Keeyask Generation Project

Physical Environment Monitoring Plan

Physical Environment Monitoring Report

PEMP-2024-01

KEEYASK

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

2023 - 2024

KEEYASK GENERATION PROJECT

PHYSICAL ENVIRONMENT MONITORING PLAN

REPORT #PEMP-2024-01

2023-2024 PHYSICAL ENVIRONMENT MONITORING REPORT: YEAR 3 OPERATION

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 the partner First Nations 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 (EIS).

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 reservoir. This report describes the physical environment monitoring activities and results for the 2023/24 monitoring period.

Water and Ice Regime

The water and ice monitoring parameters include water levels, water depth, water velocity, and ice cover. 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.

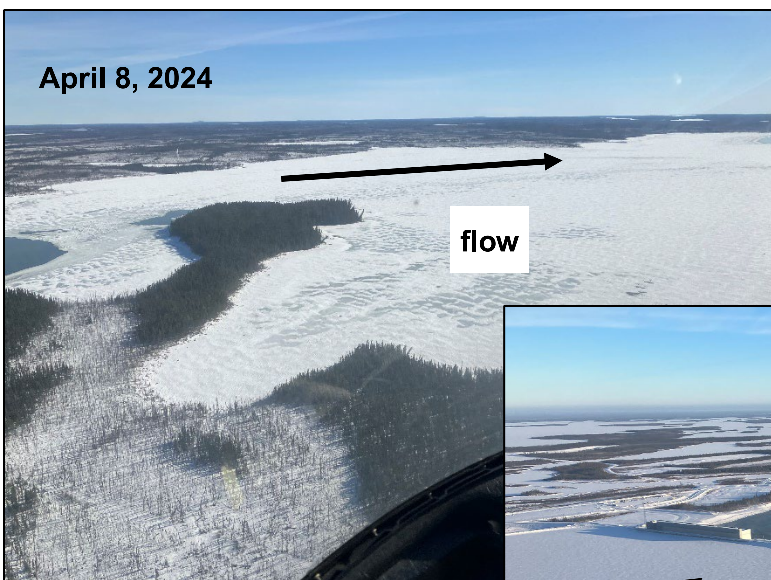
The seasonal mean daily discharge of 4,048 m^3/s during the 2022/23 winter season wasabove average, resulting from persistence of high system flows from summer 2022. Flow declined in spring 2023 but was still above average from April to June. With dry conditions in the basin, the flow steadily decreased from about median in July 2023 to below the 5th percentile by November 2023 when it reached a minimum of about 1,851 m^3/s. The summer mean flow of about 3,032 m^3/s was below the long-term average of about 3,300 m^3/s. Where summer 2022 was very wet (Manitoba Hydro 2023), summer 2023 trended toward very dry conditions. The low flows persisted into winter 2023/24, varying between the 5th and 25th percentile levels, higher than the low flow at the start of the season in November.

The 2023/24 monitoring period is the third year of Keeyask GS operation in which the levels on Gull Lake could be regulated within the operating range between 158 and 159 m asl. Through the entire period water levels were held between 158.1 and 159.1 m on Gull Lake (station 05UF596 at Caribou Island). As usual in winter/spring, water levels upstream of Gull Lake were higher due to ice effects compared with similar flows in open water conditions. Upstream levels declined over the summer in conjunction with decreasing flows up to the beginning of November. Due to low flow conditions, the water level difference between the Keeyask dam and the foot of Birthday

Rapids about 33 km upstream was only about 0.6 m at the start of summer and the decreased to about 0.1 m by November. Starting in early August, the Keeyask reservoir levels varied daily as the system operated in a peaking mode of operation where levels were drawn down during the day when more flow was passed through the powerhouse and levels were raised at night when less flow was passed.

Ice formation began in November and water levels rose due to ice effects as well as increasing flow on the Nelson River. Levels increased about 2-2.5 m at Birthday Rapids and below Clark Lake while Clark and Split lakes rose about 1 m due to ice and higher flow. Levels varied over winter due to variations in flow and ice effects. Water level increases were not as large as changes observed previously before and after the Keeyask project at higher flows and different ice conditions.

In winter, ice effects may increase water levels on Split and Clark lakes by about 0.6-1.2 m above open water levels (KHLP 2012b). Monitoring indicated levels on these lakes increased about 1.1 m in winter between the beginning of November and February due to ice effects as well as flows increasing from about 1,900 m^3/s to as much as roughly 2,900 m^3/s. Water levels were about 0.6 m higher in winter compared with summer for the same flows, which is due to ice effects. The increase over winter is consistent with expectations and ice effects observed prior to Keeyask development. As observed previously, the project does not affect Clark or Split lake levels during open water conditions, and a review of the hourly water level in winter 2023/24 did not show any indication of effects from Keeyask operation on either lake.



Clark Lake ice cover

Keeyask dam

Ice monitoring is done using satellite imagery and photographs taken along the length of the study area during monthly field trips. Gull Lake developed an ice cover between November 1-6 and advanced to Birthday Rapids November 24. Due to low flow conditions the cover advanced through Birthday Rapids in early December and by the 19th had advanced up to its maximum extent about 6.5 km upstream of Birthday Rapids, similar to previous years. Low flows also allowed the ice cover to bridge on Clark Lake so that by January 5 much of the lake was covered. More commonly the lake will have an unfrozen lead between Split Lake and the exit of Clark Lake, but it has frozen over in the past under low flow conditions. The ice cover started to thin in early April due to warm conditions and by May 17, 2023, Gull Lake was ice free.

Water velocity monitoring was also done at 52 transect locations from upstream of Birthday Rapids to the entrance of Stephens Lake just downstream of the GS. The Keeyask PEMP committed to velocity monitoring under low, average, and high flow conditions. The monitoring in 2023 obtained velocities under near-average flows conditions while the 2021 and 2022 monitoring captured low- and high-flow conditions respectively. Monitoring results have shown velocities to be generally consistent with expectations based on hydraulic modeling and predictions in the Keeyask EIS. Since velocity has been measured under low, average, and high flow conditions, this monitoring will not be required under the PEMP in the future.

Sedimentation

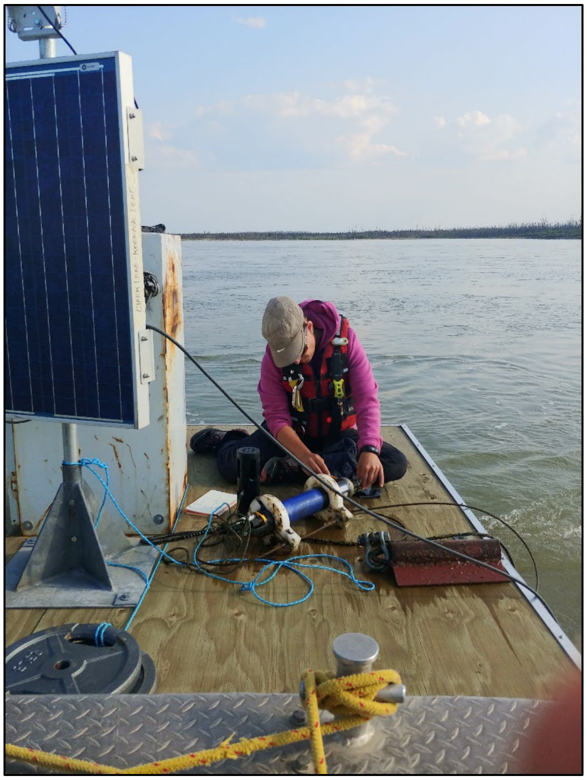
Sedimentation monitoring includes studying how sediment is carried (sediment transport) in the water and where it is deposited. It involves collecting water samples to measure the amount of sediment suspended in the water (done in a laboratory), using electronic devices that continuously measure turbidity (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 sediment being transported that could settle out (deposit) near areas of potentially important sturgeon habitat.

Winter monitoring in 2022/23 included continuous turbidity and discrete suspended sediment monitoring at four sites from Clark Lake to just downstream of the Keeyask GS from January to April. Results showed levels in Gull Lake and just downstream were relatively consistent between the two sites and were about 1-2 turbidity units higher than the upstream Clark Lake site. As in previous years, turbidity was higher in January and steadily decreased until April. Average winter turbidity was within the range observed the previous 8 winter seasons but somewhat lower than winter 2021/22. Total suspended sediment (TSS) samples were collected approximately monthly at the continuous turbidity sites and results found there was little suspended sediment in the water. Average TSS was estimated at about 1 mg/l, which is below the laboratory detection limit of 2 mg/l because values that were reported below the detection limit were assumed to be 1 mg/l for analysis purposes. This is the lowest observed winter suspended sediment for Keeyask.

Collecting Water Samples for Sedimentation Monitoring

In the 2023 summer period (Jun–Sep), turbidity was continuously monitored at 5 mainstem sites between Clark Lake and the Kettle GS as well as six back bay sites, including one on Stephens Lake. Overall, average continuous turbidity in 2023 on the mainstem was the second lowest of the years recorded (2007-2009, 2014-2023), while 2022 was the lowest despite having near record high flows. Turbidity in Keeyask back bays was much more variable than on the mainstem with periodic peaks likely associated with higher winds. More protected back bays generally had lower turbidity than the mainstem while other sites were comparable with mainstem levels. The Stephens Lake back bay site usually has higher turbidity than Keeyask back bays because of its wind exposure but, while it was higher early in summer, it was more comparable with the Keeyask sites in the latter part of summer.

Four times in summer 2023, water samples were collected at sites to test for TSS concentrations. TSS was very low overall and had a small range of variation at mainstem sites. For mainstem locations the highest average TSS was only about 3 mg/l while the average concentration was about 1 mg/l. The results suggest there was virtually no suspended sediment being transported in the river in summer 2023. Average concentrations were somewhat higher at back bay sites with a maximum of about 7.5 mg/l, but the majority of results were less than 2 mg/l. The higher TSS at back bays is likely due to wind stirring up sediment. These concentrations are significantly lower than the overall averages of about 15 mg/l prior to construction and 13 mg/l during construction. TSS concentrations displayed little change from Clark Lake upstream to just downstream of the Keeyask GS, indicating no increase due to erosion of Keeyask shorelines or decrease due to deposition as water passed through the reservoir. The processes causing low TSS are occurring upstream of the limit of the Keeyask open water hydraulic zone of influence (which is located a few kilometres downstream of Clark Lake), which indicates the decrease in TSS in the Nelson River is not due to Keeyask. The probable cause is the proliferation of zebra mussels in the Nelson River.



Continuous Turbidity Monitoring Equipment – Setting Up a Turbidity Sensor

Sediment traps have been deployed at a site downstream of Keeyask since the beginning of construction and upstream at the entrance of Gull Lake since 2020: the upstream site was not monitored during construction because equipment kept getting displaced and lost due to strong currents. Monitoring results suggest less sediment was being collected in the traps during operation, and what was being collected tended toward being finer (more clay or silt) than previously. This may be due in part to the project but the impact of zebra mussels is also a likely factor changing not only the quantity of sediment in the river but also the nature of sediment available to be collected.

Similarly, substrate upstream and downstream of the GS appears suggests more recent deposition of finer sediments and less course sediment in the past couple of years. This would be expected for the reservoir due to reduced flow velocities allowing for finer sediments to deposit. However, the nature of the sediment available to deposit is also likely being influenced by the proliferation of zebra mussels in the Nelson River.

Dissolved Oxygen (DO)

Dissolved Oxygen (DO) monitoring was performed at four mainstem sites in winter 2022/23 (Jan-Apr). Results showed DO to be at or near the saturation concentration (i.e., the maximum DO the water will usually hold depending on water temperature) at mainstem sites, including immediately downstream of the GS. This is consistent with expectation for winter DO on the mainstem.

DO monitoring in the 2023 open water season included continuous monitoring at five mainstem sites and in six back bays, where two mainstem sites and one back bay site were located on Stephens Lake. The back bay sites used two DO sensors with one near the water surface and one near the bottom of the water to check for differences between the top and bottom. As in previous years, the mainstem DO remained high. Elevated DO was observed downstream due to operation of the spillway where turbulent flow entrains more oxygen in the water. At back bay sites the surface DO remained high most of the time. Because of reduced wind mixing, the bottom DO dropped to moderate levels periodically at most of the back bay locations and a few times it dropped to low levels at several sites. But, unlike previous years, none of the sites experienced periods where there was no DO. Discrete DO measurement through the depth of the water from top to bottom also found typically high levels of DO.

Total Dissolved Gas Pressure

Total Dissolved Gas Pressure (TGP) was measured for the first time during operation. Surface water in rivers and lakes always contains dissolved gases such as oxygen, nitrogen, and carbon dioxide. The amount of dissolved gas in the water increases or decreases depending on temperature and processes like gas exchange with the atmosphere and biological activity, but excess gas can get dissolved into the water when there is very turbulent flow like at a water fall or downstream of a spillway. If TGP is too high it can be a potential concern because excess gas pressure can cause harmful effects to fish such as bulging eyes or, in the worst case, death. Generally, where water regulation might increase TGP, it is desired that TGP would remain below about 120% of saturationto mitigate the risk of high TGP effects (water naturally tries to maintain 100% saturation). Monitoring was done using a handheld probe at transects across the river width extending to about 5.5 km downstream of the GS. The results showed TDG ranged between 97.9% - 100.9% saturation. It was generally expected that TDG saturation would be near 100% under the reservoir operating conditions at the time of testing where only the powerhouse was in operation with no flow through the spillway.

Debris

In summer 2023, the woody debris management program consisted of two parts, the first being two boat patrols on the reservoir, and the second being a 20-person work crew on shore. As in 2022, the large work crew focussed its clean-up efforts in the vicinity of the Keeyask GS and the north and south dikes where quantities of woody debris accumulate on an ongoing basis. The crews removed debris near the powerhouse and upstream on the north dike that affected water flow into the powerhouse. It also worked along a few kilometres of the south dike, west of the spillway. Debris collected in 2022 that was stockpiled beside the south dike and left to dry was burned in May 2023, and debris collected in 2023 was stockpiled in the same location where it could dry before being burned in 2024.

In addition to the woody debris, Keeyask also had to manage a peat island that floated up against the powerhouse in May. During ice breakup, a peat island that had existed since the reservoir was impounded in 2020 was pulled free and transported to the powerhouse. As the island began to break apart it began to plug the trash racks in front of the dam, which resulted in a need to shut down the powerhouse for some time. Attempts to push the island away from the dam were unsuccessful so it was removed using a crane with a bucket to dig it out and to clean the trash racks, which affected powerhouse operation for more than a month.

Woody Debris Adjacent to the South Dike

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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 2021 to March 2022, the first full monitoring season after the reservoir was impounded by raising water levels to the full supply level of 159 m ASL in September 2020. Although construction activities continued in 2021/22 and not all generating units were yet in operation, this period is considered the first year of operation because it is the first season when the reservoir water level was controlled within its licensed operating range of 158-159 m ASL. Note that where information is not yet available or requires further review at the time of the annual report the information will be considered in the following year's 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:

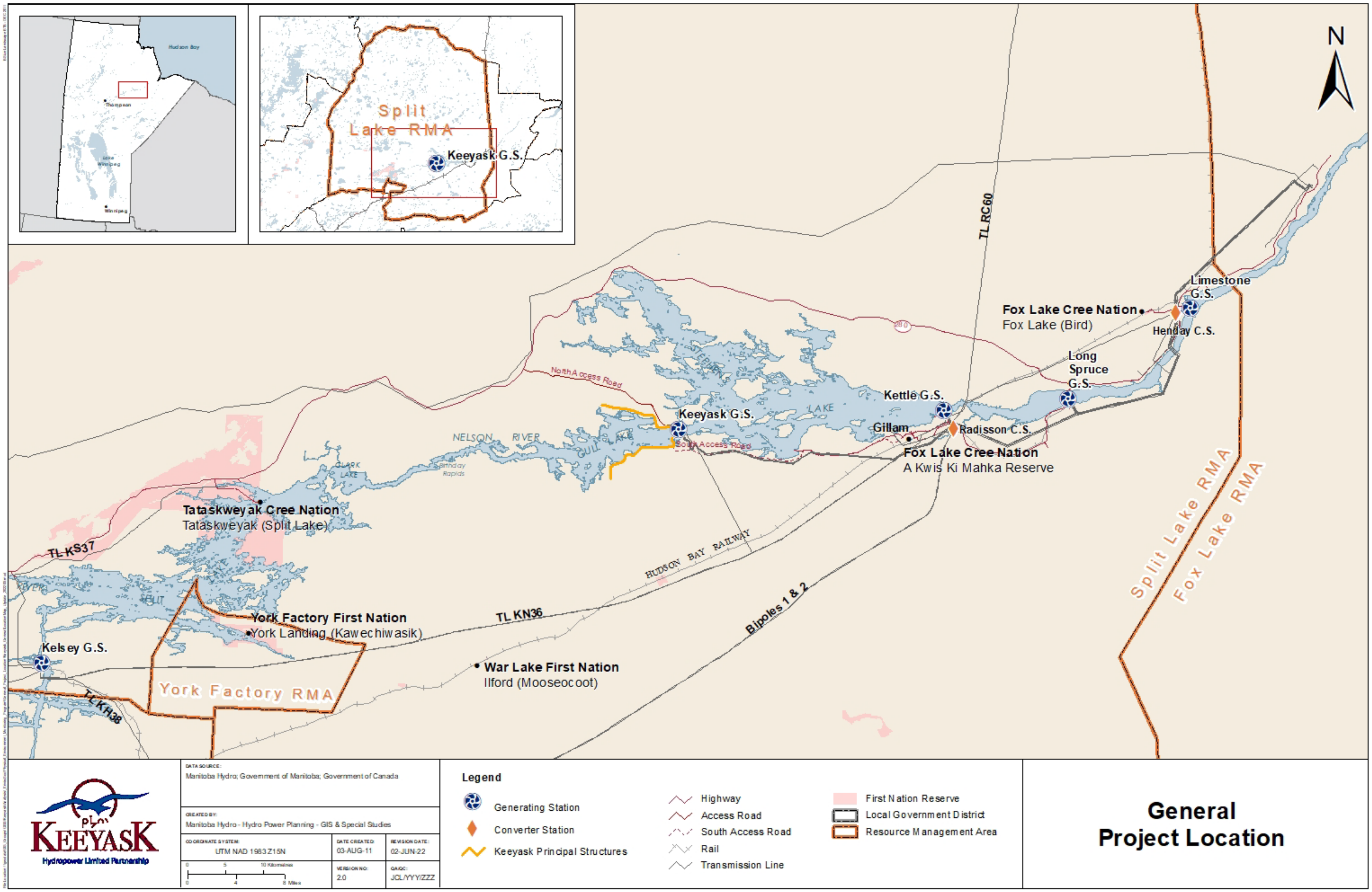
- Determine if EIS predictions of Project effects on the physical environment are correct and to identify unanticipated effects.
- Support other monitoring programs (e.g., aquatic and terrestrial) that will monitor Project effects and determine the effectiveness of mitigation and offsetting measures.

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 2023/24, physical environment monitoring included surface water and ice regime, water velocity, sedimentation, dissolved oxygen, total dissolved gas pressure, greenhouse gases, and woody debris. Monitoring for turbidity, suspended sediment, and water temperature and dissolved oxygen occurred in the 2023/24 winter period and the results will be provided in next years report. Reservoir expansion analyses using aerial imagery to map changes is being done as part of terrestrial monitoring that takes into consideration the changing boundary between aquatic and terrestrial habitats. 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 as far as about 30 km downstream 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

Prior to the 2021-22 monitoring report, river inflow to Gull Lake was reported as the outflow from Split Lake, which is not affected by the Keeyask Project, where this flow was calculated based on upstream inputs (e.g., Kelsey GS discharge, Burntwood River flow, and Split Lake water level changes). 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 were not included in the calculated flow. However, since Keeyask began operation, data on discharges from the generating station and spillway combined with changes in Gull Lake water levels have been used to calculate the inflow to Gull Lake. These Keeyask inflows are used for the Keeyask operating period starting in 2022.

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.

Table 1: Seasonal Split Lake discharges / Keeyask inflows since start of Keeyask construction

Year /Season	Minimum Daily (m^3/s)	Mean Daily (m^3/s)	Maximum Daily (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	40343	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
2021 Summer	1820	2585	3675
2021/22 Winter	1757	2307	2744
2022 Summer	2895	5763	6608
2022/23 Winter	3211	4048	5383
2023 Summer	1851	3032	4019
2023/24 Winter	1827	2524	2962

Note:
- 2014-2021 uses Split Lake calculated outflow
- 2022 onward uses Keeyask inflow calculated from downstream, which averages about 4% higher than calculated Split Lake outflow since

The seasonal mean daily discharge of 4,048 m^3/s during the 2022/23 winter season (Table 1) is above average, resulting from persistence of high system flows from summer 2022. Flow declined in spring 2023 but was still above average from April to June (Figure 1). With dry conditions in the basin, the flow steadily decreased from about median in July to below the 5^{th} percentile by November when it reached a minimum of about 1,851 m^3/s. The summer mean flow of about 3,032 m^3/s was below the long-term average of about 3,300 m^3/s. Where summer 2022 was very wet (Manitoba Hydro 2023), summer 2023 trended toward very dry conditions. The low flows persisted into winter 2023/24, varying between the 5^{th} and 25^{th} percentile levels, higher than the low flow of about 1,827 m^3/s at the start of the season in November.

