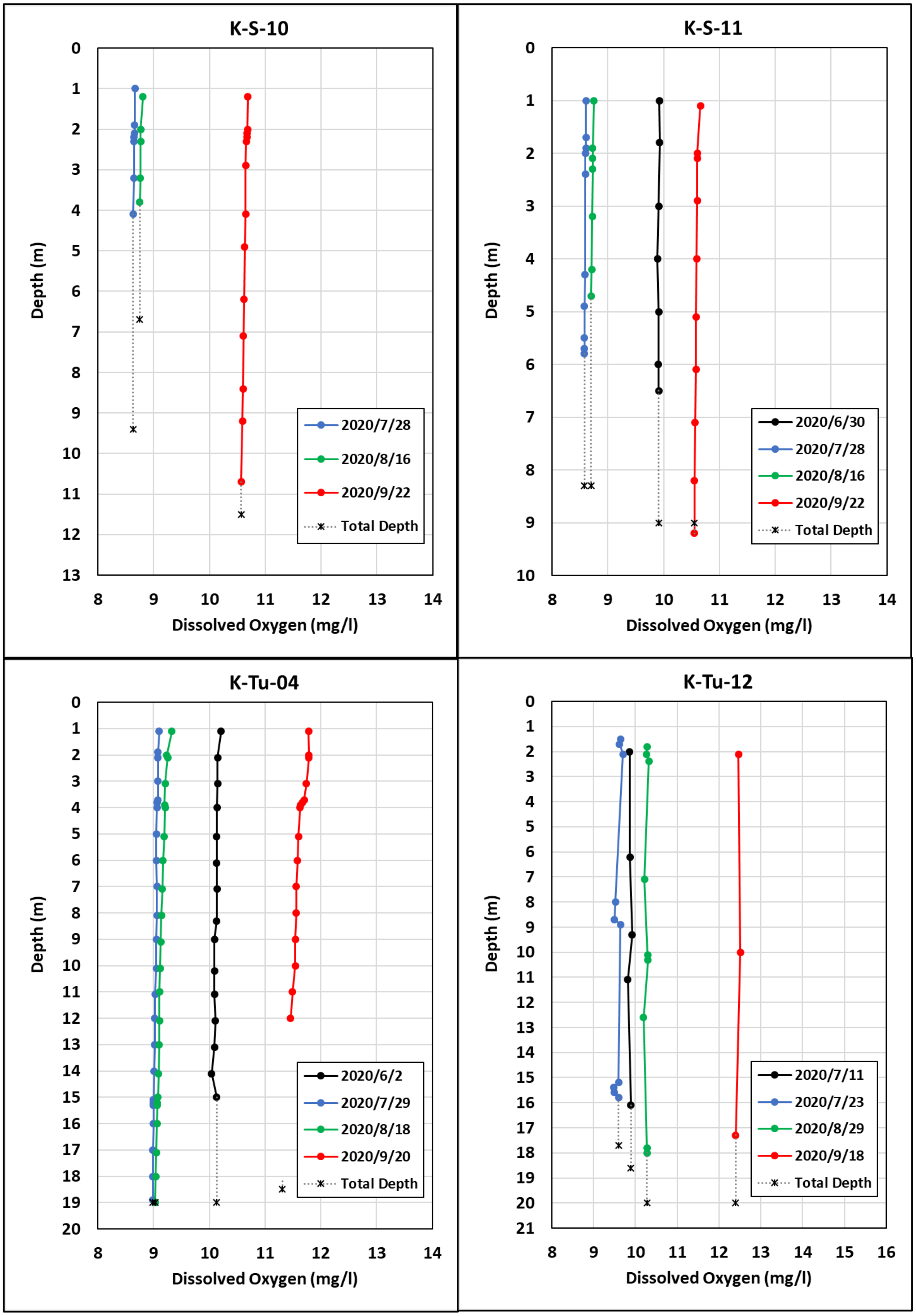


Figure 24: DO depth profiles at sites K-S-10, K-S-11, K-Tu-04, K-Tu-12

7.0 DEBRIS

7.1 WATERWAYS MANAGEMENT PROGRAM

As part of the Project, in accordance with the Joint Keeyask Development Agreement (TCN et.al. 2009), a waterways management program was started in 2015 for the Project area from Clark Lake to Gull Rapids. A component of this program is the operation of a boat patrol to identify and remove floating woody debris (Photo 12) that may pose a safety hazard to navigation. The boat patrol records the amount of debris removed each season, classifying it as either small (<1m length) or large (>1m length), and the large material is further classified as either new or old debris (generally with or without bark) or if it came from beaver activity.

Prior to 2015, this area was only visited about once each week (20% of the time) and the amount of debris collected in the Clark to Gull Lake area was estimated to be 20% of the total amount of debris collected by the work crew that also patrolled Split Lake. Starting in 2018 a new data collection program was initiated allowing for tracking of the location of floating debris and accounting for debris in the Keeyask area. Since a dedicated crew has been operating in the Project area, 10 or fewer pieces of debris have been removed each year (Table 6). While the patrol operated in the area in 2020, it did not record the removal of any debris. Except for 2003 these quantities are much less than the estimated amounts of debris removed prior to 2015, which suggests the that in those years the amounts removed from the Project area were likely much lower than estimated.

Table 6: Debris removed from the Keeyask area

Year	Small (<1 m)	Large (> 1m)			
		New	Old	Beaver	Total
2003	3	4	7	0	11
2004	36	1	140	0	141
2005	2	6	103	0	109
2006	11	1	65	0	66
2007	0	3	81	0	84
2008	1	0	49	1	49
2012	0	1	30	1	32
2014	2	1	59	0	60
2015	4	0	6	0	10
2016	3	1	2	0	6
2017	Not available				
2018	5	0	4	1	10
2019	1	4	3		8
2020	Not available				

Photo 12: Large floating debris is removed from the water by the boat patrol team

7.2 RESERVOIR IMPOUNDMENT

Starting in winter 2015/16, the Project implemented the Reservoir Clearing Plan (KHLP 2015c) to remove trees and large bushes from the area that would be flooded when the reservoir was impounded. This generally included using bull dozers equipped with shear-blades to knock down trees and brush as well as hand clearing in specified areas. Cleared material was pushed into piles and burned on site. The Keeyask EIS (KHLP 2012b) noted that the clearing plan would be implemented to reduce the potential amount of woody debris that would be present after impoundment. It was anticipated that much of the larger woody material would be removed including previously fallen trees that might be pushed up as dozers bladed the areas being clearing.

The Keeyask reservoir was impounded between Aug. 31 – Sep. 5, with water levels being raised from about 156.9 m ASL to near the full supply level of 159.8 m ASL (see Section 2.2). As the water was raised, it mobilized large and small woody debris from the flooded areas. This debris was observed floating in the reservoir and being transported in a downstream direction towards the Keeyask spillway, through which it could pass into Stephens Lake. While a lot of debris was smaller in size (e.g., twigs, branches), larger trees were not uncommon (Photo 13). There is a large amount of larger woody debris floating adjacent to some sections of the new reservoir shorelines that does not appear to be immediately mobile within the waterway (Photo 14). However, this debris could potentially become mobile depending on conditions like storm events that may dislodge the material. In off current areas such as back bays some of this large debris will likely remain rafted near the shoreline and will not be mobilized into the waterway. During and immediately after impoundment, large woody debris rafted in the corners where the north dyke meets the north dam at the powerhouse and the south dyke meets the south dam (Photo 15). These debris rafts were removed but it is likely these locations will continue to gather debris. After impoundment it was there were also several areas apparent where woody debris is likely to be generated on an ongoing basis due to erosion (Photo 16). Following impoundment, it was observed that woody debris was primarily present in the Gull Lake area while little was apparent along the upstream river reach.

The Keeyask EIS had anticipated that most of the large woody debris present on the ground would be removed as trees and large shrubs were mechanically cleared by shear blading. However, based on the quantities of large debris observed in the reservoir, it seems likely that naturally fallen trees and some mechanically felled trees were not removed during mechanical clearing. This suggests that shear blading did not scrape down to ground level such that material laying on the ground was passed over. It is possible that clearing did not get down to ground level due to deep snow conditions or ice resulting from increased water levels in winter. As a result, there is more large debris in the reservoir immediately after impoundment than had been anticipated if clearing had been done to ground level as assumed in the EIS. This additional debris will likely create a requirement for increased debris management efforts through the Waterways Management Program.

