Keeyask Generation Project

Physical Environment Monitoring Plan

Physical Environment Monitoring Report

PEMP-2020-01

KEEYASK

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

2019 -2020

KEEYASK GENERATION PROJECT

PHYSICAL ENVIRONMENT MONITORING PLAN

REPORT #PEMP-2020-01

2019-2020 PHYSICAL ENVIRONMENT MONITORING REPORT: YEAR 6 CONSTRUCTION

Prepared by

Manitoba Hydro

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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.

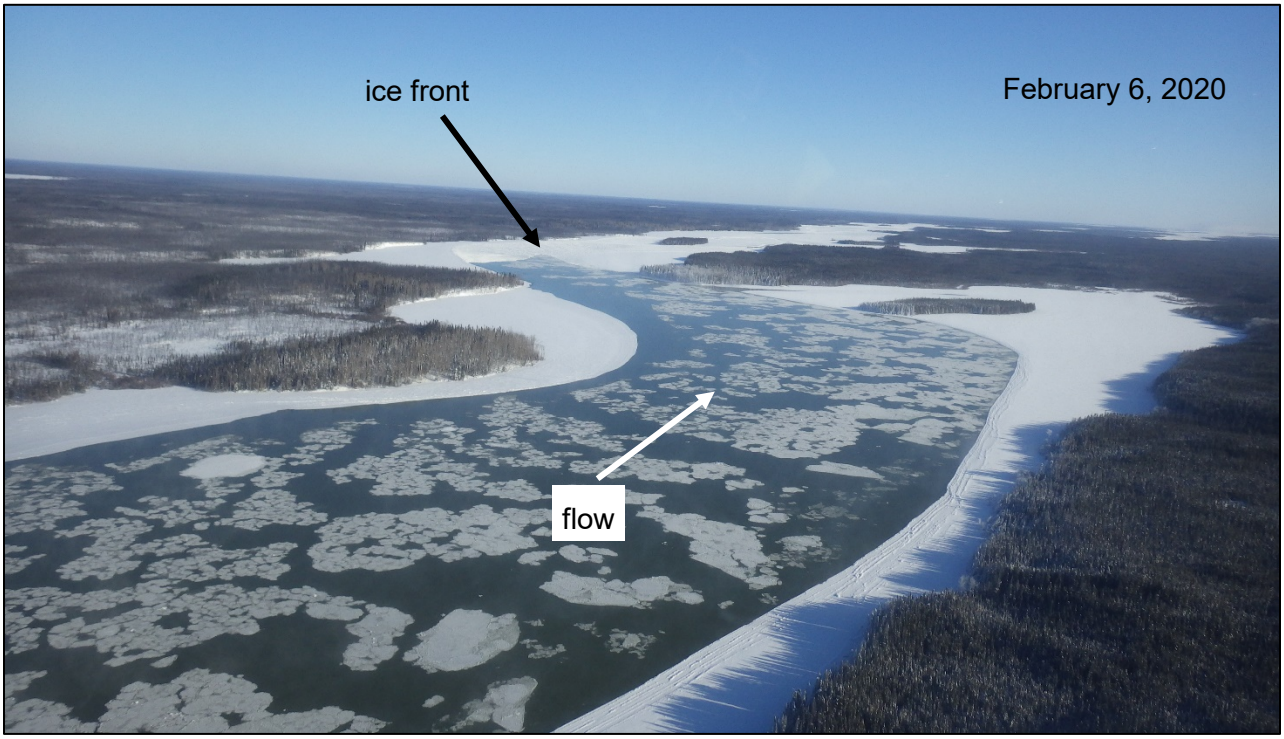
The Keeyask Physical Environment Monitoring Plan (PEMP) discusses planned monitoring during construction of the Project, which includes monitoring of water and ice regimes, shoreline erosion, sedimentation, debris, and emission of greenhouse gases from the future reservoir. This report describes the physical environment monitoring activities and results for the 2018/19 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 flows were near median flow levels between about 3,000-3,500 m^3/s through much of 2019 until about the beginning of October. Flows increased into the winter season, rising to 95th percentile flow levels between about 4,000-4,400 m^3/s and flows remained elevated through the winter.

Water levels were steady through much of the open water season due to relatively steady flow conditions. Rising flows resulted in increasing levels in October and once the ice cover began forming and expanding through November the water levels began rising due to the ice as observed in previous winter seasons. Levels rose up as much as 4-6 m between Gull Lake and Birthday Rapids due to ice effects. In February and March, the spillway gates were lowered to water-up the dewatered construction area and facilitate removal of the north channel cofferdam. Water-up caused Gull Lake water levels to be about 0.2-0.4 m higher relative to 2020 winter levels prior to water-up for similar flow conditions. As expected, levels upstream of Gull Lake were not affected during water-up. Gull Lake was at and remains near a level of 156.5 m due to water-up, which is comparable to the peak level in January 2020 prior to water-up occurring. Water levels on Clark and Split lakes were not affected by the Project during the reporting period.



Nelson River Ice Front Stalled at Birthday Rapids with Ice Pans Flowing Downstream

Ice monitoring is done using satellite imagery and photographs taken along the length of the study area during monthly field trips. The 2019/20 winter saw the early ice cover formation on Gull Lake in early November similar to the previous year; about 2 weeks earlier than the first two winters with the ice boom in place. Unlike previous four years, however, the ice front stalled at the foot of Birthday Rapids for the season so there remained an open central channel from the outlet of Split Lake up to Birthday Rapids.

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 2018-19 winter monitoring show similar results to the past three 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 2019 was the lowest observed during the nine years of monitoring done during the years of pre-construction and during construction monitoring to date and no discernable changes resulting from the Project were observed. Likewise, the average daily suspended sediment load in summer was the lowest recorded to date. This marks the second year in a row that the sediment load was the lowest since monitoring began. This is likely partially attributed to the lower flows observed in 2019, although 2019 summer average flow was slightly higher than 2018.

Continuous turbidity monitoring equipment – setting up a turbidity sensor

Debris

Manitoba Hydro operates waterway management programs on various water bodies to monitor and remove debris. A boat patrol (2 person crew in a boat) operated in the Project area from Clark Lake to Gull Rapids to identify debris such as floating logs and branches that need to be removed if they pose a safety hazard to navigation. Patrols also marked reefs and engaged with waterway users. The amount of floating debris reported in 2019 was 8 pieces which is similar to amounts recorded since a boat patrol dedicated to the Project area began operating in 2015.

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 reservoir creation.

Reservoir GHG monitoring was conducted annually prior to construction of the Project from 2009 to 2013 and during the first year of construction in 2014 and 2019.

The amount of carbon exchanged between the oceans, atmosphere, land, and living things is known as the carbon dioxide flux. The flux results recorded in 2019 were in general agreement with previous Gull Lake monitoring and within ranges of published concentrations of dissolved gas and greenhouse gas fluxes for rivers and wetlands.

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

Data Collection

Andrew Benger

Darrel Brunet

Keith Dobson

Leslie Gbeve

Paiten Harapiak

Leslie Klassen

Joseph Langan

Saul Mayham

Jarod Morrison

Greg Petryk

Justin Pollick

Marney Ritchot

Data Analysis, Report Preparation, and Report Review

Wil DeWit

Bob Gill

Danielle Kerr

Tim Papakyriakou

Russell Schmidt

Ashley Soloway

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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 2019 to March 2020, the sixth year of construction monitoring. When information is not available the information will be reported in the following year's monitoring report.

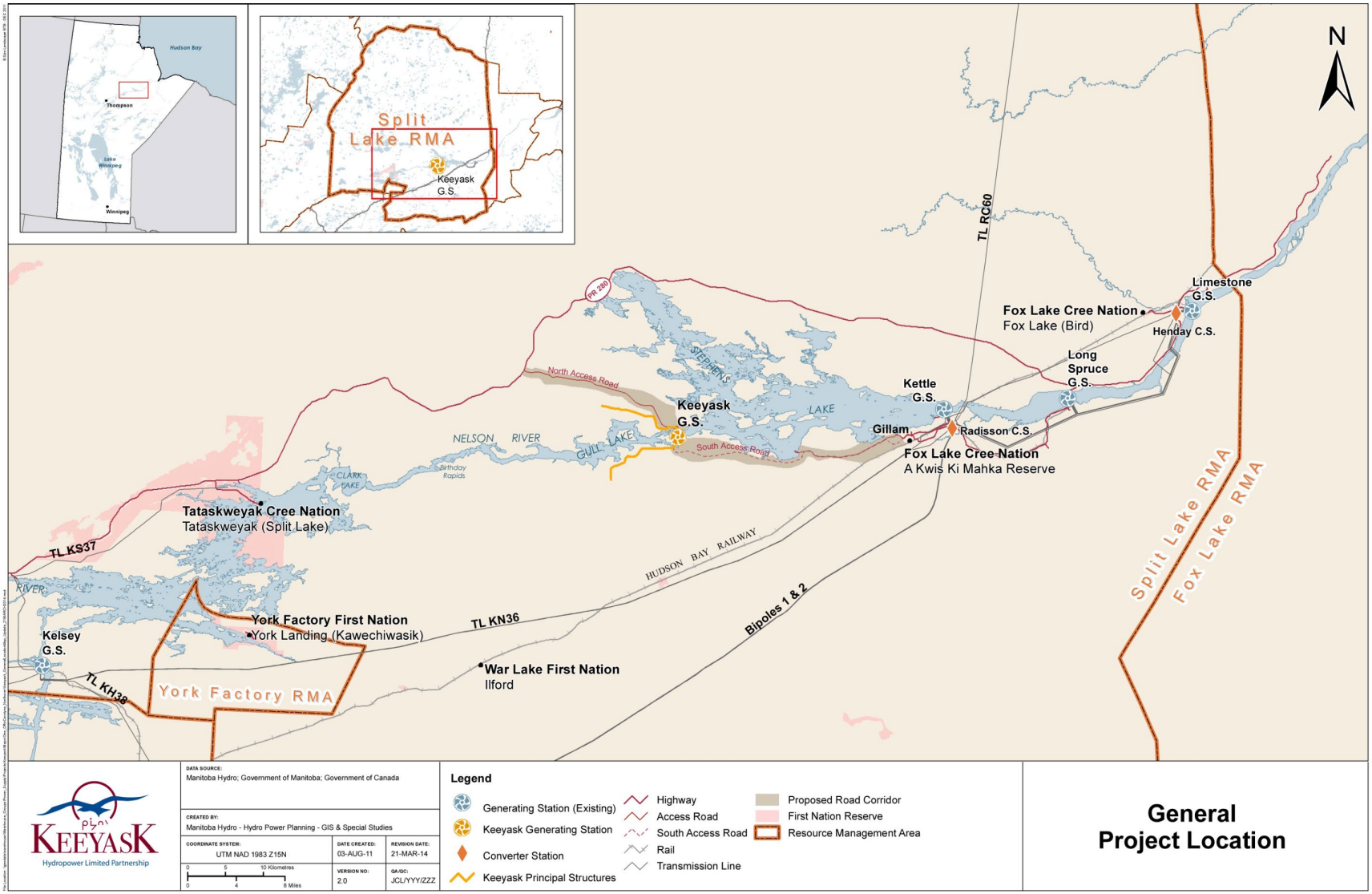
The physical environment is defined as the physical and chemical make-up of an ecosystem and describes the area where things live and includes the air, water and land within the ecosystem. Monitoring and follow-up activities focus on effects to key components of the physical environment to:

- 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 2019/20, physical environment monitoring included surface water and ice regime, sedimentation, dissolved oxygen, greenhouse gases, and woody debris monitoring. Monitoring for surface water temperature, 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 A).



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. Annual 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 2019 was close to the median historical flow between about 3,000-3,500 m^3/s until October when it briefly declined before gradually rising to near the 95th percentile level by the end of November (Figure 1) and remaining there till the end of the reporting period.

Table 1: Annual Seasonal Discharges

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

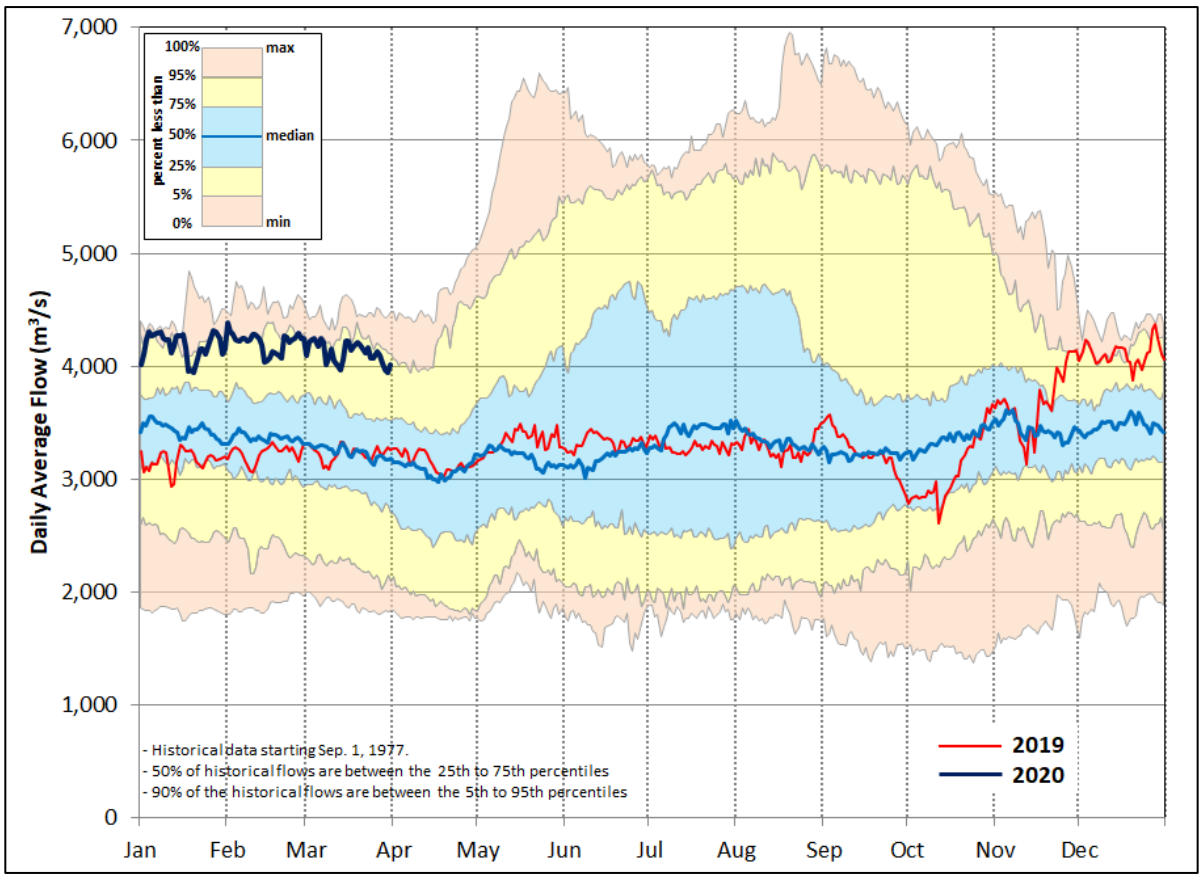


Figure 1: Split Lake 2019/2020daily average outflow and historical statistics

2.2 OBSERVED WATER LEVELS – SUMMER AND WINTER

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.

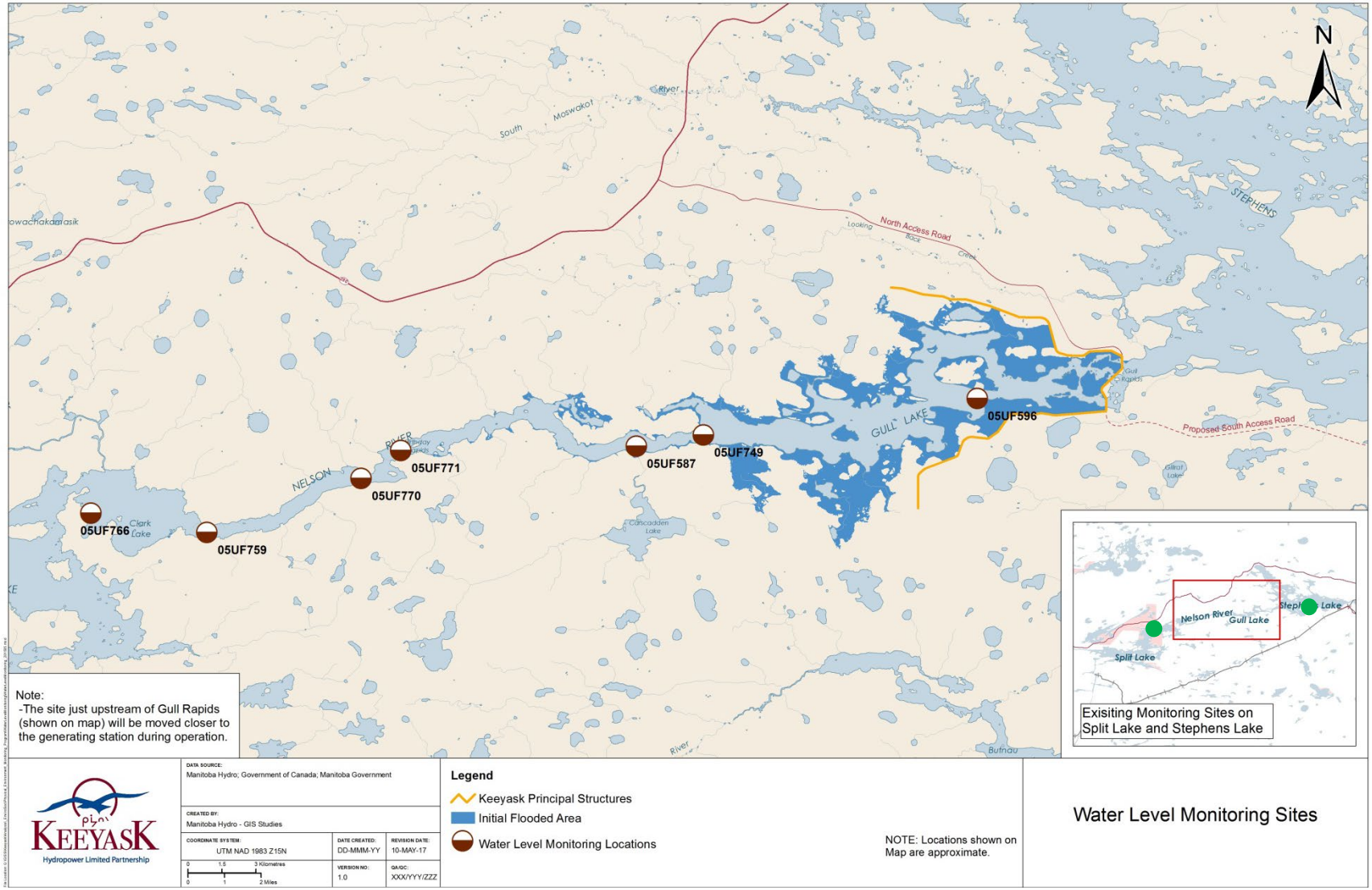
Steady flows over much of the summer in 2019 resulted in steady water levels until early October (Figure 2). Water levels increased through October as flows also increased. While flows continued to gradually increase in November, the initiation of an ice cover early in the month also caused water levels to start increasing more sharply as usual at that time of year. Peak winter levels were generally reached in January 2020 and, depending on location, levels began to decline by about the beginning of February at upstream sites and later in the month at downstream sites. As in previous years, the largest winter water level increases of about 4-5 m occurred at the gauges located at Birthday Rapids and just upstream of Gull Lake.