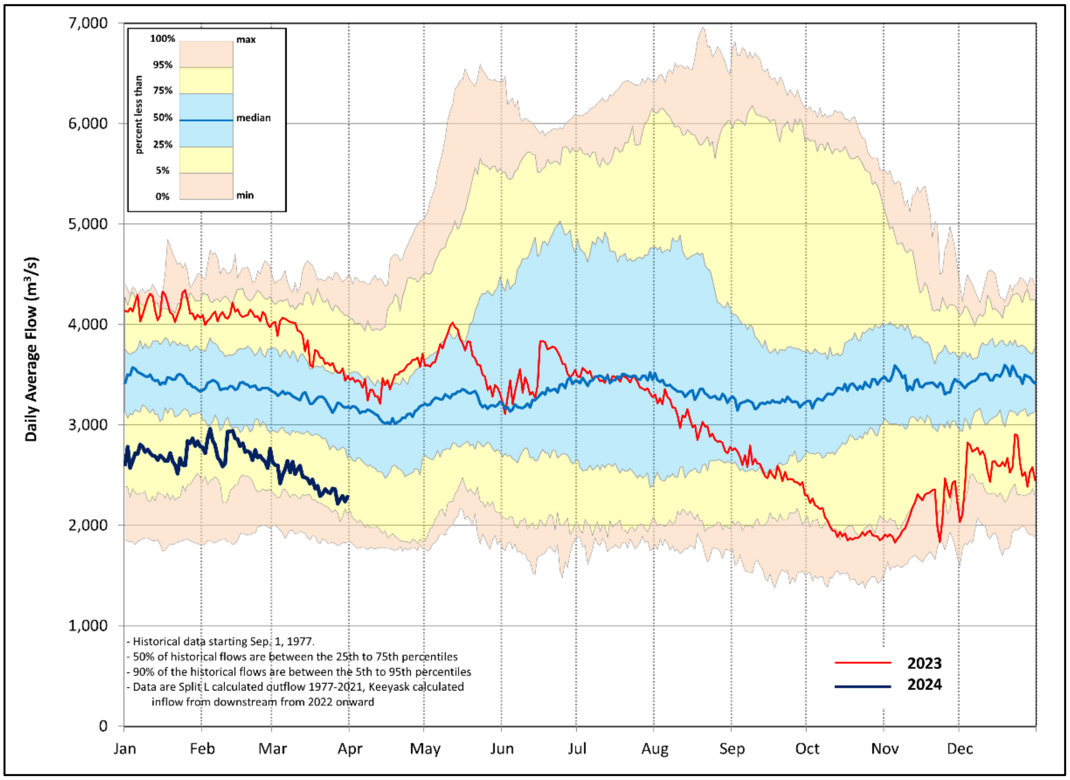


Figure 1: 2023/2024 Keeyask Daily Average Inflow and Historical Statistics

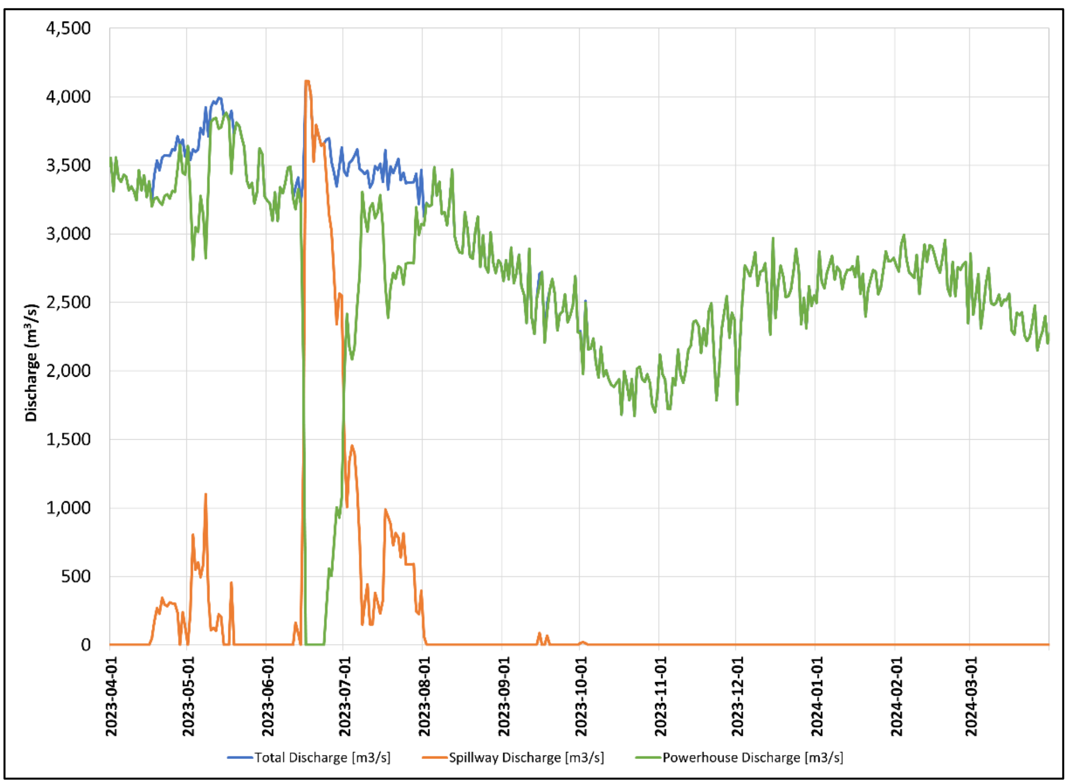


Figure 2: 2023/2024 Keeyask GS and Spillway Mean Daily Discharge

During most of the monitoring period the flow was only being passed through the powerhouse (Figure 2). The spillway was used to pass relatively low discharges of generally less than 500 m^3/s in late April and early May, with a peak of a little more than 1,000 m^3/s. In June, however, all of the flow was passed through the spillway for about a week due to debris issues at the powerhouse. Over the next 5 weeks, flow through the spillway flow decreased while powerhouse flows correspondingly increased as debris was gradually removed from trash racks in front of the intakes for each of the 7 generators.

2.2 OBSERVED WATER LEVELS

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.

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

The 2023/24 monitoring period is the third year of Keeyask GS operation in which the levels on Gull Lake could be regulated within the operating range between 158 and 159 m asl. Through the entire period (Figure 3) water levels were held between 158.1 and 159.1 m on Gull Lake (station 05UF596 at Caribou Island).

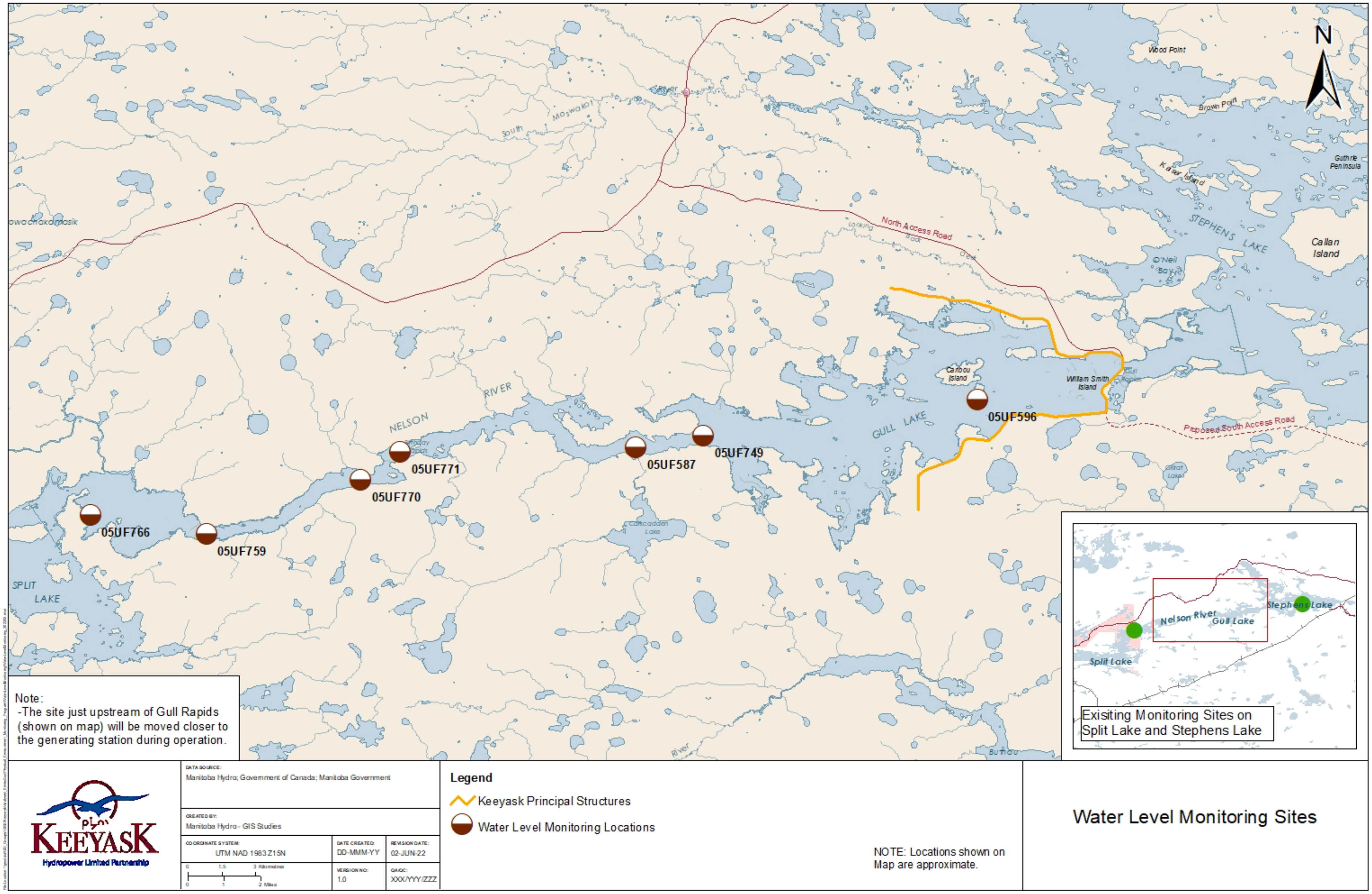
In the late winter and spring of 2023 water levels were influenced by river ice. Even as flows increased, the levels generally decreased until the latter part of May as ice effects diminished (Figure 3). Water levels gradually declined over the summer in conjunction with the corresponding decrease in flows up to the beginning of November. Due to low flow conditions, the water level difference between the Keeyask dam and the foot of Birthday Rapids about 33 km upstream was only about 0.6 m at the start of summer and the decreased to about 0.1 m by November. Starting in early August, the Keeyask reservoir levels varied daily as the system operated in a peaking mode of operation where levels were drawn down during the day when more flow was passed through the powerhouse and were raised at night when less flow was passed.

In response to increasing flows and the start of ice formation in mid-November, water levels increased about 2.5 m at the gauge below Birthday Rapids and about 2 m above the rapids and below Clark Lake (Figure 3). Clark and Split lakes increased about 1 m due to ice and higher flow. Levels upstream of Gull Lake varied over winter in response to ice and flow, but by the start of March they began to decline in response to decreasing flows and diminishing ice effects (less frazil, erosion of ice cover). Water level increases in the river section upstream of Gull Lake were not as large as have been seen in the past before and since Keeyask construction under higher flow conditions. On Gull Lake and at the gauge just upstream, the levels varied with operation, although levels at the upstream gauge were about 0.5 m higher due to ice effects.

2.3 CLARK LAKE AND SPLIT LAKE WATER LEVELS

The water levels on Clark and Split lakes show the same pattern of variation due to flow and ice effects, differing by about 0.4 m in April 2023 under ice affected conditions (Figure 3). In summer, the difference between the two lakes decreased as flows declined, so that by November Split Lake was only about 0.2 m higher than Clark Lake and then through winter the difference increased to about 0.3 m.

In winter, ice effects may increase water levels on Split and Clark lakes by about 0.6-1.2 m on above open water levels (KHLP 2012b). Monitoring indicated levels on these lakes increased about 1.1 m in winter between the beginning of November and February due to ice effects as well as flows increasing from about 1,900 m^3/s to as much as roughly 2,900 m^3/s. Water levels were about 0.6 m higher in winter compared with summer for the same flows, which is due to ice effects. The increase over winter is consistent with expectations and ice effects observed prior to Keeyask development. As observed previously, the project did not affect Clark or Split lake levels during open water conditions, and a review of the hourly water level win winter 2023/24 did not show any indication of effects from Keeyask operation on either lake.



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

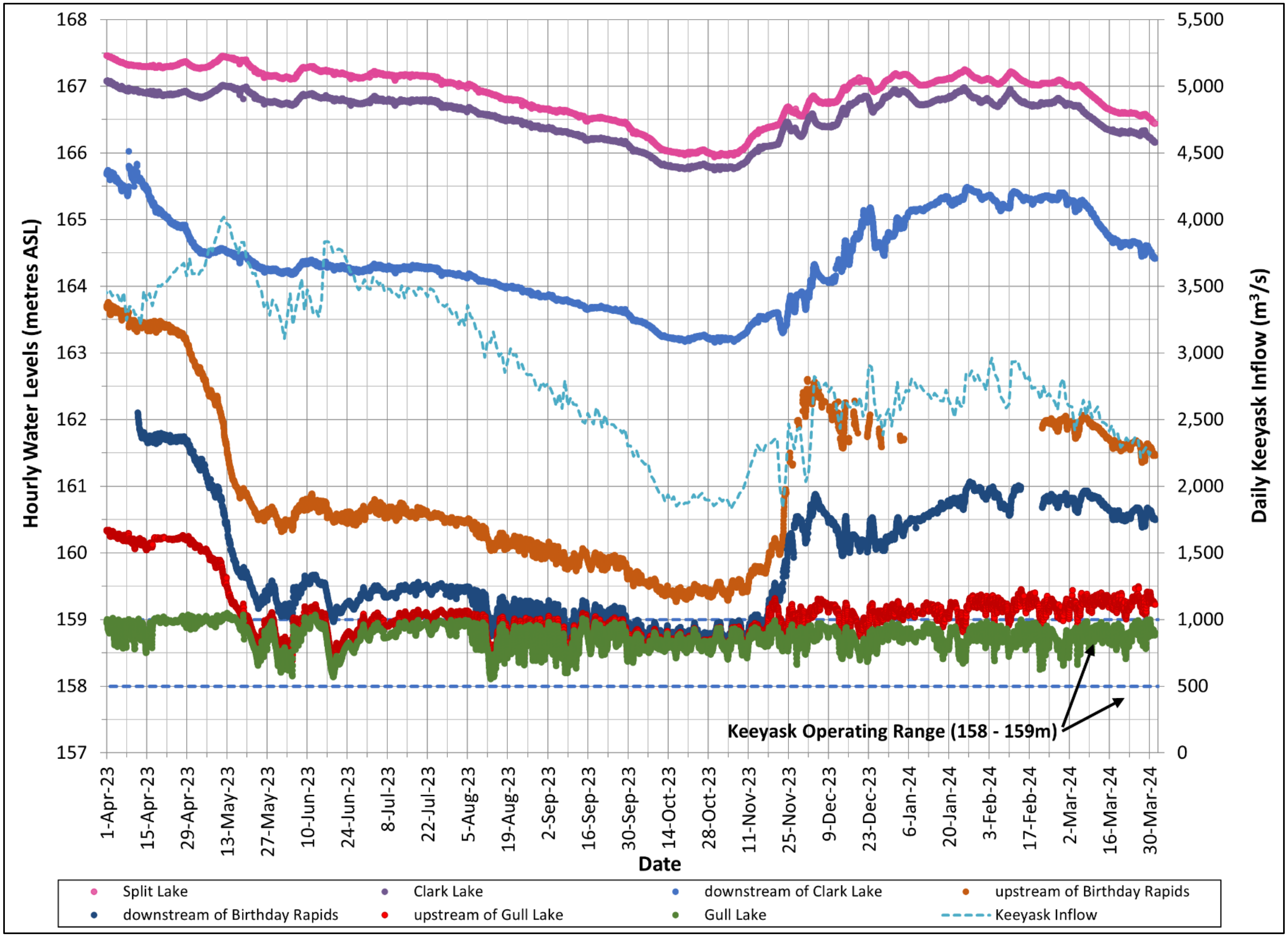


Figure 3: Observed water levels at PEMP monitoring sites in 2023/2024

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.

Winter 2023/2024 saw the initiation of an ice cover in the first week of November, occurring between Nov. 1, when the lake was open except for some ice in back bays, and Nov. 6, when ice had reached the upstream end of the lake (Table 3, Figure 4). The start of freeze-up has occurred in the first week of November in 5 of the 10 winter seasons since the start of construction. By at least Nov. 11, the ice front had reached about 3 km upstream of the lake and by Nov. 24 it was at the foot of Birthday Rapids (Figure 5). The ice advance relatively quickly through the rapids due to low flow conditions. By Dec 1, the ice front had progressed through Birthday Rapids to just upstream and by Dec 19 it reached its maximum extent about 6.5 km upstream of the rapids (Figure 6), which is the roughly the maximum extent observed the previous 2 years under both high and low flow conditions. Nelson River flows were low enough for the open lead from Split Lake through Clark Lake to freeze, with ice bridging beginning around January 1 and a significant ice cover in place by January 5 that gradually grew in extent (Photo 2, Figure 7). More commonly the lake will have an unfrozen lead between Split Lake and the exit of Clark Lake, but it has frozen over in the past under low flow conditions. The ice cover near the dam developed as generally expected, with a solid cover upstream and open water extending about 1.2 km downstream of the powerhouse due to high flow while there was no open water below the spillway because it was no in operation (Photo 3).

In early April, the ice cover upstream of Birthday Rapids began to show signs of thinning in response to warmer weather and increase sunshine, with open water lead developing upstream of Birthday Rapids and a number also developing or expanding between the rapids and Gull Lake (Figure 8). The ice cover continued to gradually thin so that by May 14 (Figure 9) the ice on Gull Lake started to break up while the river upstream was ice free, and by May 17 Gull Lake was ice free except for some remnant is in back bay areas.

Overall, the 2023/24 ice conditions were generally consistent with expectations in the Keeyask EIS.

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 6 km upstream of Birthday Rapids	May 22-23, 2021
2021/22	Nov 19-20, 2021	About 6.5 km upstream of Birthday Rapids	May 18-21, 2022
2022/23	Nov 7-11, 2022	About 6.5 km upstream of Birthday Rapids	May 13-15, 2023
2023/24	Nov 1-6, 2022	About 6.5 km upstream of Birthday Rapids	May 17, 2024