Impoundment of the reservoir flooded terrestrial peatlands. The Keeyask EIS (KHLP 2012) noted that some flooded peat would float up as a result of impoundment and that the floating peat could be mobile within the reservoir. During and following impoundment, floating peat was observed to varying degrees in all the flooded areas around Gull Lake (Photo 17). Although floating peat may be become mobile and could be transported to different areas of the reservoir or downstream, no peat islands were observed to be doing so during or shortly after impoundment. It is possible that the floating remains attached to submerged peat and is held in place. It is expected that floating peat will become mobile as the peat breaks down and mats break off. In addition, the Keeyask EIS also predicts that some peat that is currently submerged will eventually break off and float up to become mobile within the reservoir.

In accordance with the Joint Keeyask Development Agreement (TCN et.al. 2009), a more intensive waterway management program will be initiated during the first several years of operation. This will include an additional boat crew to patrol the area and one or more teams of workers to clear woody debris from selected areas of the reservoir (e.g., near creek mouths, at safe landing sites, etc.).

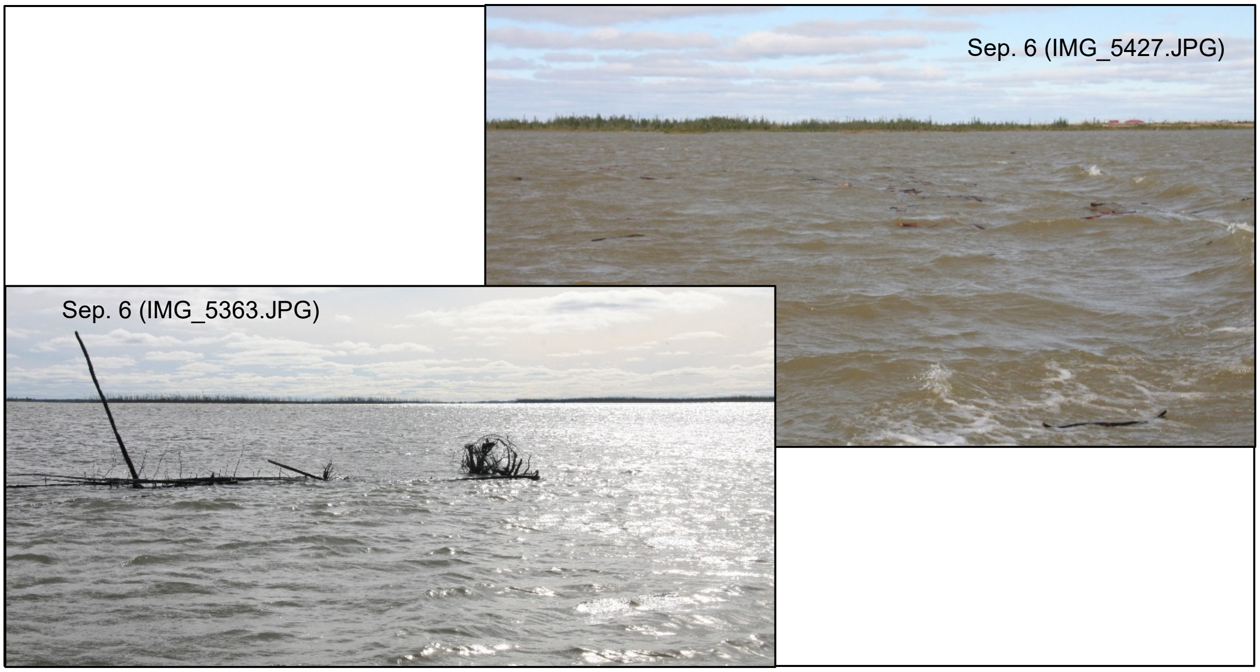


Photo 13: Small & large floating debris after impoundment

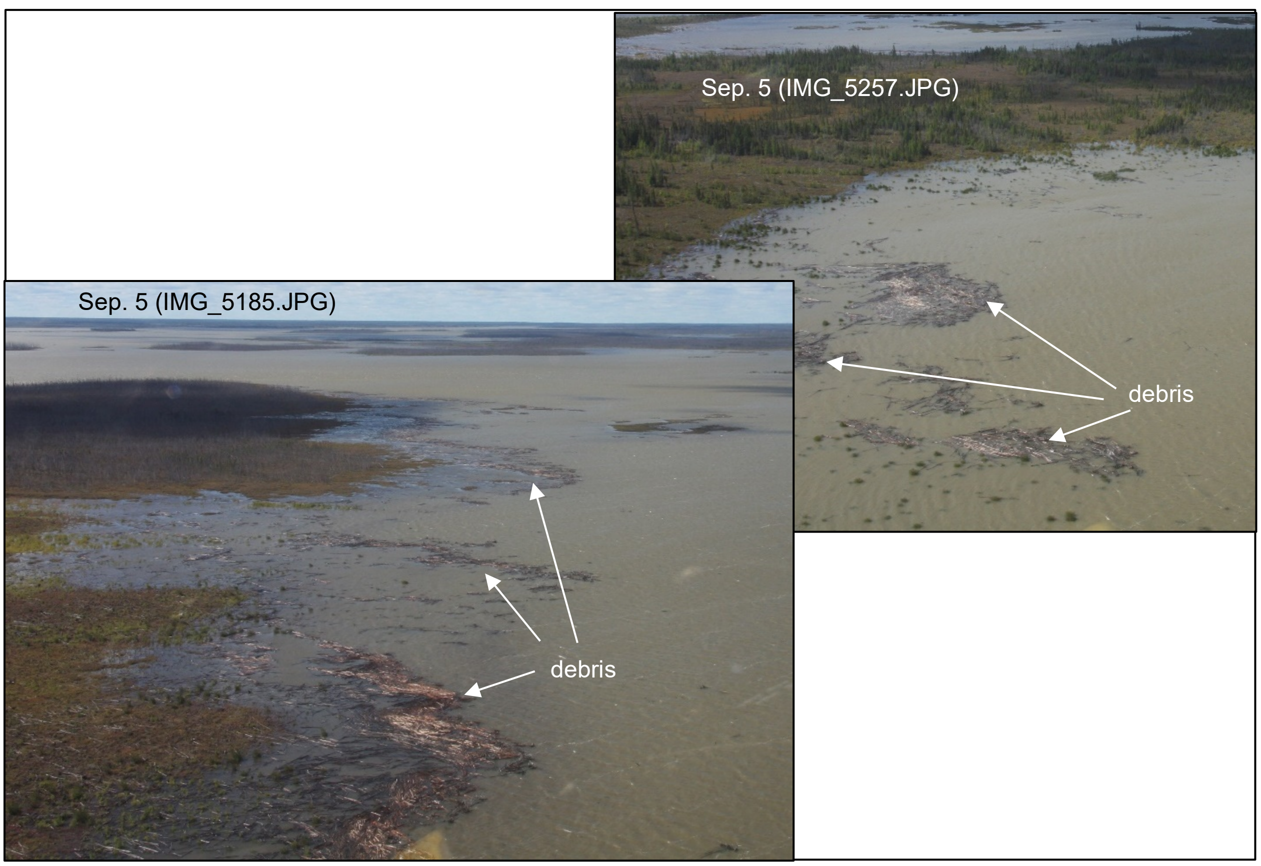


Photo 14: Woody debris adjacent to shorelines

Photo 15: Rafted woody debris where N & S dykes meet N & S dams

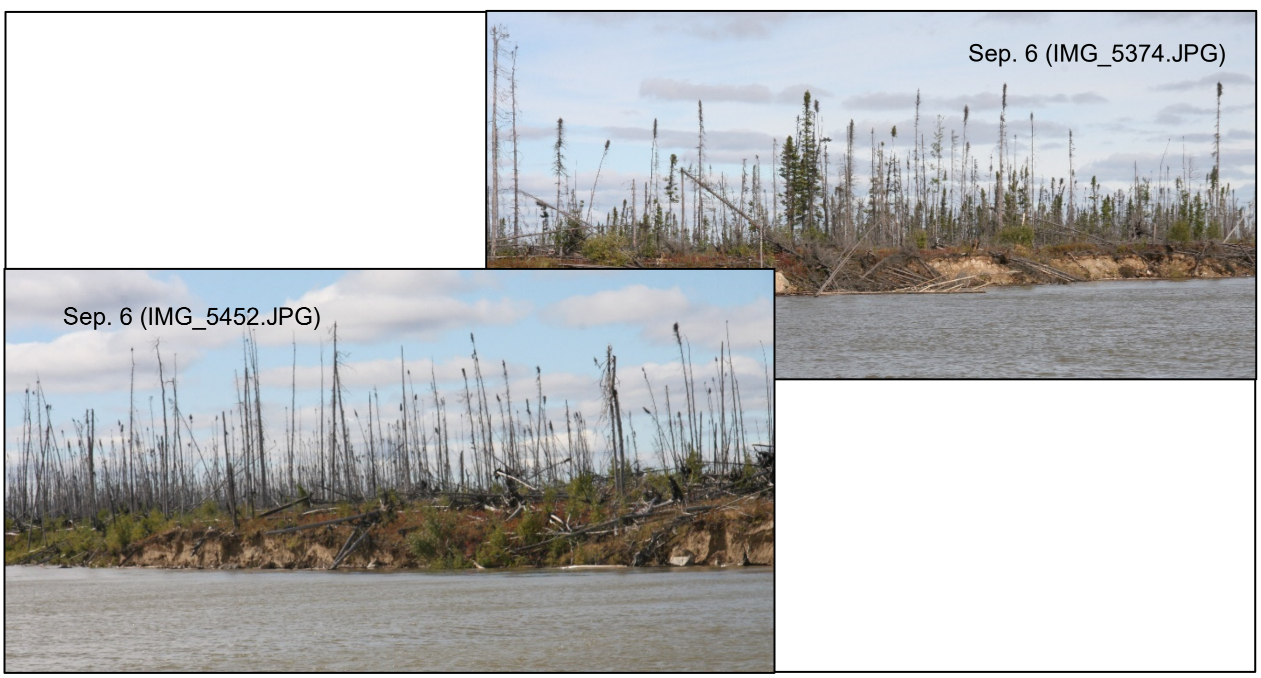


Photo 16: Eroding banks producing woody debris

Photo 17: Floating peat in flooded areas

8.0 RESERVOIR GREENHOUSE GAS

The purpose of Keeyask reservoir greenhouse gas monitoring program is to enable the comparison of aquatic greenhouse gas (GHG) concentrations and emissions before and after flooding and reservoir creation.

Studies have shown that GHG emissions from hydroelectric reservoirs in boreal ecosystems increase shortly after flooding (Teodoru et al. 2012). The size and duration of the change in GHG emissions ("reservoir effect") is influenced by many factors including reservoir size, type and amount of biomass flooded, location, water residence time, temperature, etc. (Demarty and Tremblay 2017; Goldenfum 2012). The Keeyask Physical Environment Supporting Volume (KHLP 2012b) predicted that carbon dioxide (CO_2) emissions would approach background levels by approximately 10 years after impoundment and that methane (CH_4) emissions would remain elevated throughout the 100-year life of the Keeyask Generation Project. These predictions were based on IPCC (2006) guidance at that time. Since then, reservoir GHG science has continued to evolve (Delsontro et al. 2018, Prairie et al 2018). Studies have focussed on GHG processes and emission pathways, and how GHG emissions may relate to reservoir characteristics and location. Similarly, the methods used to study GHGs at the future Keeyask reservoir have evolved and are described in this report.

8.1 2020 RESERVOIR GHG MONITORING

8.1.1 BACKGROUND

The over-all objective of monitoring is to acquire pre- and post-flood information on rates, variability and controls of GHG exchange. Ultimately the information will be used to determine the net impact of the Keeyask Hydropower Project on reservoir GHG emissions.

During the Baseline Period and Year 1 of the Construction Period, the GHG measurement methods have followed industry best practices (i.e. UNESCO/International Hydropower Association (2010) guidance) and have kept current as technology has improved. The primary focus of those monitoring events was on measuring dissolved GHGs in water and their release to the atmosphere ("diffusive emissions").