On February 26, spillway gates were operated to raise water levels immediately upstream to water-up (i.e., flood) the dewatered work area upstream of the powerhouse. This resulted in Gull Lake water levels rising between 0.2-0.3 m to an elevation of about 156.5 m. Once water-up of the dewatered area was complete, the level dropped to about 156 m as temporary river management structures were lowered or removed. Following that, the spillway was again used to raise upstream levels for removal of the north channel rock groin, which again increased Gull Lake to about 156.5 m, or about 0.3-0.4 m above levels in 2020 prior to water-up for similar flow conditions. It is noted that Gull Lake reached elevations of about 156.5 m earlier in the winter, prior to water-up activities to flood the dewatered area and for rock groin removal. Water level increases at the spillway during water-up did not result in water level changes at any water level gauges upstream of Gull Lake.

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



Map 2: PEMP water level monitoring sites

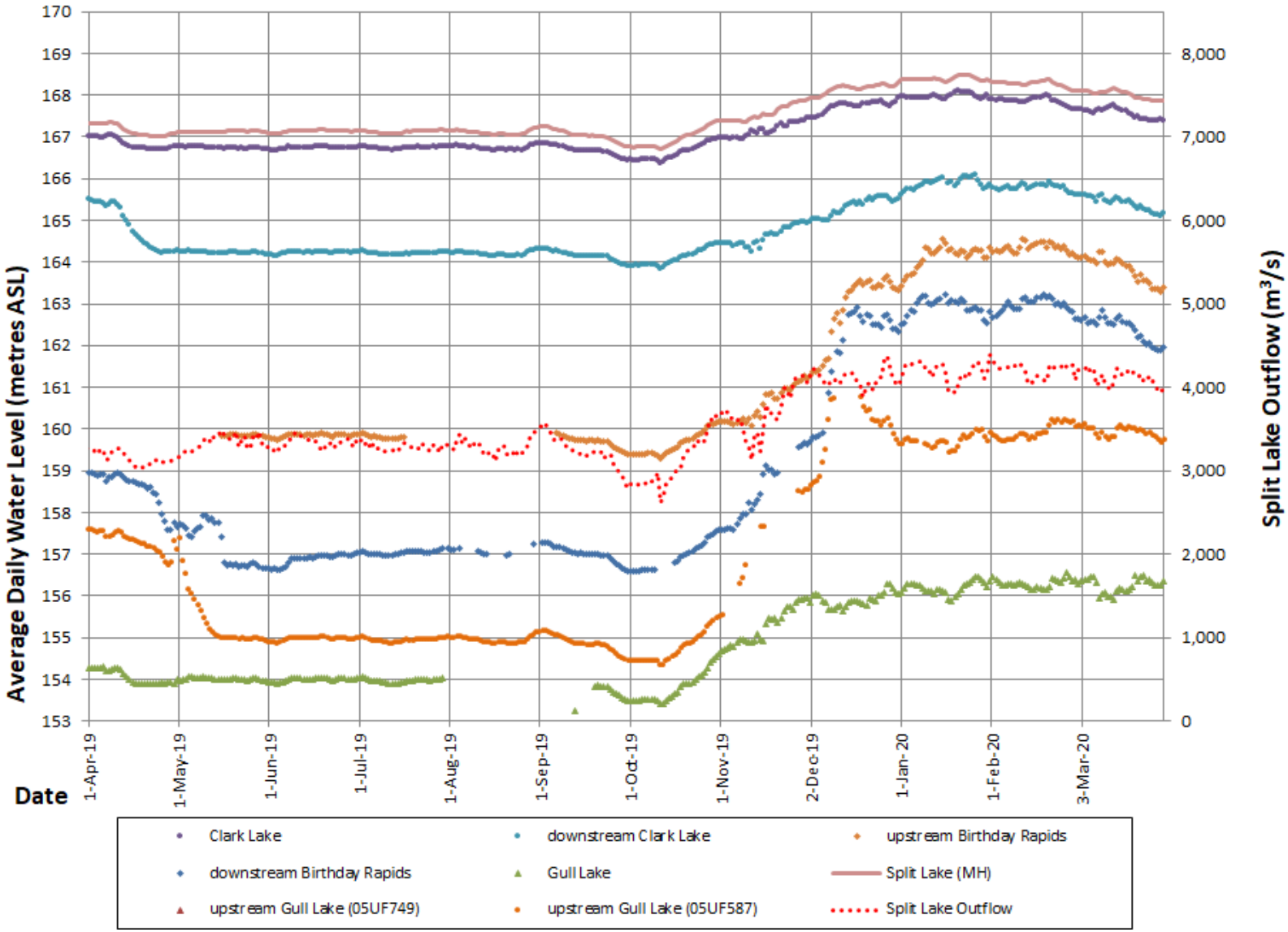


Figure 2: Observed water levels at PEMP monitoring sites in 2019/2020

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 (Figure 3). 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. While flows were relatively steady from late November to late January, the levels on Clark and Split lakes increased about 0.6 m primarily because of anchor ice at the Clark Lake outlet. This is a typical winter water level increase for these lakes: water levels on Split and Clark lakes typically increased 0.3-1.2 m each winter with an average increase of about 0.6 m prior to the start of the Project (KHLP 2012b). There has been no impact on Split Lake water levels due to the Project.

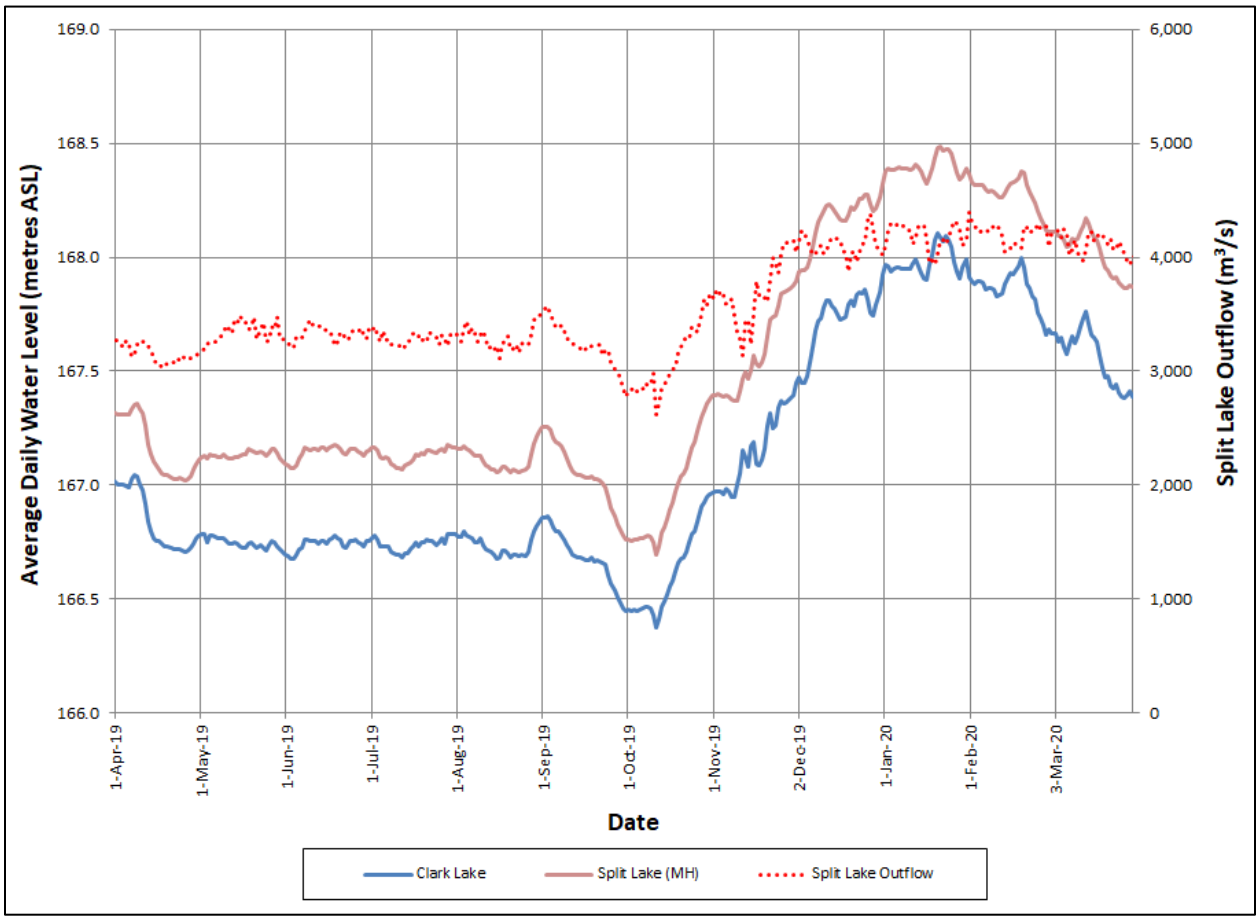


Figure 3: Observed water levels at Clark Lake and Split Lake in 2018/2019

While daily average water levels (Figure 3) show the overall impact of ice on winter levels on Split and Clark lakes, a review of average hourly levels shows that anchor ice affects levels on almost a daily basis. Average hourly levels recorded at Split Lake, Clark Lake and downstream of Clark Lake were considered for the period from March 21-31, 2020 (Figure 4). For each site the average water level from March 21-31 was calculated and deducted from the hourly water levels to reduce each time series to a common scale representing each site's deviation from its average. There are periods in the chart where water levels on Clark and Split Lake rise and then decline while levels at the site downstream of Clark Lake show an opposite pattern of variation; declining as Clark Lake increases and increasing as Clark Lake declines (indicated by red braces). This is counter-intuitive because a rising level on Clark Lake would typically mean (under open water conditions) flows are increasing so that downstream levels should also be increasing, and vice versa if levels are dropping on Clark Lake.

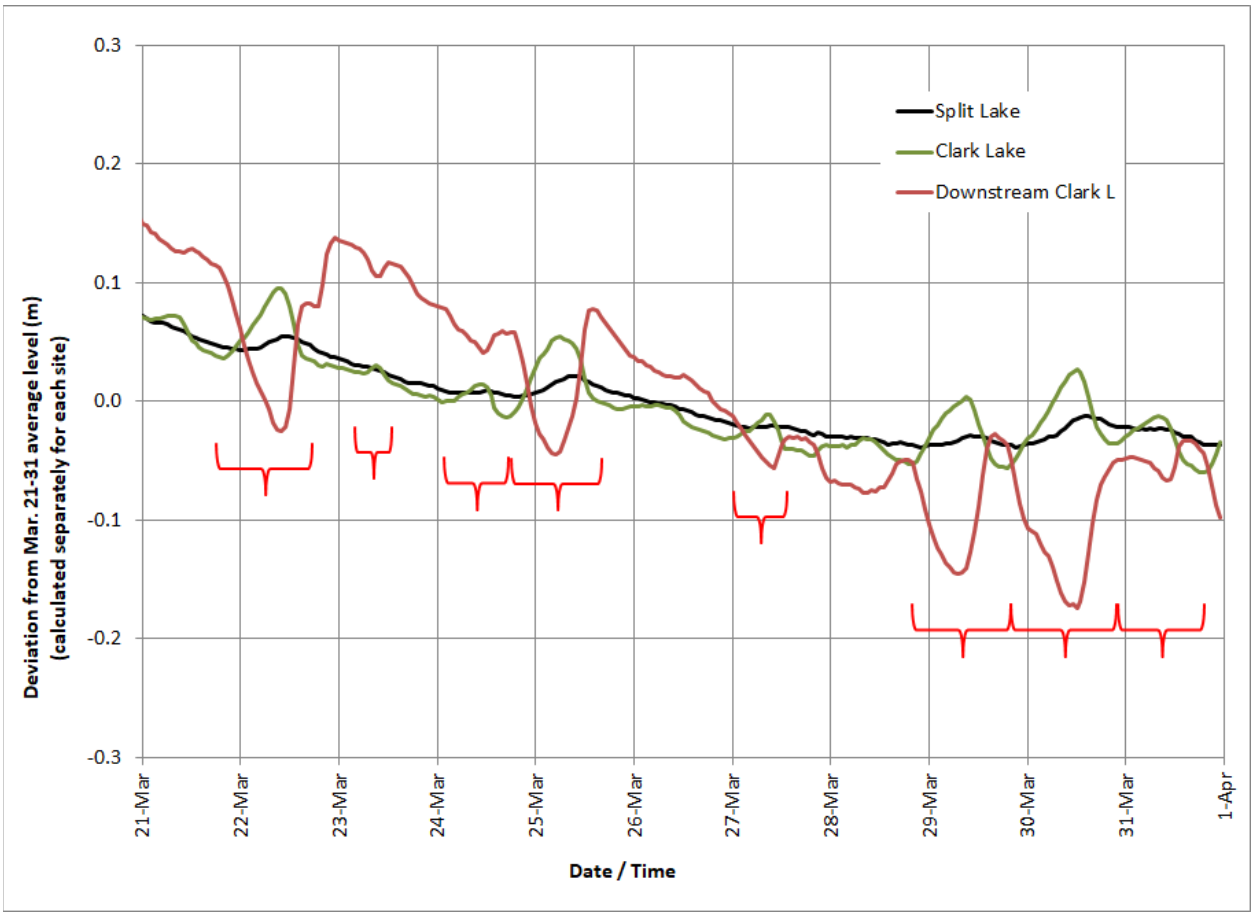


Figure 4: Comparison of water level variation at Split L., Clark L. and downstream of Clark L., Mar. 21-31

The divergent pattern of water level variation on Clark Lake and just downstream results from the intermittent growth and reduction of anchor ice at the Clark Lake outlet, with anchor ice generally growing over night and reducing during the day. For example, from about 7 p.m. on Mar. 28 to

9 a.m. on the 29th, the level on Clark Lake increases about 5 cm while over the same period the level just downstream declines by about 10 cm as anchor ice grows at the outlet due to colder over night temperatures. Split Lake water levels also increase, but by an amount less than 2 cm. Then, from about 9 a.m. to 7 p.m., Clark Lake levels decline about 5 cm as anchor ice decreases and the additional outflow causes levels just downstream to rise by about 10 cm. Another pattern of increasing and decreasing Clark Lake levels and opposite changes downstream then occurs between the 29th and 30th, with levels rising about 7.5 cm on Clark lake and dropping about 15 cm just downstream before declining/rising again to the evening of the 30th, at which point another cycle begins. The effects do not necessarily occur every night or only at night, and in some cases the occurrences of diverging water levels are short and produce small effects (e.g., effects indicated on Mar. 23 and 24). These transient effects due to Clark Lake anchor ice occur to varying degrees over much of the winter period.

Effects corresponding with those observed just downstream of Clark Lake were also observed at the sites upstream and downstream of Birthday Rapids, upstream of Gull Lake and on Gull Lake, however these sites were not included in the figure of water level deviations (Figure 4) for clarity. While the effects just downstream of Clark Lake occur almost simultaneously with effects on Clark Lake, the corresponding effects further downstream are delayed due to flow travel time. Corresponding effects occur within a couple of hours at the Birthday Rapids sites and 10-12 hours later or more on Gull Lake.

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 2019/20 winter saw the same early initiation of an ice cover as in previous years.

In early November 2019, temperatures rapidly decreased near the time ice formed upstream of the ice booms as seen in Photo 2, which were taken before and after ice developed. Figure 5 shows satellite images of the ice cover as it advanced upstream during the winter. By November 10, the leading edge of the ice front was at the upstream end of Gull Lake. The ice front continued to advance upstream reaching Birthday Rapids by late December. The leading edge of the ice front stalled at the foot of Birthday Rapids for the remainder of the winter season. This is different

than the previous four winters in which the ice front stalled temporarily at the foot of the Birthday Rapids but later in the winter advanced up to about 4-6 km upstream of the rapids. The fact the ice front did not advance through Birthday Rapids in 2019/20 is likely due to a combination of differences in flow and weather conditions this winter.

The ice cover below Birthday Rapids began to show signs of degradation and development of open water leads by April 20, 2020. Increasing day length and warming temperatures by that time of year reduces the supply of new ice from upstream while the flow continues to smooth and thin the ice cover (). By May 10, open water leads have extended so that the channel up to the entrance of Gull Lake is largely open while areas of thinning ice where new open water leads are likely to develop are apparent on Gull Lake. By May 20, open water extends several kilometres into Gull Lake and additional areas of degrading ice are apparent. Just 5 days later, on May 25, the river reach from Birthday Rapids to the Keeyask GS is essentially free of ice except in off current areas, and water levels have returned to open water conditions.

Table 3: Ice Dates and Cover

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

*Ice formation start date before ice boom failed

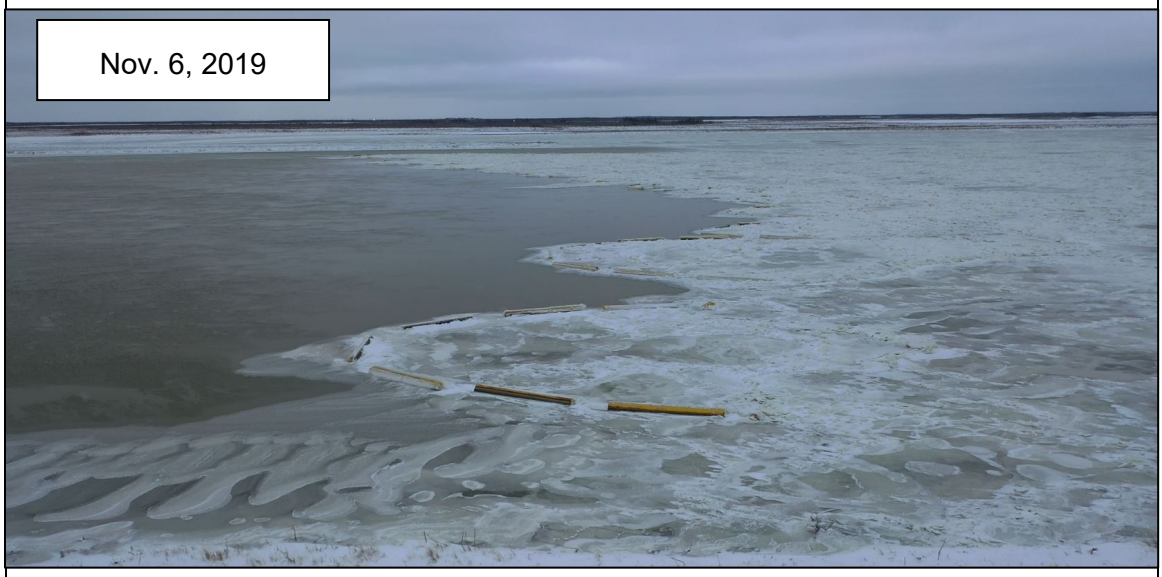


Photo 2: Ice Boom B on south side of Caribou Island (Nov. 4 & 6, 2019)