*Ice formation start date before ice boom failed

Photo 2: Ice Cover on Clark Lake

Photo 3: Ice formation upstream and downstream of Keeyask

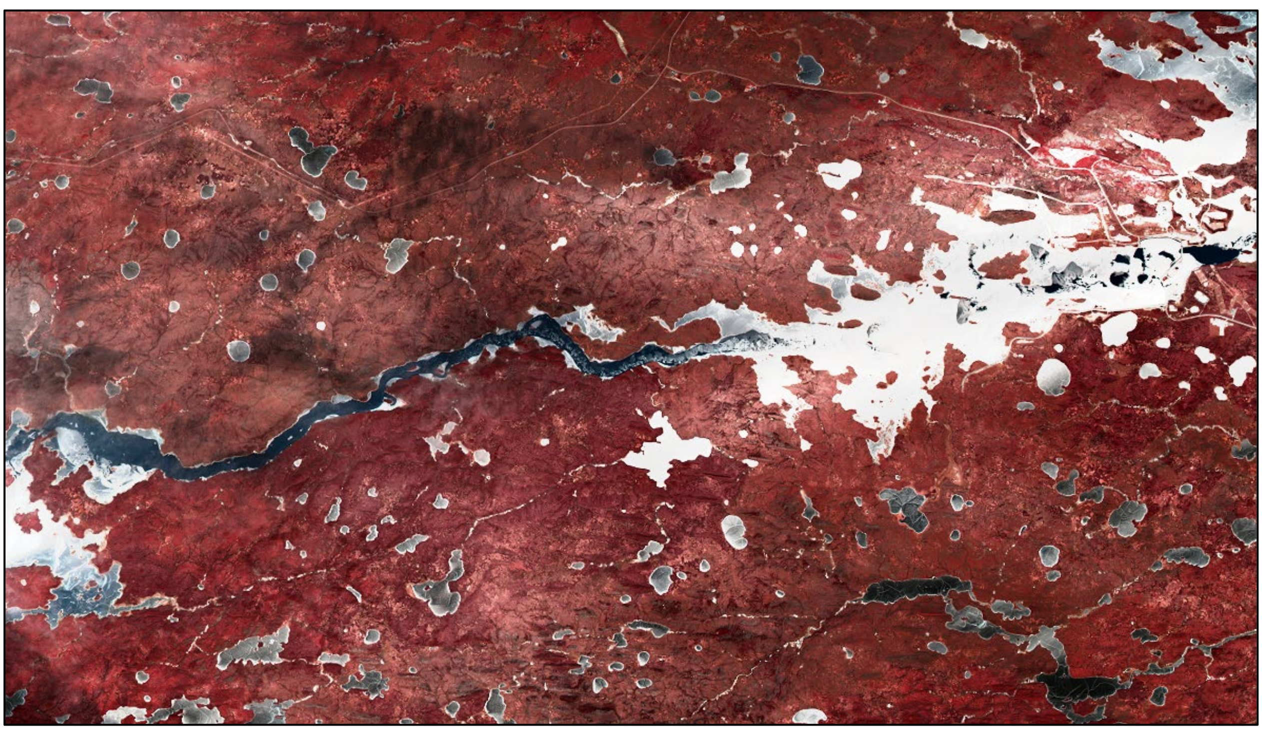


Figure 4: Ice cover development observations from satellite images 2023/11/06

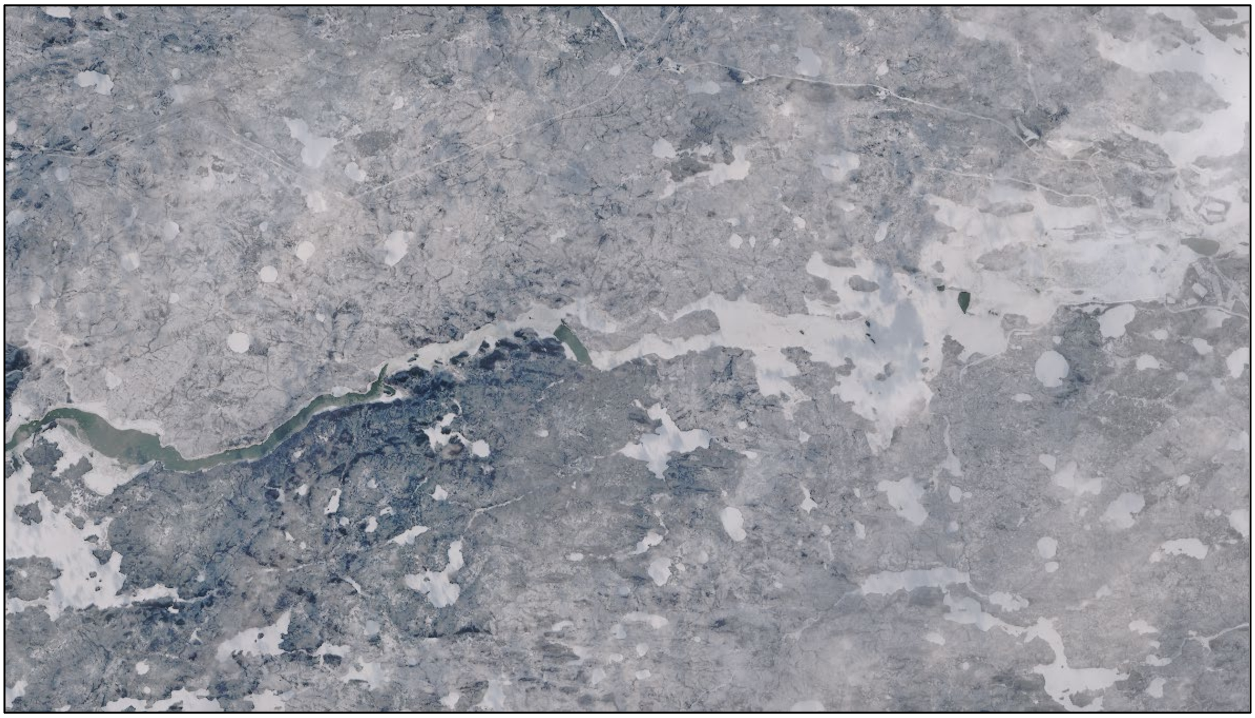


Figure 5: Ice cover development observations from satellite images 2023/11/26

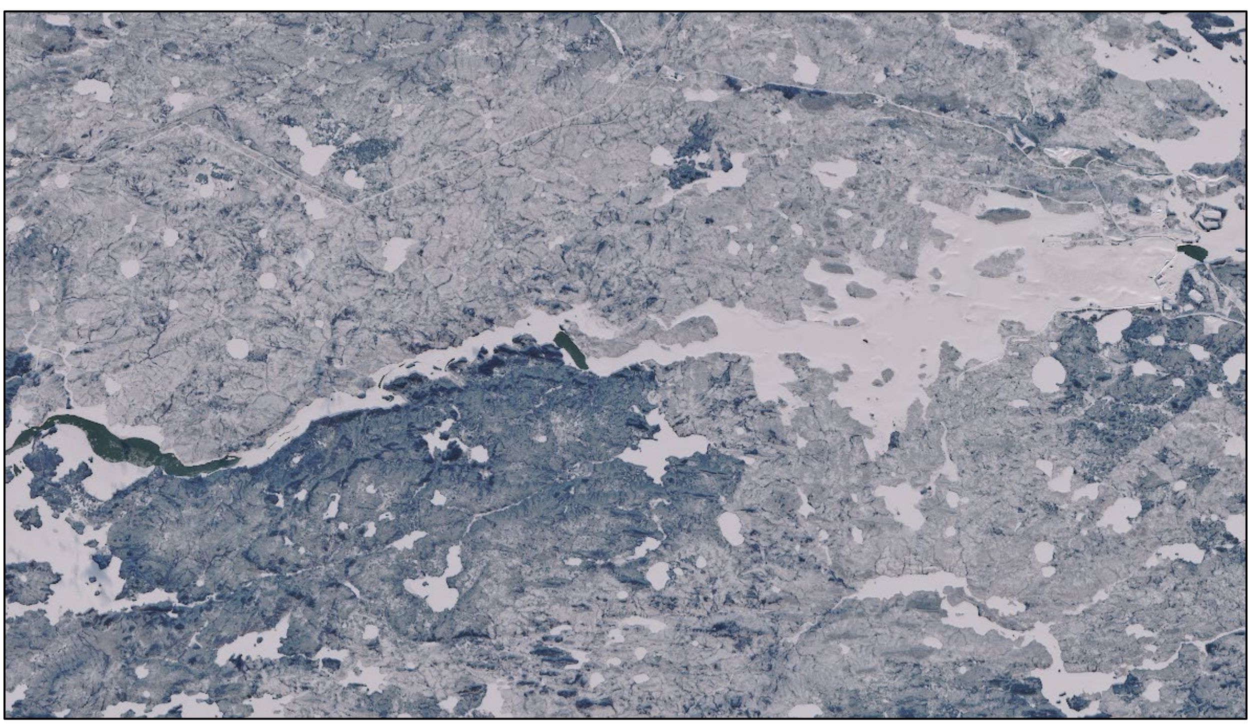


Figure 6: Ice cover development observations from satellite images 2023/12/19

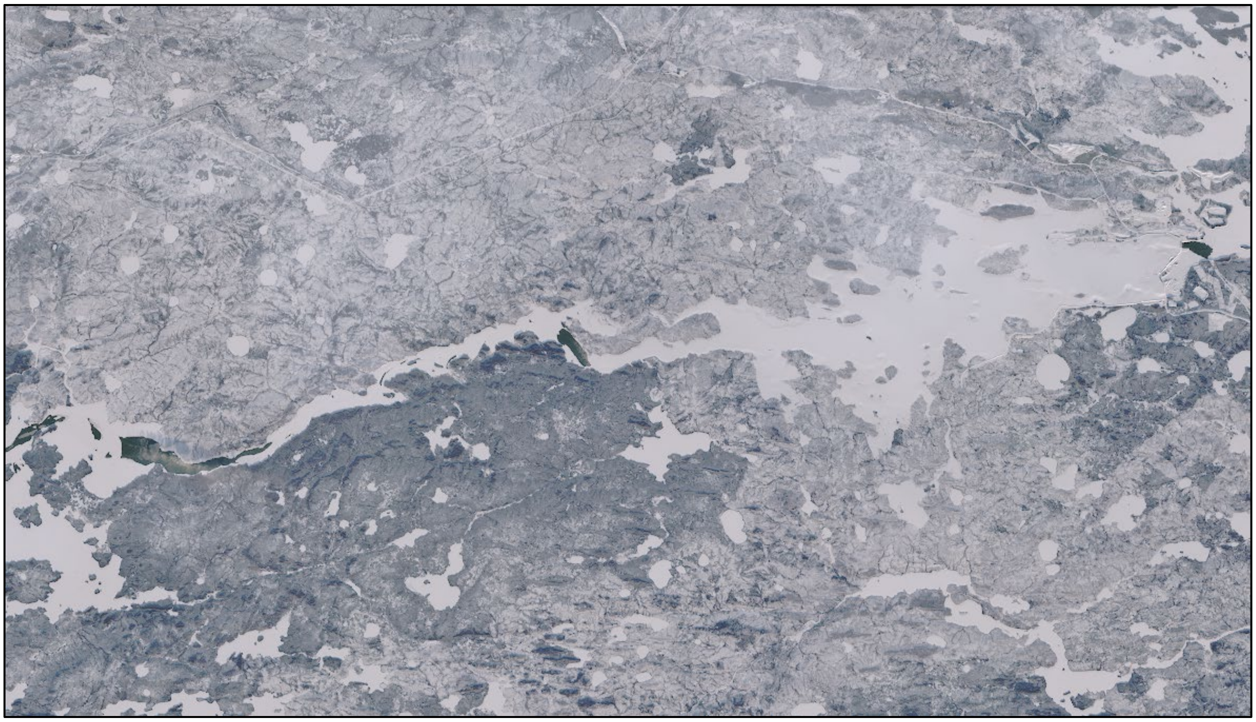


Figure 7: Ice cover advancement observations from satellite images 2024/01/05

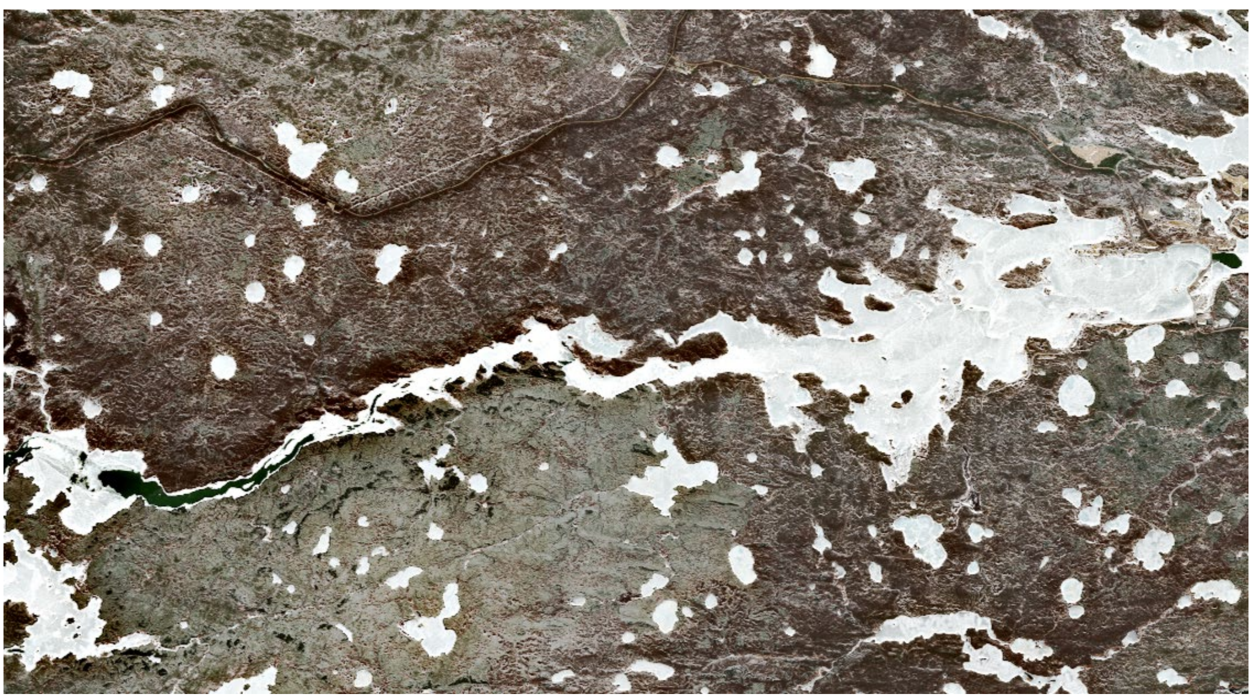


Figure 8: Ice cover advancement observations from satellite images 2024/04/27

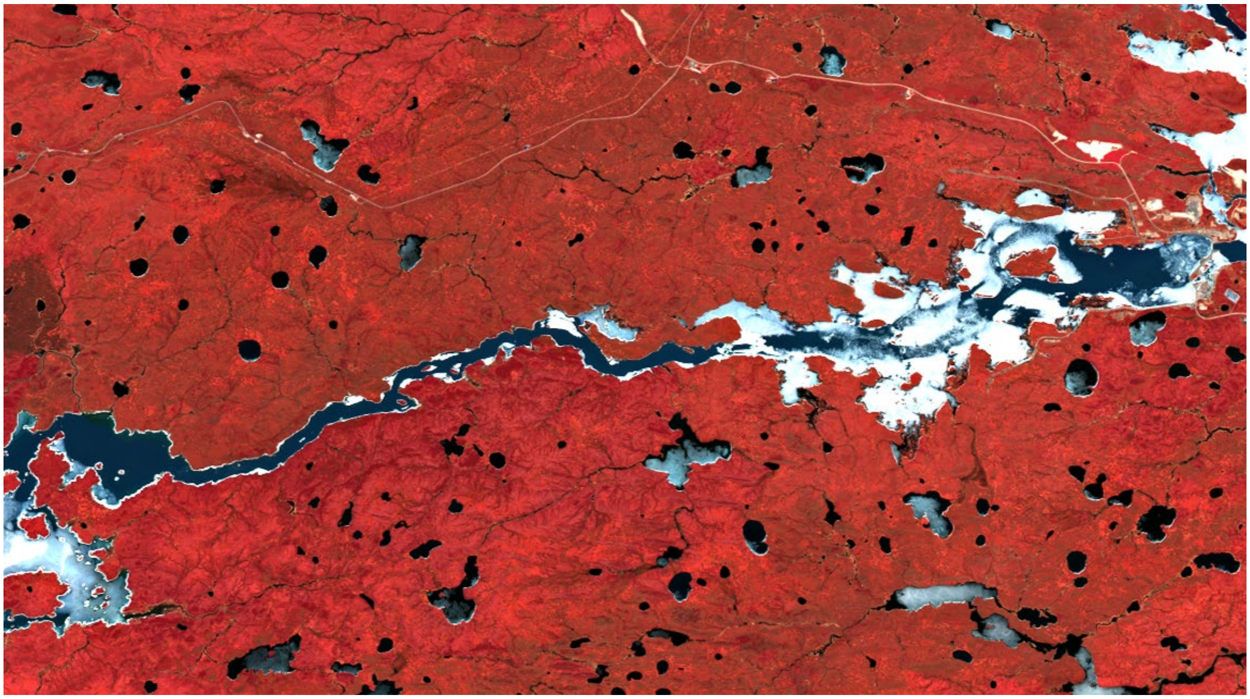


Figure 9: Receding ice cover observations from satellite images 2024/05/14

2.5 WATER VELOCITY

The Keeyask PEMP committed to measuring water velocities under low, moderate, and high flow conditions (i.e., approximately 5th, 50th, 95th percentile flows) during the operating period to identify the range of velocities occurring in various aquatic habitat areas affected by the project. Because moderate flows were forecast to occur in summer 2023, velocity monitoring was initiated during the open water season. The aquatic environment monitoring team identified several areas for velocity monitoring from above Birthday Rapids to the entrance of Stephens Lake downstream of the GS. The PEMP monitoring crew measured velocities at 52 transects from August 16-20. Velocities were obtained upstream of Keeyask on the 16th, 19th, and 20th at average inflows that varied from about 2,900-3,150 m^3/s. These inflows are comparable with the estimated 50th percentile future environment inflow of 3,125 m^3/s used in the Keeyask EIS (KHLP, 2012b). Because the powerhouse was being run in a peaking mode of operation where discharge is higher during the day and lower at night, the velocity measurements downstream in Stephens Lake on the 17th were obtained when discharge from the powerhouse was about 3,800 m^3/s. Under moderate inflows the powerhouse will typically run in a peaking mode of operation, so the conditions observed are indictive of normal operation for these inflows.

Overall, there was generally good agreement between measured and predicted velocity classifications (i.e., standing, low, moderate, and high), in each area (Figure 10 to Figure 14). At upstream transects about two-thirds (66%) of measured velocities matched the modeled velocity classification while downstream about 80% matched. Less than 1% of measurements were more than one classification different than the modeled class. Where classification differences did occur, the measured values tended to be somewhat greater than modeled at the transects above Birthday Rapids, at Gull Lake, and at Caribou Island, while they tended to be lower at sites below Birthday Rapids and the Keeyask GS in Stephens Lake. In terms of velocity differences, about two-thirds of the measured values were within +/-0.1 m/s of the modeled value and about 90% were within +/-0.2 m/s.