Further measurement methods have been included to address additional post flooding GHG emission pathways that are anticipated to result from impounding a variety of affected ecosystems. This is particularly the case for flooded peatlands, floating peat islands, backbays and associated wetlands that will be connected to the resulting reservoir. The additional GHG pathways of interest include: (1) emissions that may emanate directly from partially submerged/floating peat and (2) from methane bubbles originating in the flooded sediments. Both emission pathways may occur at rates that are heterogeneous in time and space and therefore are difficult to characterize.

In previous years (2017-2019) eddy covariance (EC) monitoring was added to the suite of measurement techniques. The EC method requires high frequency measurement of GHG concentrations in the air, along with 3D wind components. This is one of the few techniques allowing direct, nearly continuous ecosystem monitoring of fluxes, and is recognized by the UNESCO/IHA (2010) guidance for reservoir GHG measurement, but to date, has not been widely used for measuring aquatic GHG emissions from rivers or boreal hydroelectric reservoirs. The approach enables calculations of GHG emissions from a wide zone of influence (10s to 100s of metres) and at Keeyask includes emissions released from water surfaces (those attributed to gas diffusion, and other sources including bubbles), as well as emissions originating from unflooded, partially submerged and floating peat, if these features reside within the flux footprint. Two EC systems were deployed in 2019: one along the bank of the Nelson River ~15 km upstream of the Keeyask axis (56°18'34.62"N, 95°26'30.33" W) and the other in the wetland system connected to the Nelson River through Rabbit Creek (56°17'53.02"N, 95°28'16.42"W). The information resulting from the EC flux measurement was supplemented in 2019 using data resulting from submersible sensors for the measurement of dissolved gases, including carbon dioxide (CO_2) and methane (CH_4), and analyses on discrete water samples. In 2019 submersible sensors were deployed in the main channel and in Rabbit Creek (wetland/creek system).

8.1.2 2020 MONITORING ACTIVITIES

The 2020 field season saw the acquisition of water samples 5 separate times between mid-March and the end of September at 8 locations along the Nelson River spanning from Birthday Rapids in the west to the forebay of the Long Spruce generating station in the east (Figure 25). The winter sampling campaign (March and April), included sites K-SMP-3R, K-SMP-3L, K-SMP-2R, Li-S-02b, K-Tu-6 and K-SMP-1 and from June to September sampling was conducted at sites K-Tu-4, K-Tu-5, K-Tu-6, K-SMP-1 and K-SMP-2R. When possible, water was sampled at two depths corresponding respectively to the upper 20% and lower 80% of the water column. Water samples were tested for the chemical and physical properties listed in Table 7. Because travel north of 53° latitude was restricted in 2020 due to the COVID-19 pandemic, the eddy covariance systems could not be deployed and only one submersible sensor could be deployed for the near continuous measurement of dissolved CO_2 in the Nelson River. The submersible sensor was deployed from a floating raft located in the main channel at site K-Tu-5 from July 28 to September 19, however the raft came off its anchor and moved downstream on Sep. 11, so any data after the 11th was not used in the GHG analysis. The equipment was programmed to take a burst of 10 CO_2 measurements in rapid succession every 4 hours. More detailed discussion of the 2020 monitoring program is provided in the Keeyask GHG monitoring report (Papakyriakou et.al. 2020).

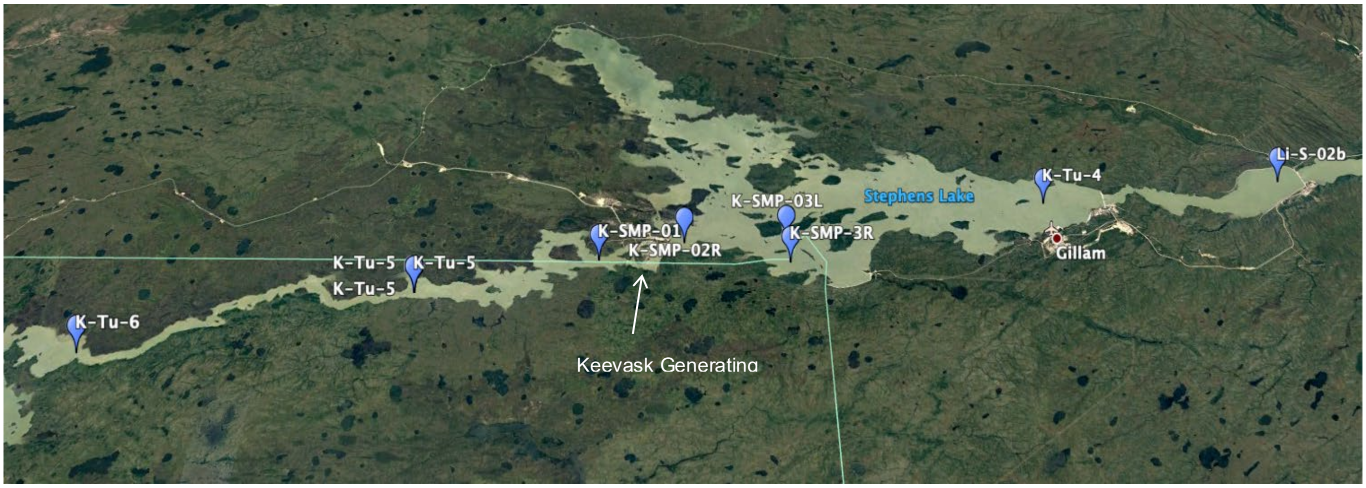


Figure 25: Location of stations used for discrete GHG water sampling in 2020.