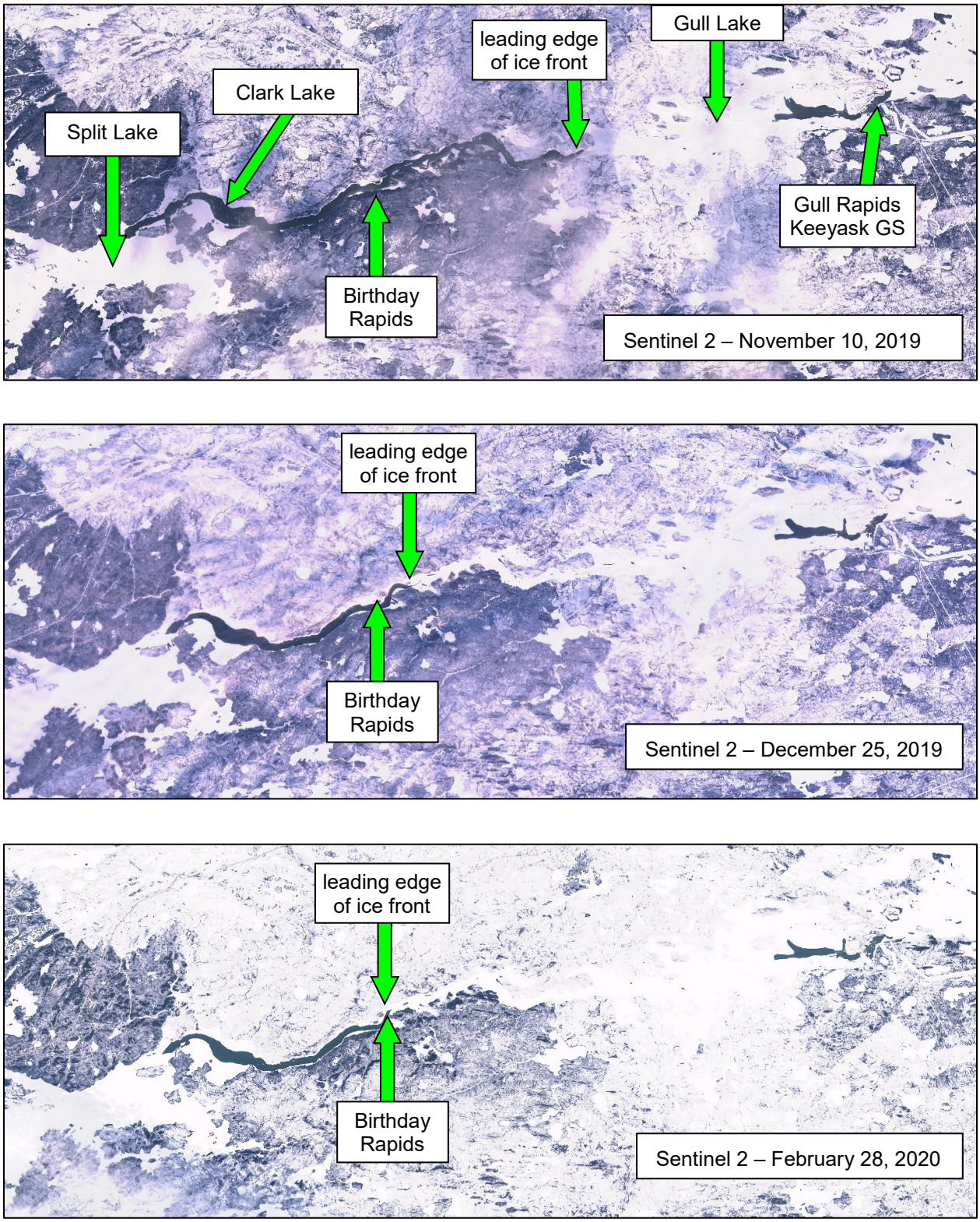


Figure 5: Ice Cover Development Observations from Satellite Images

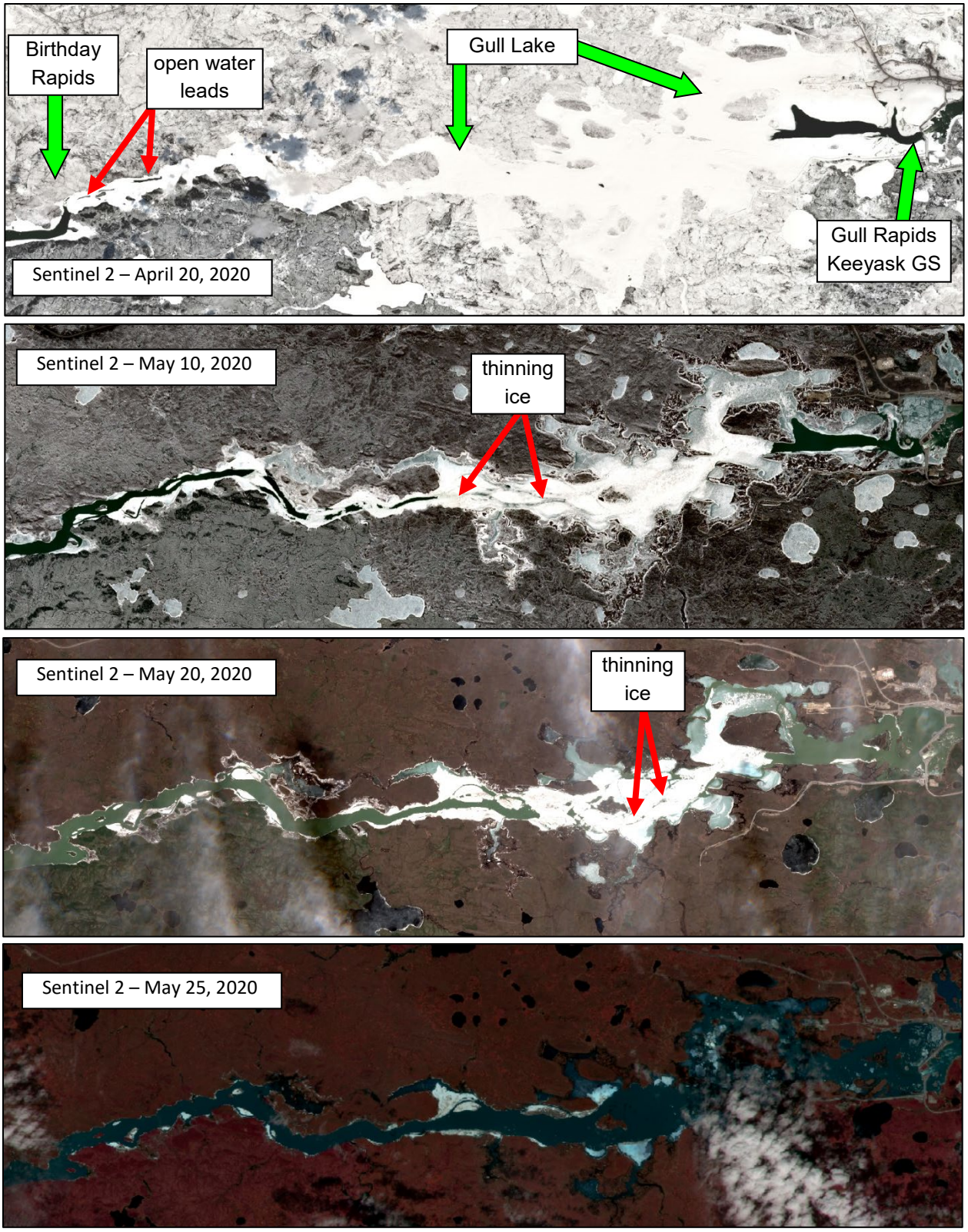


Figure 6: Receding Ice Cover Observations from Satellite Images

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 planned to occur 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 2020).

Sediment transport monitoring is done through the collection of discrete water samples, continuous turbidity monitoring and sediment traps at locations shown in Map 5 (detailed site maps are provided in Appendix A). 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 2018-2019

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 2018-19 winter sedimentation data.

4.1.1 CONTINUOUS AND DISCRETE TSS AND TURBIDITY

Winter monitoring in 2018-19 was conducted at three sites (Table 4); at the SMP-03 location two sensors were installed adjacent to each other and are labelled L (left) and R (right). Each year the equipment is installed after suitable ice conditions develop at the sites and removed before ice break up.

Table 4: 2018-2019 Winter Monitoring Locations

Site ID	Dates
K-Tu-06 (Clark Lake)	01-Feb-2019 to 12-Apr-2019
SMP-01 (Gull Lake)	28-Jan-2019 to 05-Apr-2019
SMP-03L (Stephens Lake)	27-Jan-2019 to 19-Apr-2019
SMP-03R (Stephens Lake)	26-Jan-2019 to 19-Apr-2019

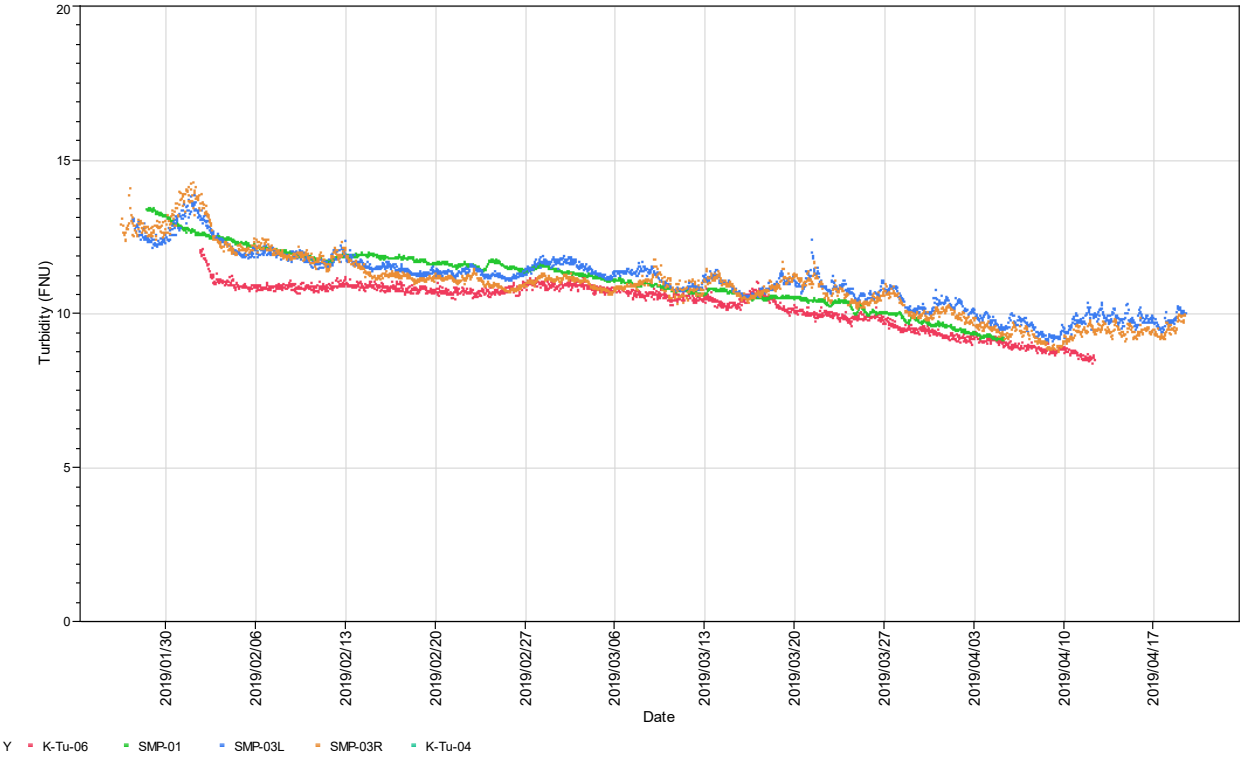


Figure 7: 2018-2019 Winter Continuous Turbidity

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.

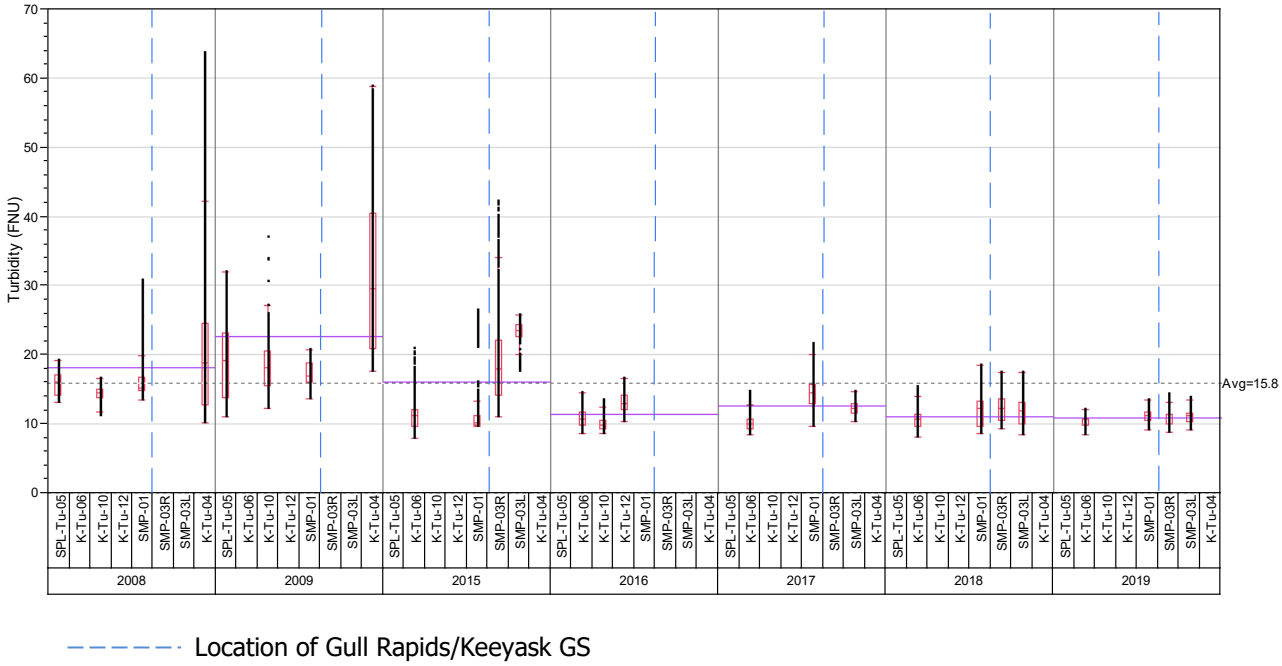


Figure 8: Summary of Winter Continuous Turbidity

Results from the 2018-19 winter monitoring show similar results to the past three 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 9) 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.

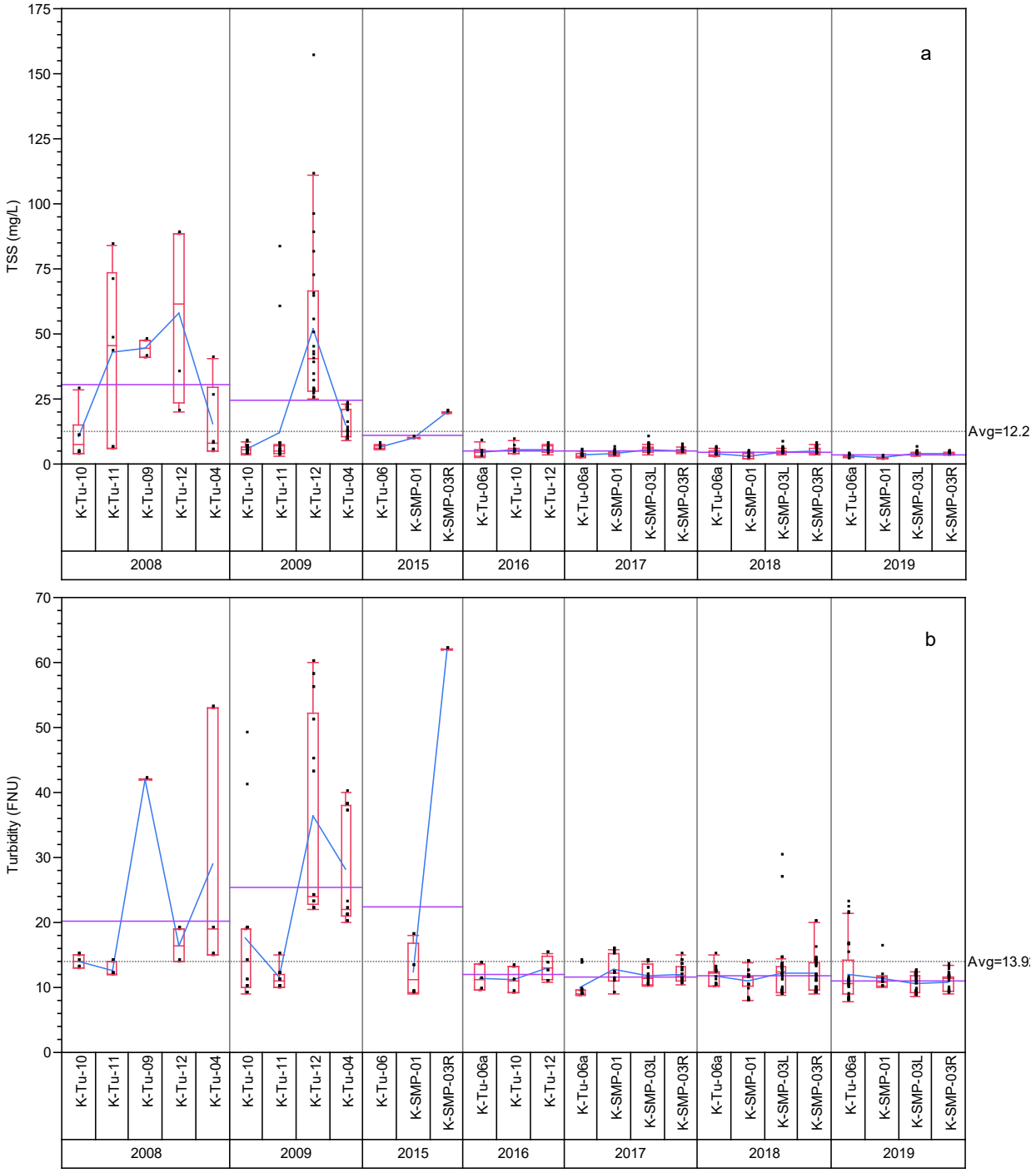


Figure 9: Summary of Winter Discrete TSS (a) and Turbidity (b)

4.1.2 ESTIMATED SUSPENDED SEDIMENT LOAD

The winter suspended sediment loads (Figure 10) are estimated based on the average daily turbidity and Keeyask Inflow discharge. Turbidity is converted to TSS concentrations using a Turbidity-TSS relationship developed for the SMP.

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 five 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.

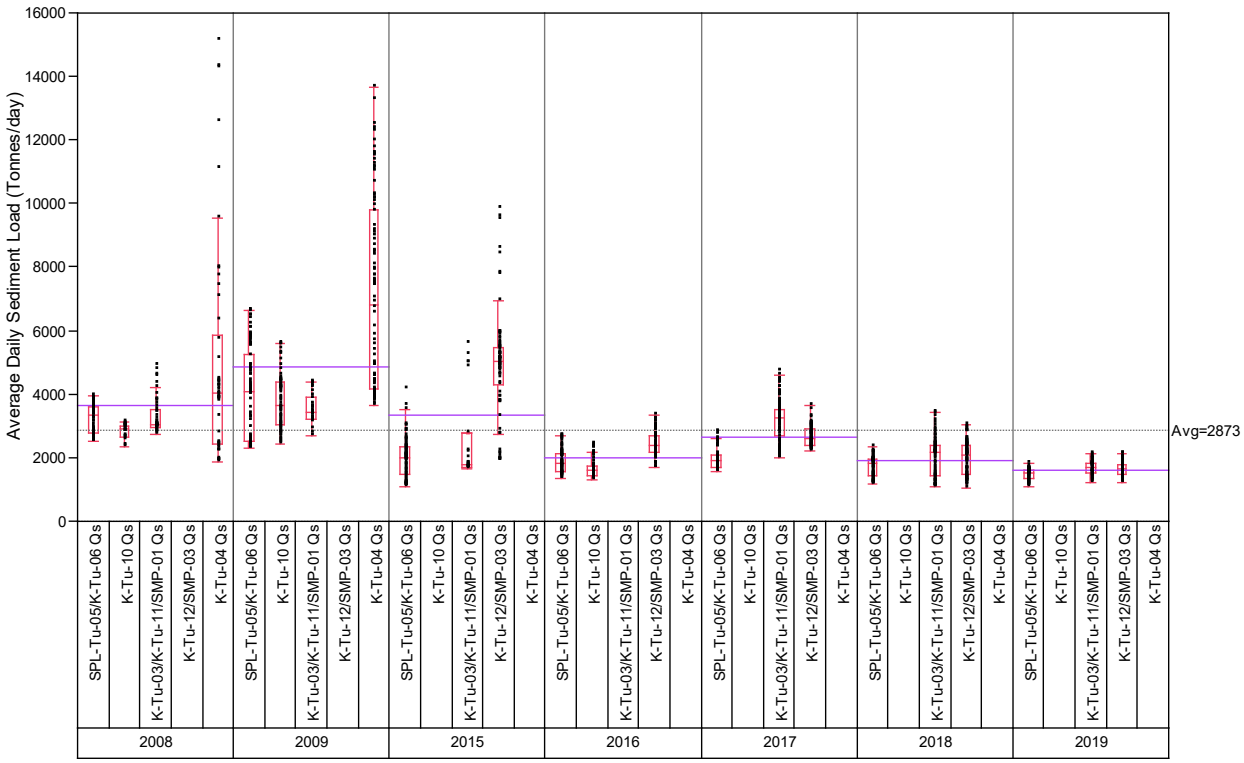


Figure 10: Summary of Winter Daily Suspended Sediment Load

4.2 SUMMER 2019

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 2019 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 3) 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)	2019/06/13 to 2019/09/18
*K-Tu-05 (Nelson River)	2019/06/13 to 2019/09/18
K-Tu-03 / SMP-01 (Gull Lake)	2019/06/21 to 2019/09/23
K-Tu-02 / SMP-02 (Stephens Lake Entrance)	2019/06/03 to 2019/09/29
K-Tu-04 (Stephens Lake)	2019/06/11 to 2019/09/17

*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 11) were also compared with the discrete readings (Figure 13) 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 entrance channel) and SMP-02R (right side of entrance channel) were averaged to represent the average turbidity entering Stephens Lake.