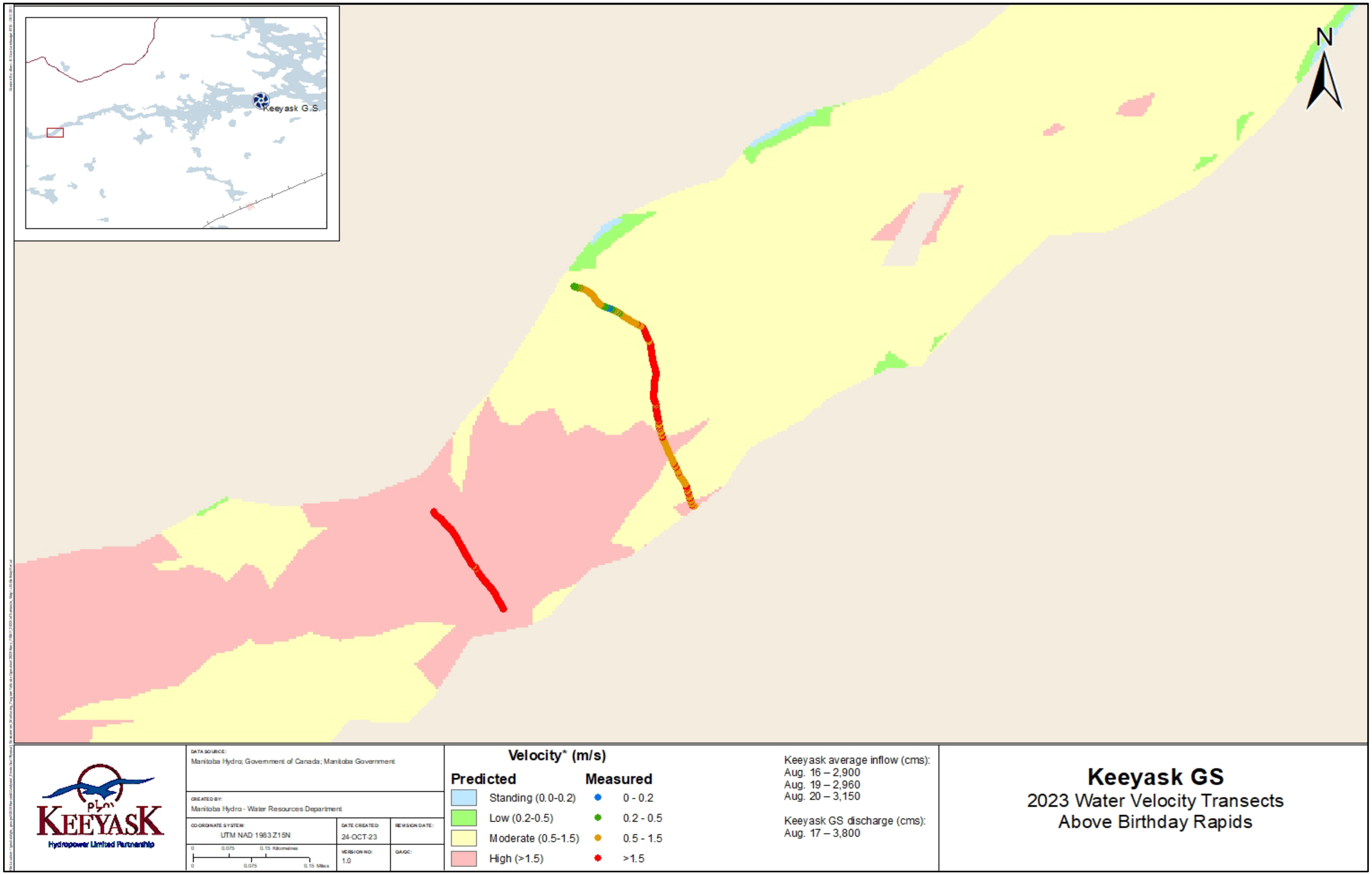


Figure 10: Velocity transects above Birthday Rapids

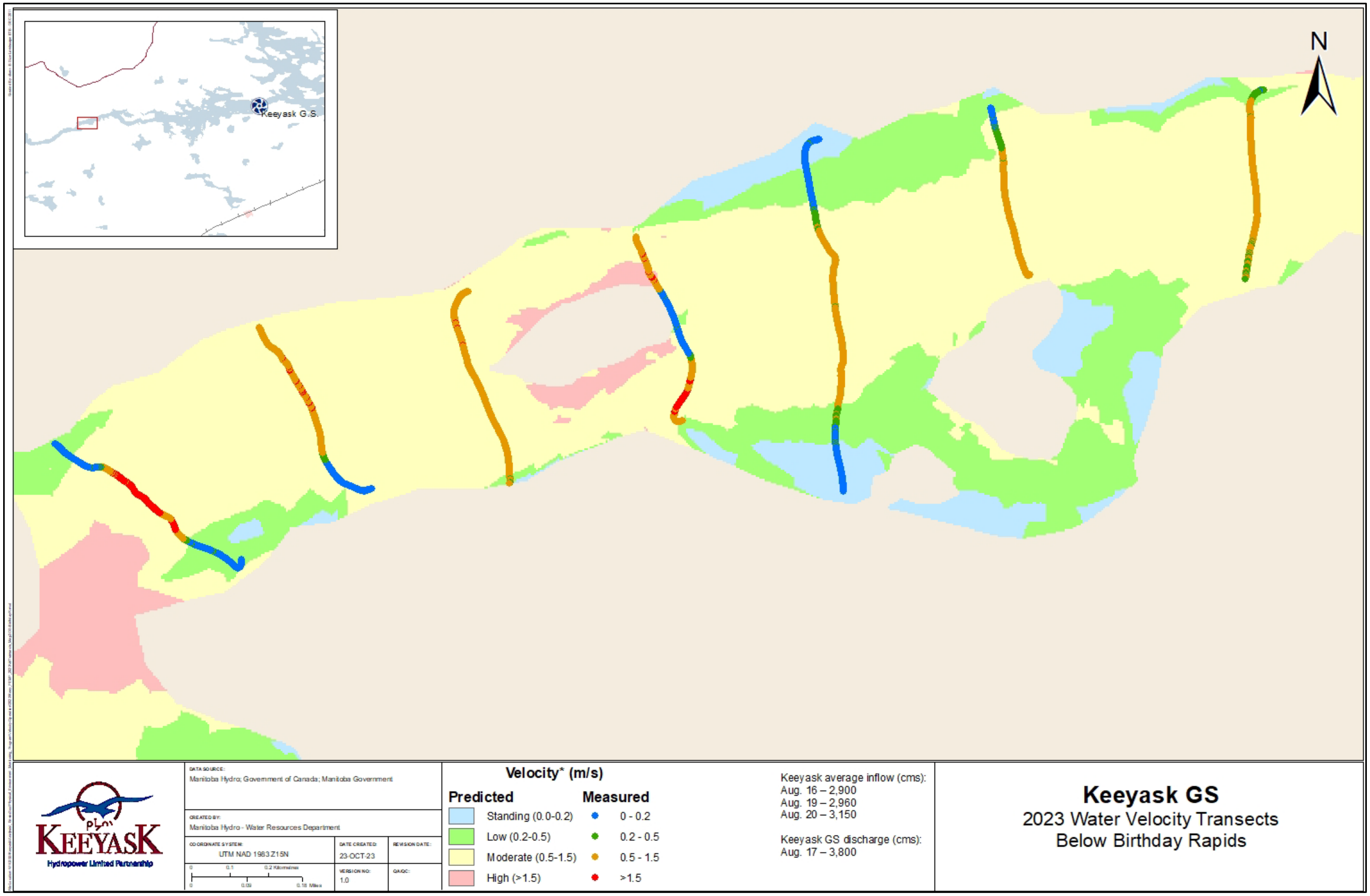


Figure 11: Velocity transects below Birthday Rapids

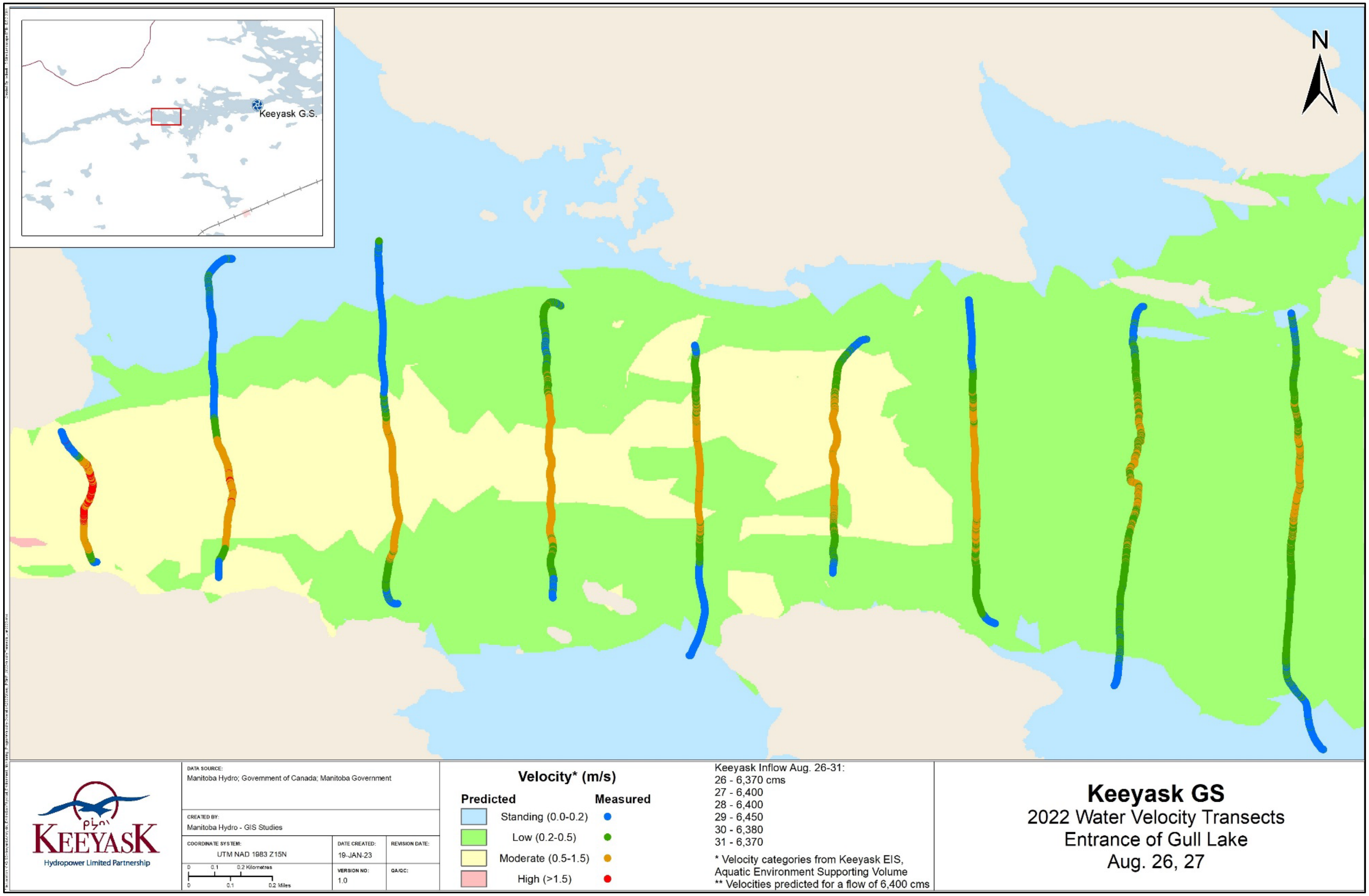


Figure 12: Velocity transects at entrance to Gull Lake

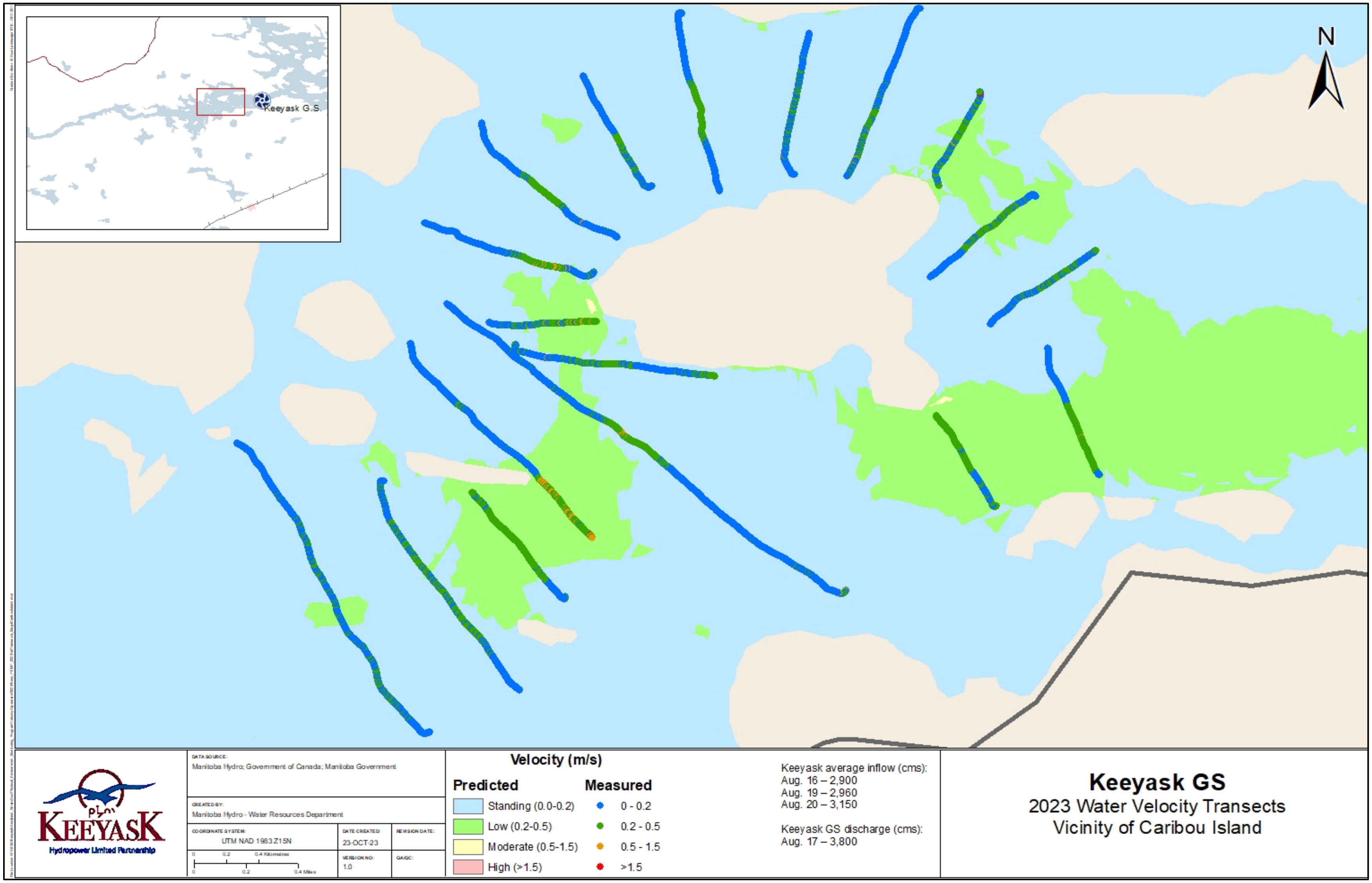


Figure 13: Velocity transects around Caribou Island

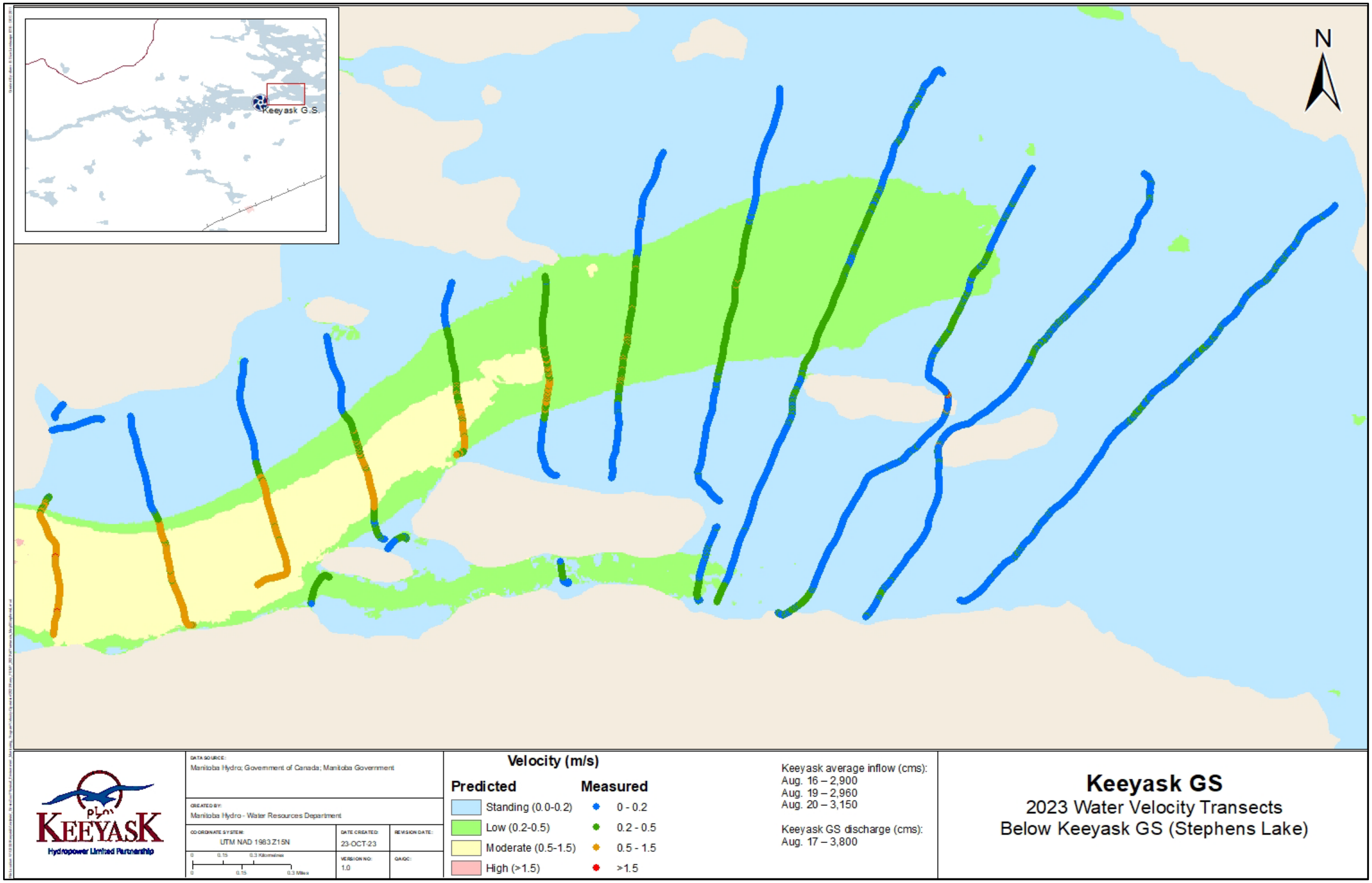


Figure 14: Velocity transects downstream of Keeyask GS (Stephens Lake)

3.0 SHORELINE EROSION

The Keeyask PEMP indicates erosion monitoring will be done to track changes in the shoreline over time. However, reservoir change analyses using aerial imagery to map effects is also required as part of terrestrial monitoring that takes into consideration the changing boundary between aquatic and terrestrial habitats. To avoid duplication the terrestrial monitoring program will be generally relied upon to identify changes in reservoir area and the reader is referred to the annual terrestrial monitoring reports for further information.

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 were predicted to occur during operation 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 was generally done to collect data that will support conclusions of the effects of the Project on sediment transport and deposition after impoundment.

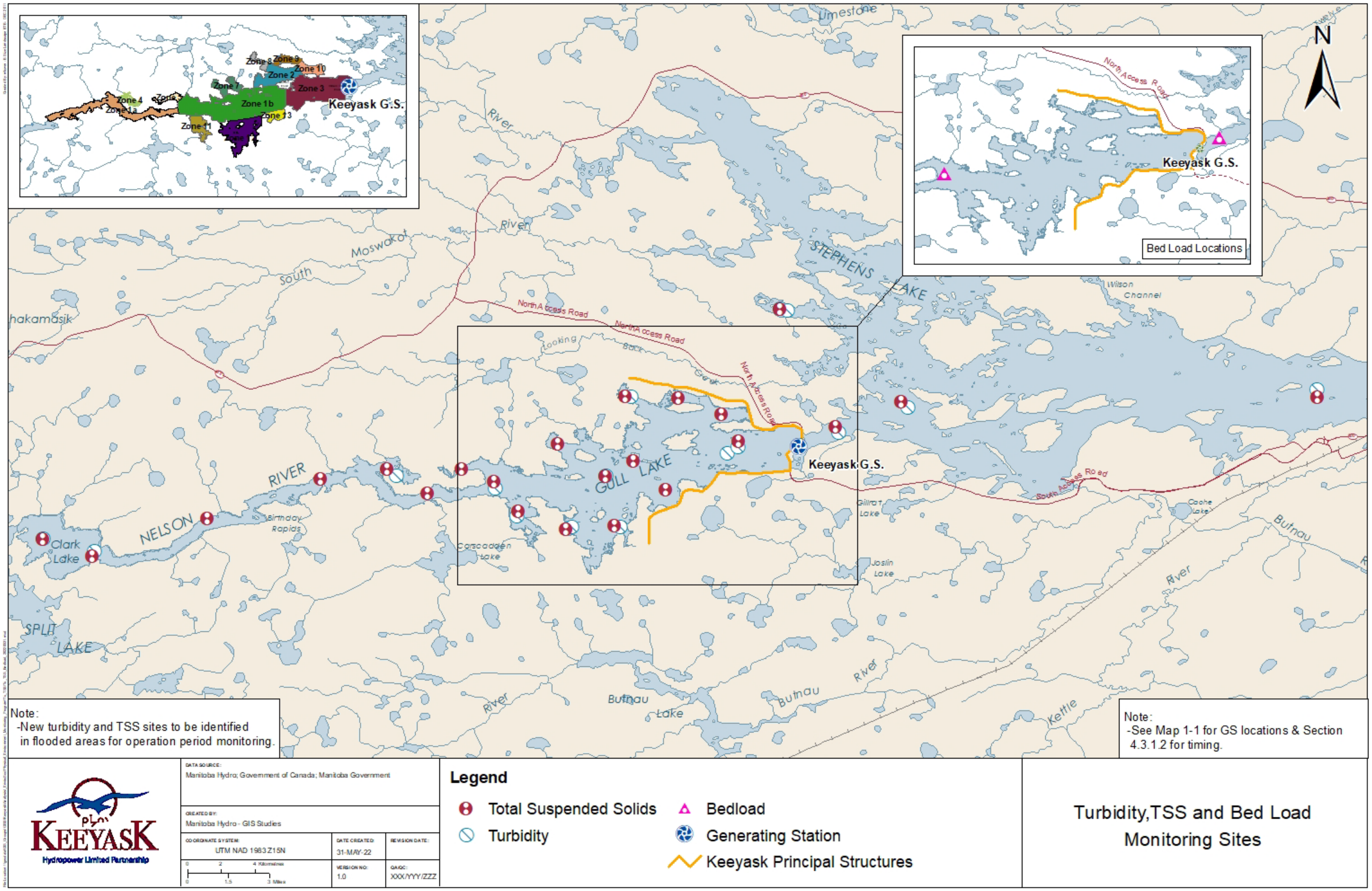
Sediment transport monitoring is done through the collection of discrete water samples, continuous turbidity monitoring and sediment traps at locations shown in Map 3 (detailed site maps are provided in Appendix 1). Discrete sampling involves the collection of water samples and in-situ measurements by 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 2022-2023

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 2022-23 winter sedimentation data.

4.1.1 CONTINUOUS AND DISCRETE TURBIDITY AND TSS

Winter discrete monitoring in 2022-23 was conducted monthly at four continuous turbidity sites (Table 4), upstream of the Project area in Clark Lake, upstream and downstream ends of Gull Lake, and downstream of the Project in the entrance to Stephens Lake (seep maps Appx. 1). Equipment was installed in January after suitable ice conditions developed at all the sites and was removed in April before ice break up. The data collected at each of the monitoring sites was reviewed to identify and remove poor quality data from factors such as ice, dead batteries, and



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

equipment malfunction. The continuous data were also compared with the discrete readings obtained on each maintenance site visit and adjustments made for any sensor drift.

Table 4: 2022-2023 winter continuous TU & discrete TSS monitoring locations

Site ID	Dates
CL-1 (Clark Lake)	19-Jan-2023 to 20-Apr-2023
KE-5 (Gull Lake upstream)	19-Jan-2023 to 20-Apr-2023
KE-9 (Gull Lake downstream)	24-Jan-2023 to 19-Apr-2023
STL-4 (entrance to Stephens Lake)	24-Jan-2022 to 18-Apr-2023

Turbidity levels at the Clark Lake site (CL-1) were generally 1-2 FNU lower than the sites KE-10-c and STL-4 just upstream and downstream of the Keeyask dam (Figure 15). Each site started out higher in January at about 12-14 FNU and gradually declined over winter to 8-10 FNU. This is a typical turbidity pattern over winter with higher levels in January that gradually and steadily decline until the probes are removed in April. KE-10-c levels were about 1 FNU higher than STL-4 to start, but the two converged by mid February and were about the same after that. Turbidity at site KE-5 was high initially at about 16 FNU but then dropped to within the range of the other sites. There is a gap due to poor quality data, but the last month of data is near the level at other sites but rising somewhat from March to April. It is unclear why the pattern of turbidity at KE-5 is different than the other sites, but it may be related to ice conditions or high flows during the winter.

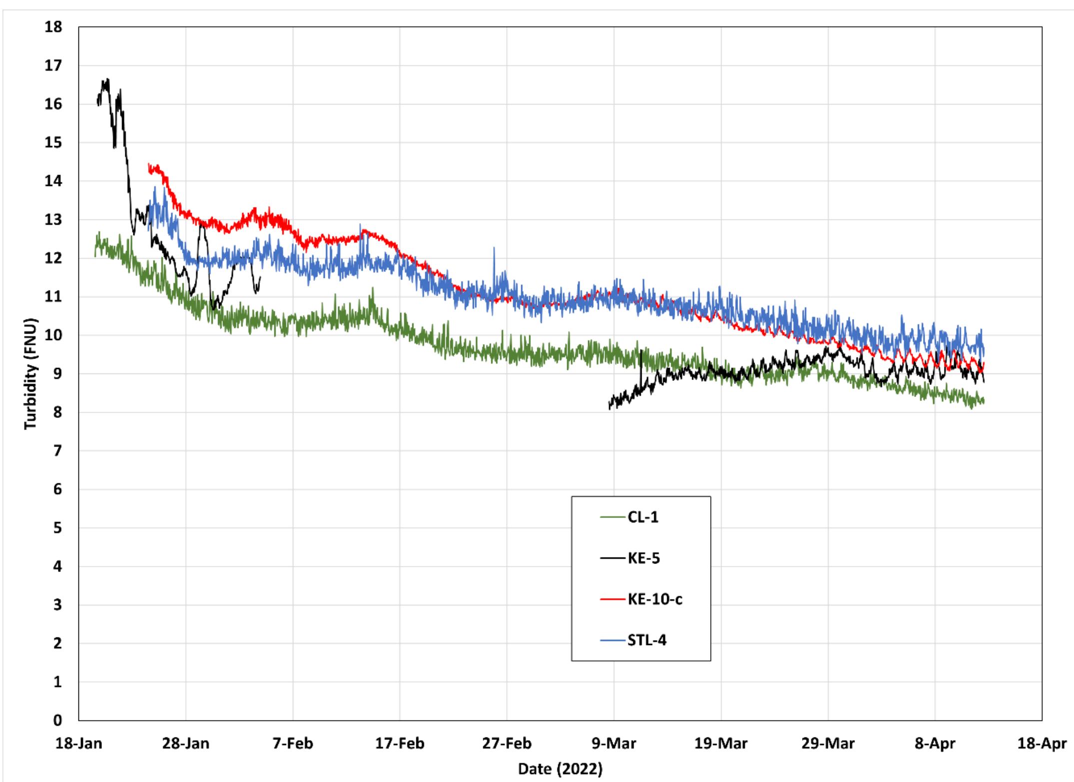


Figure 15: 2022-2023 winter continuous TU

The range and average of continuous turbidity was summarized and compared with continuous turbidity observed prior to and during construction (Figure 16). In 2023, as in the years since 2016, the turbidity levels in Stephens Lake downstream of the Keeyask GS have been generally lower than observed prior to construction, with much narrower range and lower peak levels. This is consistent with the Keeyask EIS prediction that the Project would “significantly reduce erosion potential” downstream of the Project after construction, which would result in lower turbidity downstream. Prior to the project a large hanging ice dam formed each winter at the entrance to Stephens Lake and would cause water levels to rise and flows to be redirected along erodible shorelines, which would add sediment to the river. With the Keeyask GS in operation, this hanging ice dam does not form, which mitigates the entrainment of sediment from eroding shorelines.

Discrete TSS was lower in 2022-2023 than in any previous winter monitoring period (Figure 17), with an overall average TSS concentration of about 1 mg/l. This indicates that most sample results returned a TSS concentration below the lab detection limit of 2 mg/l because test results reported below the detection limit were all set to an assumed value of 1 mg/l. While TSS was lower than previous years, discrete turbidity was comparable with results in 2020 and 2021 (Figure 18). Discrete turbidity was largely between about 7-12 FNU, with a high of 15 FNU recorded at site KE-5.

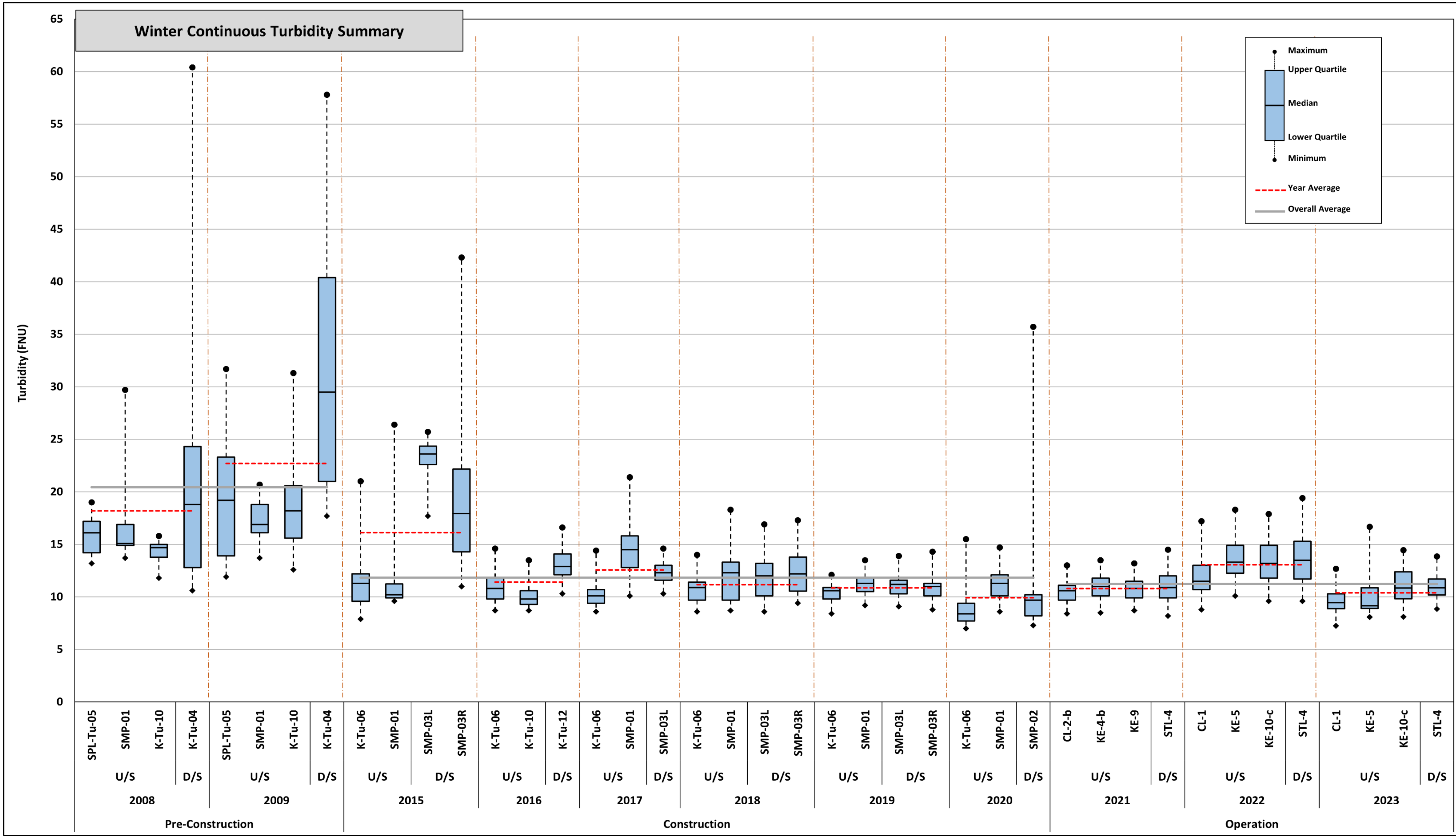


Figure 16: Summary of winter continuous TU (2008-2023)

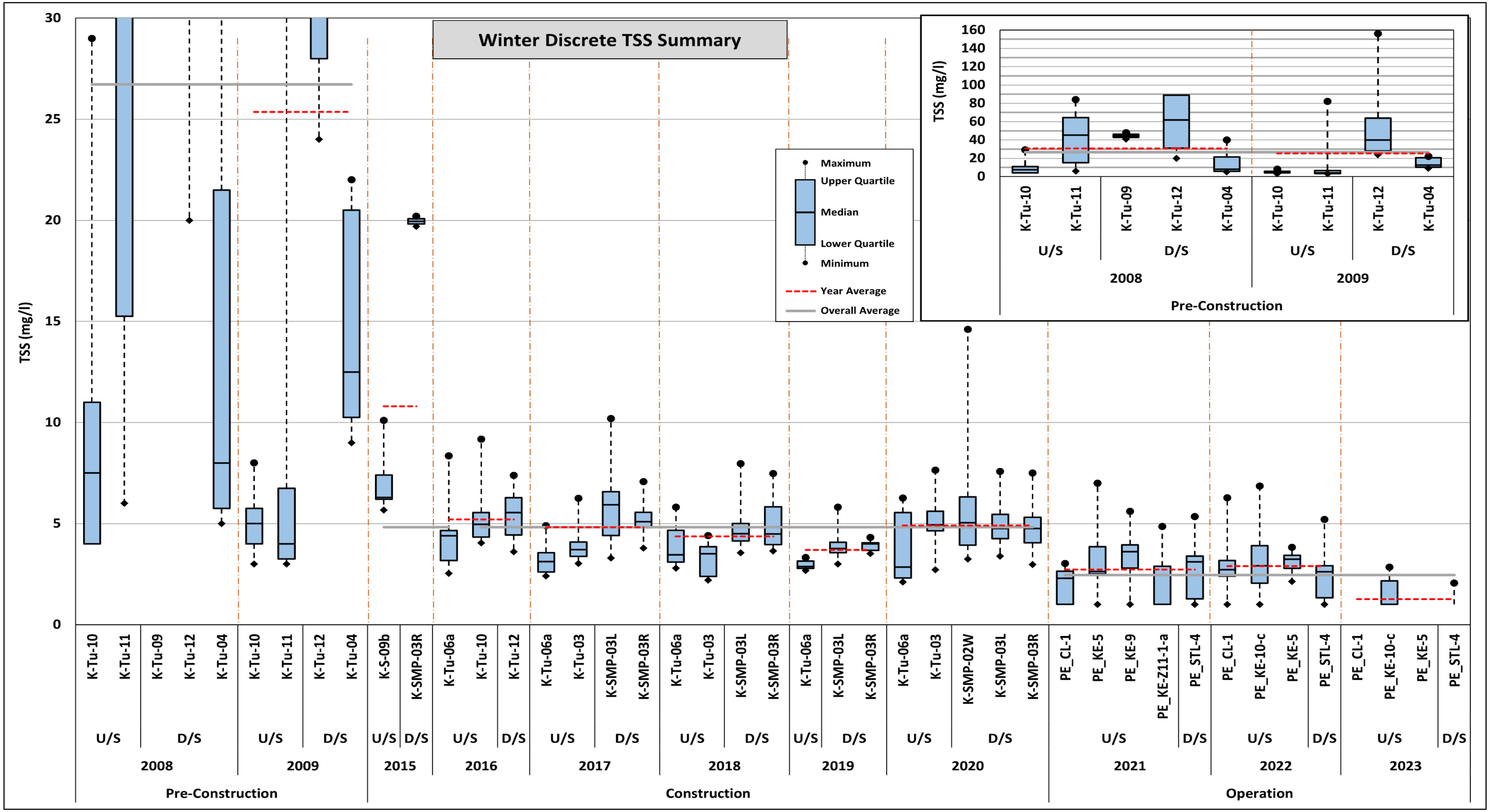


Figure 17: Summary of mainstem winter discrete TSS (2008-2023)