Table 7: Water analyses for the 2020 Keeyask GHG water sampling program

Variable	Units	LAB Doing Analysis*	Analysis Uncertainty** (±)
Nitrate (NO_3^-)	mg/L	FWI	<1% or 1 mg NO_3-N/L
Nitrite (NO_2^-)	mg/L	FWI	<1% or 1 mg NO_2-N/L
Suspended nitrogen (SuspN)	mg/L	FWI	5% or 6 mg/L
Total dissolved nitrogen (TDN)	mg/L	FWI	2% or 13 mg /L
Soluble reactive phosphorus (SRP)	mg/L	FWI	<1% or 1 mg/L
Total dissolved phosphorus (TDP)	mg/L	FWI	13% or 2.6 mg/L
Suspended phosphorus (SuspP)	mg/L	FWI	6% or 0.6 mg/L
Conductivity	mS/cm @ 25°C	FWI	0.01 mS/cm
pH (FWI)	pH units	FWI	<1% or 0.02
dissolved organic carbon (DOC)	mM/L	FWI	2% or 10 mmol/L
pH (UM)	pH units	UM	0.01
Dissolved inorganic carbon (DIC)	mM/kg	UM	2 mmol/kg
Total alkalinity (TA)	mMl/kg	UM	3 mmol/kg
Particulate organic carbon	mg/L	UM	30 mg/L
dissolved methane (C_{CH4w})	nM/L	UBC	3.3% and 0.4 nmol/L DL

** Freshwater Institute (FWI), University of Manitoba (UM), University of British Columbia (UBC)

** Analysis uncertainty is given as relative and/or absolute uncertainty, and in some cases detection limit (DL) is also provided.

8.2 RESULTS

The following sections provide a summary of the monitoring results from the 2020 monitoring program. More detailed discussion of the 2020 results is provided in the Keeyask GHG monitoring report (Papakyriakou et.al. 2020).

8.2.1 ANALYSES ON DISCRETE WATER SAMPLES

Some water analyses could not be summarized in this report because of COVID related slow-down of water analyses at the water chemistry lab. Results that are missing include: dissolved organic carbon (DOC), particulate organic carbon (SUSPC), nutrients (TDP, SUSPP, TDN, NO2 and NO3) and the concentration of chlorophyll *a* (CHLA). The results from the other variables (pH, TA, DIC, pCH_4 and pCO_{2calc}) are summarized in Table 8.

Table 8: Summary statistics for 2020 discrete GHG water sample test results

	T (°C)	pH	TA (mmol/kg)	DIC (mmol/kg)	pCH_4 (matm)	pCO_2calc* (matm)
Min	0.0	7.71	1614.76	1524.16	5.5	667.3
10th	0.0	7.75	1642.61	1578.08	7.3	720.5
Ave	10.3	7.97	1876.50	1823.08	24.0	1081.0
Med	11.0	8.01	1727.70	1669.22	18.3	955.5
90th	20.1	8.11	2209.72	2167.50	46.1	1752.6
Max	20.6	8.12	2268.51	2253.59	116.5	1992.4

* pCO_2calc was calculated using pH and DIC

The water pH ranged between 7.71 and 8.12 across sites with a median of 8.01. Median CH_4 concentration (as pCH_4) was 18.2 μatm, and ranged between 5.5 and 116.5 μatm, while the median pCO_2 was 955.5, and ranged between 667.3 and 1992.4. Water temperature ranged between 0°C to 20°C over the sampling period. Both TA and DIC are important components of the water inorganic system and are provided for reference.

- It appears pCO_2 was high at all sites sampled, including K-Tu-6, which is upstream of the direct reservoir influence.
- It appears the 2020 median pCH_4 measurement is less than 2009-2013 baseline.

Atmospheric CH_4 and CO_2 concentrations were not measured in 2020. For context, during the 2019 monitoring program the median atmospheric pCH_4 and pCO_2 was respectively 1.89 μatm and 402.61 μatm. Values will not have appreciably varied between summers of 2019 and 2020, indicating that the river, at median concentrations, was a strong source for atmospheric CH_4 and CO_2 in 2020. In particular, the median pCH_4 in the river was close to a factor of 10 higher than the expected atmospheric values.

The distribution of each variable across sites is shown graphically by month of sampling for each variable corresponding to the upper and lower measurement depth (Figure 26). Values corresponding to the two depths tracked well for each variable, and in fact the distributions (for upper and lower measurement depths) were not statistically different (i.e., all p-values >> 0.05) based on Kruskall-Wallis non-parametric test.

Temporally, at all sites, and for upper and lower measurement locations, TA, DIC, and pCO_2calc was highest in March and April, while under a full ice cover, and substantially lower in the summer and early fall (June to September). Total alkalinity (TA) defines the buffering capacity of the water and we observed ~ 20% drop in median TA for measurements between early (March-April) relative to later in the season (June to September). On the other hand, pH increased from the early spring through the summer months and into September, showing as expected, an inverse relationship to pCO_2. The partial pressure of CH_4 was lowest in the early spring and peaked in July and August.

8.2.2 CONTINUOUS MEASUREMENT OF pCO_2

The time series of near surface pCO_2 measured at K-Tu-05 between July 28 and September 11 is shown in Figure 27. Provided for context in the figure is the global 2020 average atmospheric CO_2 concentration at sea level, converted to partial pressure (412.45 μatm). For reference the median atmospheric concentration measured in 2019 at the channel site was 402.61 μatm. Over the 2020 late summer period the average pCO_2 measured in the river was 709.5±92.1 μatm (median of 720.4 μatm) and ranged between 866.7 μatm on August 7 to 554.7 μatm on September 9. Thus, the river water was clearly over-saturated relative to atmospheric levels throughout the measurement program. The air-river difference in median river pCO_2 was ~307 μatm, ~464 μatm on August 7, and 152 μatm in September 9 relative to the 2019 median atmospheric concentration, indicating the river was over-all a strong source of atmospheric CO_2, and in August a very strong source of CO_2relative to 2019 measurements.

Baseline studies conducted from 2009 to 2013 demonstrated a similar pattern. Continuous pCO_2 measurements conducted during the open water period indicated the portion of the Nelson River within the future Keeyask reservoir was a larger source of atmospheric CO_2 during July and August than in September (Environnement Illimité 2014).

The continuous pCO_2 measurements were derived from an underwater sensor during July 28 to September 11, 2020. This measurement period is truncated relative to previous monitoring years, because of COVID-19 related travel restrictions. The 2020 values are higher than those observed using the same sensor in 2019. The 2020 values (including minimum, maximum, and median) are also higher than those reported during the 2009-2013 baseline. A direct comparison of 2020 and baseline results is not possible as the period encompassed in the 2020 record is skewed largely to August.

These results are not unexpected as fluctuations in pCO_2 occur naturally throughout the year and amongst years. Furthermore, the Keeyask EIS predicted that pCO_2 would be elevated for approximately 10 years following reservoir impoundment and pCH_4 would be elevated for the lifetime of the reservoir (KHLP 2012b).

Submersible sensors will be installed within the Keeyask Reservoir during the open water period in 2021 to continuously measure pCO2 and pCH4 in the main Nelson River channel and within a representative backbay. Similarly, above ground sensors will be installed to measure CO_2 and CH_4 emissions arising from the reservoir.

8.3 SUMMARY

The 2020 GHG field program was less intensive than in 2019 because of COVID related restrictions on travel north of 53° latitude. Omitted from the 2020 program were flux measurements using eddy covariance. Only one submersible sensor was installed for pCO_2, and this sensor was positioned on the main channel of the Nelson River. Submersible sensors were not installed at a back-bay site and sensors for the measurement of dissolved CH_4 were not part of the 2020 program. The coverage of water sampling increased geographically relative to the 2019 program. Some water analyses could not be summarized in this report because of COVID related slow-down of water analyses at the water chemistry lab.