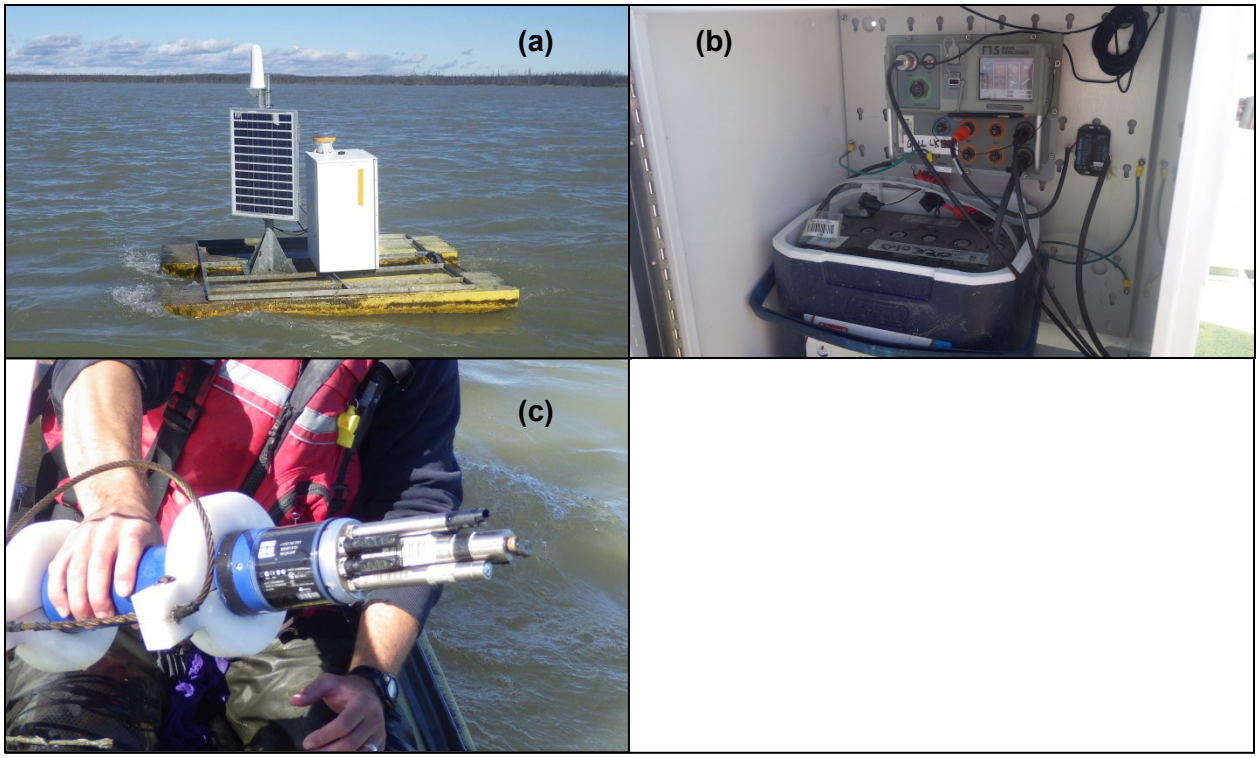


Photo 3: Continuous turbidity monitoring site: (a) catamaran with solar panel, transmitter and electronics cabinet, (b) electronics in cabinet, (c) probe with turbidity sensor installed

The turbidity at each of the sites follows a similar pattern (Figure 11) throughout the monitoring period with the exception of the site near the Kettle GS (K-Tu-04). Turbidity increased through June while remaining relatively steady in July and August with some short term increased related to windy periods/storms. The wind speed shown in Figure 11 is taken from the Environment Canada Station at Gillam.

The average summer turbidity (Figure 12) was the lowest observed during the nine years of monitoring. Differences between the sites are similar to observations seen in other years and no discernable changes resulting from the Project were observed.

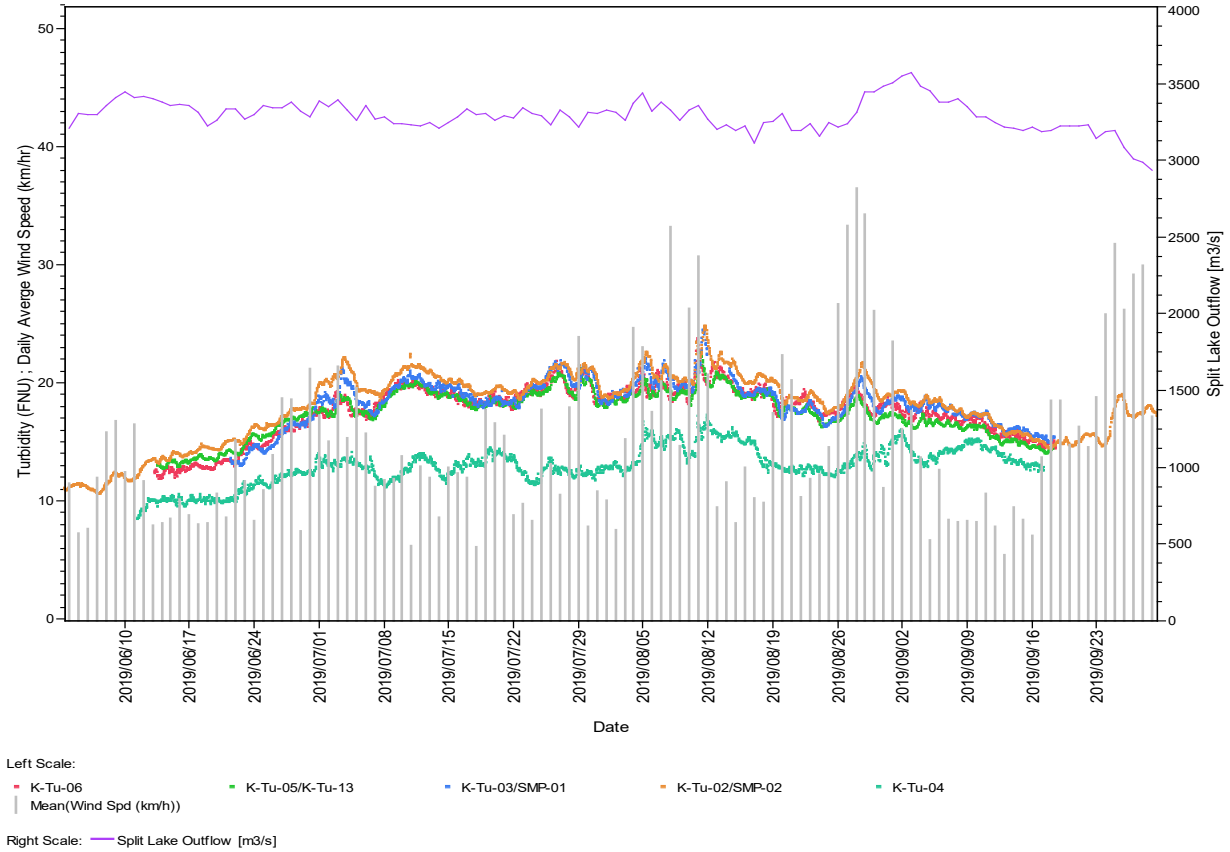


Figure 11: 2019 Summer Continuous Turbidity, Daily Discharge and 24-hr Wind Speed

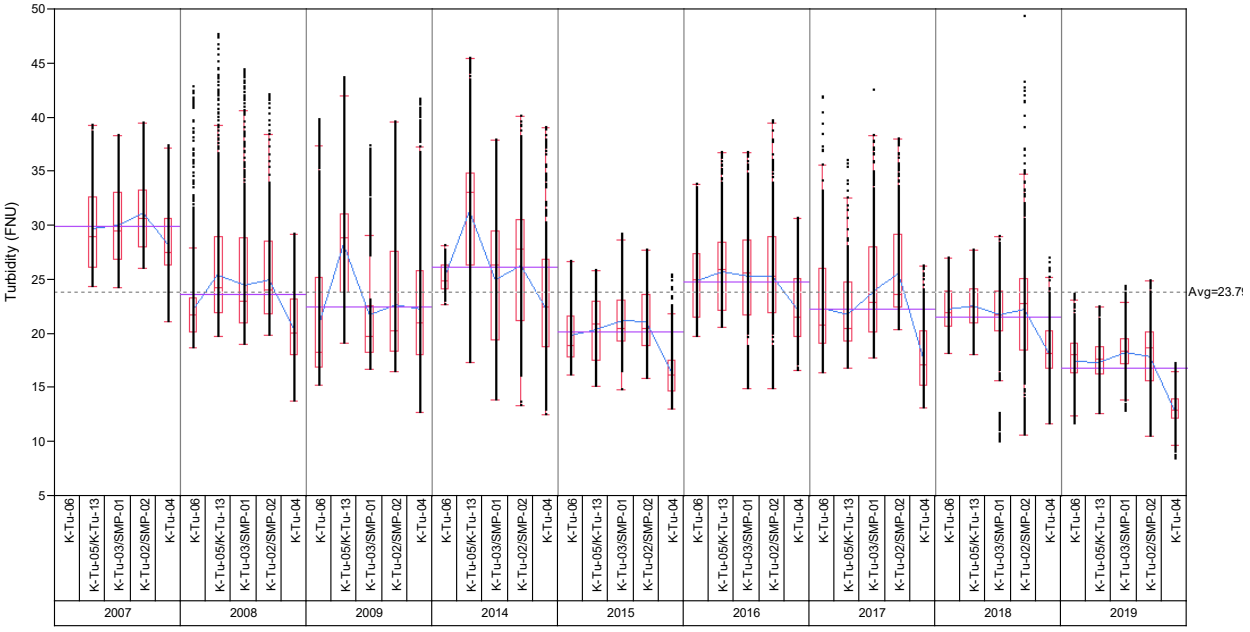


Figure 12: Summary of Annual Summer Continuous Turbidity

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 2019 TSS results (Figure 13) generally ranged between 5 and 18 mg/L with a few higher values reported. Figure 14 and Figure 15 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 2019 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.

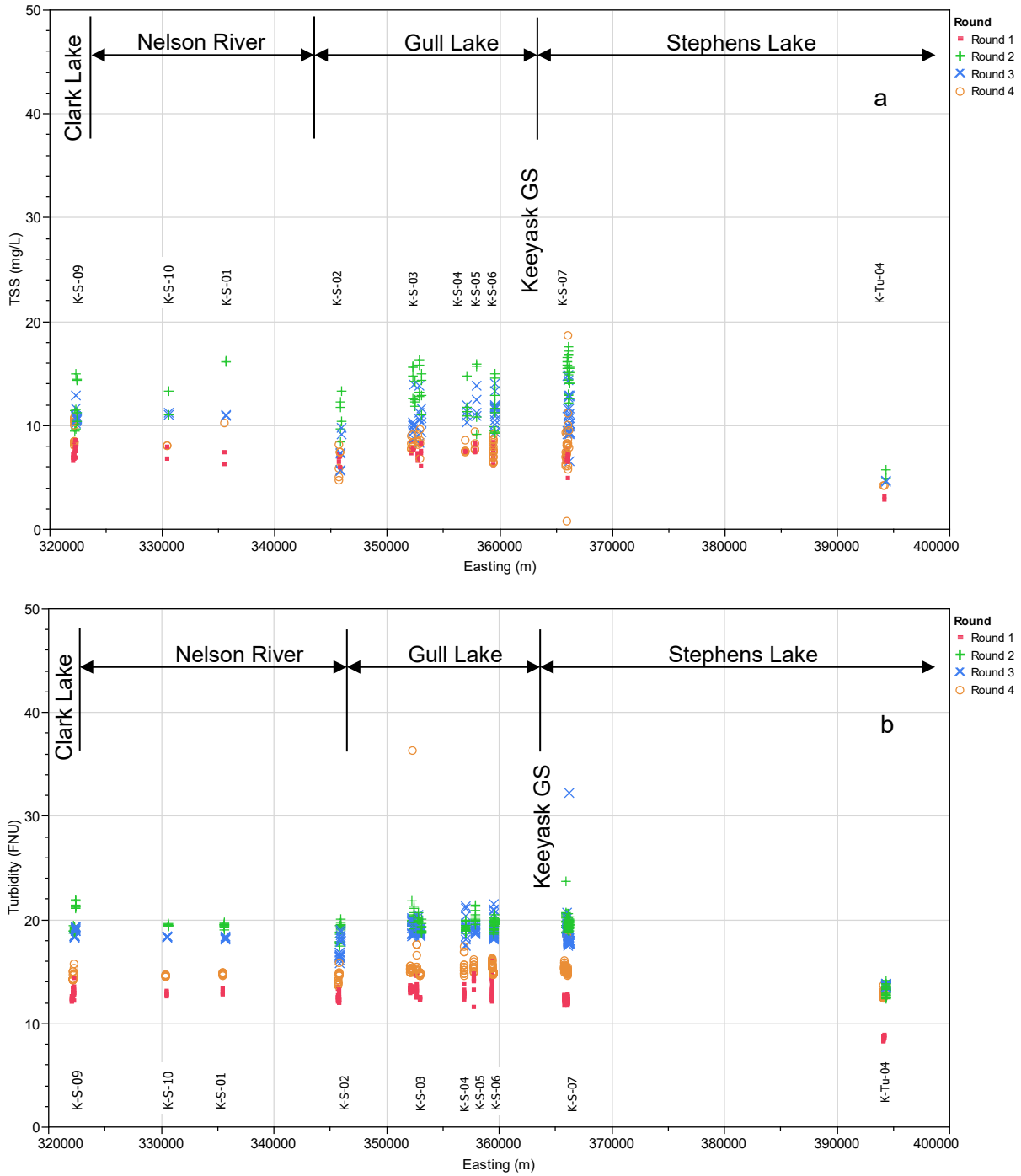
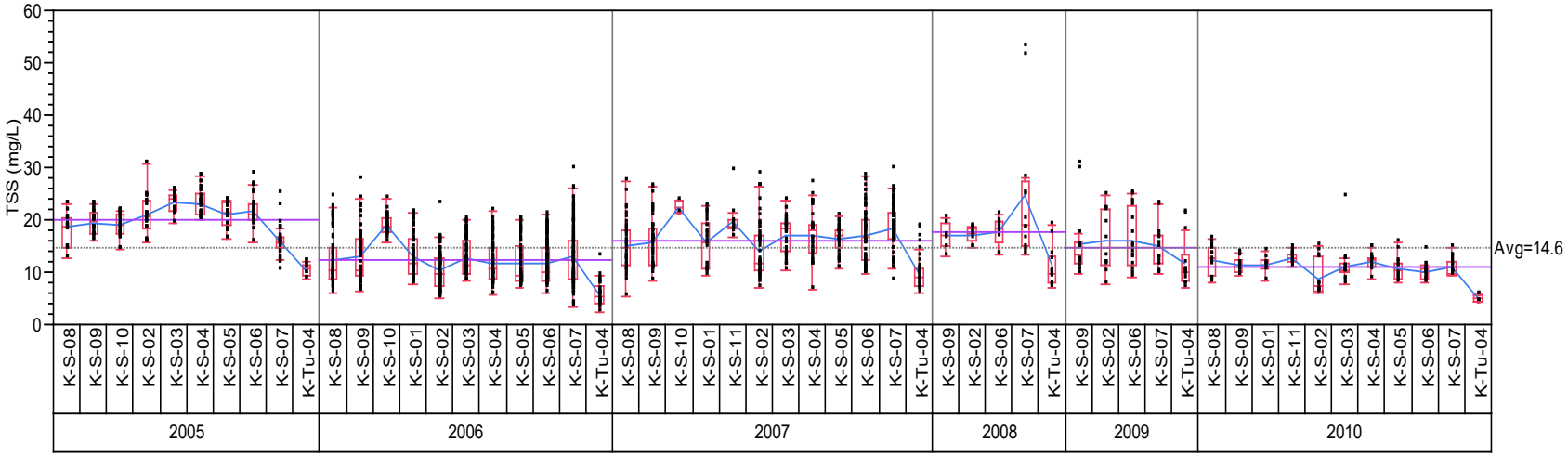


Figure 13: 2019 Summer Discrete TSS (a) and Turbidity (b)

Pre-Construction Period



During Construction Period

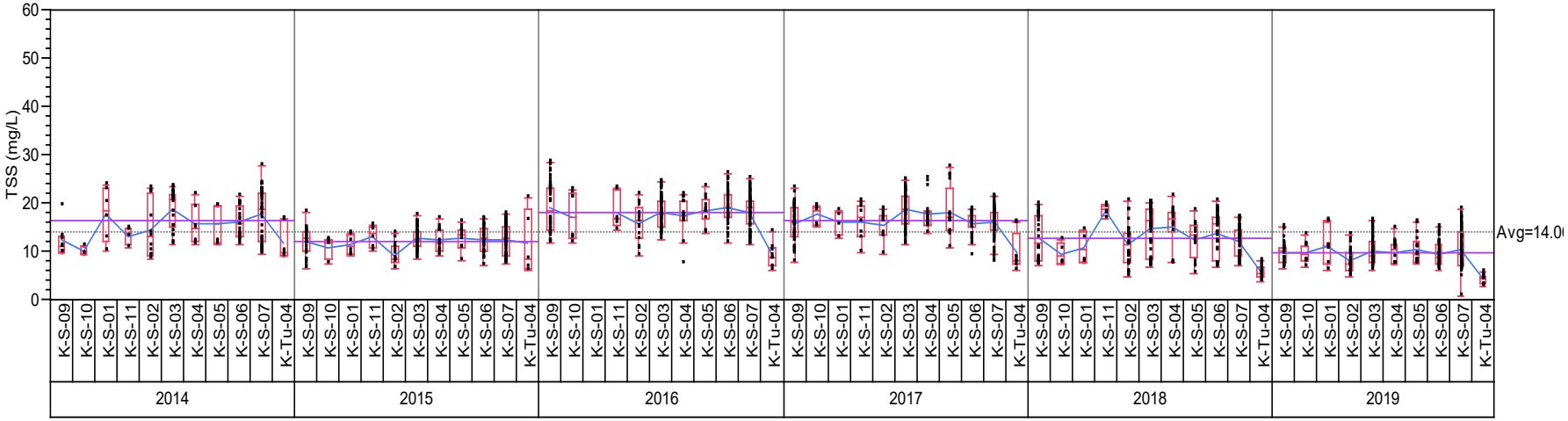
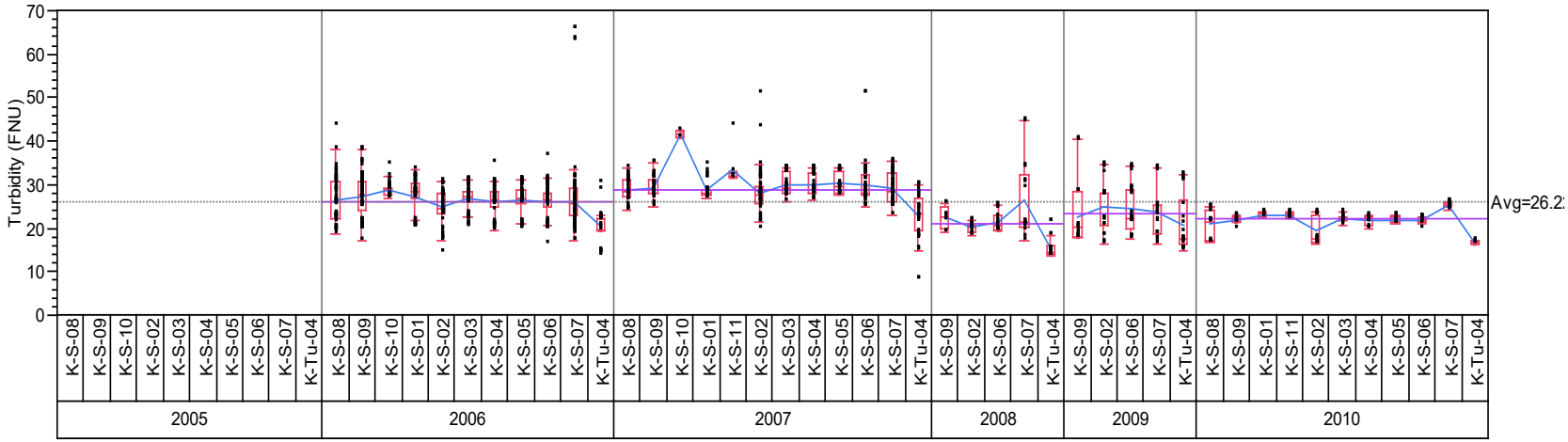