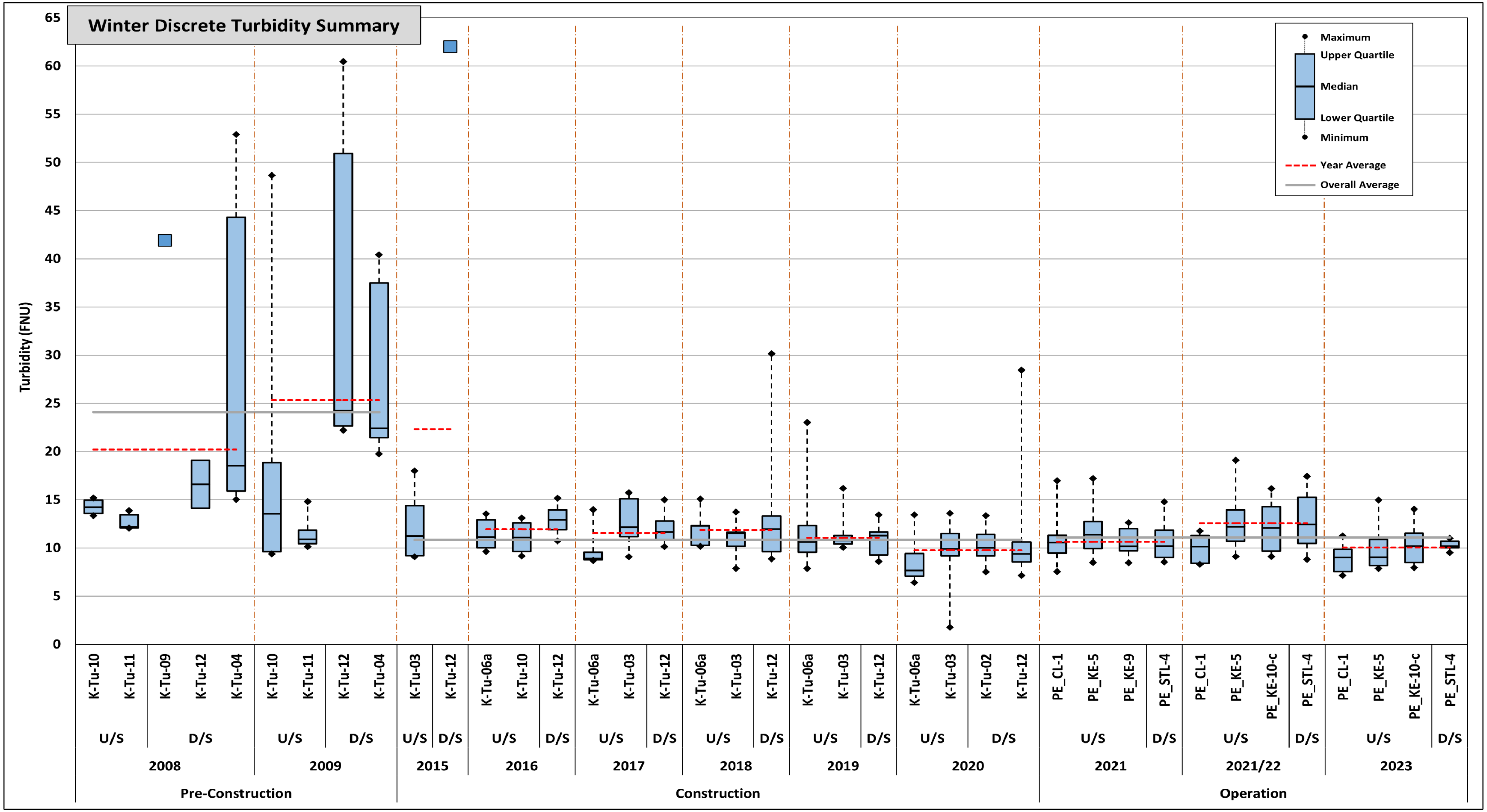


Figure 18: **Summary of mainstem winter discrete TU (2008-2023)**

4.1.2 ESTIMATED SUSPENDED SEDIMENT LOAD

The winter suspended sediment loads (Figure 19) are estimated based on the average daily turbidity and discharge. Turbidity was converted to TSS concentrations using a Turbidity-TSS relationship developed for the Sediment Management Plan (KHLP 2014) based on pre-project discrete monitoring.

The estimated daily sediment load at Clark Lake (sites SPL-Tu-05 & K-Tu-06 before operation, and CL-1 & CL-2-b during operation) upstream of expected hydraulic effects due to Keeyask indicates that the winter average was higher during the two pre-construction years than the winters monitored since 2015. In 2023, the sediment loads at the sites just upstream and downstream of the GS (KE-10-c, STL-4) were about 25% greater than at Clark Lake, which is consistent with previous years during construction when the downstream loadings have generally been about 10-30% greater (Figure 19). The median loading at the entrance to Gull Lake (KE-5) was lower than the other sites but varied over a wider range. The overall average daily load in 2023 was about 1,570 t/d, which is lower than the previous two years of operation monitoring, which were about 1650 t/d and 1800 t/d, and lower than observed prior to construction.

As noted above, a downstream reduction in turbidity (suspended sediment) has resulted in a reduced sediment load entering Stephens Lake since 2016 as compared with the pre-construction period and in 2014-15 when the ice boom failed. Loads are reduced because a stable ice cover forms earlier upstream and a hanging ice dam no longer forms at the entrance to Stephens Lake, which reduces scour of the bed and banks in this area. These changes result in less sediment being transported into Stephens Lake and downstream along the Nelson River to Hudson Bay, which was an expected effect of the project. It is worth noting that while zebra mussels have significantly reduced turbidity and TSS levels in summer since 2021 (see Section 4.2), the winter levels do not show a corresponding effect because the mussels are dormant in winter.

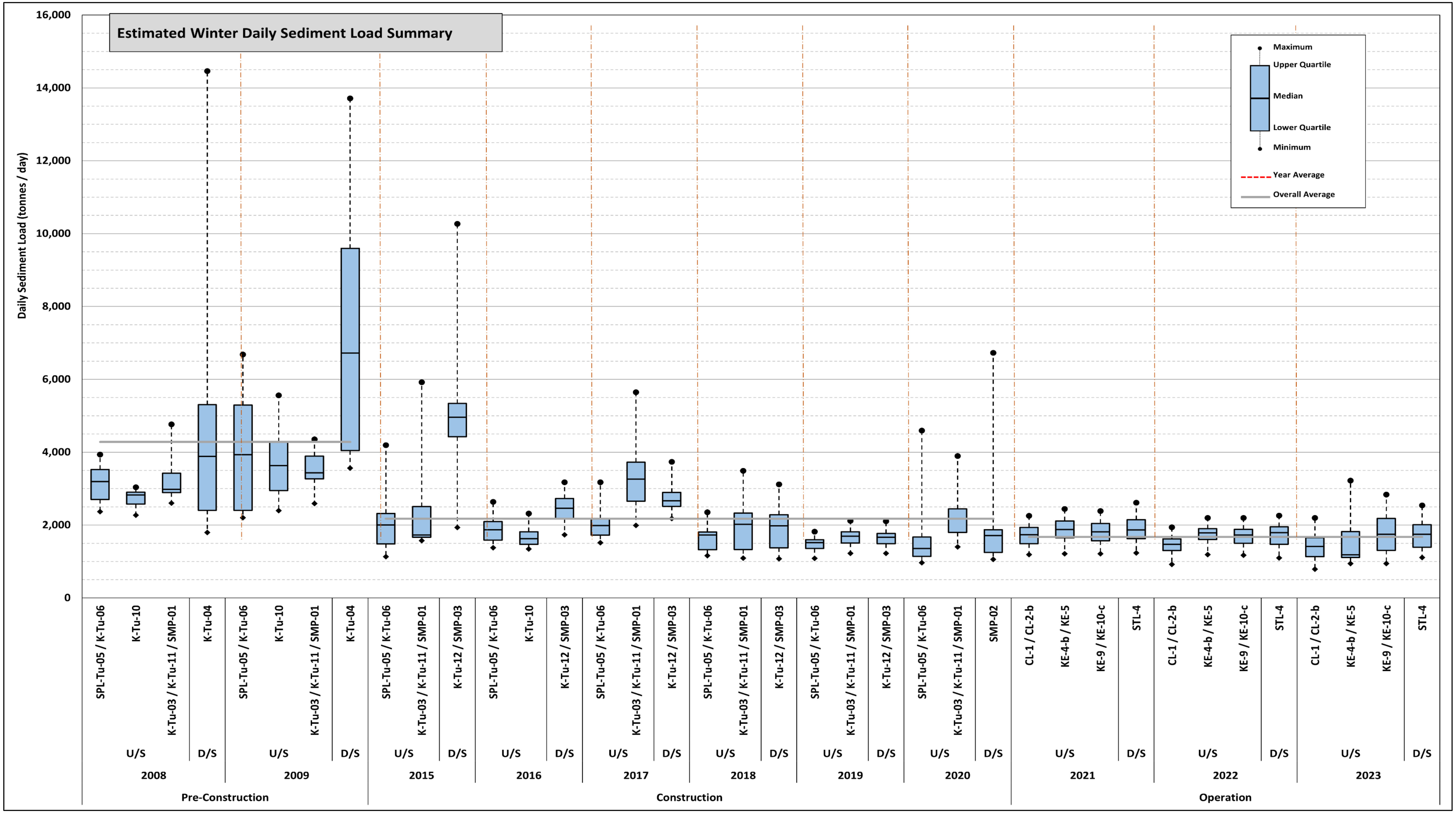


Figure 19: Summary of winter daily suspended sediment load (2008-2023)

4.2 SUMMER 2023

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 to early October).

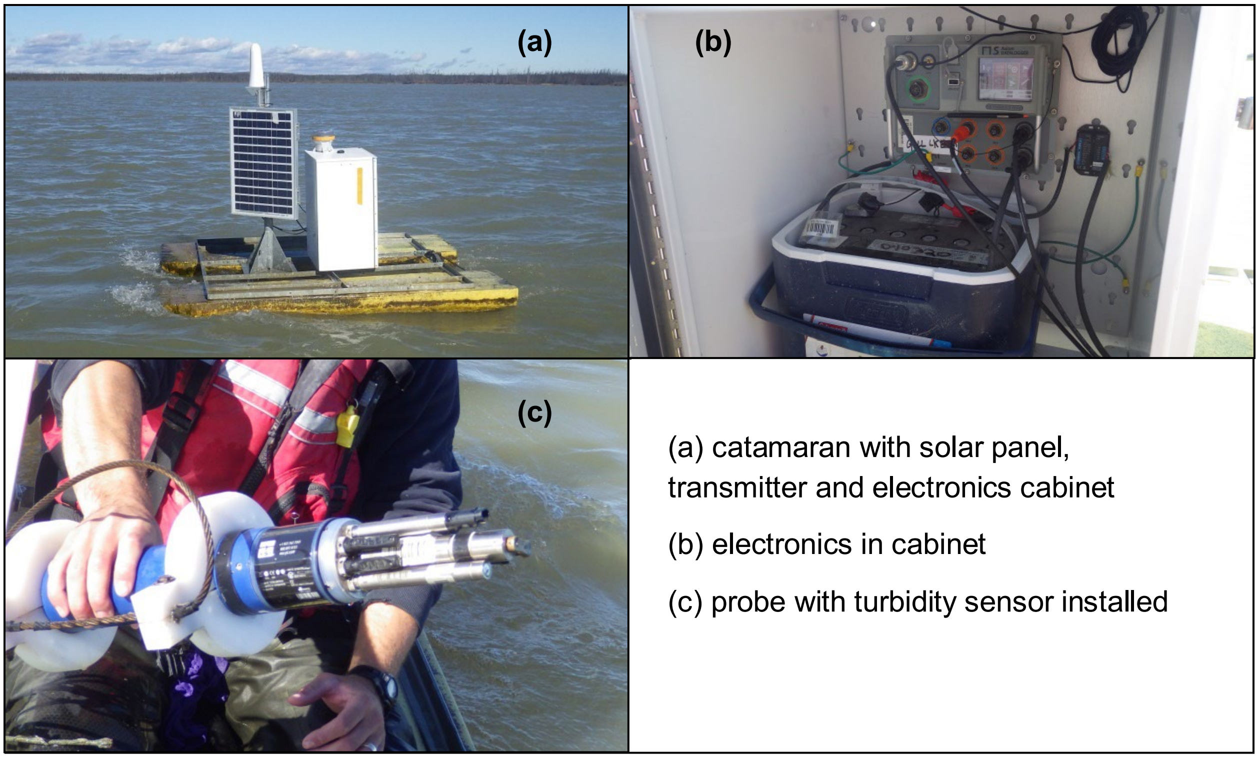
4.2.1 CONTINUOUS TURBIDITY

Eleven continuous turbidity sites were monitored in summer 2023. This included 5 sites on the Nelson River mainstem between Clark Lake upstream of project effects to 30 km downstream of the Keeyask GS in Stephens Lake near Kettle GS, as well as 5 flooded back bays upstream of Keeyask and a bay on Stephens Lake (Table 5; location maps in Appendix 1).

Table 5: 2023 summer continuous turbidity monitoring locations

Site ID / Location	Dates
Mainstem Sites	
CL-2-b (Clark Lake)	Jun 14 – Sep 19
KE-4-b (entrance Gull Lake)	Jun 13 – Sep 19
KE-10-c (just upstream Keeyask GS)	Jun 13 – Sep 20
STL-2-d (entrance Stephens Lake)	Jun 13 – Sep 21
STL-5 (Stephens Lake near Kettle GS)	Jun 15 – Sep 18
Back bay Sites	
KE-Z4-1-a	Jun 22 – Sep 20
KE-Z8-2	Jun 21 – Sep 20
KE-Z11-1-a	Jul 18 – Sep 20
KE-Z12-1-b	Jun 22 – Aug 31
KE-Z12-2-b	Jun 22 – Sep 20
STL-1-c (Stephens Lake)	Jun 20 – Sep 21

The continuous turbidity monitoring stations consist of either a catamaran equipped for satellite data transmission (Photo 4) or a stand-alone buoy system requiring manual downloading of data. Both systems were equipped with a YSI multi-parameter sonde (EXO series) suspended two metres below the surface of the water.



(a) catamaran with solar panel, transmitter and electronics cabinet

(b) electronics in cabinet

(c) probe with turbidity sensor installed

Photo 4: Continuous turbidity monitoring equipment

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 were also compared with the discrete readings obtained on each maintenance site visit and adjustments made for any sensor drift. As a result of the review some data was excluded at several sites but it was not necessary to remove extended periods of poor-quality data so there are no large gaps in these 2023 summer records other than periods when equipment failure resulted in missing data.

As observed in 2021, 2022 and during construction, the turbidity at each of the 3 mainstem sites upstream of the Keeyask GS and at STL-2-d just downstream followed each other closely, generally within about 1-2 FNU (Figure 20). There is a month-long gap in the KE-4-b record, but the remaining sites have complete data sets. Site STL-5 near Kettle GS followed the same general trend but was typically 1-2 FNU lower than the other sites, which is consistent with past observations that turbidity (and suspended sediment) generally deceases due to deposition in Stephens Lake. The KE-10-c site upstream of the Keeyask GS experienced several short periods of random turbidity spikes that are likely the result of floating debris in the water column.

The mainstem turbidity results generally dropped about 4 FNU over the course of the summer and do not indicate any significant change in turbidity due to the Keeyask reservoir: i.e., no notable increase due to erosion of flooded shorelines or decreases resulting from deposition due to lower velocities in the reservoir (Figure 20).

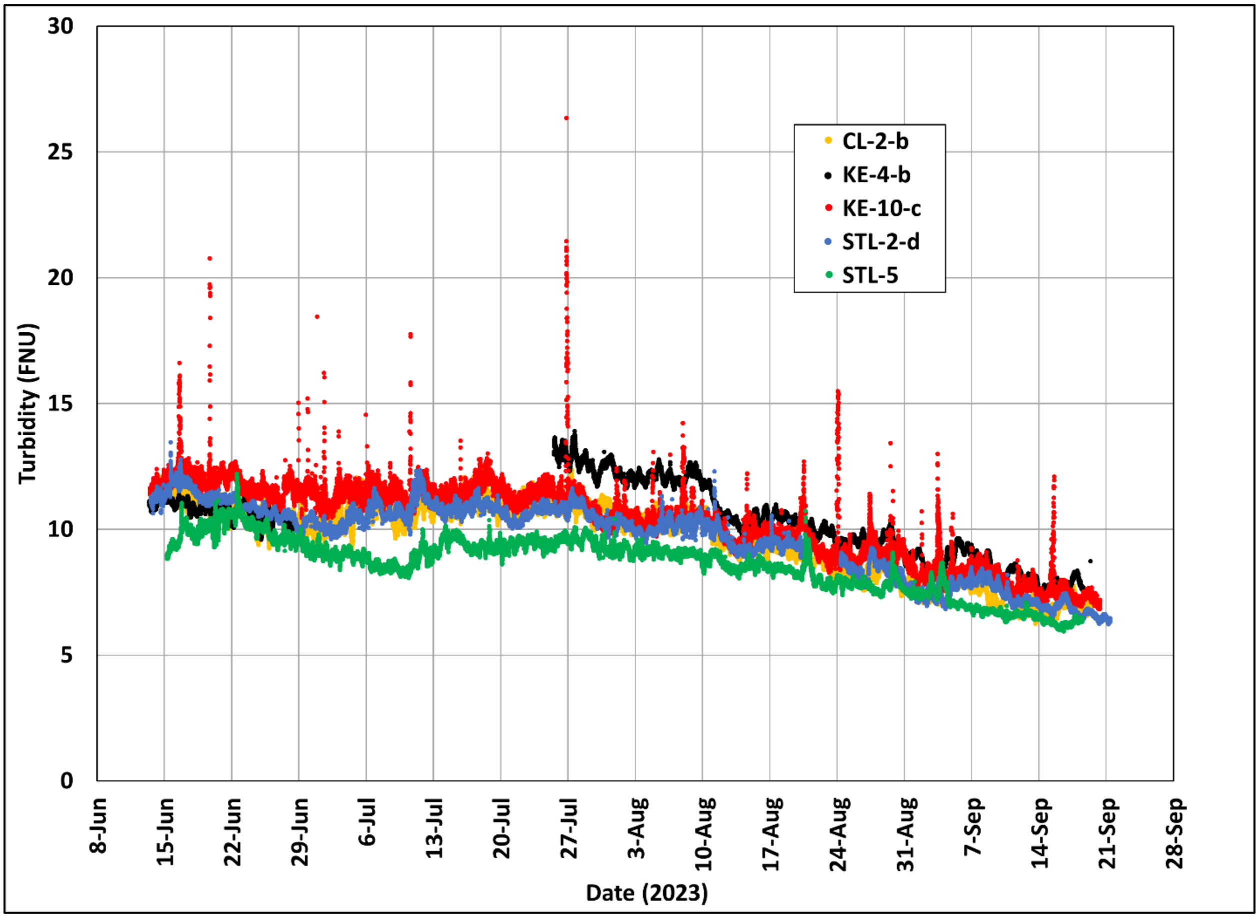


Figure 20: 2023 summer continuous turbidity – mainstem sites

Continuous turbidity monitoring was also conducted in 5 back bay locations in the Keeyask reservoir, plus one site on Stephens Lake which is the Kettle GS reservoir (Figure 21). Each site has a relatively good record over the entire summer despite some periods of missing data at sites KE-Z4-1-a, KE-Z8-2, KE-Z11-1-a, and KE-Z12-1-b.

Three sites, KE-Z4-1-a and KE-Z8-2 on the north side and KE-Z11-1-a on the south side, showed relatively low turbidity values with little variation and no high peaks over the summer. Among all the sites, back bay and mainstem, Site KE-Z4-1-a had the lowest average turbidity near 3 FNU (Figure 21). The previous season, KE-Z8-2 had the lowest turbidity with about 80% of readings between 1-2 FNU while this year the minimum value was 3 FNU at that location.

The two sites on the south side in Zone 12, KE-Z12-1-b and KE-Z12-2-b, both experienced short periods of higher turbidity reaching near 30 FNU (Figure 21). The highest turbidity levels were observed at the STL-1-c reference back bay site in Stephens Lake where a couple of high peaks exceeding 50 FNU were observed. Later in the season this site dropped to about 5-15 FNU, more comparable with other sites. The STL-1 site is typically higher than other back bay locations. Site KE-Z12-2-b had the highest seasonal average turbidity among upstream sites at around 10 FNU and was similar to turbidity levels on the main stem. The short duration spikes in turbidity are likely due to wind events causing local erosion and suspension of bottom sediments, which increase suspended sediment in the water. Peaks due to wind were likely lower at KE-Z4-1-a, KE-Z11-1-a, and KE-Z8-2 because those bays tend to be more sheltered from predominant winds.

The 2023 mainstem continuous turbidity data was summarized to show the overall ranges of turbidity as well as quartile and median values and results were plotted along with summary data from 2007-2022 (Figure 22). The 2023 results show average turbidity levels for each site were the second lowest observed among the 13 years that have been monitored, 2022 had been the lowest observed to date. Overall average turbidity in 2023 was just under 10 FNU while in 2022 it was about 8 FNU. From 2007 to 2020, the annual averages ranged from about 17-30 FNU. Average overall turbidity in the pre-construction (2007-2009) and construction (2014-2020) periods both exceeded 20 FNU at 25 FNU and 23 FNU respectively. The overall average during operation has been less than half those levels at only 10 FNU.

The low turbidity levels observed in since the start of operation in 2021 are not caused by the Keeyask project as the Clark Lake site upstream of project also has low turbidity levels. While not specifically studied, the low turbidity levels coincide with the arrival of zebra mussels, an aquatic invasive species, and is considered the likely cause of the low turbidity levels since the mussels filter sediment out of the water.