The concentration of dissolved CO_2 (expressed as a partial pressure) in the Nelson river was substantially higher in March and April relative to the June to September period. Conversely, the methane concentration was lowest in March and April and peaked in July and August. Throughout the monitoring program the water was heavily over-saturated in both CO_2 and CH_4 relative to atmospheric levels, and hence a source of these GHGs to the atmosphere.

Results indicate that the river water was well-mixed throughout the monitoring program as the water properties could not be statistically distinguished between the upper and lower measurement depths.

The data resulting from the submerged pCO_2 sensor on the main channel indicate that the river water was supersaturated in CO_2 relative to atmospheric level throughout the measurement program. The level of supersaturation was largest in early August and lowest in September.

During 2020, pCO_2 in the Nelson River was high relative to 2019 and the 2009-2014 baseline. This includes a station upstream of the direct influence of watering up suggesting that pCO_2 in the lower Nelson could have been higher in 2020 relative to recent years. There is insufficient data to attribute the high pCO_2 to watering up given only station was measured upstream of the zone of influence.

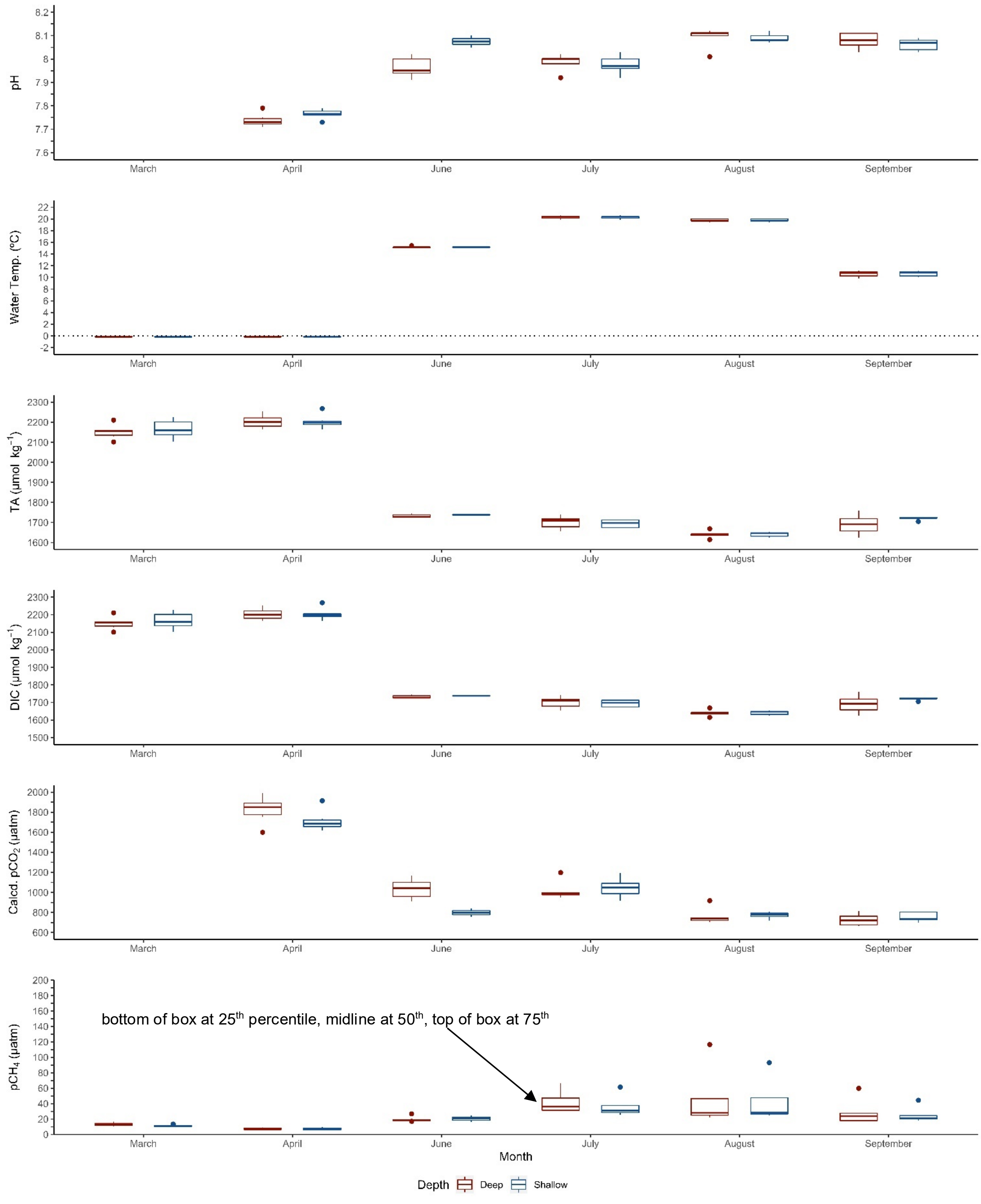


Figure 26: Summary charts of 2020 discrete GHG water sample test results

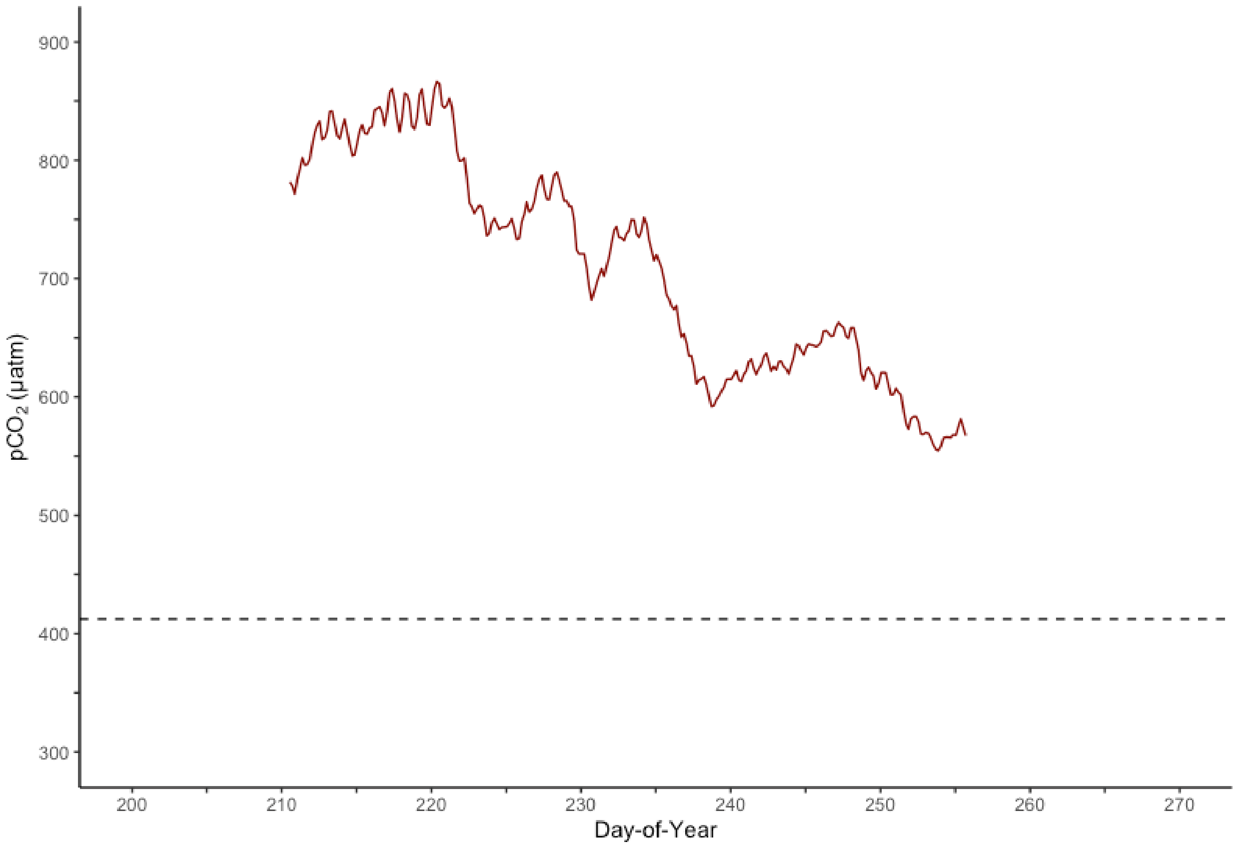


Figure 27: Time series of pCO2 measurements at Site K-Tu-05 (measured 6 times per day).