Figure 14: Summary of Annual Summer Discrete TSS

Pre-Construction Period



During Construction Period

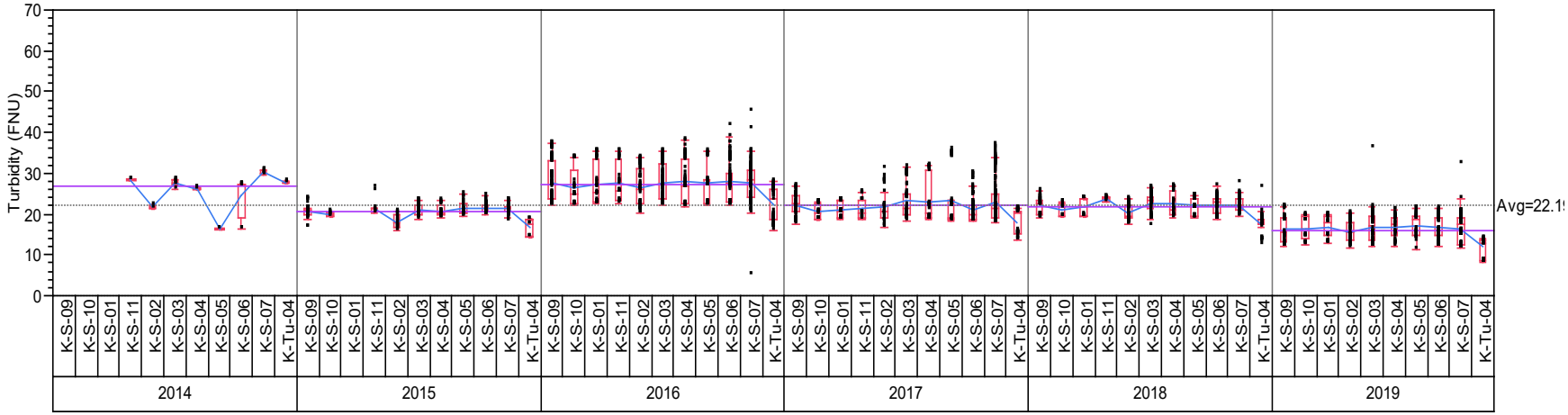


Figure 15: Summary of Annual Summer Discrete Turbidity

4.2.3 ESTIMATED SUSPENDED SEDIMENT LOAD

The summer suspended sediment loads (Figure 16) are estimated based on the average daily turbidity and Keeyask inflow discharge. Turbidity is converted to TSS concentrations using a Turbidity-TSS relationship developed for the Sediment Monitoring Program.

The 2019 average summer suspended sediment load was the lowest recorded during the years of pre-construction and during construction monitoring to date. This marks the second year in a row that the sediment load was the lowest since monitoring began. This is likely partially attributed to the lower flows observed in 2019, although 2019 summer average flow was slightly higher than 2018 (Table 1). As seen in other years, there was a drop in suspended sediment load through Stephens Lake (K-Tu-02 to K-Tu-04).

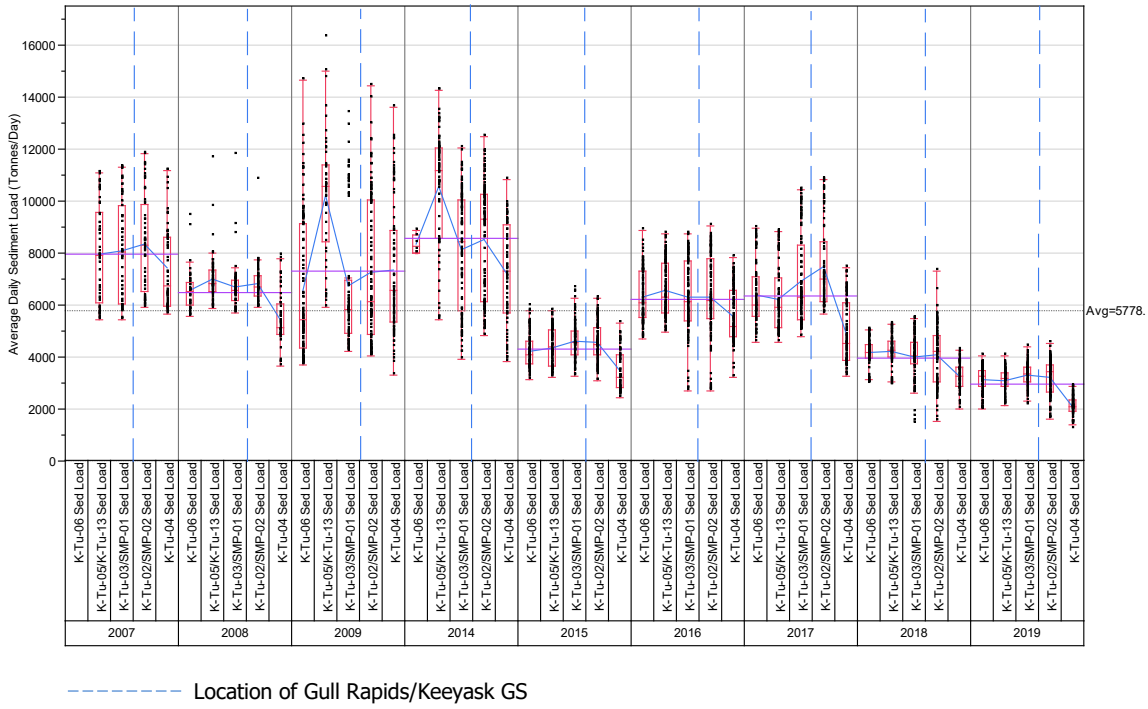


Figure 16: Summary of Summer Daily Sediment Load

4.2.4 DEPOSITION

Sediment traps with two vertical tubes (Photo 4) were installed in Stephens Lake to monitor the sediment accumulation rate over the 2018/19 winter and the 2019 summer period. One tube is a settling trap that is open at the top and the second tube is a flow through trap that has hole in the side to allow water and sediment to flow into it.

Two sets were installed over the 2018/19 winter and 3 sets were installed over the 2019 summer period. One of the winter traps was not located in the spring and was presumed lost. Results from the monitoring are shown in Table 6: 2018-19 Winter Sediment Trap Monitoring Results on Stephens Lake (K-ST-02)

Sample Period	Flow 1	Settle 1	Average
Dates	October 10, 2019 to June 5, 2019		
# of Days		238	
Total Dry Mass (g)		na	
Accumulation Rate (g/m2/day)		na	
Sand	19.0	25.2	22.1
Silt	65.0	60.7	62.8
Clay	16.0	14.1	15.1

Table 7 and Table 7. A testing error at the laboratory resulted in no total dry weight of the samples being measured and as a result the deposition rate could not be calculated.

Photo 4: Sediment Traps - 2 Tube Design

Grain size distributions of the sediment trap samples (Figure 17 and Figure 18) indicate a majority of the sediment is silt sized material with very fine and fine sand collected during the winter period.

Table 6: 2018-19 Winter Sediment Trap Monitoring Results on Stephens Lake (K-ST-02)

Sample Period	Flow 1	Settle 1	Average
Dates	October 10, 2019 to June 5, 2019		
# of Days	238		
Total Dry Mass (g)	na		
Accumulation Rate ($g/m^2/day$)	na		
Sand	19.0	25.2	22.1
Silt	65.0	60.7	62.8
Clay	16.0	14.1	15.1

Table 7: 2019 Summer Sediment Trap Monitoring Results on Stephens Lake (K-ST-02)

Sample Period	Flow 1	Settle 1	Flow 2	Settle 2	Flow 3	Settle 3	Average
Dates	June 26, 2019 to September 28, 2019						
# of Days			94				
Total Dry Mass (g)			na				
Accumulation Rate ($g/m^2/day$)			na				
Sand	2.7	4.7	7.2	4.2	0.6	4.9	4.1
Silt	72.9	72.7	70.3	72.5	73.5	70.7	72.1
Clay	24.4	22.6	22.4	23.3	25.9	24.4	23.8

Table 8: Average Sediment Trap Accumulation Rates for Site K-ST-02 (Stephens Lake)

Monitoring Period	Average Accumulate Rate ($g/m^2/day$)	Number of Days
Winter 2014-15	100	277
Summer 2015	173	72
Winter 2015-16	157	309
Summer 2016	120	68
Winter 2016-2017	225	245
Summer 2017	na	na
Winter 2017-2018	na	na
Summer 2018	49	97
Winter 2018-2019	na	238
Summer 2019	na	94

na – not available

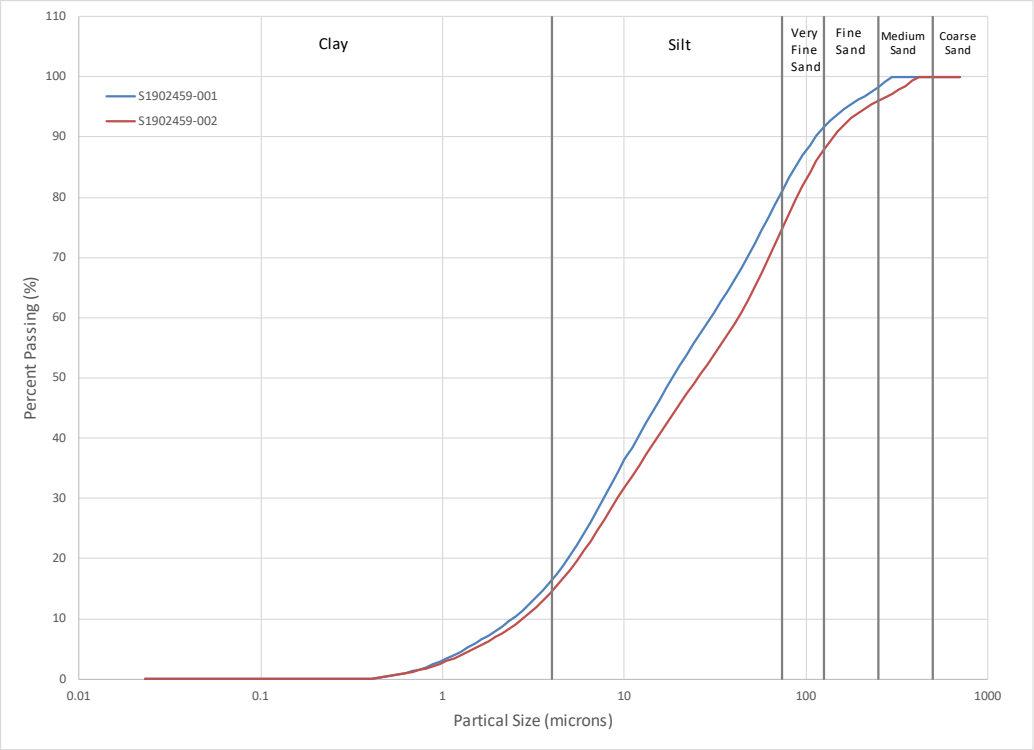


Figure 17: Sediment Trap Grain Size Distributions from 2018-19 Winter

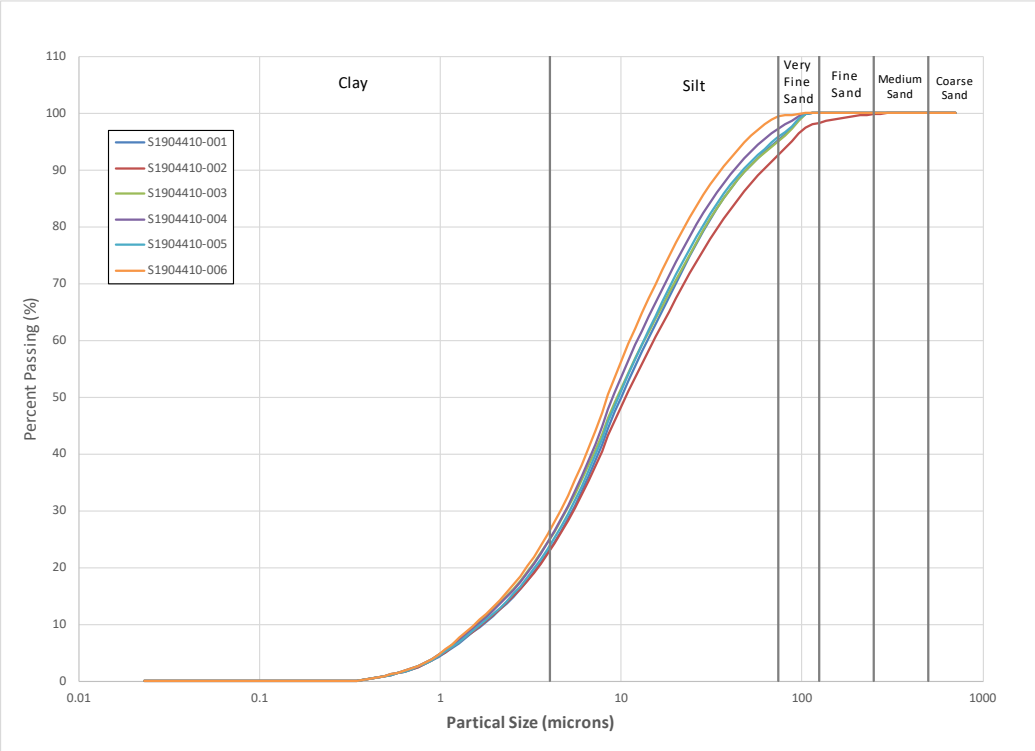
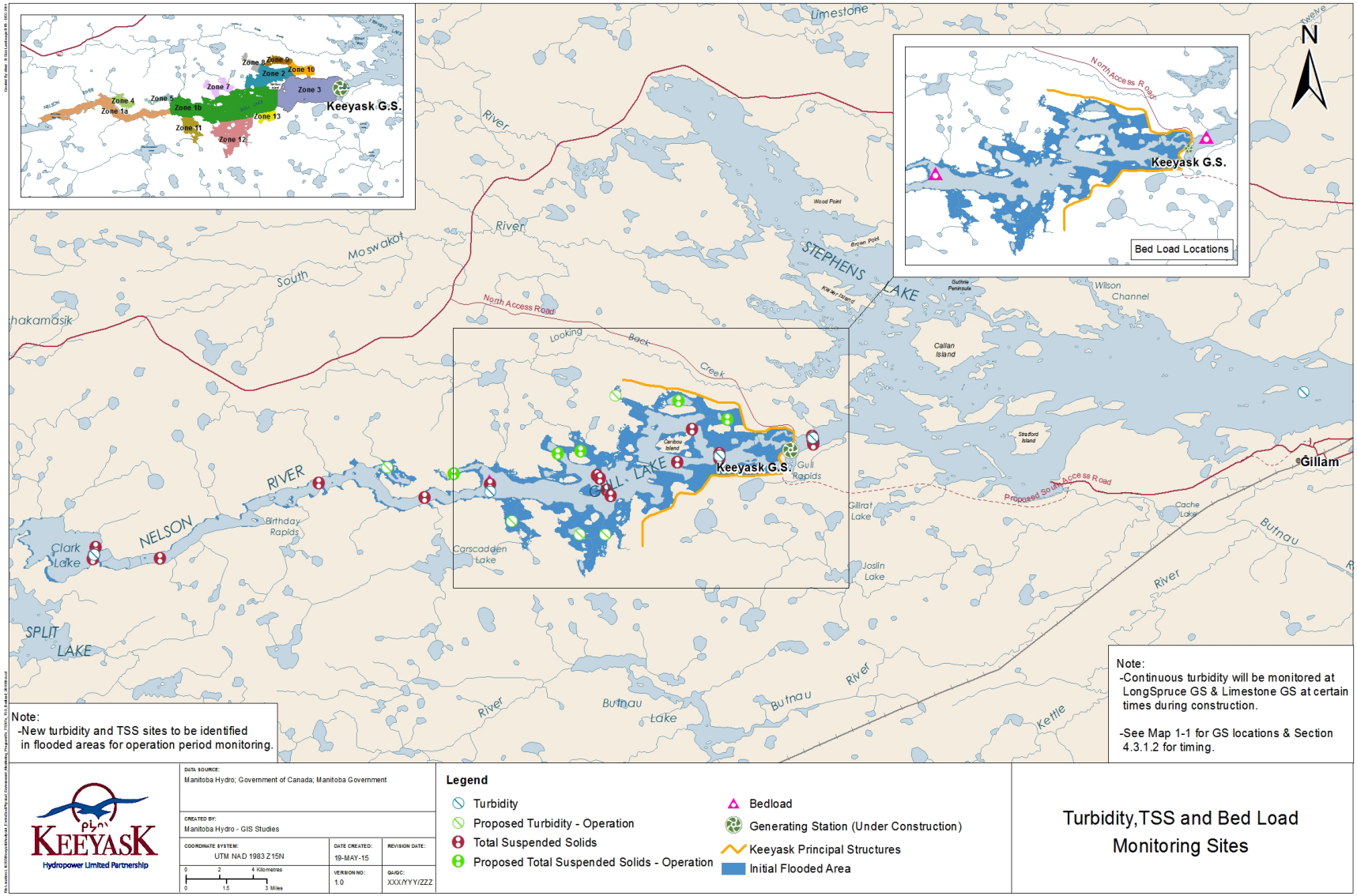


Figure 18: Sediment Trap Grain Size Distributions from 2019 Summer



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 10 sites once a month from June to September 2019, and up to 4 sites from January to April 2020. Multiple samples were typically collected at each monitoring site on each day of monitoring. 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. 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 19).

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 can occur 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 7.5-8.5 mg/L and was predominantly comprised of DOC as site averaged POC was typically 0.5 mg/l or less in those cases where TOC was greater than DOC (Figure 19). In each month the site average TOC concentrations vary by 1 mg/L or less across the sites and over the season it only varies over a range of less than 2 mg/l. The total organic carbon concentrations measured in summer 2019 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.