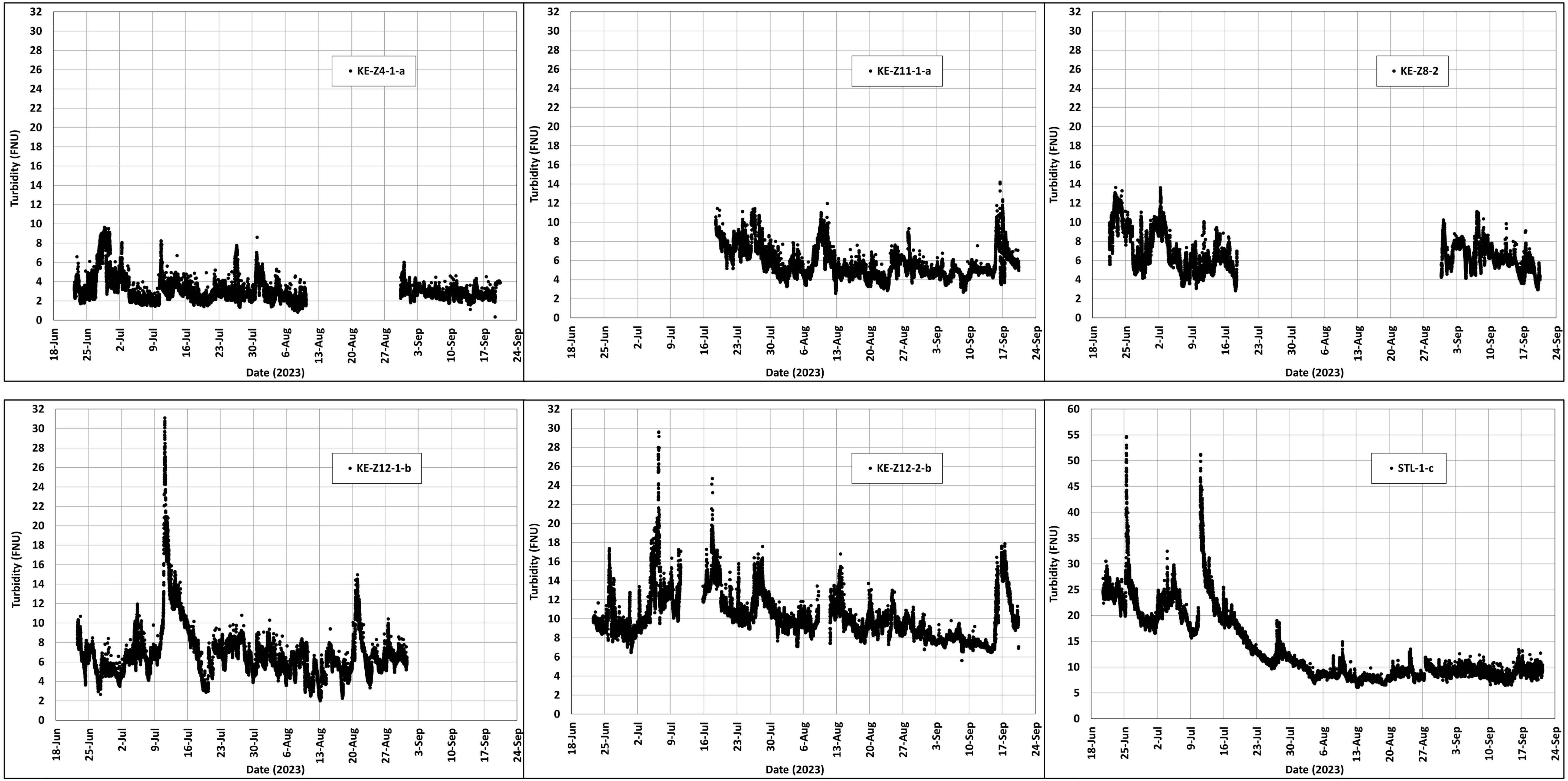


Figure 21: 2023 summer continuous turbidity – back bay sites

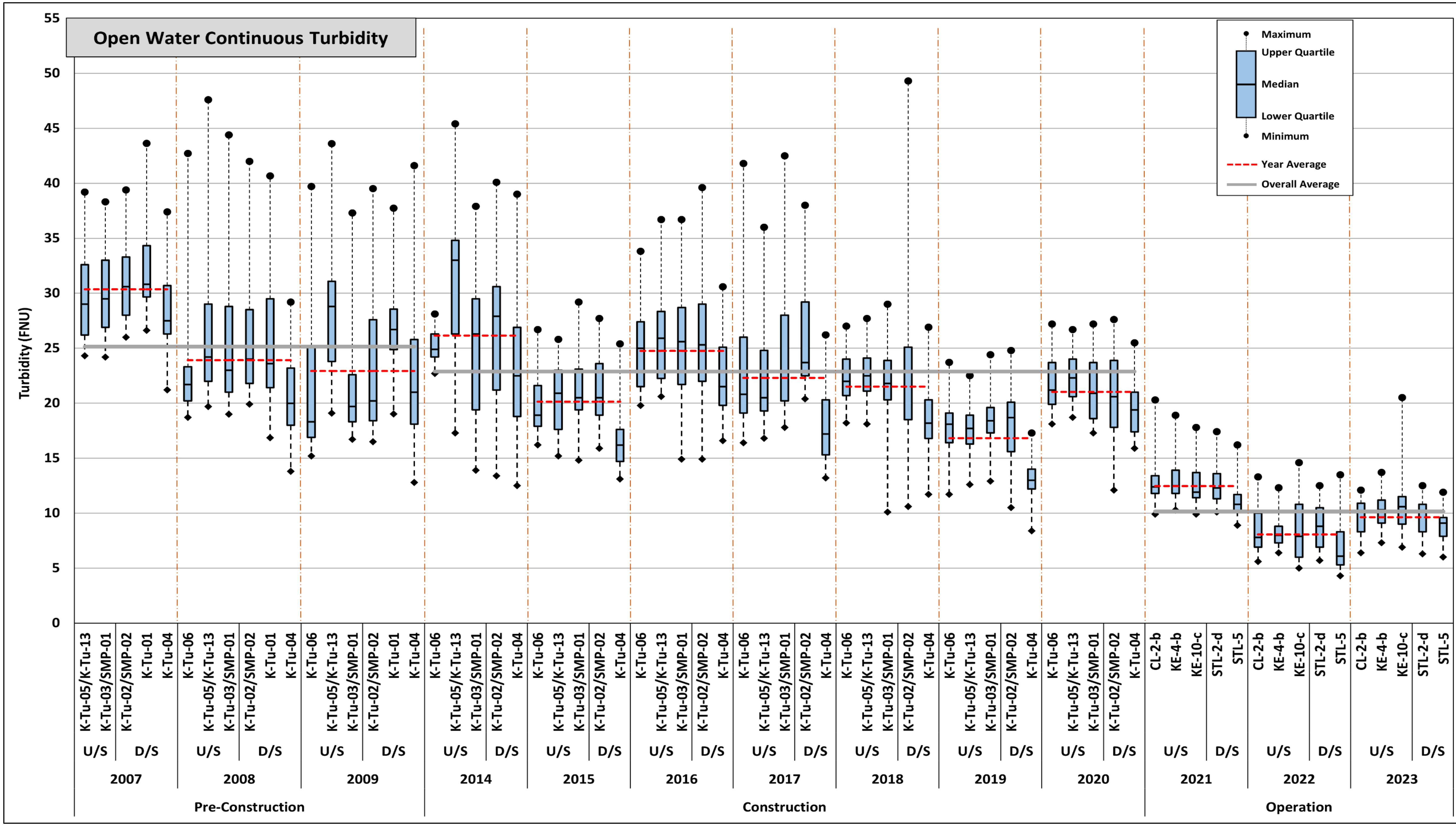


Figure 22: **Summary of mainstem annual summer continuous turbidity (2007-2023)**

4.2.2 DISCRETE TOTAL SUSPENDED SEDIMENT

During the summer period, site visits were performed at both the discrete monitoring sites and at the continuous turbidity sites between Clark Lake and a site in Stephens Lake just upstream of Kettle GS, about 30 km downstream of Keeyask GS (see maps in Appendix 1). Visits were performed to obtain water samples for total suspended sediment (TSS) and in-situ turbidity (TU) readings. The sites were visited 4 times, approximately monthly in June, July, August, and September, typically coinciding with the scheduled monthly maintenance visits at the continuous turbidity sites. Discrete water samples were collected for TSS testing from 33 locations across 10 monitoring sites (1-6 locations sampled per site) along the mainstem and at 12 locations at 12 back bay sites. Two water samples for TSS testing were typically collected at each location at 20% and 80% of site depth. Turbidity measurements were obtained at each of the 33 mainstem water sampling locations and at 47 locations across the 12 back bay sites (up to 4 locations at each site). Turbidity was measured at multiple depths at the monitoring locations. The discrete readings are used to verify the continuous readings, identify variability over depth of the site, and to correlate TSS and TU. Monitoring results were reviewed for vertical variation at the sites but, since values did not have notable vertical variation, the results were summarized considering depth averaged values.

The 2023 TSS concentrations (Figure 23) were generally below the lab minimum detection limit (mdl) of 2 mg/l at mainstem sites. Back bay locations showed slightly higher TSS concentrations, but a majority of the time TSS was below mdl. TSS results below 2 mg/l were assumed to be 1 mg/l for reporting purposes (i.e., half the minimum detection limit): therefore, an average TSS less than 2 mg/l indicates it includes results below the detection limit.

The mainstem TSS in 2023 was the lowest since monitoring began (Figure 24). This is not consistent with the continuous turbidity data where 2022 was the lowest. The reason for the difference is not known but could be due to changes in the sediment reflective properties that can influence turbidity or a fining of the sediment so that it is not collected in the filtering process. No changes in data collection or testing were reported that could cause this change in results. The data suggests that there is essentially no measurable sediment being transported in the mainstem of the Nelson River.

The Keeyask EIS (KHLP 2012b) predicted that TSS would decrease about 2-5 mg/l relative to pre-project conditions due to the reservoir, but the results indicate the concentrations in the first three years of operation were about 10-14 mg/l lower than observed prior to the project and during construction. However, as noted in the preceding section for continuous turbidity, the large decrease in TSS is also observed at the Clark Lake monitoring site (CL-2), upstream of the Keeyask's hydraulic zone of influence (Figure 24). This indicates the large decrease in TSS is not caused by the Keeyask project but rather likely due to the arrival of zebra mussels on the Nelson River.

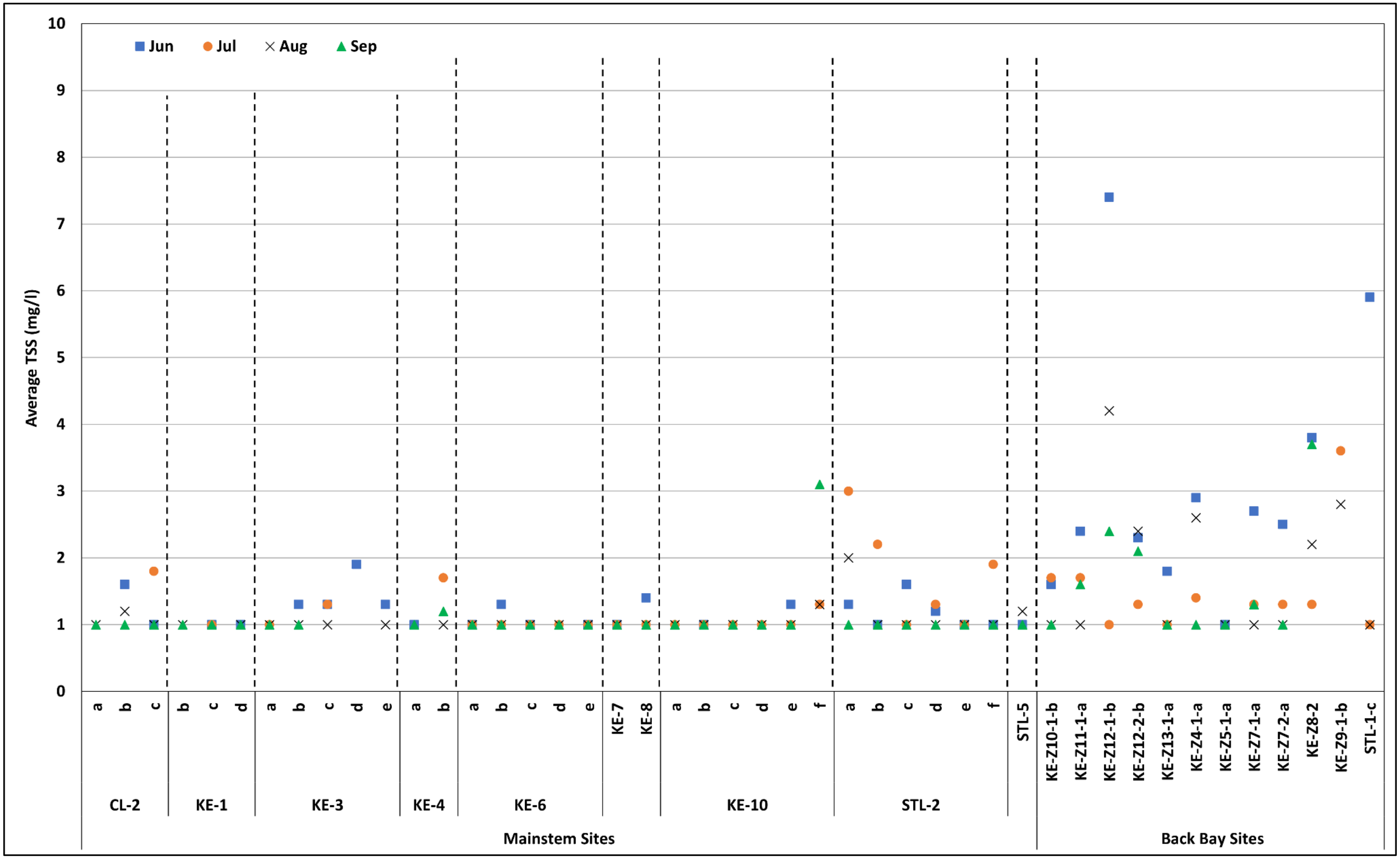


Figure 23: 2023 summer discrete TSS

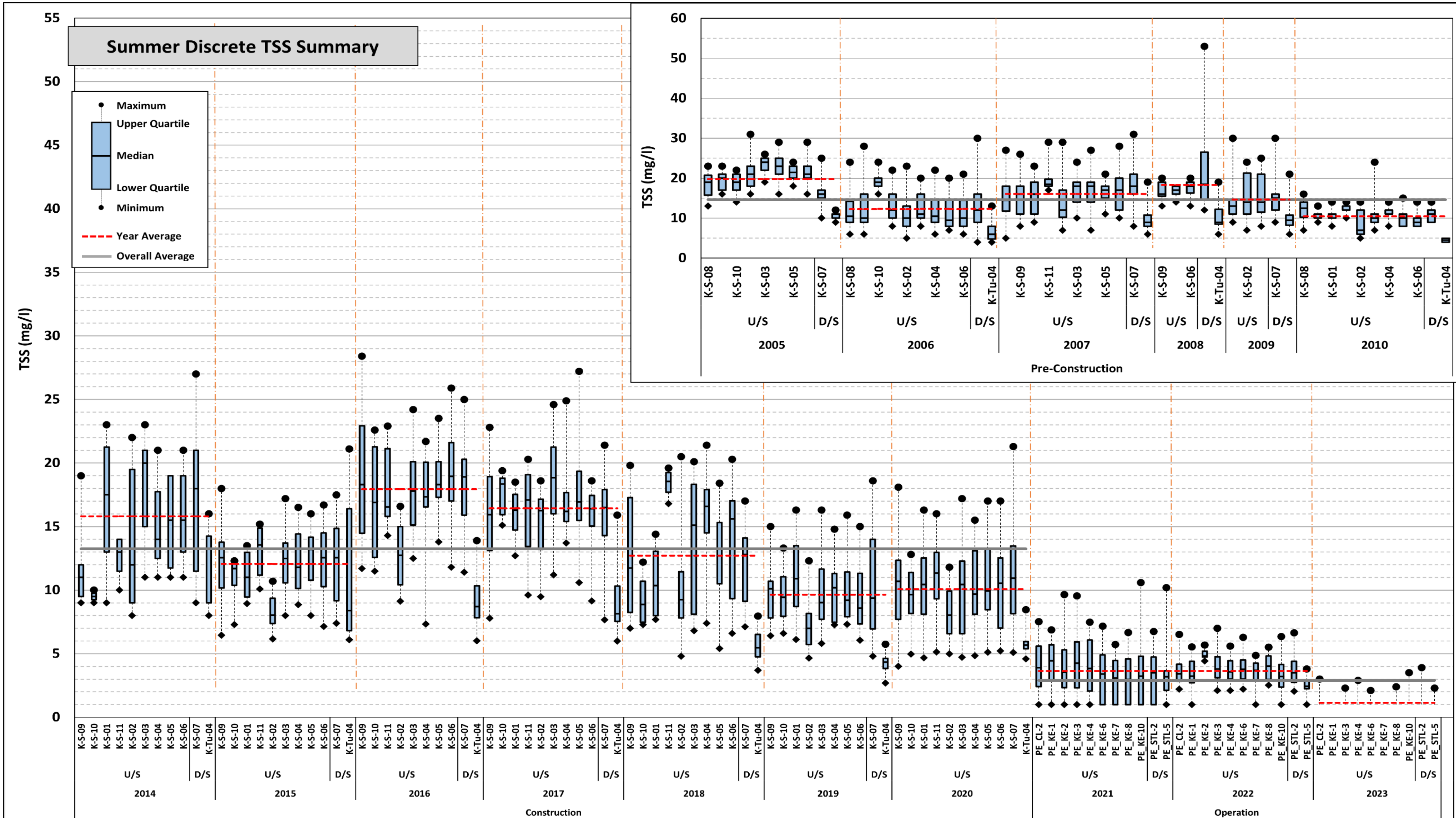


Figure 24: **Summary of annual summer discrete TSS at mainstem sites (2005-2023)**

4.2.3 DISCRETE TURBIDITY

The discrete turbidity is used in verifying the continuous data and monitoring turbidity across sections of the river and reservoir. The general trends match closely with that of the continuous turbidity. Discrete turbidity monitoring shows greater variability in the back bay sites than at the mainstem sites (Figure 25) which is consistent with the continuous turbidity reported earlier.

The discrete data are collected across the mainstem and at transects in the back bay areas (Figure 25). The back bay sampling locations are labeled in order with the ‘a’ location (or 1 for site KE-Z8) being closer to the shore (i.e. further from the main stem flow) while locations b, c and d (or 2, 3, 4 for KE-Z8) are progressively nearer the mainstem. At the mainstem sites the turbidity across the sections generally shows well mixed conditions with some small differences (1 to 2 FNU) across the river in June and July at several sites. At the back bay sites turbidity tends to be lowest at the ‘a’ (or 1) location furthest from the mainstem and incrementally increases to the ‘d’ or ‘4’ location closest to the mainstem. The lowest back bay turbidity was observed for site KE-Z9 with readings less than 2 FNU. This back bay is not well connected to the mainstem and experiences no meaningful mixing from the mainstem flow the way other sites do to varying degrees.

Remote sensing data from Sentinel 2 satellite imagery was used to estimate TSS in the study area from Clark Lake to Stephens Lake. The results highlight the spatial variation of TSS between areas upstream of Keeyask and the west side of Stephens Lake (Figure 26). Images from June 14, August 21, and September 27, 2023, show decreasing TSS from upstream to downstream consistent with continuous and discrete measurements. It also shows higher levels of turbidity along the west side of Stephens Lake north of Keeyask GS as compared with areas upstream of the GS. Generally, the high TSS on Stephens Lake is due to wind effects, particularly strong north and east winds. The variability observed in the satellite imagery is consistent with turbidity and TSS observations.

4.2.4 RECOMMENDATION FOR MONITORING 2024

Monitoring in the first 3 years of operation has been done at multiple points across the width of the river and reservoir at the monitoring sites. Results from these 3 years has shown little variation from upstream to downstream along the mainstem and less so across the river width. Since many of the sites show largely the same conditions, it is recommended that the number of sites being discretely monitored in summer 2024 be reduced. The mainstem sites are reduced to one monitoring point at Clark Lake (CL-2-b) and the entrance of Gull Lake (KE-4-b), and the 6 transect points just upstream of the GS (KE-10-a to f) and downstream of the GS (STL-2-a to f), and site STL-5 near Kettle GS. Additional mainstem sites between Clark Lake and the GS will not be monitored. In backbays, the continuous monitoring will continue as before, but only one of the four transect points in each back bay will be monitored discretely.