9.0 LITERATURE CITED

Demarty, M. and A. Tremblay, 2017. Long term follow-up of pCO2, pCH4 and emissions from

DelSontro, T., J. J. Beaulieu, J. A. Downing, 2018. Greenhouse gas emissions from lakes and impoundments: Upscaling in the face of global change, Limnology and Oceanography Letters 3, pp. 64–75, doi: 10.1002/lol2.10073.

Environnement Illimité inc. 2014. Keeyask Technical Summary: Monitoring Aquatic Greenhouse Gas (GHG) Emissions (2009-2014), Report prepared for Manitoba Hydro, 11 pages.

Goldenfum, J.A., 2012. Challenges and solutions for assessing the impact of freshwater reservoirs on natural GHG emissions, Ecohydrology Hydrobiology, Volume 12, No. 12, pp. 115-122.

IPPC 2006. IPCC Guidelines for National Greenhouse Gas Inventories, Volume 4 Agriculture, Forestry and Other Land Use, Chapter 7 Wetlands, 24 pages.

Keeyask Hydropower Limited Partnership (KHLP). 2012a. Keeyask Generation Project: Response to EIS Guidelines. June 2012. Winnipeg, Manitoba.

Keeyask Hydropower Limited Partnership (KHLP). 2012b. Keeyask Generation Project: Physical Environment Supporting Volume. June 2012. Winnipeg, Manitoba

Keeyask Hydropower Limited Partnership (KHLP). 2012c. Keeyask Generation Project: Aquatic Environment Supporting Volume. June 2012. Winnipeg, Manitoba

Keeyask Hydropower Limited Partnership (KHLP). 2015a. Keeyask Generation Project: Physical Environment Monitoring Plan. October 2015. Winnipeg, Manitoba.

Keeyask Hydropower Limited Partnership (KHLP). 2015b. Keeyask Generation Project: Aquatic Effects Monitoring Plan. June 2015. Winnipeg, Manitoba.

Keeyask Hydropower Limited Partnership (KHLP). 2015c. Keeyask Generation Project: Reservoir Clearing Plan. April 2015. Winnipeg, Manitoba.

Keeyask Hydropower Limited Partnership (KHLP). 2014. Keeyask Generation Project: Sediment Management Plan for In-stream Construction. July 2014. Winnipeg, Manitoba.

KGS Acres Ltd. 2011. Keeyask Generating Station, Stage IV Studies: Existing Environment Sedimentation (Memorandum GN9.2.3, Mb Hydro File No. 00195-11100-0154_03). June 2011. Winnipeg, Manitoba.

Manitoba Hydro. 2015. 2014–2015 Physical Environment Monitoring Report: Year 1 Construction. June 2016. Winnipeg, Manitoba.

Manitoba Hydro. 2016. 2015–2016 Physical Environment Monitoring Report: Year 2 Construction. June 2016. Winnipeg, Manitoba.

Manitoba Hydro. 2017. 2016–2017 Physical Environment Monitoring Report: Year 3 Construction. June 2017. Winnipeg, Manitoba.

Manitoba Hydro. 2018. 2017–2018 Physical Environment Monitoring Report: Year 4 Construction. June 2018. Winnipeg, Manitoba.

Manitoba Hydro. 2019. 2018–2019 Physical Environment Monitoring Report: Year 5 Construction. June 2019. Winnipeg, Manitoba.

Manitoba Hydro. 2020. 2019–2020 Physical Environment Monitoring Report: Year 6 Construction. June 2020. Winnipeg, Manitoba.

Manitoba Hydro. 2020. Sediment Management Plan for In-Stream Construction Annual Report April 2019 – March 2020. June 2020. Winnipeg, Manitoba.

TCN, WLFN, YFFN, FLCN and the Manitoba Hydro-Electric Board. 2009. Joint Keeyask Development Agreement. May 2009. Winnipeg, Manitoba.

Papakyriakou, T., A. Soloway, D. Gedig and R. Gill, 2021. Keeyask Greenhouse Gas Monitoring Program – 2020 Report. Report prepared for Manitoba Hydro. May 2021. 14 pp. plus 1 appendix.

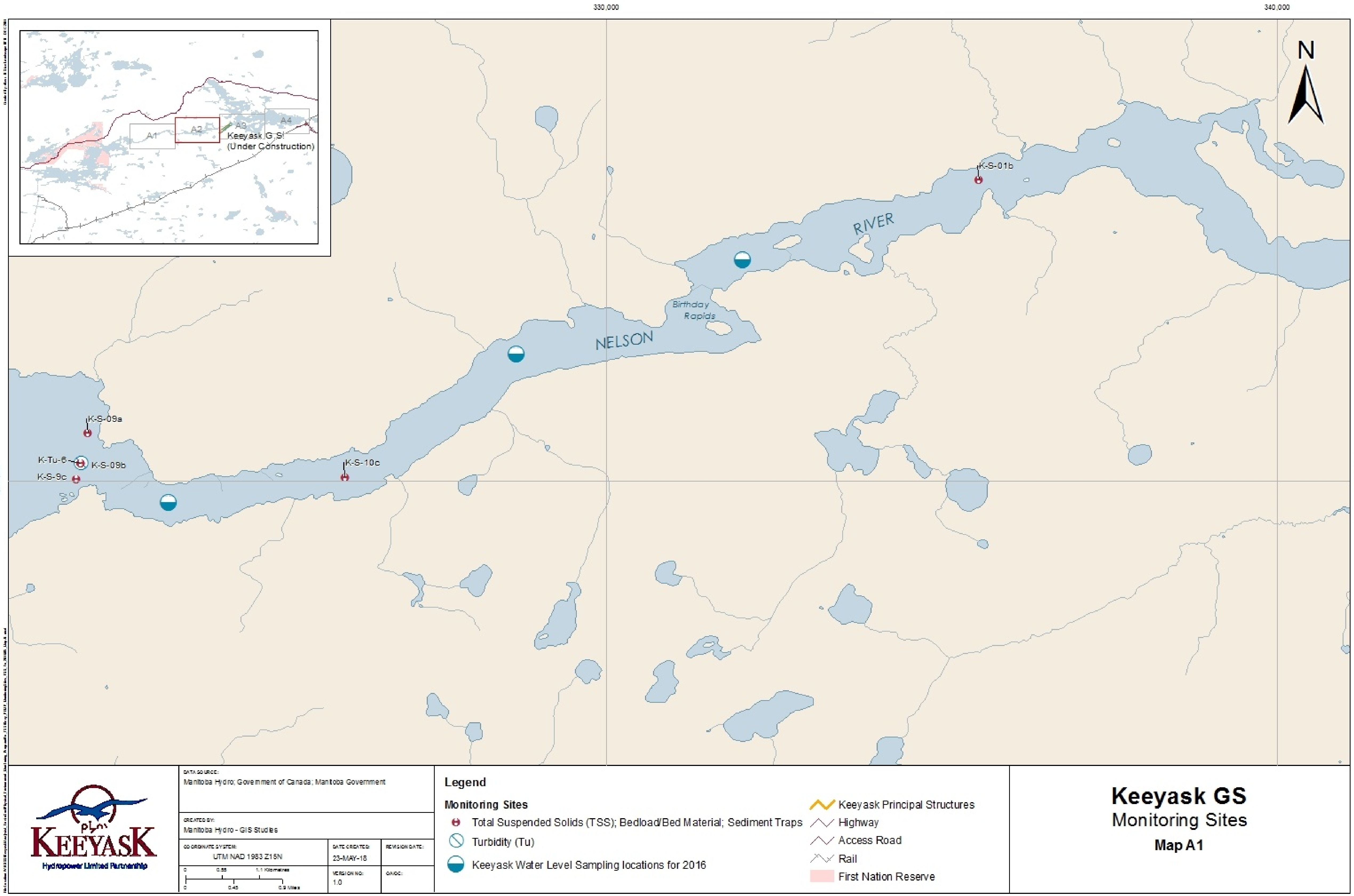
Prairie, Y.T., Alm, J., Beaulieu, J. and others. 2018. Greenhouse Gas Emissions from Freshwater Reservoirs: What Does the Atmosphere See? Ecosystems, 21, pp. 1058 -1071. DOI: 10.1007/s10021-017-0198-9