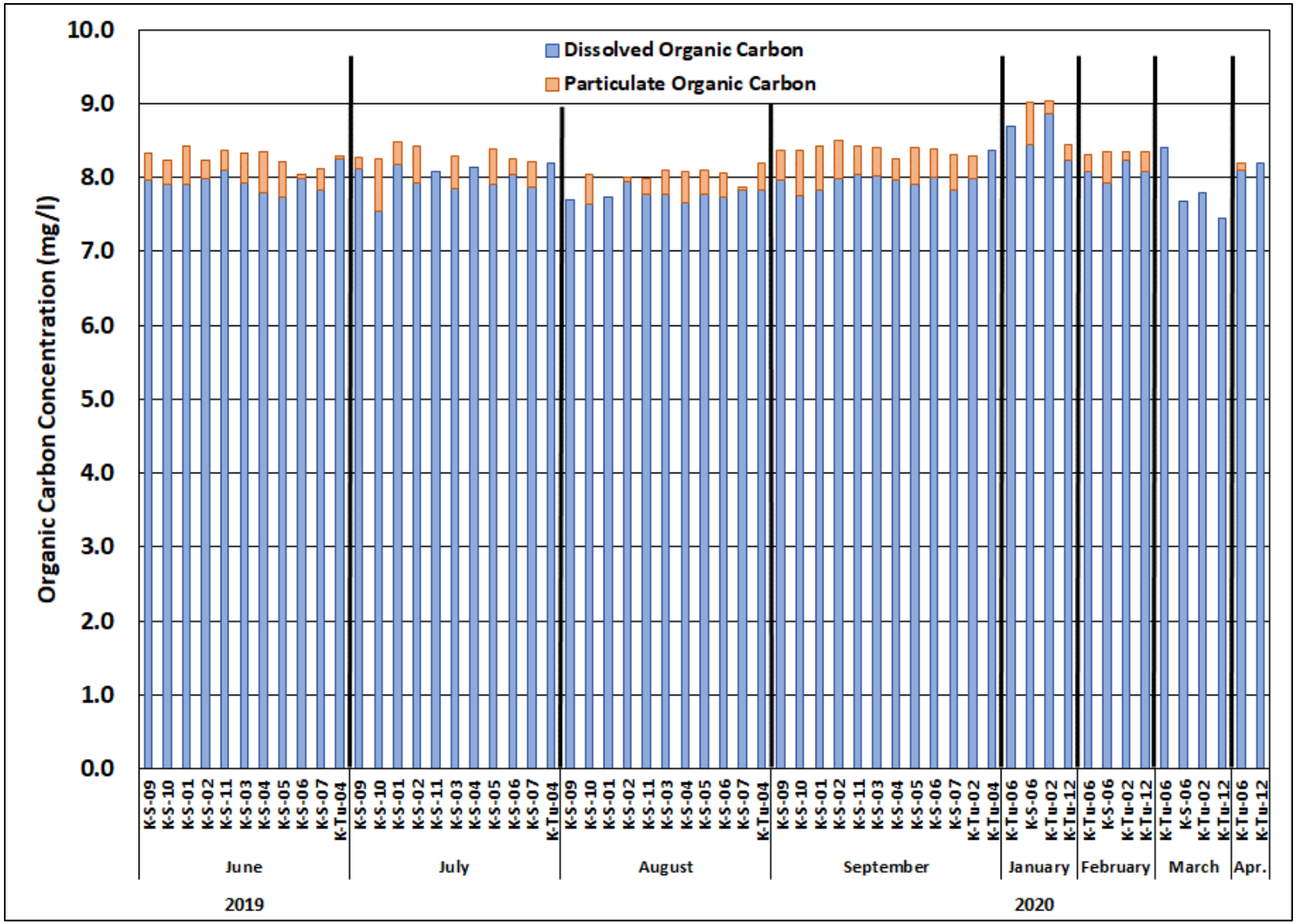


Figure 19: Summary of particulate, dissolved and total organic carbon

6.0 DISSOLVED OXYGEN

The in-situ monitoring included measuring the water temperature and dissolved oxygen (DO) concentration at the 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.

Pre-construction monitoring found that DO concentrations were typically at or near saturation concentration. During construction, prior to reservoir impoundment, the Project is not anticipated to affect DO (KHLP 2012b, Section 9). As observed in previous years, the monitoring results from summer 2019 confirmed this. In summer, DO concentrations ranged from a low of 9 mg/L in July to a high of 11.5 mg/L in June (Figure 20a). Winter concentrations were higher due to colder water temperatures, and range from about 14.8-16.5 mg/L.

Overall, the saturation levels (Figure 20b) varied from a low of about 95% to a super saturated high of 112%. In the summer, results from August and September were generally about 95%-100% saturation while June and July were somewhat higher, generally at supersaturated levels from 100%-105% saturation. The winter values indicate higher supersaturation conditions generally between 105%-112% saturation. Overall, the 2019/20 results indicate a greater amount of super-saturation than observe in previous monitoring periods. Given that hydraulic conditions were really no different than in previous years it is uncertain why a greater degree of super-saturation was observed in 2019/20: however, a 5-10% variance in measurement accuracy (biased high) could account for the difference. Regardless, the results indicate that DO conditions remain at or near saturation throughout the year as previously observed.

DO 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 21 to Figure 23). 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).

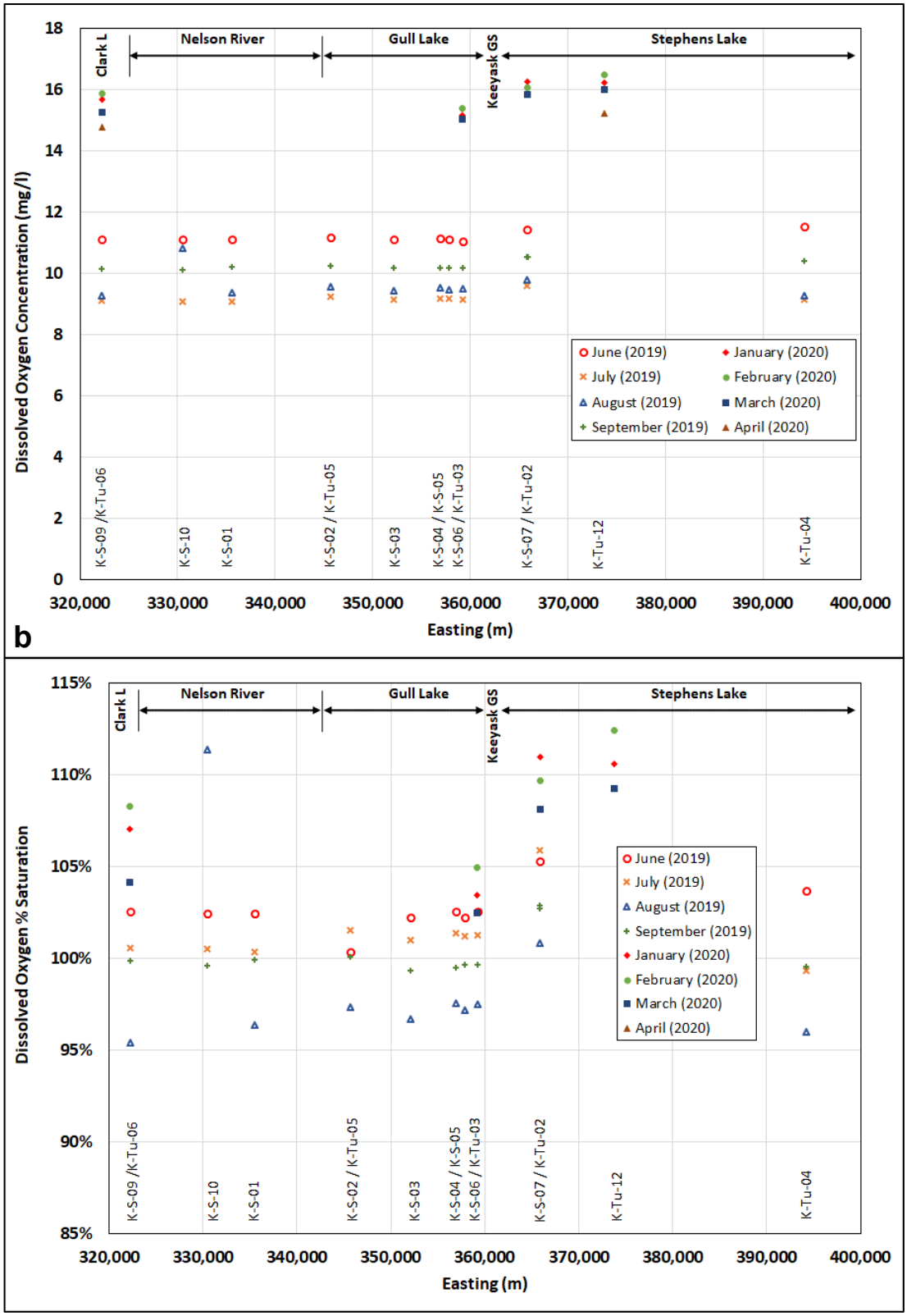


Figure 20: 2019/20 discrete monitoring results: (a) dissolved oxygen concentration (b) degree of saturation

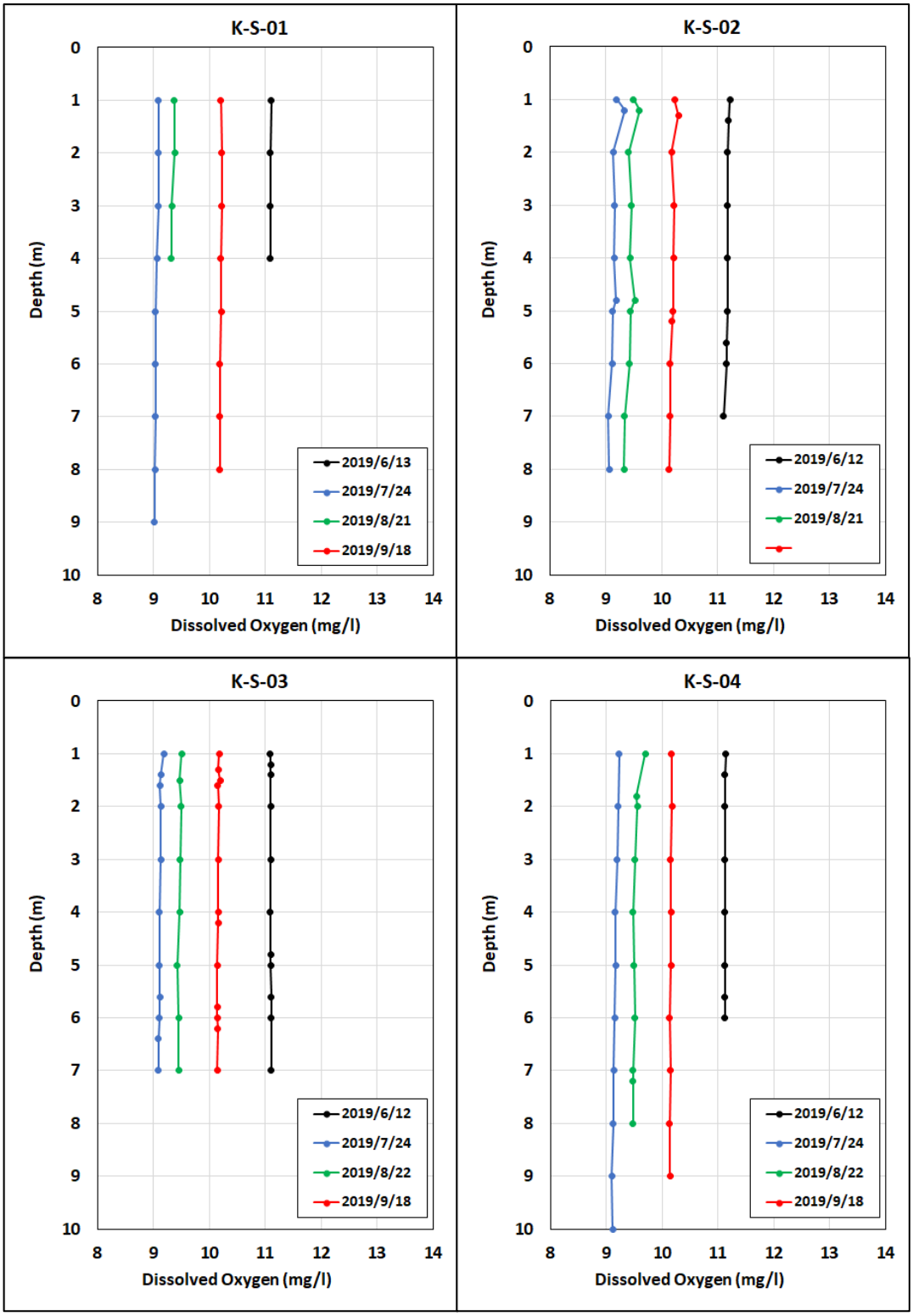


Figure 21: DO depth profiles at sites K-S-01, K-S-02, K-S-03, K-S-04

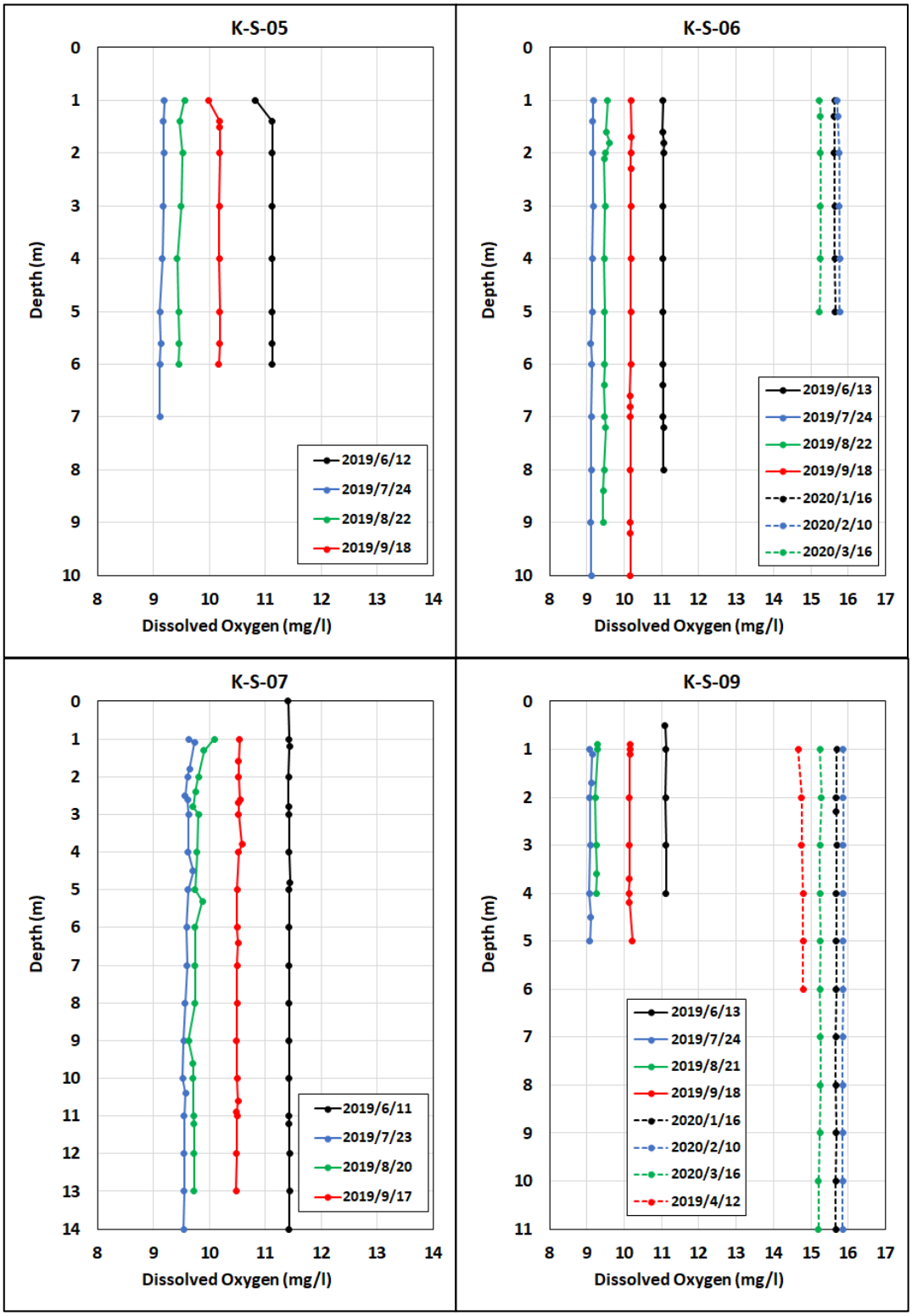


Figure 22: DO depth profiles at sites K-S-05, K-S-06, K-S-07, K-S-09

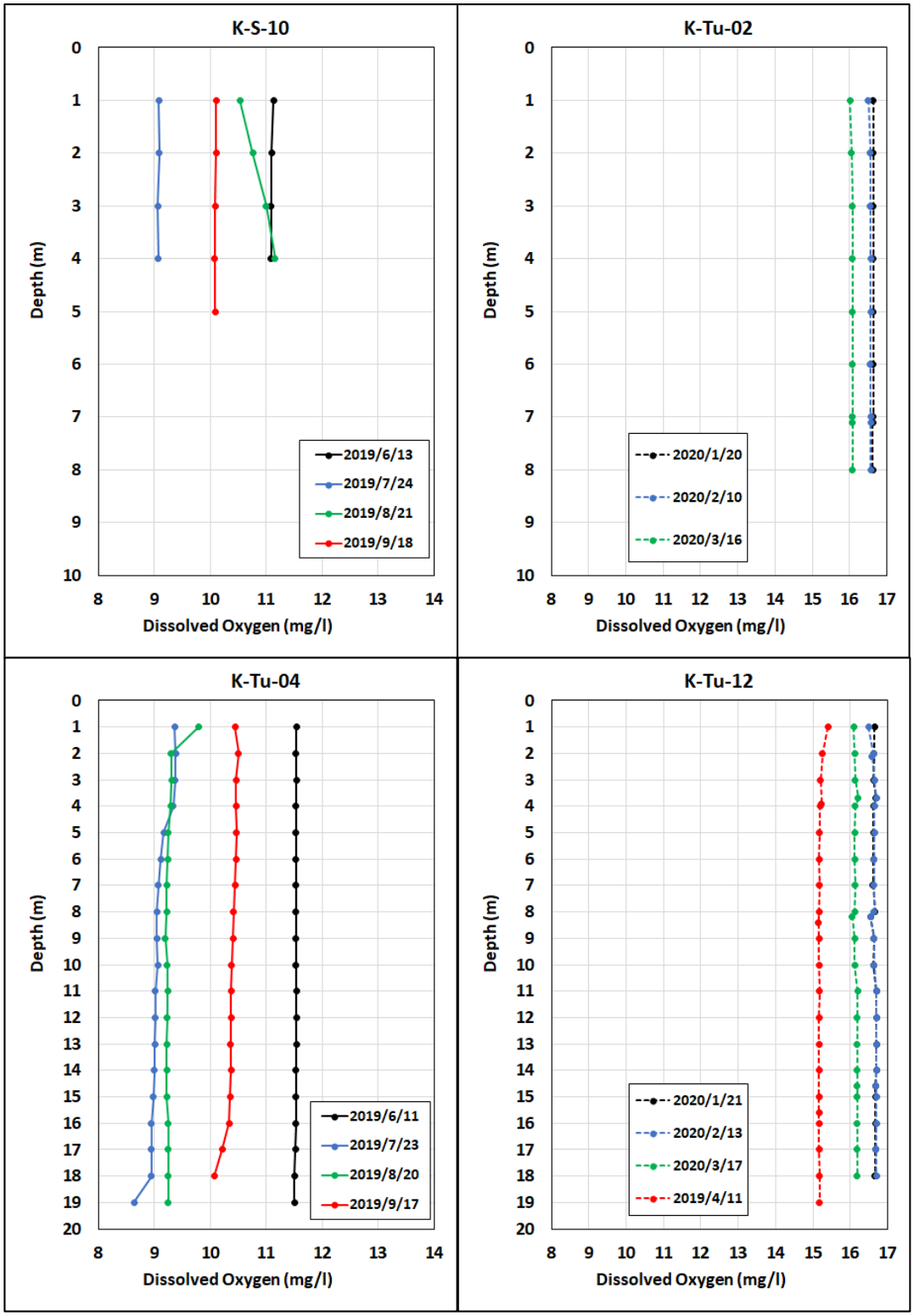


Figure 23: DO depth profiles at sites K-S-10, K-Tu-02, K-Tu-04, K-Tu-12

7.0 DEBRIS

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 5) 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 9). 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 9: 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

Photo 5: Large floating debris is removed from the water by the boat patrol team

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 PRE-PROJECT AND YEAR 1 CONSTRUCTION PERIOD

As reported in detail in the Keeyask 2014–2015 Physical Environment Monitoring Report: Year 1 Construction report (Manitoba Hydro 2015), measurement of aquatic GHG concentrations was conducted upstream, within and downstream of the planned Keeyask reservoir.