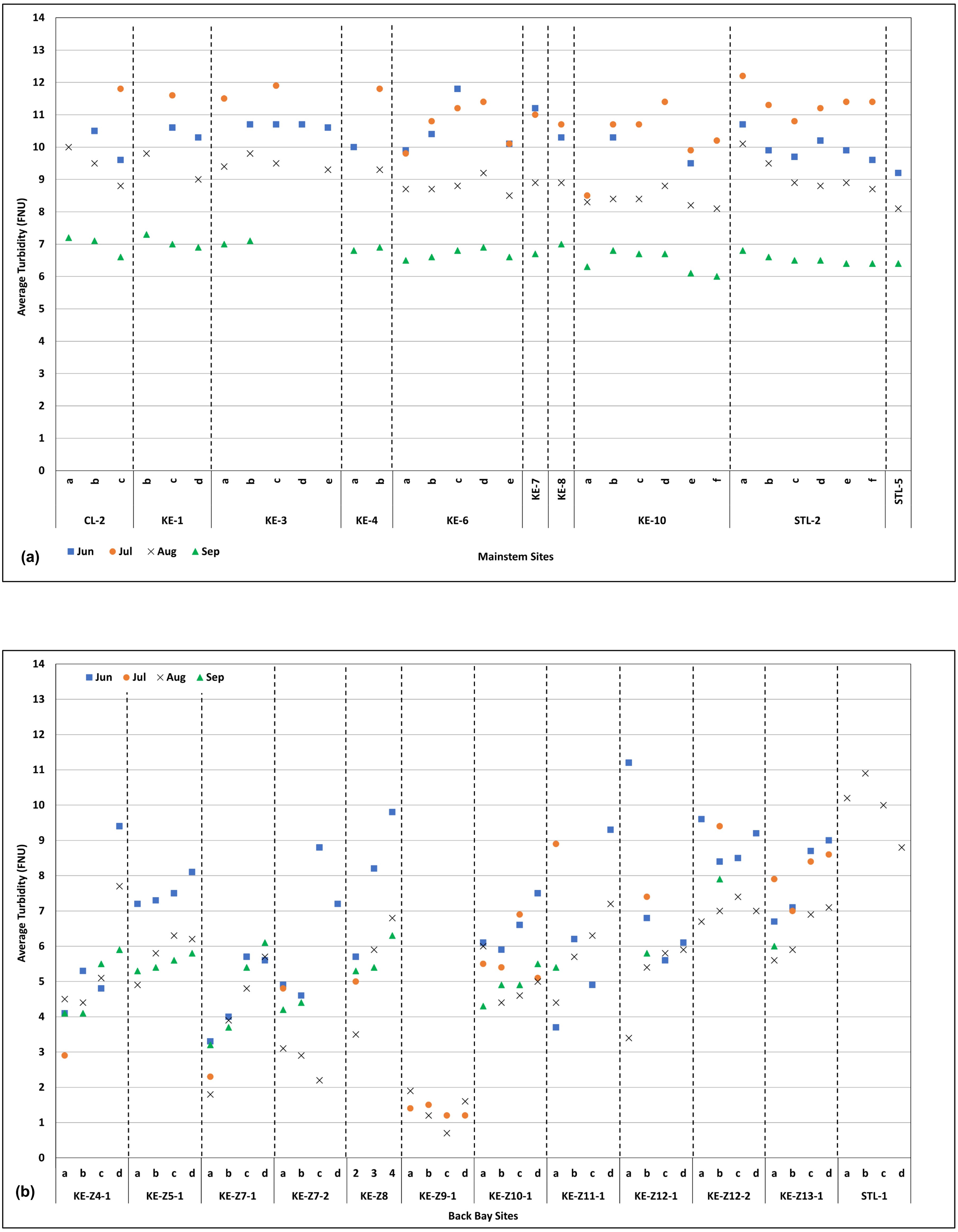


Figure 25: **2023 summer discrete TU at (a) mainstem sites, (b) back bay sites**

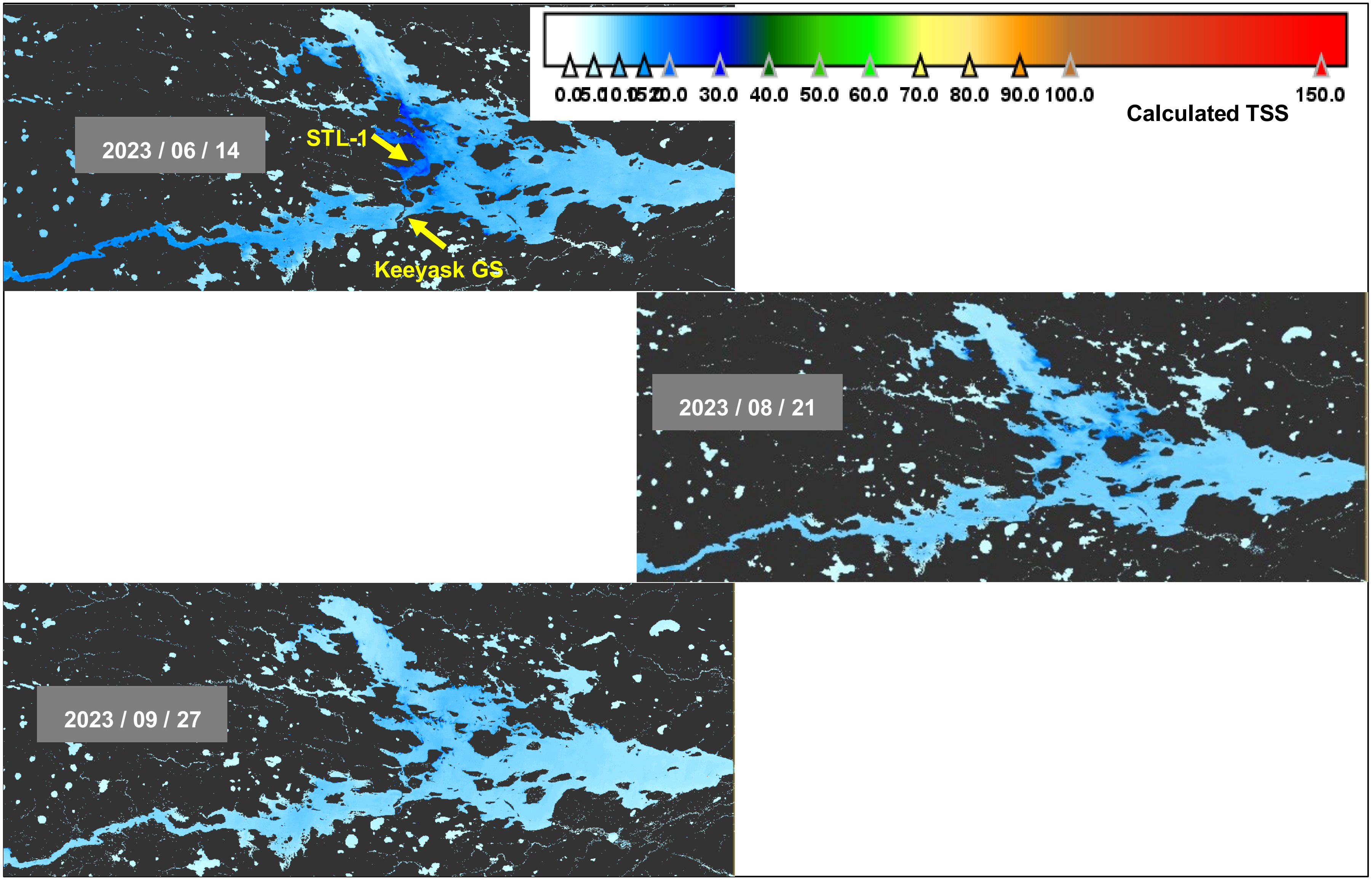


Figure 26: Spatial variation of TSS calculated from Sentinel 2 satellite data

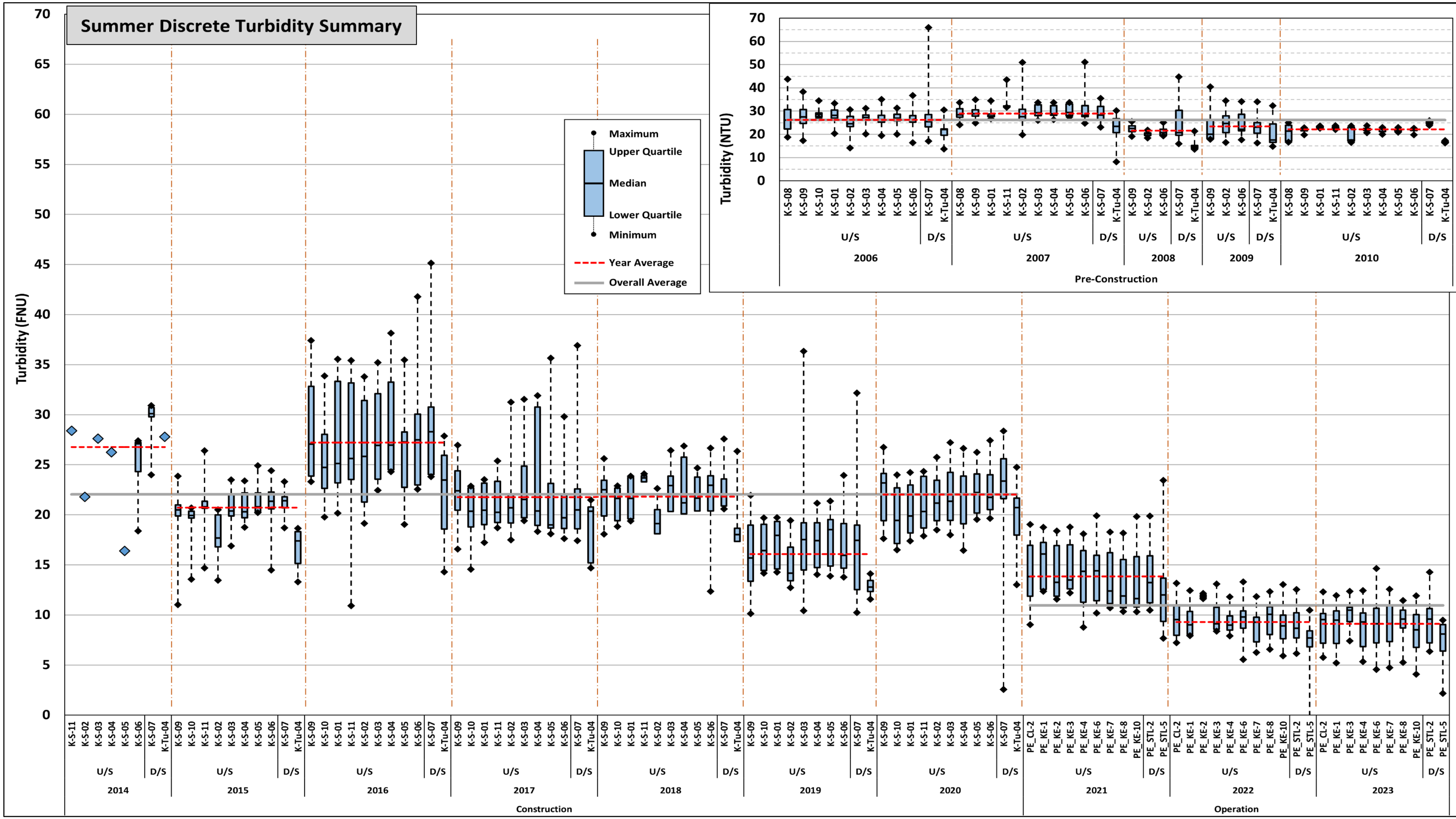


Figure 27: Summary of annual summer discrete Turbidity at mainstem sites (2006-2023)

4.2.5 ESTIMATED SUSPENDED SEDIMENT LOAD

The summer suspended sediment loads (Figure 28) were estimated based on the average daily turbidity calculated from the continuous monitoring data and the calculated Keeyask inflow. Turbidity was converted to TSS concentrations based on TSS-Turbidity relationships derived from discrete data obtained each monitoring year prior to operation and using a relationship derived from the combined discrete data for the operating years.

The 2023 average summer suspended sediment load of about 750 t/d was the lowest since monitoring started, somewhat lower than 900 t/d calculated for 2021 and continued the trend of much lower loading than before and during construction. The sediment load in 2023 is lower than the previous low in 2021 due further reduction of suspended sediment concentrations, and the estimated load was lower despite as the average river flow being nearly 500 m^3/s greater in 2023 than in 2021.

The average daily sediment loading in 2023 was approximately 80% and 85% lower than observed during the construction and pre-construction periods respectively. It is also notable that the summer sediment loads in 2021-23 were as much as half the sediment loads in winter during that period. This is a notable change from the construction and pre-construction periods when summer sediment loads were typically larger, and potentially much larger, than winter loads at about the same time.

Again, as noted in previous sections, the marked decrease in loading during operation is not due to Keeyask since the change is also observed at the upstream Clark Lake site CL-2 (Figure 28), indicating the effect is due to processes further upstream of Clark Lake and the hydraulic influence of the Keeyask project: rather, the reduction is likely a result of zebra mussels that are now present in the Nelson River.

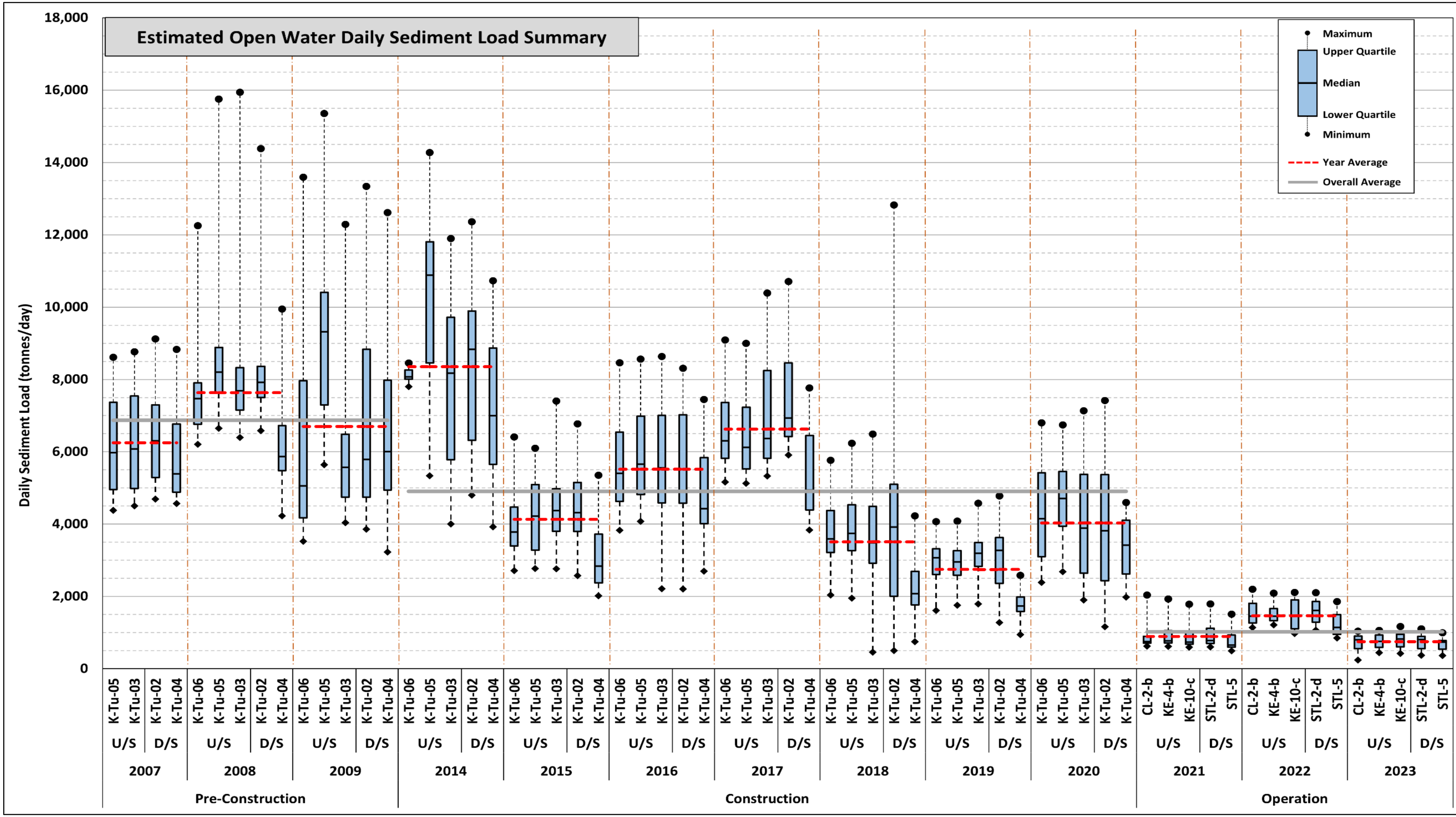


Figure 28: Summary of estimated summer daily sediment loads (2007-2023)

4.3 SEDIMENT TRAP MONITORING

4.3.1 OVERVIEW

The Keeyask PEMP committed to deposition monitoring during the construction phase and first 5 years of the operation phase that included using sediment traps deployed at the entrance to Gull Lake (site K-ST-02 during construction, KE-5 during operation) and downstream of the Keeyask GS at the inlet to Stephens Lake (site K-ST01 during construction and STL-4 during operation). Samples obtained from sediment traps were sent for laboratory testing to determine the weight of material collected, the organic carbon content, and sediment grain size classification.

The deposition monitoring has encountered challenges in terms of deploying and recovering sediment trap equipment, and consistency in lab reporting. The PEMP indicates a review of monitoring would occur after the first 3 years of Keeyask operation and, after consideration of some of the challenges and inconsistencies affecting the data collection along with limitations on the results, the decision was made to discontinue deployment of the sediment traps after the 2023 season. A notable limitation of the monitoring is that amount of sediment collected by the traps and the rate of collection, calculated as grams per square meter per day ($g/m^2/d$) based on trap size, does not provide an indication of the actual deposition rates at the monitoring sites. Rather, the sediment collected is indicative of the amount of sediment being transported through the area: for example, the sediment traps collected clay size material although they were located where clay would not likely deposit.

Sediment trap monitoring has been performed using traps that incorporate what are referenced as either settling tubes or flow tubes. The tubes are 5 cm (outside diameter) poly-carbonate cylinders mounted in a frame with a sample collection bottle under the tube to capture the sediment that settles in the tube (Photo 5a, b). The settling tubes are open on top and can collect sediment that is dropping down through the water column. Flow tubes are closed on top and have a plastic disc around the tube with 18 mm holes drilled around the circumference of the tube above the disc. The flow tubes collect sediment that is carried into the tube by the flow of water through the holes.

The first winter of monitoring used temporary sediment traps with 3 smaller diameter settling tubes because the 5-tube traps were not yet available. In the following 3 years, the sediment traps were set up as a frame carrying 2 settling tubes and 3 flow tubes (Photo 5a). These traps proved to be very heavy for deployment and retrieval, necessitating the use of winches mounted on the boats to handle the weight. Difficulty working with the traps raised safety concerns for field staff and a lack of boats with approved winches was also a problem. Starting in June 2018, new traps were configured with 1 settling tube and 1 flow tube (Photo 5b). Being much lighter and not requiring winches improved safety and deployment options. Because of this change, the monitoring was performed by deploying 2 or 3 of the 2-tube traps instead of one 5-tube trap.

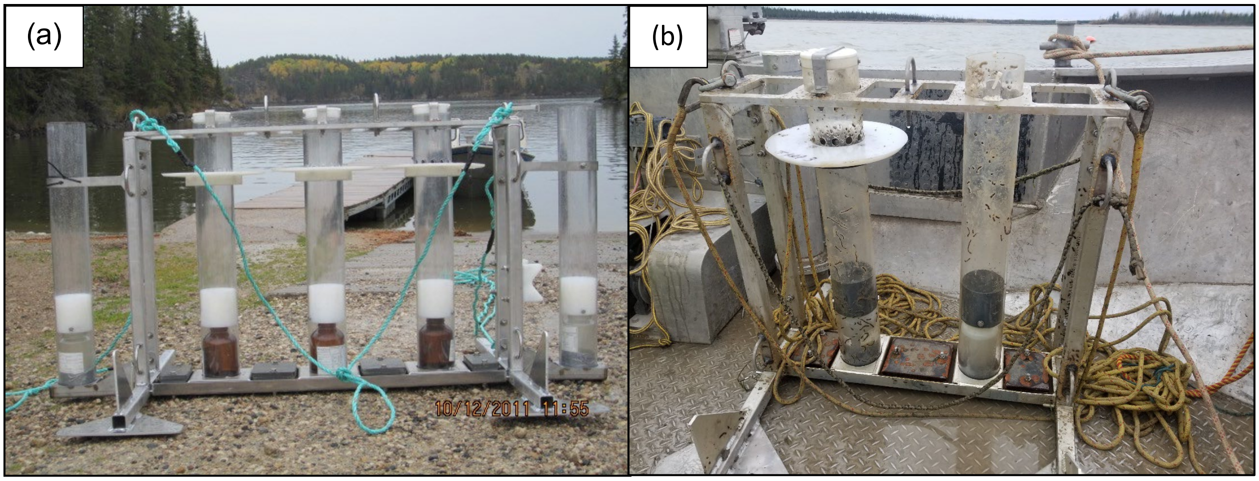


Photo 5: Sediment traps – a) 5-tube design, and b) 2 tube design

In the first winter and summer during construction (Oct 2014 – Oct 2015), sediment traps were deployed at the upstream end of Gull Lake. Both times the field crews could not locate the trap when it came time to recover it because strong currents in the monitoring area displaced the traps. Despite multiple efforts to recover the traps by dragging the lakebed, they were never recovered. In addition to the loss of upstream sediment traps in the first year of monitoring, traps have also been lost at other times at the upstream and downstream locations. Samples were not collected at the downstream location in summer 2017 season due to an error leading to the trap not being deployed. There were also a few cases where results were unavailable due to lab errors and where lab results could not be matched with the correct field sample. Following this, field protocols and lab methods were re-evaluated and modified to resolve this issue from happening again.

Laboratory testing for sediment gradation has been performed at 3 different labs while the Manitoba Hydro chemistry lab did total organic carbon testing except for the last 3 seasons when it was done by ALS Environmental. The Bureau Veritas lab was used in the first two seasons. The next two seasons, the Manitoba Hydro soil lab was used, but testing returned to Bureau Veritas after Hydro's soil lab was shut down. The last three seasons, gradation testing was done by ALS Environmental. The use of different labs introduces some challenges in comparing data. In some cases, reported masses represent subsample dry weights which is assumed to be roughly half the sediment collected as the sample was split for organic carbon and gradation testing. Hydro's soil lab reported the total dry weight and ALS appears to also report the total since they did both the gradation and organic carbon testing. The gradation results may vary somewhat due to different test methods because Bureau Veritas used an optically-based electronic particle-counting device to measure sediment grains and classify their distribution while the Manitoba Hydro and ALS labs used more traditional hydrometer testing: while deviations between test methods may exist, the results are assumed to be comparable for the purposes of the Keeyask PEMP.

4.3.2 MONITORING RESULTS

While the previous section highlighted some of the challenges in executing the monitoring and factors that may make interpretation of results more complicated, the following discuss observations that may be made from the sediment trap monitoring results.

Mass & Rates of Sediment Collection

In general, the masses of sediment collected in both the flow and settling tubes were comparable in magnitude within each season of sampling, with one notable exception (Table 6). The results for summer 2020 at the upstream monitoring site showed substantially more sediment collected in the flow tubes (120-169 g) versus the settling tubes (25-98 g) and the reason for the difference is uncertain. Otherwise, there does not appear to be an obvious differentiation between the two types of collection tubes. For this reason, the average masses of sediment collected and corresponding average collection rates (as grams per square meter per day) were calculated using the combined masses from both types of tubes. Note that average masses collected can be quite variable not just because of differing amounts of sediment being transported, but also because of different durations over which the traps are deployed: winter deployments could last 7-8 months while summer deployments might be 2-3 months.

For the downstream location, the results generally indicate much lower rates of sediment collection have been observed since the reservoir was impounded in September 2020 (Table 6), although a high collection rate of 140 g/m^2/d is shown during operation in summer 2022 in association with record high flows. Three of the operation period collection rates were less than 30 g/m^2/d, which is less than the two lowest collection rates of 49 g/m^2/d that occurred when flows were near or below average during construction. Two of the highest rates observed during construction occurred in winter 2016/17, when record high flows were observed, and winter 2019/20 when river flows exceeded the 95th percentile high flow. The 2019/20 winter period also saw water levels upstream of the dam raised in February to water-up the upstream construction area (i.e., re-wetting the de-watered construction area upstream of the GS) and removal of the upstream cofferdam and north channel rock groin. Increased water levels and removal of granular cofferdams may have contributed additional sediment to the flow. A high collection rate was also observed in summer 2020 when flows were as high as the 75th-95th percentile. The high deposition rate may also be related to the increased levels that persisted after water-up as well as raising the water level the final 2 m to fill the reservoir to the full supply level at 159 m above sea level.

In the six seasons of upstream monitoring, reported collection rates have been higher than the downstream rates in 3 seasons and lower in 3 seasons (Table 6). The three highest years reported correspond with periods of very high flows, and the results for summer periods in 2020 and 2022 were also periods of high collection rates downstream. The 2020 season is also associated with potential effects from water-up earlier in the year and filling the reservoir in September which resulted in flooding of shorelines and terrestrial areas. Unlike the high collection rates in 2020 and 2022, the high collection rate of 181 g/m^2/d in winter 2022/23 at the upstream site was significantly greater than the downstream rate of 22 $g/m^2/d$ winter, which was the lowest rate recorded for that location. The downstream site had its lowest reported collection rates in the 3 winter periods since operation began, even under high flows, while the upstream site has had higher rates of collection in winter, and markedly so when the flow was high. Because the upstream site could not be monitored during construction, it is not possible to conclude if upstream rates of sediment collection in the sediment traps is higher or lower during operation versus before operation.

The preceding discussion on deposition masses and rates has not noted the interesting results obtained in summer 2023, the last season of monitoring. In all 3 of the 2-tube sediment traps deployed at both the upstream and downstream monitoring sites, the amount of sediment collected over the summer was insufficient to be able to perform the gradation testing and as a result the mass was not reported (Table 6), although organic carbon was measured. The 2023 summer period had somewhat lower flows that were between 25^{th} to 50^{th} percentile, which may partly account for reduced sediment. While creation of the reservoir and operation Keeyask has affected sediment deposition, another notable factor that is affecting sediment transport since the start of operation is the virtual elimination of total suspended sediment (TSS) in the Nelson River due to the proliferation of zebra mussels (see section 4.2). TSS concentrations were much lower in 2021 and 2022 than previous years (Figure 24), coinciding with the appearance of zebra mussels. While those years were very low, TSS concentrations were even lower in 2023, with almost all TSS measurements falling below the lab detection limit of 2 mg/l. It is likely that zebra mussels are removing most of the sediment that might otherwise be collected by sediment traps.

Total Organic Carbon in Sediment

Total organic carbon in the sediment samples was typically less than 3% at the upstream site and at the downstream site prior to construction. The upstream site had a high value of 8.7% in winter 2022/23 in association with elevated flows in the 75^{th} to 95^{th} percentile range (Table 6). Although the upstream site was not monitored prior to summer 2020, it is likely that organic carbon content at the upstream site was generally low and similar to results observed at the downstream location. Except for winter 2020/21, which was less than 3%, total organic carbon at the downstream site has ranged from 5% to 10.5% since water-up and impoundment of the reservoir in 2020. The 10.5% high value may be related to record high flows in summer 2022 that may have displaced organic material from upstream shorelines due to high water levels and flow velocities. The downstream total organic carbon of 8.8% in winter 2022/23 is about the same as the 8.7% value noted at the upstream site and it does not appear that the breakup and removal of a peat island at the powerhouse in spring 2023 (see Debris section) caused the downstream sediment trap to have increased organic carbon. Overall, the downstream total organic carbon content of the sediment during operation is about two to four times greater than prior to water-up and impoundment, which is likely attributable to the creation of the reservoir.

Sediment Classification

Sediment classifications for the two monitoring sites are variable. At the downstream site prior to construction the clay content typically ranged from about 15%-25% but was reported as low as 1%-4% during operation (Table 6). The silt content ranged from 18% to 72%, with most results above 60% during construction, but during operation it was generally lower at 22%-35%. Sand content was quite variable during construction, ranging from 4% to 79% and has also had a wide range of 20%-76% during operation. The 3 periods with the highest sand content at the downstream site during construction were in winter 2016/17, winter 2019/20 and summer 2020, which were all associated with very high river flows, consistent with periods when sand may be more likely to be suspended. At the upstream site, the clay content was less than 10% the first 4 monitoring seasons, with the two lowest occurring during the summer 2020 and 2022 high flow periods when relatively more sand may have been transported by the river. The silt content typically ranged from 34%-62% with a low of 18%, while sand typically varied from 31%-67% with a low of 5%.

Comparing the results obtained in the five monitoring seasons from 2019/20 to 2021/22 it is apparent the results are quite different in these seasons versus seasons before that for the downstream site and after that at both sites. At both locations the sand content was quite low during the 2019/20 to 2021/22 period, being less than 7% and 4% at the upstream and downstream sites respectively. In these five seasons the silt content was generally lower than earlier monitoring at the downstream site at about 20%-36% while the sand content was correspondingly higher at 61%-79%. The upstream site was less consistent between sand and silt, with either about 1/3rd silt and 2/3rd sand, or 2/3rd silt and 1/3rd sand, or about 50% each from 2020 to 2021/22. In the final two periods of monitoring, 2022 and 2022/23, at each site the clay content was much higher than in the preceding 4 periods, with 35%-61% clay upstream and 38%-46% downstream. This appears to come mainly from a decrease in sand at the downstream site and either a change in silt or sand at the upstream.