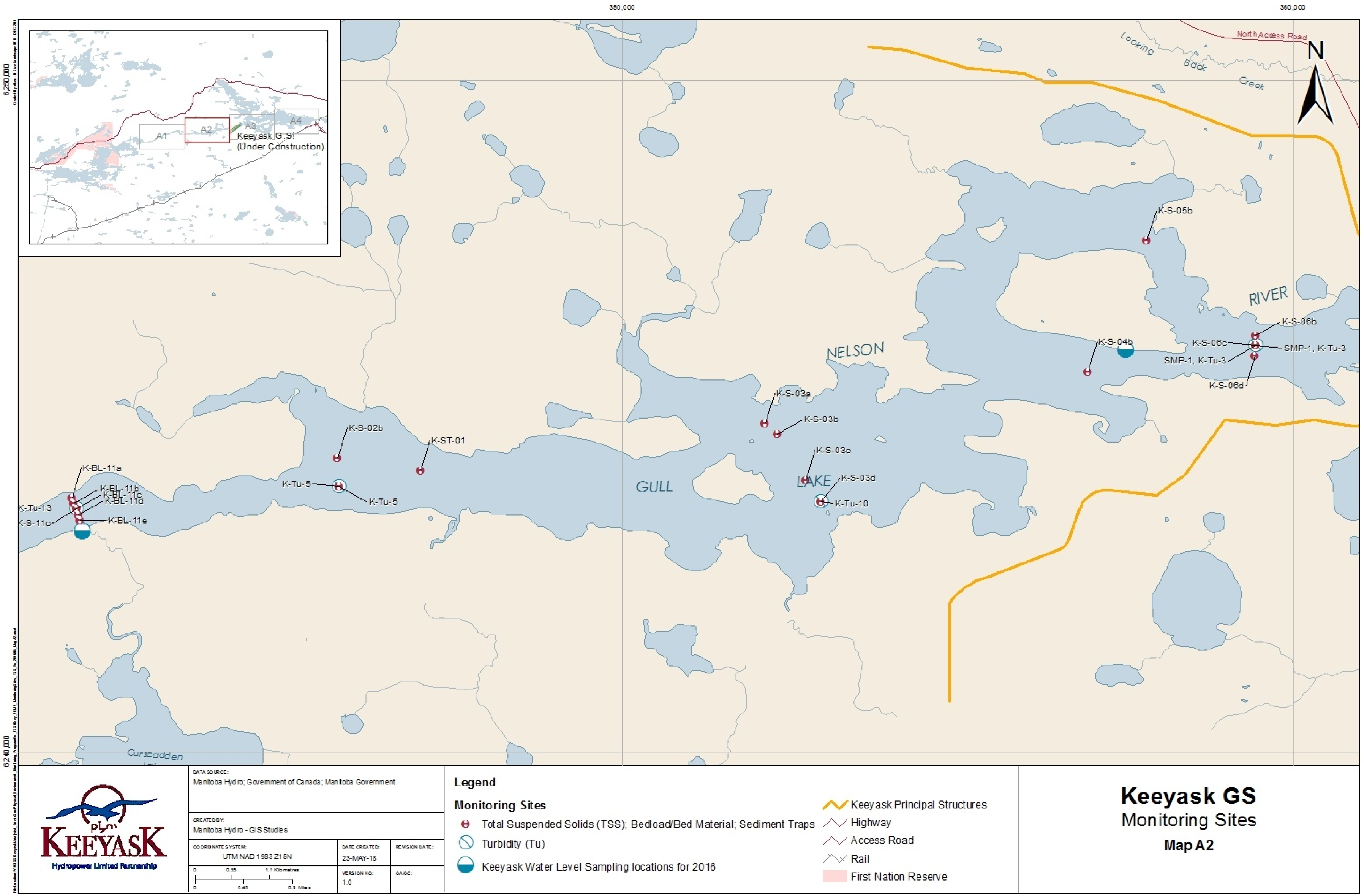
Teodoru, C.R., J. Bastien, M. Bonneville, P. A. del Giorgio, M. Demarty, M. Garneau, J. Hélie, L. Pelletier, Y. T. Prairie, N.T. Roulet, I.B. Strachan, A. Tremblay, 2012. The net carbon footprint of a newly created boreal hydroelectric reservoir, Global Biogeochemical Cycles, 26, Issue 2, 14 pages doi: 10.1029/2011GB004187.

UNESCO/IHA 2010. GHG Measurement Guidelines for Freshwater Reservoirs, The International Hydropower Association, London, 139 pages, ISBN 978-0-9566228-0-8.

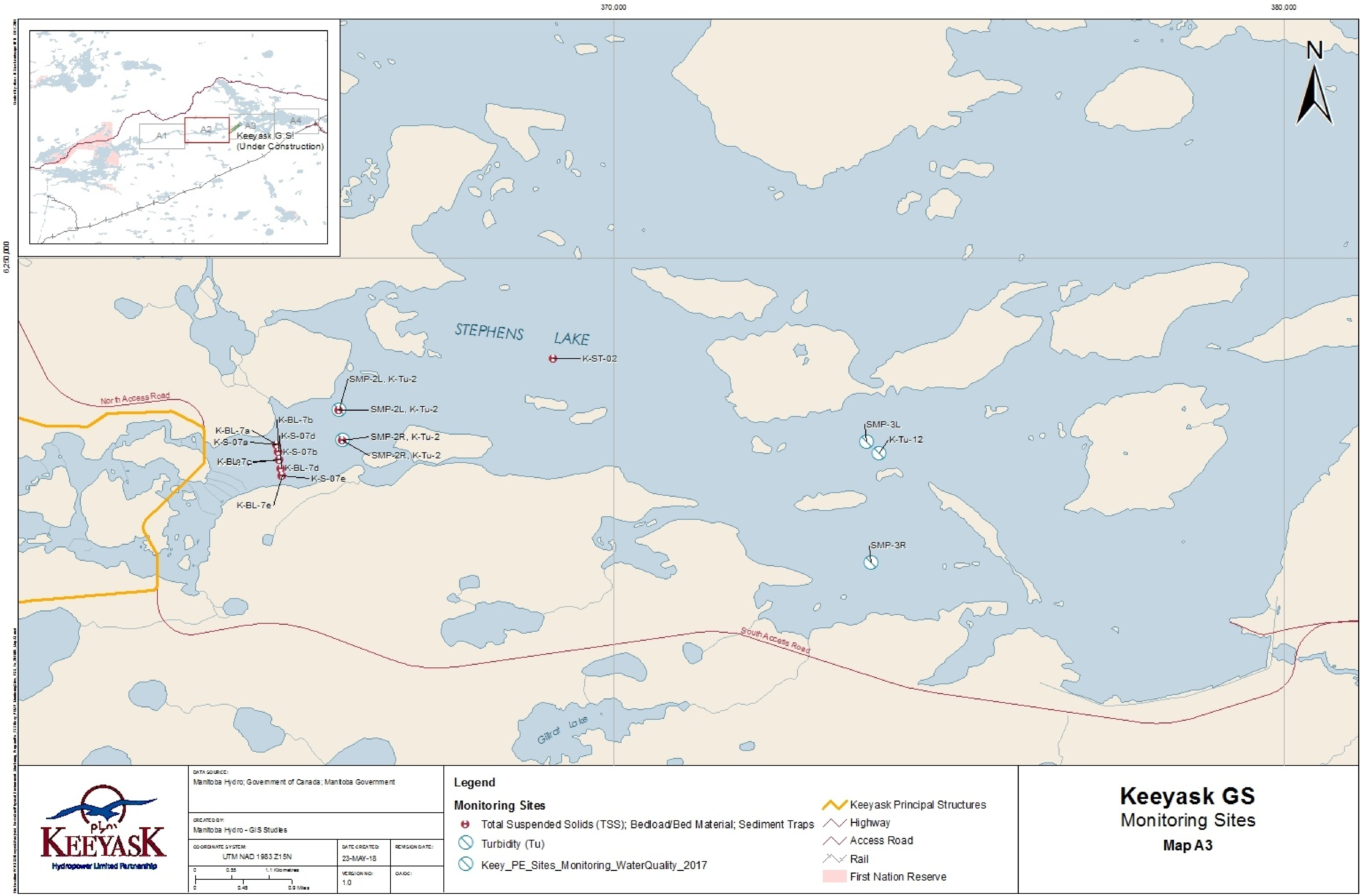
United States Environmental Protection Agency (USEPA), 1985. Rates, Constants, and Kinetics Formulations in Surface Water Quality Modeling. Second Edition (EPA/600/3-85/040). Environmental Research Laboratory, Office of Research and Development. June 1985. Athens, GA.