GHG concentrations were measured by discrete sampling (point-in-time measurements) and by continuous monitoring. Discrete sampling was conducted during the open water season and under the winter ice at various locations throughout the waterway to determine if aquatic GHG concentrations vary within the waterway. Continuous monitoring of CO_2 and CH_4 concentrations was conducted during the open water season at fixed locations to record seasonal and annual trends in aquatic GHG concentrations.

Reservoir GHG monitoring was conducted during the pre-Project period of 2009-2013 and during Year 1 of the Construction Period in 2014. The report concluded that in 2014, construction activities did not affect GHG aquatic concentrations or emissions. The data collected in 2014 along with data collected in the pre-Project period from 2009-2013 will provide suitable baseline data to compare against post-impoundment GHG concentrations and emissions.

8.2 2019 RESERVOIR GHG MONITORING

The 2019 reporting year marks the third year of monitoring since construction started devoted to the understanding of GHG exchange dynamics of the future Keeyask reservoir. Project details and summary results are described by Papakyriakou et al. (2020). The over-all project objective 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, GHG measurement methods followed industry best practices (i.e. UNESCO/International Hydropower Association (2010) guidance) and kept current as technology improved. The primary focus of those monitoring events was on measuring dissolved GHGs in water and their release to the atmosphere ("diffusive emissions").

Through testing of monitoring methodologies, additional 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, and back bays 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 as space and therefore are difficult to characterize.

Eddy covariance (EC) monitoring has been added to the suite of measurement techniques being used. The EC method measures GHG concentrations in the air, along with 3-dimensional wind components (vertical and 2D horizontal). This enables calculations of GHG emissions from a wide zone of influence and includes emissions released from water surfaces, bubble emissions as well as emissions originating from unflooded, partially submerged and floating peat.

The EC method is proven technology for environmental and industrial emission measurements, 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 boreal hydroelectric reservoirs.

8.2.1 METHODS

In 2019, two EC systems were deployed: one on the southern bank of the Nelson River (at 56.309614°N, 95.441758°W) referred to as the channel site, approximately 15 km upstream of the Keeyask GS; and a second beside a wetland associated with Rabbit Creek (at 56.298061°N, 95.471228°W) and referred to as the creek/wetland complex (Figure 24). The systems measured air-water exchange of greenhouse gases in an area that will become flooded after reservoir impoundment.

The creek/wetland complex site was representative of a shallow low energy creek with local drainage from the surrounding peatland. Interspersed in the channel were partially submerged peat hummocks covered in shrubs, grasses, lichens and mosses (Photo 6). This location will become a flooded back bay on flooding, increasing the area and volume of water in the area through the flooding of surrounding peatland. The southerly fetch at this site is characteristic of peatland, some of which was inundated with water, and peatland forest, and in general a more heterogeneous system than exhibited to the north of the site. Much of the surrounding peatland was cleared of trees and shrubs during the winter of 2017/18.

Sensors installed on a 4 m tall tripod at the site allowed the application of the eddy covariance technique for the measurement of CO_2 and CH_4 fluxes from the Nelson River channel and creek/wetland complexes (Photo 7, Photo 8). Measurements took place over a period between May and September 2019. Intermittent power issues at the channel site led to measurement gaps, particularly in August and September so the channel flux data set was augmented using the bulk equation for diffusive fluxes.

In addition to EC-based flux monitoring, water was sampled from shore (Photo 9) and by boat roughly every second week from the end of May to September 2019. Water was sampled at three locations (sites 1, 2 and 3) on the Nelson River, and at two locations (at the Rabbit Creek raft and near a beaver lodge adjacent to the EC tower) in the creek/wetland complex (Figure 24). The water samples were analyzed for chemical and biogeochemical parameters, including dissolved CH_4, and variables needed to calculate dissolved CO_2. In addition, the dissolved concentration of CO_2 was measured using submerged automated sensors mounted on floating rafts at a fixed location (site 3) on the Nelson River, and in Rabbit Creek (Photo 10) near to its confluence with the Nelson River (Figure 24). The measured and calculated concentrations of dissolved CO_2 and CH_4 were used to calculate CO_2 and CH_4 diffusive fluxes at the water surface. This approach is similar to that used during the baseline and first year of construction monitoring. Coupling EC monitoring with measurements of water quality, including variables that describe the water's chemistry, improves the understanding of the drivers of GHG fluxes, and allows comparison with other similar aquatic environments.

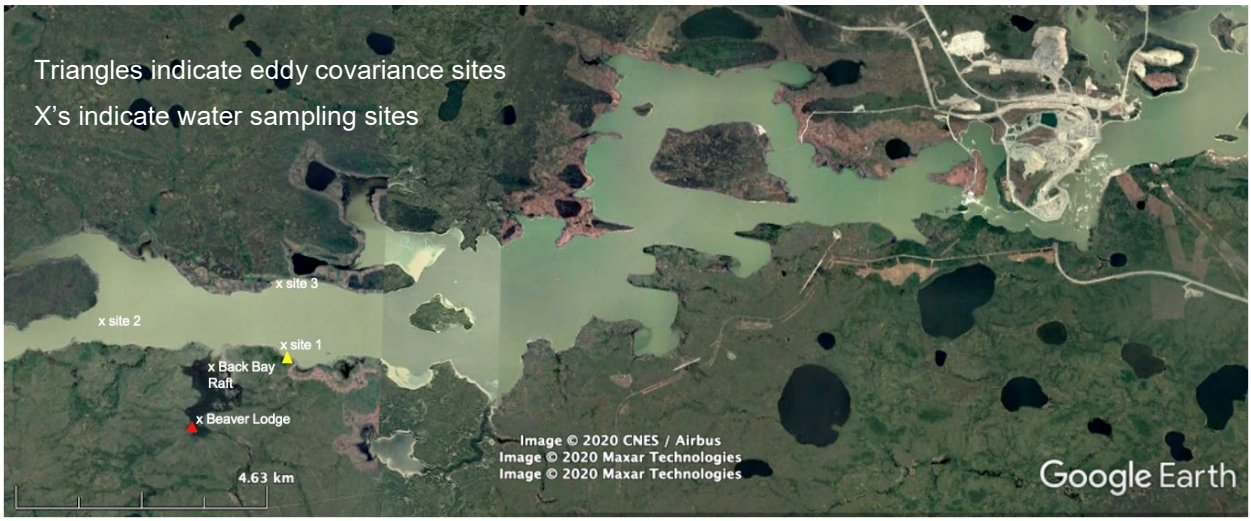
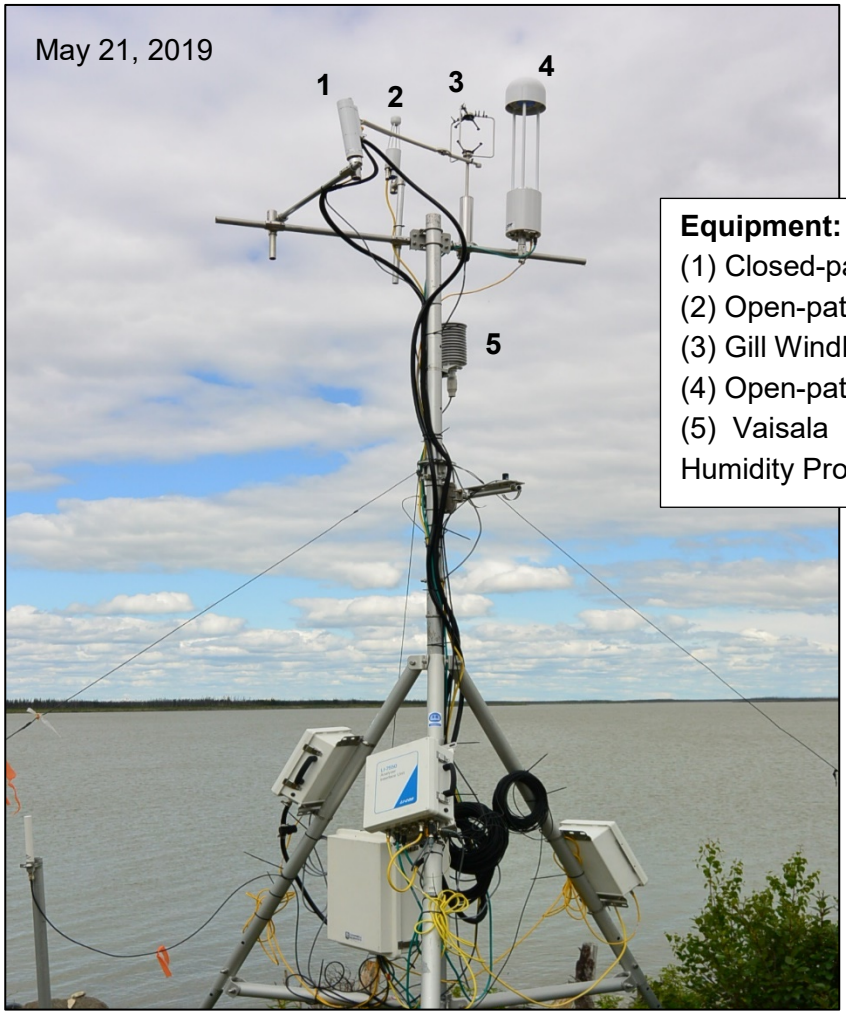


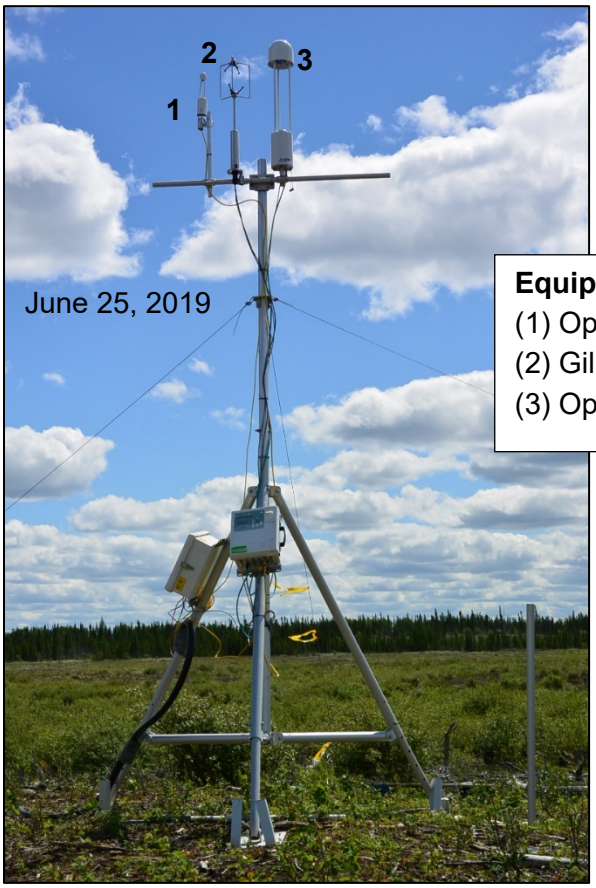
Figure 24: Locations of 2019 eddy covariance systems and water sampling sites

Photo 6: Rabbit Creek wetland facing north of the EC flux tower



Equipment:
(1) Closed-path CO_2/H_2O Analyzer LI-7200
(2) Open-path CO_2/H_2O Analyzer LI-7500
(3) Gill WindMaster Pro Sonic Anemoeter
(4) Open-path CH_4 Analyzer LI-7700
(5) Vaisala Hmp155A Temperature Relative Humidity Probe.

Photo 7: Micrometeorological tower at the channel site on the Nelson River.



Equipment:
(1) Open-path CO_2/H_2O Analyzer LI-7500
(2) Gill WindMaster Pro Sonic Anemometer
(3) Open-path CH_4 Analyzer LI-7700

Photo 8: Flux tower at the creek/wetland site along Rabbit Creek.

Photo 9: Water sampling from shore at the beaver lodge in the creek/wetland complex.

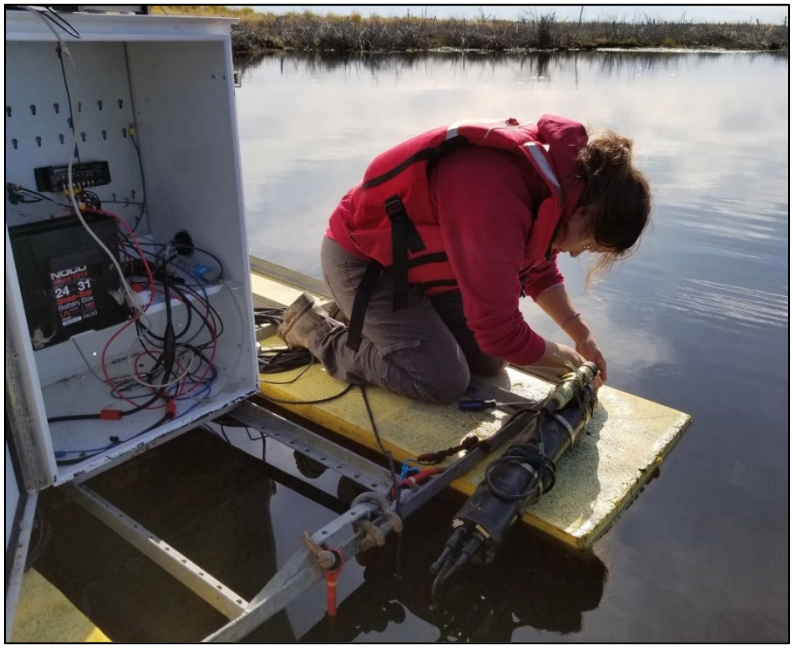


Photo 10: Raft on Rabbit Creek on which a submersible CO_2 sensor (Pro-Oceanus, Pro-CV-CO_2) was moored.

8.2.2 RESULTS

8.2.2.1 CO_2 FLUX – CHANNEL SITE

- The partial pressure of CO_2 in the Nelson River averaged 422.4 ± 26.8 µatm (± SD) and was on average only modestly supersaturated in CO_2 relative to atmospheric concentrations (ΔpCO_2 = 22.1 ± 29.4[1] µatm). The 25th to 75th percentile of pCO_2 ranged from 399.8 to 443.1 µatm with an overall median partial pressure of 424.4 µatm. Distinct periods of CO_2 under- and over-saturation relative to atmospheric levels were observed. Generally, pCO_2 in the river declined through August and September.
- Eddy covariance fluxes were of acceptable quality and footprint analysis confirmed the majority of measurements were representative of the channel proper.
- The CO_2 flux measured from the Nelson River averaged 0.64[2] ± 1.15 g $CO_2/m^2/d$. Fluxes between the 25th and 75th percentile ranged from 0.03 to 1.02 $gCO_2/m^2/d$, with a median flux of 0.44 $gCO_2/m^2/d$.

[1] mean ± SD
[2] A positive flux is an emission, directed from the surface to the atmosphere, and a negative flux denotes gas uptake.

- CO_2 emissions increased from the start of the study period (May average of 0.68 g/m^2/d), reaching a peak in July (average of 1.9 ± 1.71 gCO_2/m^2/d). Emissions then decreased in August through September and transitioned the CO_2 flux from average emission to uptake (September average of -0.07 ± 0.3 gCO_2/m^2/d). CO_2 uptake corresponds to the observation that pCO_2 in the river became undersaturated relative to the atmosphere in August and September.

8.2.2.2 CO_2 FLUX – CREEK/WETLAND COMPLEX

Under northerly wind conditions in which the air being sampled is representative of a shallow, low energy creek with local drainage from the surrounding peatland, the following conditions were observed.

- Measured partial pressure of CO_2 in water near to the confluence of Rabbit Creek and the Nelson River averaged 347.6 ± 137.7 μatm between June 26 and September 24, showing modest undersaturation relative to atmospheric CO_2 concentration. The 25th to 75th percentile of pCO_2 ranged from 237.9 to 444.5 μatm with an overall median partial pressure of 330.8 μatm.
- The footprint analysis indicates the fluxes are representative of the creek/wetland complex, and fluxes were determined to be of acceptable quality. The contributing area for measured fluxes was largely within inundated portion of the creek/wetland complex, although the flux signal from peat hummocks in the channel, and surrounding banks (e.g., Photo 6) may have been incorporated to some of the measured fluxes, despite restricting the wind direction considered in our analysis to emphasize the water signal.
- Over the field season, CO_2 was directed into the wetland complex at an average rate of -2.74 ± 5.89 gCO_2/m^2/d. The 25th to 75th percentile flux ranged from -5.97 gCO_2/m^2/d to 1.25 gCO_2/m^2/d.
- On average, CO_2 was taken into the system every month, and the rate of uptake increased from May (-1.06 ± 3.04 gCO_2/m^2/d) and peaked in August (-5.02 ± 7.11 gCO_2/m^2/d).

Under southerly wind conditions in which the air being sampled is of characteristic of peatland, some of which was inundated with water, and peatland forest, the following results were observed.

- Modest CO_2 uptake (-0.84 ± 11.03 gCO_2/m^2/d) was on average associated with southerly wind over the field season. The 25th to 75th percentile flux ranged from -7.83 gCO_2/m^2/d to 6.88 gCO_2/m^2/d.
- All months except for September showed an average CO_2 uptake. In September the average rate of CO_2 emission was 3.5 ±5.97 gCO_2/m^2/d. Peak CO_2 uptake (on average) occurred in July (-5.48 ± 13.31 gCO_2/m^2/d).

8.2.2.3 METHANE FLUX – CHANNEL SITE

- The partial pressure of CH_4 (pCH_4) in Nelson River water averaged 20.4 ± 6.2 μatm over the field experiment, meaning the channel was over-saturated in CH_4 relative to the average measured atmospheric concentration (pCH_{4atm} of 1.86 μatm). The 25th and 75th percentile concentrations were 17.3 μatm and 23.4 μatm, respectively.
- The majority of measured CH_4 fluxes were below the detection limit of the eddy covariance system, which is estimated to be ± 6.91 $mgCH_4/m^2/d$ from zero. Within this range it is not possible to confidently discriminate the flux from zero.
- The diffusive CH_4 flux that was estimated using the bulk flux equation confirms that CH_4 emissions were small, corroborating EC measurements. The diffusive emission averaged 3.2 ± 1.1 $mgCH_4/m^2/d$. The 25th and 75th percentile diffusive fluxes were 2.44 $mgCH_4/m^2/d$ and 3.89 $mgCH_4/m^2/d$, respectively. This approach is similar to that used during the baseline and first year of construction monitoring.

8.2.2.4 METHANE FLUX – CREEK/WETLAND COMPLEX

Under conditions with north winds, the following effects were observed.

- The pCH_4 in water near to the confluence of Rabbit Creek and the Nelson River averaged 457.7 ± 129 μatm, far exceeding the atmospheric concentration mentioned above. The 25th and 75th percentile concentrations were 391.7 μatm and 530.4 μatm respectively. Higher concentrations were observed at the monitoring site upstream of the wetland (the 'lodge' site), where water was shallower and presumably with a longer residence time. At this site, pCH_4 averaged 827.5 ± 326.7 μatm, highlighting both that the wetland was a CH_4 hotspot, and there existed a high degree of variability in dissolved CH_4 across the creek/wetland complex.
- Despite the water being heavily supersaturated in CH_4, the CH_4 fluxes from the eddy covariance footprint were on average small. Over the monitoring program the eddy flux averaged 5.54 ± 9.7 $mgCH_4/m^2/d$. Many measurements could not be confidently discriminated from zero. The 50th, 75th and 90th percentile fluxes were 2.77, 6.9 and 15.2 $mgCH_4/m^2/d$, respectively. The largest mean monthly emissions were observed in July (8.32 ± 12.47 $mgCH_4/m^2/d$).
- The EC footprint was relatively large. While not all of the contributing area for all of the EC measurements was water, when the area transitions into a back bay after flooding, a greater proportion of the EC footprint will be inundated, and thus CH_4 fluxes measured in 2019 will provide a good basis for comparison to emission characteristics in the post flood environment. By way of comparison, the mean diffusive flux from creek water at the confluence of Rabbit Creek and the Nelson River was 17.3 ± 19.2 $mgCH_4/m^2/d$ over the experiment, while those measured upstream within the wetland were nearly twice as large at 27.34 ± 17.68 $mgCH_4/m^2/d$. Diffusive fluxes were calculated using the bulk equation.

For periods when predominantly south winds occurred the following results were observed.

- The site's southerly fetch was also associated with small CH_4 emissions (5.54 ± 5.54 mg $CH_4/m^2/d$), and again, many measurements could not be confidently discriminated from measurement noise. The 75th and 90th percentile fluxes were 6.91 and 11.09 mg$CH_4/m^2/d$, respectively. Fluxes from the terrestrially dominating EC fetch to the south were smaller than measured for north winds, indicating that the creek/wetland emitted CH_4 at a rate greater than the surrounding peatland.
- The largest average monthly emissions occurred in August (6.91 ± 6.91 mg $CH_4/m^2/d$).

8.2.3 SUMMARY OF 2019 AND PREVIOUS RESERVOIR GHG MONITORING

Monitoring results from the 2019 monitoring period were in general agreement with previous Keeyask/Gull Lake monitoring and within ranges of published concentrations of dissolved gas and greenhouse gas fluxes for rivers and wetlands.

A summary of GHG partial pressures in river water among the 2019, 2009-13, and 2014 monitoring programs is provided in Table 1. Over the different programs there were differences in sampling location, monitoring dates and duration, none-the-less it is useful to see how values compared. In the channel, and in general, lower central values (mean and median) were observed for pCO_2 in 2019, whereas median pCH_4 was similar. The reported pCO_2 had a smaller range, lower peak concentration and lower central values than observed prior to 2015. The central values of pCO_2 for Rabbit Creek are slightly lower than observed for Gull Lake prior to 2015, however, they were higher than observed for the channel in 2019. On the other hand, pCH_4 in the creek water was much higher than reported in Gull Lake prior to 2015, and higher than observed in the channel. The pCO_2 calculated in the shallow upstream water of Rabbit Creek is higher than observed by automated monitoring from 2009 to 2019, however it is not obviously different than values reported for 2014 in Gull Lake. The central values for pCH_4 at this site are higher than previously reported from any of the GHG monitoring between 2009 and 2019.

A preliminary comparison of CO_2 fluxes among monitoring programs is provided below.

- Average channel CO_2 fluxes in 2019 were smaller than reported for the channel in 2018. In both years eddy covariance was used. The average flux in 2018 was 1.9 ± 1.3 g $CO_2/m^2/d$ as compared to with 0.65 ± 1.1 g $CO_2/m^2/d$ in 2019.
- Average channel fluxes of CO_2 in 2019 were smaller (0.65 ± 1.1 g $CO_2/m^2/d$) than those measured by floating chambers from Gull Lake during the 2009-13 and 2014 pre- and construction phases of Keeyask (1.0 g $CO_2/m^2/d$ and 2.2 g $CO_2/m^2/d$, respectively).
- Average CO_2 fluxes in 2018, using eddy covariance (1.9 ± 1.3 g $CO_2/m^2/d$), were similar to those reported for 2014 using chamber sampling (2.2 g $CO_2/m^2/d$).
- Average fluxes estimated using chamber sampling differed by a factor of two between the 2009-13 (1.0 g $CO_2/m^2/d$) and 2014 (2.2 g $CO_2/m^2/d$) monitoring programs.

Table 10: Summary of GHG partial pressures from automated monitoring and discrete sampling campaigns for pre-flooding (2009-13) and construction conditions (2014 and 2019)

Parameter	Gull Lake 2009-13*		Gull Lake 2014*		Keeyask 2019		
	Automated	Field Campaign	Automated	Field Campaign	Channel**	Creek**	Lodge***
pCO_2 (µatm)							
Min	331	11	398	488	371	130	539
Max	753	731	724	845	533	775	905
Median	515	521	551	678	424	331	673
Mean	507	507	549	697	422	458	689
St Dev.	-	-	-	-	27	138	127
pCH_4 (µatm)							
Min	2	6	4	19	10	282	428
Max	42	1,050	27	657	31	647	1160
Median	18	27	15	26	21	440	764
Mean	18	75	16	137	20	457	805
St Dev.	-	-	-	-	6	129	297

* Values for 2009-13, and 2014 were taken from the 2014 Keeyask Technical Summary (046-2280-5_1-EN-R-0001-01.doc)

** For pCO_2, automated and gap filled with calculated (discrete samples), where available, while pCH4 was measured analytically (discrete samples)

*** pCO_2 was calculated, while pCH4 was measured, both based on discrete water samples.

A preliminary comparison of CH_4 fluxes among monitoring programs is provided below.

- Median diffusive CH_4 fluxes were similar between the 2018 and 2019 programs (3.2 versus 5.01 mg$CH_4/m^2/d$), while the difference in mean fluxes was more pronounced (3.2 ± 1 mg $CH_4/m^2/d$ as compared to with 8.2 ± 9 mg $CH_4/m^2/d$). There was pronounced variation in the 2018 flux data set (standard deviation of ± 9 mg $CH_4/m^2/d$).
- Median diffusive fluxes of CH_4 from 2018 and 2019 programs (3.0 versus 5.0 mg $CH_4/m^2/d$) were similar to chamber flux values reported between 2009-13 (5 mg $CH_4/m^2/d$ and 2014 (7 mg $CH_4/m^2/d$).

There appears to be considerable inter-annual variation in GHG exchange from the river and future monitoring will continue to add to the understanding of the observed variability.

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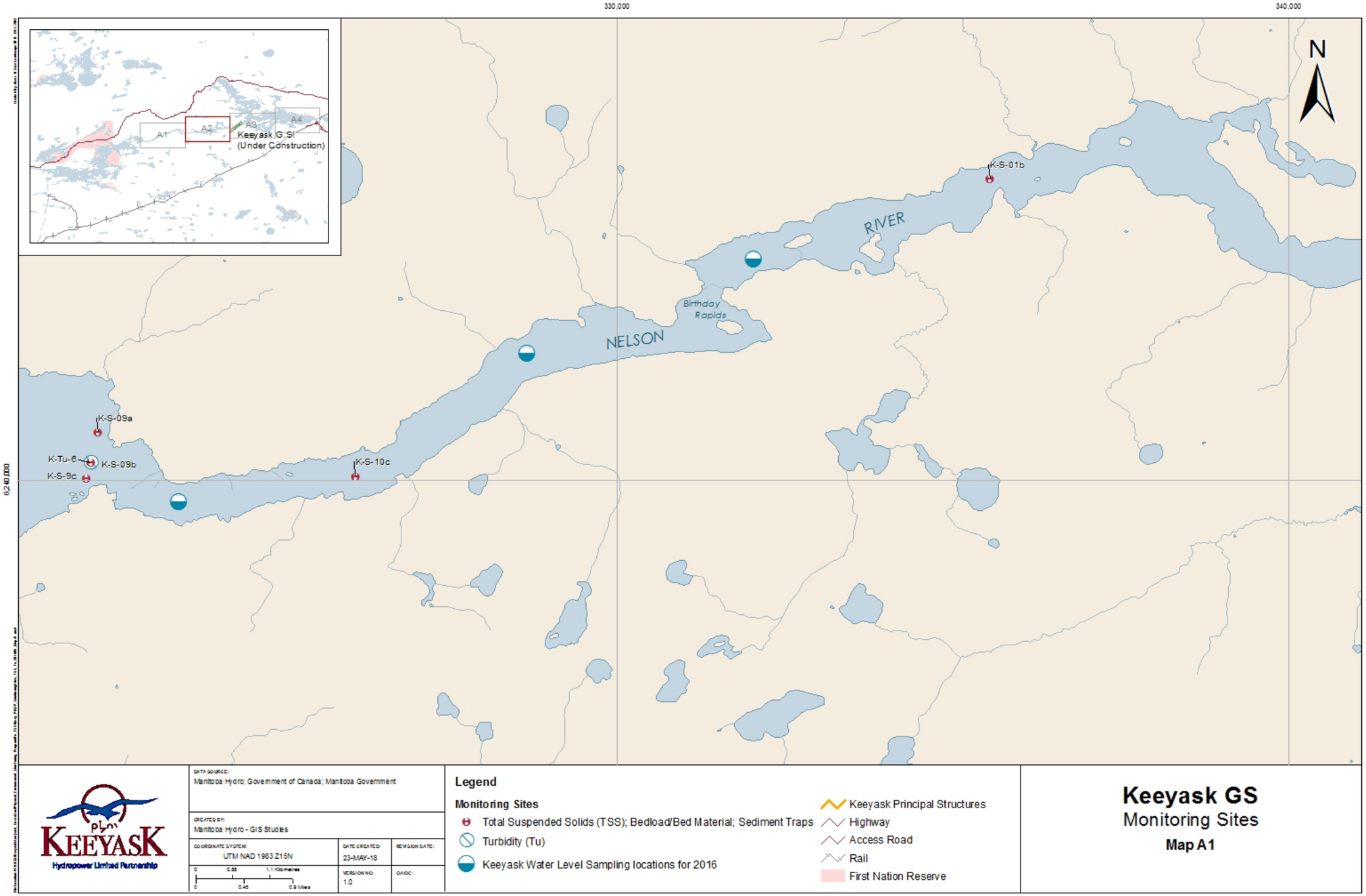
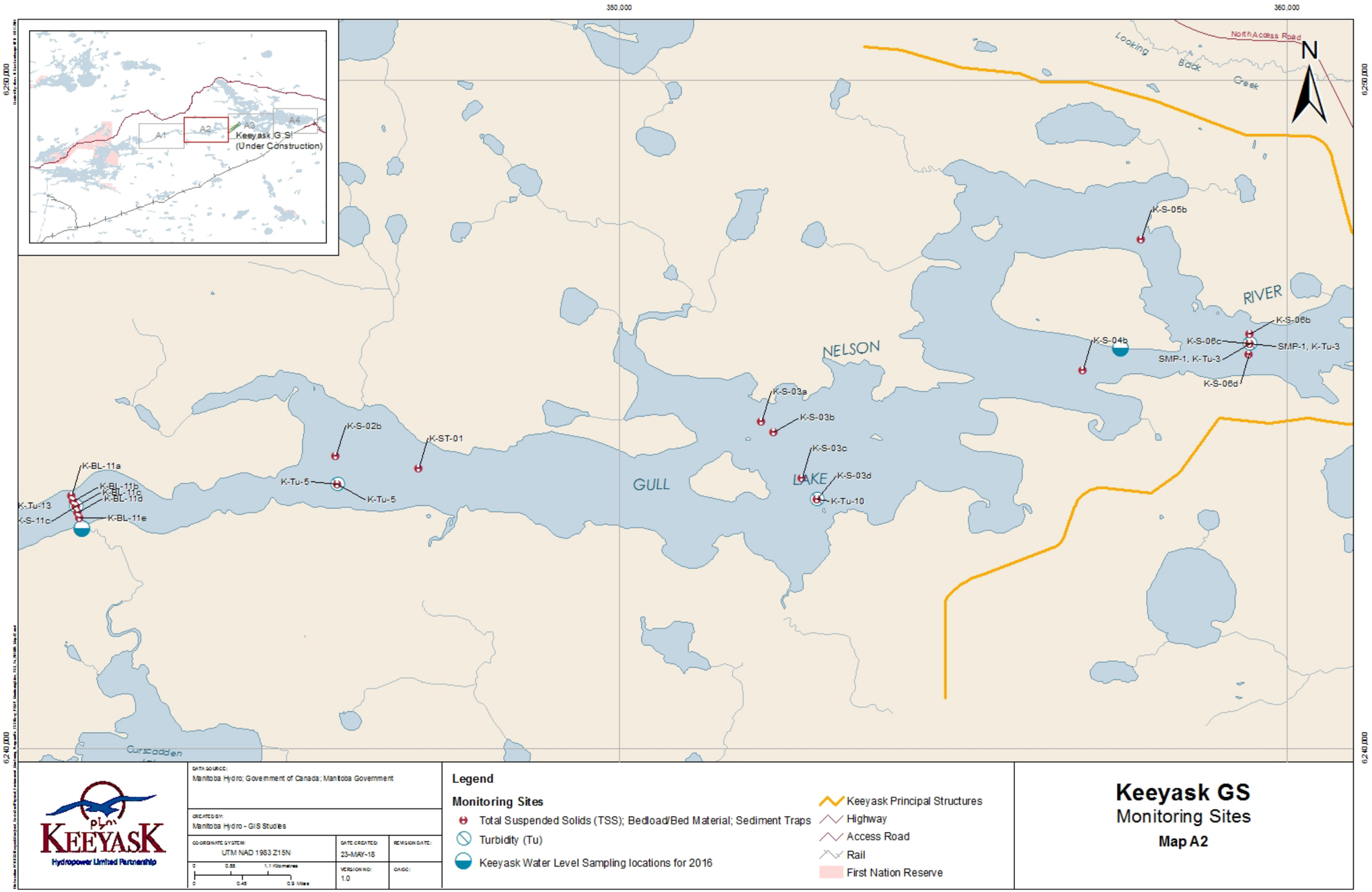
APPENDIX 1:
DETAILED MAPS OF TURBIDITY AND TSS MONITORING SITES


330,000
340,000
6240,000
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:
VERSION NO:
1.0
CHECK:
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
A1
A2
A3
A4
Keeyask GS
(Under Construction)
North Access Road
Looking Back Creek
N
RIVER
NELSON
GULL
LAKE
Curscadden
K-S-05b
K-S-06b
K-S-06c
K-S-06d
K-S-04b
SMP-1, K-Tu-3
K-S-03a
K-S-03b
K-S-03c
K-S-03d
K-Tu-10
K-S-02b
K-ST-01
K-Tu-5
K-BL-11a
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K-BL-11c
K-BL-11d
K-BL-11e
K-Tu-13
K-S-11c
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

DATA SOURCE:
Manitoba Hydro; Government of Canada; Manitoba Government

CREATED BY:
Manitoba Hydro - GIS Studies

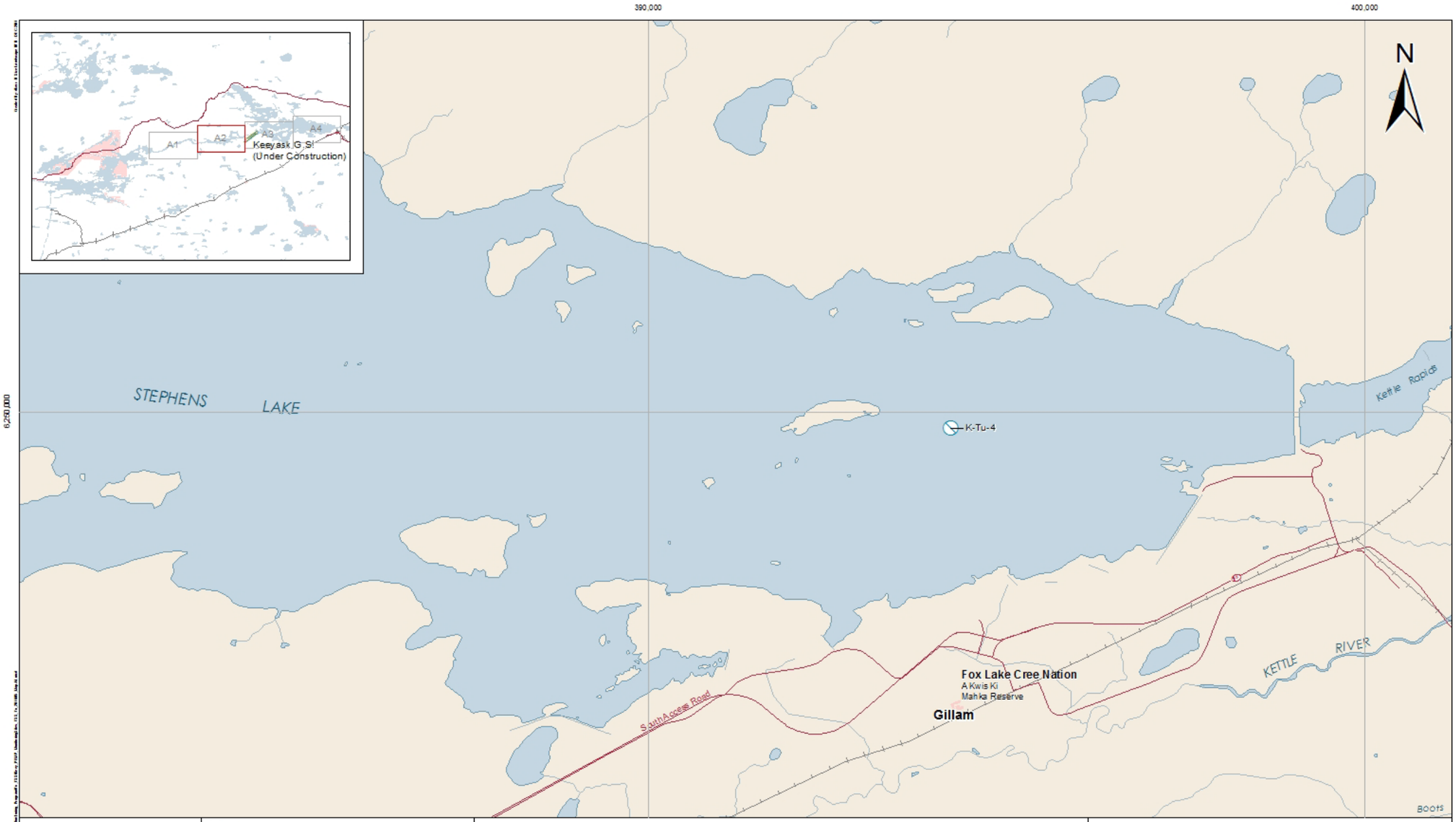
COORDINATE SYSTEM:	DATE CREATED:	REVISION DATE:
UTM NAD 1983 Z15N	23-MAY-18	
0 0.55 1.1 Kilometers / 0 0.45 0.9 Miles	VERSION NO: 1.0	QA/QC:

Legend

Monitoring Sites

- Total Suspended Solids (TSS); Bedload/Bed Material; Sediment Traps
- Turbidity (Tu)
- 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

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

CHKD:

0 0.55 1.1 Kilometres

0 0.45 0.9 Miles

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