APPENDIX 1: DETAILED MAPS OF TURBIDITY AND TSS MONITORING SITES

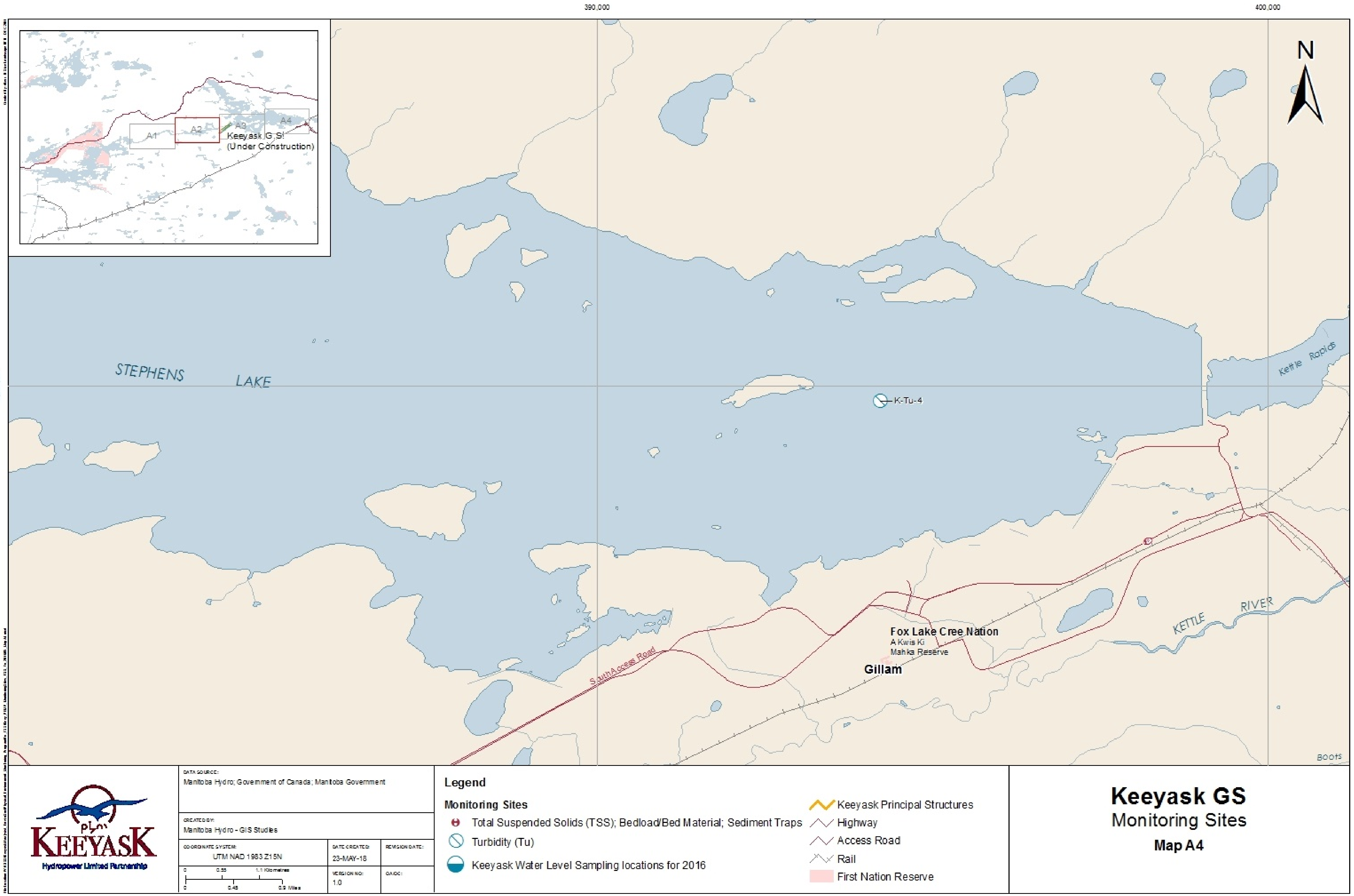

330,000
340,000
6,240,000
N
A1
A2
A3
A4
Keeyask G.S.
(Under Construction)
K-S-01b
RIVER
Birthday
Rapids
NELSON
K-S-09a
K-Tu-6
K-S-09b
K-S-9c
K-S-10c
KEEYASK
Hydropower Limited Partnership
DATA SOURCE:
Manitoba Hydro; Government of Canada; Manitoba Government
CREATED BY:
Manitoba Hydro - GIS Studies
COORDINATE SYSTEM:
UTM NAD 1983 Z15N
DATE CREATED:
23-MAY-18
REVISION DATE:
0 0.55 1.1 Kilometres
0 0.45 0.9 Miles
VERSION NO:
1.0
QA/QC:
Legend
Monitoring Sites
Total Suspended Solids (TSS); Bedload/Bed Material; Sediment Traps
Turbidity (Tu)
Keeyask Water Level Sampling locations for 2016
Keeyask Principal Structures
Highway
Access Road
Rail
First Nation Reserve
Keeyask GS
Monitoring Sites
Map A1



350,000
360,000
6,250,000
6,240,000
North Access Road
Looking Back Creek
N
K-S-05b
RIVER
K-S-06b
K-S-06c
SMP-1, K-Tu-3
SMP-1, K-Tu-3
K-S-06d
K-S-04b
NELSON
K-S-03a
K-S-03b
K-S-03c
K-S-03d
K-Tu-10
GULL
LAKE
K-S-02b
K-ST-01
K-Tu-5
K-Tu-5
K-BL-11a
K-BL-11b
K-BL-11c
K-BL-11d
K-Tu-13
K-S-11c
K-BL-11e
Curscadden
A1
A2
A3
A4
Keeyask G.S.
(Under Construction)
KEEYASK
Hydropower Limited Partnership
DATA SOURCE:
Manitoba Hydro; Government of Canada; Manitoba Government
CREATED BY:
Manitoba Hydro - GIS Studies
COORDINATE SYSTEM:
UTM NAD 1983 Z15N
DATE CREATED:
23-MAY-18
REVISION DATE:
VERSION NO:
1.0
QA/QC:
Legend
Monitoring Sites
Total Suspended Solids (TSS); Bedload/Bed Material; Sediment Traps
Turbidity (Tu)
Keeyask Water Level Sampling locations for 2016
Keeyask Principal Structures
Highway
Access Road
Rail
First Nation Reserve
Keeyask GS
Monitoring Sites
Map A2



370,000
380,000
6,250,000
N
A1
A2
A3
A4
Keeyask G.S.
(Under Construction)
STEPHENS LAKE
K-ST-02
SMP-2L, K-Tu-2
SMP-2L, K-Tu-2
SMP-2R, K-Tu-2
SMP-2R, K-Tu-2
K-BL-7b
K-BL-7a
K-S-07d
K-S-07a
K-S-07b
K-BL-7c
K-BL-7d
K-S-07e
K-BL-7e
North Access Road
SMP-3L
K-Tu-12
SMP-3R
South Access Road
Gilrat Lake
DATA SOURCE:
Manitoba Hydro; Government of Canada; Manitoba Government
CREATED BY:
Manitoba Hydro - GIS Studies
COORDINATE SYSTEM:
UTM NAD 1983 Z15N
DATE CREATED:
23-MAY-18
REVISION DATE:
VERSION NO:
1.0
QA/QC:
Legend
Monitoring Sites
Total Suspended Solids (TSS); Bedload/Bed Material; Sediment Traps
Turbidity (Tu)
Keey_PE_Sites_Monitoring_WaterQuality_2017
Keeyask Principal Structures
Highway
Access Road
Rail
First Nation Reserve
Keeyask GS
Monitoring Sites
Map A3
KEEYASK
Hydropower Limited Partnership


390,000
400,000
6,250,000
N
A1
A2
A3
A4
Keeyask G.S.
(Under Construction)
STEPHENS
LAKE
K-Tu-4
Kettle Rapids
Fox Lake Cree Nation
A Kwis Ki
Mahka Reserve
Gillam
KETTLE RIVER
South Access Road
DATA SOURCE:
Manitoba Hydro; Government of Canada; Manitoba Government
CREATED BY:
Manitoba Hydro - GIS Studies
COORDINATE SYSTEM:
UTM NAD 1983 Z15N
DATE CREATED:
23-MAY-18
REVISION DATE:
VERSION NO:
1.0
QA/QC:
Legend
Monitoring Sites
Total Suspended Solids (TSS); Bedload/Bed Material; Sediment Traps
Turbidity (Tu)
Keeyask Water Level Sampling locations for 2016
Keeyask Principal Structures
Highway
Access Road
Rail
First Nation Reserve
Keeyask GS
Monitoring Sites
Map A4