It is unclear why the 2022 and 2022/23 results had high clay content while the 5 preceding seasons were low. These two periods had elevated river flow, but in previous years higher flow appeared to favour greater sand content. Lab testing in the two periods with the higher clay content was performed by ALS Environmental while the preceding periods with low clay content was analyzed by Bureau Veritas and differences in test procedures may partly be a factor in the differences, although different procedures are generally expected to produce comparable results. Creation of the reservoir, differences in flow, and the increasing presence of zebra mussels may be factors influencing the observed differences, but the specific influence of any one factor cannot be determined.

Conclusion on Sediment Trap Monitoring

While there are difficulties in conclusively interpreting the sediment trap monitoring results, a few conclusions do appear to come out of the data.

- First, the results suggest amount of sediment being transported downstream of the reservoir has been substantially reduced, which may be partly due to the reservoir trapping sediment. However, a larger factor is likely the virtual elimination of TSS in the Nelson River due to the proliferation of zebra mussels, which would significantly limit how much sediment would be available to be collected in the sediment traps.
- Second, periods of very high river flows result in higher rates of sediment collected by the traps upstream and downstream as might be expected due to the higher energy available to transport sediment.
- Third, while the amount of sediment being transported may be lower, the relative amount of organic material in the sediment has increased at the downstream site, which is likely due to organic matter from the reservoir. Organic content at the upstream site has generally remained low during operation and likely similar to what it was during construction.

4.4 SUBSTRATE SAMPLING

The Keeyask PEMP committed to deposition monitoring first 5 years of operation phase that included obtaining grab samples of bed material from locations upstream and downstream of the Keeyask GS. Grab samples were obtained using a ponar grab sampler, which is a device with two spring loaded jaws that are open when dropped to the lakebed and then close to grab a sample of the bottom sediment when the springs are released Photo 6). During construction, crews attempted to obtain bed material samples at the downstream and upstream sediment trap locations, K-ST-01 and K-ST-02 respectively, in 2015 but found the substrate to be large cobble type material and samples for gradation could not be obtained and for this reason sampling was not done again until 2020 when upstream water levels were raised during water-up in February (i.e., re-wetting the dry construction area inside the cofferdam upstream of the GS and impoundment of the reservoir to full supply level of 158 m ASL in September. During sampling, crews attempted to collect up to 3 or 4 sediment grab samples in the vicinity of the sampling sites. These were sent for lab testing to determine the fractions of clay, silt, and larger grain sizes and organic content.

Sediment grab sampling was performed at 7 locations from 2020 to 2023, which were: KE-4-b at the upstream end of Gull Lake, KE-11 and KE-6-c about 5 km and 8 km downstream of KE-4-b, KE-7 and KE-12 south and north of Caribou Island respectively, KE-10-d about 4 km upstream of the GS, and about 5 km downstream of the GS at the K-ST-01 sediment trap location in 2020 and the KE-STL-6 location about 300 m further downstream in 2021-23. From the sampling, 81 samples were obtained and reported for testing. For 33 of those samples, the ponar could not grab enough material for gradation testing, although organic carbon could be obtained for 27 of them. The remaining 48 samples were tested for grain size classification and total organic carbon, and the results were plotted for all the samples to show the percent of each classification along with organic content (Figure 29).

Table 6: Summary of results from sediment trap monitoring (2014-2023)

	Equipment	Installed	Removed	Duration (d)	UPSTREAM (mass collected)								DOWNSTREAMUPSTREAM (mass collected)								Average Total Organic Carbon		Average Sediment Classification						Test Lab
					Settling (g)			Flow (g)			avg mass	avg rate	Settle (g)			Flow (g)			avg mass	avg rate			upstream			downstream			
					1	2	3	1	2	3	(g)	($g/m^2/d$)	1	2	3	1	2	3	(g)	($g/m^2/d$)	u/s	d/s	clay	silt	sand	clay	silt	sand	Test Lab
CONSTRUCTION	1 x 3 tube	2014-10-18	2015-07-22	277	L	L	L						46	52	E				49	76		0.4%				19%	64%	17%	Maxxam (Bureau Veritas)
	1 x 5 tube	2015-07-22	2015-10-02	72	L	L		L	L	L			86	86		97	96	103	94	176		2.1%				22%	69%	9%	Maxxam (Bureau Veritas)
	1 x 5 tube	2015-10-02	2016-08-06	309	N	N		N	N	N			360	328		435	330	345	360	158						16%	38%	46%	MB Hydro soil lab
	1 x 5 tube	2016-08-06	2016-10-13	68	N	N		N	N	N			53	70		59	62	57	60	120						25%	69%	7%	MB Hydro soil lab
	1 x 5 tube	2016-10-15	2017-06-17	245	N	N		N	N	N			328	515		391	418	385	407	225		1.9%				4%	18%	78%	Maxxam (Bureau Veritas)
	1 x 5 tube	Summer 2017			N	N		N	N	N			E	E		E	E	E											no samples collected
	1 x 5 tube	Winter 2017-2018			N	N		N	N	N			L	L	L	L	L	L											
	2 x 2 tube	2018-07-05	2018-10-10	97	N	N		N	N				39	L		30	L		35	49		2.1%				23%	69%	8%	Bureau Veritas
	2 x 2 tube	2018-10-10	2019-06-05	238	N	N		N	N				E	L		E	L					2.6%				15%	63%	22%	Bureau Veritas
	3 x 2 tube	2019-06-26	2019-09-28	94	N	N	N	N	N	N			32	40	32	33	35	31	34	49		2.2%				24%	72%	4%	Bureau Veritas
	3 x 2 tube	2019-09-28	2020-06-28	274	N	N	N	N	N	N			715	476	606	421	289	387	482	238		2.6%				1%	20%	79%	Bureau Veritas
	3 x 2 tube	2020-06-28	2020-09-19	83	42	25	98	168	169	120	104	169	137	178	147	107	162	102	139	226	1.6%	5.0%	7%	62%	31%	3%	36%	61%	Bureau Veritas
OPERATION	3 x 2 tube	2020-09-19	2021-06-26	280	124	122	139	122	165	116	131	64	26	I	81	29	49	64	50	24	2.9%	2.2%	4%	34%	62%	4%	35%	61%	Bureau Veritas
	3 x 2 tube	2021-07-13	2021-10-05	84	47	39	24	37	35	52	39	63	E	E	16	E	E	70	43	69	2.1%	5.8%	4%	29%	67%	2%	22%	76%	Bureau Veritas
	3 x 2 tube	2021-10-05	2022-06-24	262	L	76	58	L	111	73	80	41	L	68	49	L	49	53	55	28	2.3%	6.0%	7%	45%	48%	E	E	E	Bureau Veritas
	3 x 2 tube	2022-06-24	2022-09-14	82	L	69	72	L	51	73	66	109	131	52	L	80	78	L	85	140	1.9%	10.5%	61%	34%	5%	38%	32%	30%	ALS Environmental
	3 x 2 tube	2022-09-14	2023-06-15	274	297	198	346	431	465	462	367	181	54	48	18	50	66	28	44	22	8.7%	8.8%	35%	18%	47%	46%	33%	20%	ALS Environmental
	3 x 2 tube	2023-06-15	2023-09-18	95	I	I	I	I	I	I			I	I	I	I	I	I			1.9%	6.3%							ALS Environmental

Notes: N = trap not deployed / L = lost trap, deployed but not recovered / E = field/lab error resulting in missing data / I = insufficient sample to run test
5-tube samplers comprised of 2 flow tubes and 3 settling tubes (flow tube has a closed top and holes drilled through the sides of the tube to allow flow through; settling tube has open top and no holes drilled in the sides)
2-tube sampler has 1 flow tube and 1 settling tube

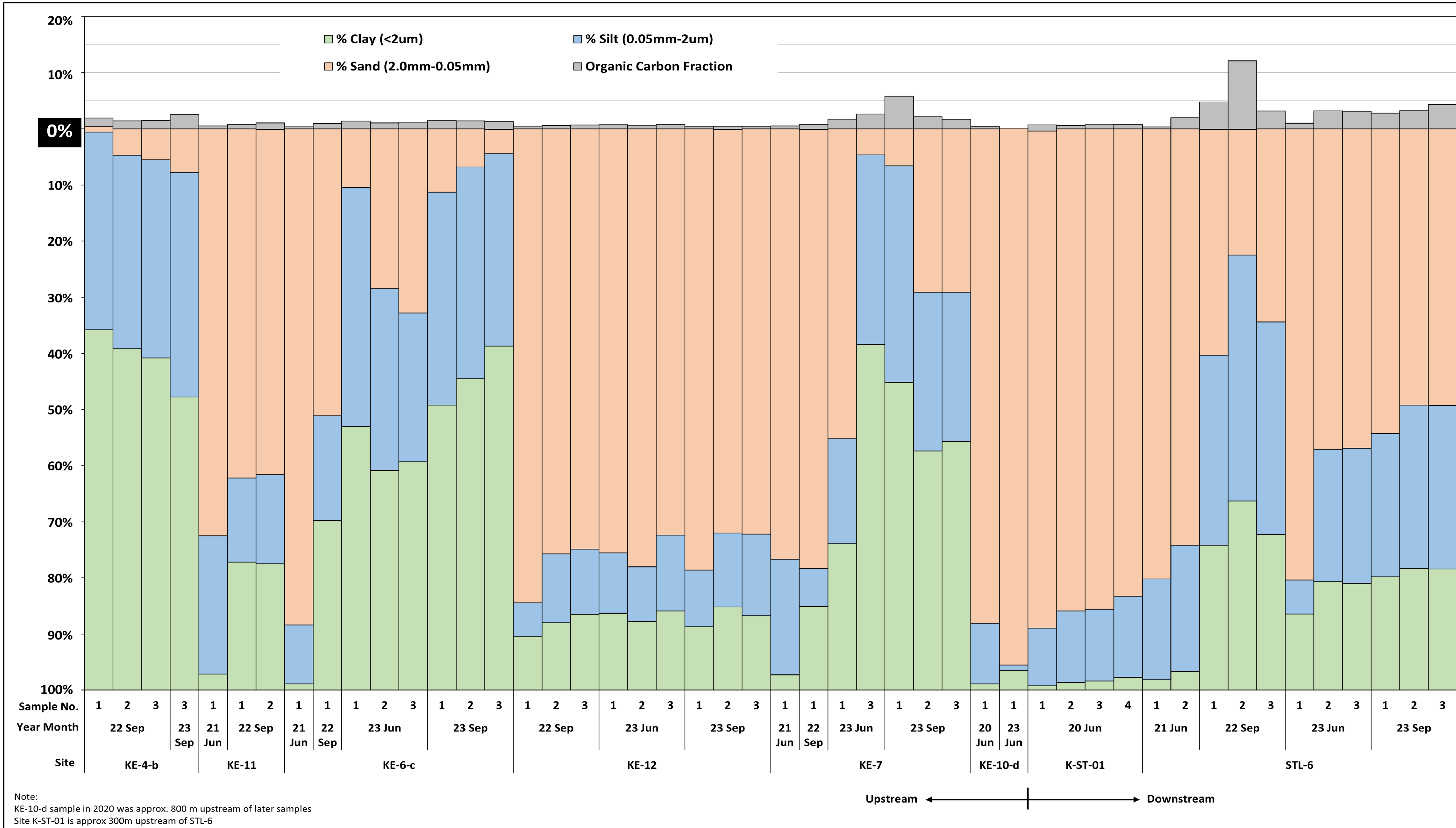


Figure 29: Summary of bed material classifications

Photo 6: Ponar sediment grab sampler

Periods when insufficient samples were collected for gradation testing one or more sample grab locations at each site were:

- KE-4-b – Jun 2022; Sep 2023
- KE-11 – Jun & Sep 2022; Jun & Sep 2023
- KE-6-c – Jun & Sep 2022; Sep 2023
- KE-12 – Jun 2022; Sep 2023
- KE-7 – Jun 2022; Sep 2023
- KE-10-d – Jun 2022; Sep 2023
- KE-STL-6 – Jun 2022

In general, the earlier results in 2020 and 2021 had lower fine fractions (clay, silt) and more coarse material (sand) than in 2022 and 2023, which suggests deposition of more fine material may be occurring, as would be anticipated in the reservoir (Figure 29). For the upstream sites (i.e., not K-ST-01 and STL-6) the pre-project bed was identified as largely gravel and cobble, except for KE-12 which was described as sand (KHLP 2012c). Site KE-4-b only had results for 2022 and 2023 and in both years the sand was less than 10%, silt was about 35%-40% and clay was about 50%-65%. Site KE-11 had mostly sand and silt in 2021 with almost no clay, but in 2022 clay increased to about 20% as both sand and silt reduced by about 10%.

The next downstream site, KE-6-c, was almost 90% sand and about 10% silt with a small amount of clay in 2021 (Figure 29). The lone result for 2022 had less sand and more clay, and then in 2023 the amount of clay was again higher at about 40%-60% while sand ranged from about 7%-30%. Site KE-12 north of Caribou Island had the most consistent results for sampling in 2022 and 2023 with clay varying from 10%-15%, silt about 6%-15%, and sand about 72%-85%. At this location the high predominance of sand is consistent with pre-project conditions that identified the area as sandy. South of Caribou Island, at KE-76-c, the results for 2021 and 2022 were mostly sand at almost 80% with higher clay and less silt in 2022 than 2021. Two samples in June 2023 at this site had quite different results, with one having sand at about 55% and clay and silt at about 26% and 19% respectively, while the other sample had about 5% sand, 34% silt, and 62% clay. Then in Sep 2023, one sample again had low sand at about 7% while the other two were about 30% while silt varied from about 27%-39% and clay from 43%-55%. While the sand fraction decreased and finer fractions increased relative to 2021 and 2022, the results indicate the variability that can occur between samples obtained in the same area at the same time. The final site upstream of Keeyask, KE-10-d, only had results reported for Jun 2020 and Jun 2023, but in both years the samples were predominantly sand at about 88% and 96%, with some silt at 1% and 11%, while sand was about 1% and 4% (Figure 29).

Downstream of the GS, site K-ST-01 was only sampled in 2020 and was mostly sand at 83%-89%, some silt at 10%-14%, and little clay at about 1%-3% (Figure 29). Nearby site STL-6 had similarly low clay in Jun 2021 but more silt at 18%-23%, and less sand at about 74%-80%. In Sep 2021, the sand fraction decreases substantially to about 22%-40% while silt increases to 34%-44% and clay increases to 25%-34%. In 2023, however, the sand increases again to about 50%-60%, with one high value up to 80%, while clay remains high at 14%-22% and silt is about 24%-30% with a low value of 6%. Pre-project monitoring indicated this area as being a transitional zone where substrates change from gravel upstream, to gravel/sand, to sand, and then silt over a relatively short distance because the flow path is widening here as the Nelson River enters Stephens Lake (KHLP 2012c). The K-ST-01 site sampled in 2020 is further upstream and may have been on coarser sediment than STL-6. The results for STL-6 suggest there may be some deposition of finer silt and clay sediment at this site, however this is a transitional area and sediment conditions may be variable over time depending on flow and water level.

The total organic content of the sediment is low at most sites upstream of the Keeyask GS and is less than 2% at all sites but KE-7 (Figure 29). At KE-7, the organic content is about 2%-6% for several samples in 2023 and corresponds with periods when the sediment is characterized as less sand and more clay. Downstream, the organic content is low in 2020 at K-ST-01 and in 2021 at STL-6 at about 1%-2%. In 2022, the organic content increases between 3% to a high of 12%, and then in 2023 it is lower again at about 3%-4%, though still somewhat higher than 2020 and 2021. The period of high organic content in 2022 corresponds with the lowest sand fraction at STL-6, with the lowest sand occurring with the highest organic carbon. While there appears to be some correlation between higher organic content and more fine sediment, the connection is not obvious, although it could be that fine organic sediment from breakdown could be a factor.

As noted above (section 4.2) the amount of sediment being transported in the Nelson River has been significantly reduced due to zebra mussels (Figure 27, Figure 28). It is likely that this would be affecting the composition of the sediment being deposited in the monitoring area. If the mussels are removing most of the sand and less of the clay, it may be that what does settle tends toward being the finer clay and silt fractions. Additionally, while the presence of more organic material in the sediment is likely due in part to flooded peat, the presence or organic waste from the proliferation of zebra mussels may also be a contributing factor. Additional monitoring over the next two open water seasons may help clarify the trends in sediment conditions.

5.0 ORGANIC CARBON

5.1 PREDICTED PROJECT EFFECTS ON ORGANIC CARBON

Organic carbon (total, dissolved and particulate) in the water was not expected to be affected by construction prior to impoundment of the reservoir but was measured during construction to provide baseline data. Although changes to organic carbon were not specifically predicted, the Keeyask EIS did estimate the potential increase in organic sediment concentration (i.e. peat, of which carbon is but one of the component elements) in the mainstem areas of Gull Lake (zones 1-3) and the flooded back bays (PESV Vol. 7, Table 7.4-5). The analysis was based on estimated volumes of broken-down peat being suspended in the different peat transport zones in Gull Lake and its flooded back bays during open water conditions. It considered the increase for year 1, the first year after impoundment when the greatest amount of breakdown was predicted, and years 2 and 5 which were predicted to have progressively less peat breakdown.

In the mainstem areas (zones 1-3) peak estimated increases in suspended organic sediment concentration were low, ranging from 0-2 mg/l (PESV Vol. 7, Table 7.4-5). Among back bay zones, the predicted peak increases in zones 5, 10 and 13 were low, ranging from 2-4 mg/l. More moderate peak increases of 8-10 mg/l were predicted for zones 7, 9 and 12, although this would represent a large overall increase in suspended material considering typical TSS concentrations. Large peak increases of 15 and 21 mg/l were predicted for zones 11 and 8 respectively due to the large amount of peat predicted to break down in these areas and their small overall volumes. Although changes in organic carbon concentrations were not directly predicted in Keeyask EIS, the estimates of peak suspended organic sediment effects may suggest which areas are more or less likely to experience larger or smaller effects on organic carbon concentrations.

5.2 WINTER 2022

Discrete water samples were obtained at up to 4 sites once a month from January to April 2022 between Clark Lake and the entrance to Stephens Lake along the mainstem of the river: back bays were not sampled. 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. Note that in some cases the lab reported DOC is greater than the reported TOC, although the two values tend to be relatively close (1-2 mg/l difference), suggesting POC is likely limited.

Typically, water samples were obtained at two or three depths in the water column (e.g., 20% & 80% depth) on each sampling visit. For purposes of this analysis, the respective TOC or DOC results obtained from multiple depths at a site for each sampling day were averaged to get a single concentration value for the site and the results for each month were plotted (Figure 30).

Where the average TOC exceeds DOC the plot shows the calculated POC, but where DOC exceeds TOC only the DOC is plotted: thus the plot shows the maximum organic average organic carbon concentration. The results do not suggest any apparent trend during the winter period, nor do they indicate trend from upstream to downstream.

The organic carbon concentration varied from about 7-10 mg/l, although most values were above 8 mg/l, while the overall average was about 8.6 mg/l (Table 7). The range and average of TOC in winter 2022 was similar to conditions observed in previous winter periods. The results do not suggest any significant change in winter resulting from reservoir impoundment and project operation.

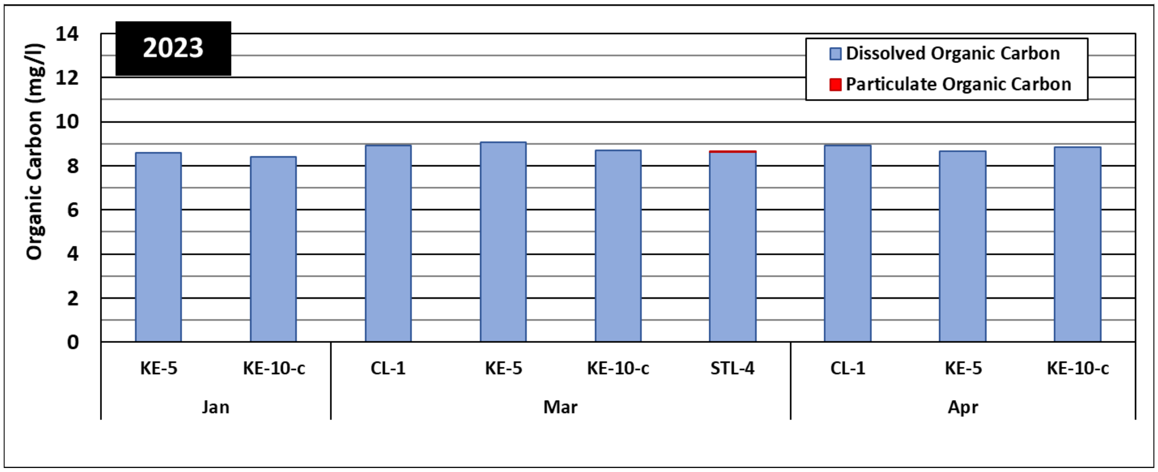


Figure 30: Site average DOC, POC and TOC in winter 2023

Table 7: Summary of TOC concentration during construction and operation

Year	Open Water (Jun-Sep)				Winter (Jan-Apr)	
	Mainstem		Back bays		Mainstem	
	Range	Avg	Range	Avg	Range	Avg
2015	8 - 9	8.4				
2016	7.5 - 9.5	8.3				
2017	8 - 10	8.4			8 - 10	9.5
2018	9 - 10	9.5			9 - 10	9
2019	7.5 - 8.5	8.2			8 - 11	9
2020	8.5 - 10	9			7 - 9	8
2021	7.5 - 10.5	8.8	8 - 16	10.3	6 - 10	8.6
2022	7 - 13	8.6	6.1 - 13.5	8.6	7 - 10	8.6
2023	7.6 – 9.3	8.5	7.9 - 11.2	9.4	8.4 - 8.6	8.5

5.3 SUMMER 2023

Discrete water samples were obtained at up to 48 separate sampling locations at up to 22 sampling sites: e.g., sampling site STL-2 has 5 sampling locations a-f across the width of the river.

Samples were obtained once a month from June to September 2023, between Clark Lake and Stephens Lake near Kettle GS. This included up to 30 locations along the mainstem of the river and up to 12 sites in flooded back bays. As was the case for winter organic carbon, the POC was calculated as the difference between lab measured TOC and DOC, but for about 40% of the results the DOC exceeds TOC. Where DOC was higher, it was less than 1 mg/l greater than TOC with a maximum difference of 0.5 mg/l. Because the difference between the two is small, the TOC is assumed to be equal to DOC when the DOC is larger for the purposes of analysis and plotting.

The averaged organic carbon concentrations were plotted for each sampling location for the mainstem and back bay sites in each month (Figure 31). The results do not suggest any trend in organic carbon concentrations along the mainstem from upstream to downstream, indicating no increases occurring due to the reservoir. An upstream to downstream trend would not be expected for the back bay sites. Like observations in 2021 (KHLP 2022), higher organic carbon concentrations tended to occur in back bays. Although back bays tended to be higher than the mainstem overall, conditions were more similar in both areas in July and September than in June and August. The organic carbon results do not indicate a seasonal trend in conditions.

In June, July and August, the mainstem organic carbon concentrations 8-9 mg/l and in September they were all near 8 mg/l (Figure 31). Most back bay locations were also between 8-9 mg/l in July and September, with a few higher results exceeding 10 mg/l in July and 9 mg/l in September. In June and August, most back bay sites were between 9-10 mg/l, or about 1 mg/l higher than the mainstem, with some several sites reaching 10-11 mg/l. While mainstem TOC varied over a smaller range than previously observed during operation in 2021-2022, the season average concentration of 8.5 mg/l was about the same as previous years both before and during construction (Table 7). As noted, the back bay TOC varied over a larger range and higher maximum values compared with the mainstem. The range of back bay concentration was within conditions observed in 2021 and 2022, with lower maximum values than in the two previous years. The seasonal average concentration in the back bays was about 9.4 mg/l, which lies exactly between the averages of 10.3 mg/l and 8.6 mg/l in 2021 and 2022 respectively (Table 7). It is of interest to note that while the presence of zebra mussels has had a significant effect on TSS concentrations, they do not appear to have had any discernible effect on organic carbon concentrations.

Overall, the results from 2023 are consistent with previous observations and do not suggest any significant effect of the project on organic carbon concentrations along the mainstem from Clark Lake to the Keeyask GS, nor in the water discharged downstream.

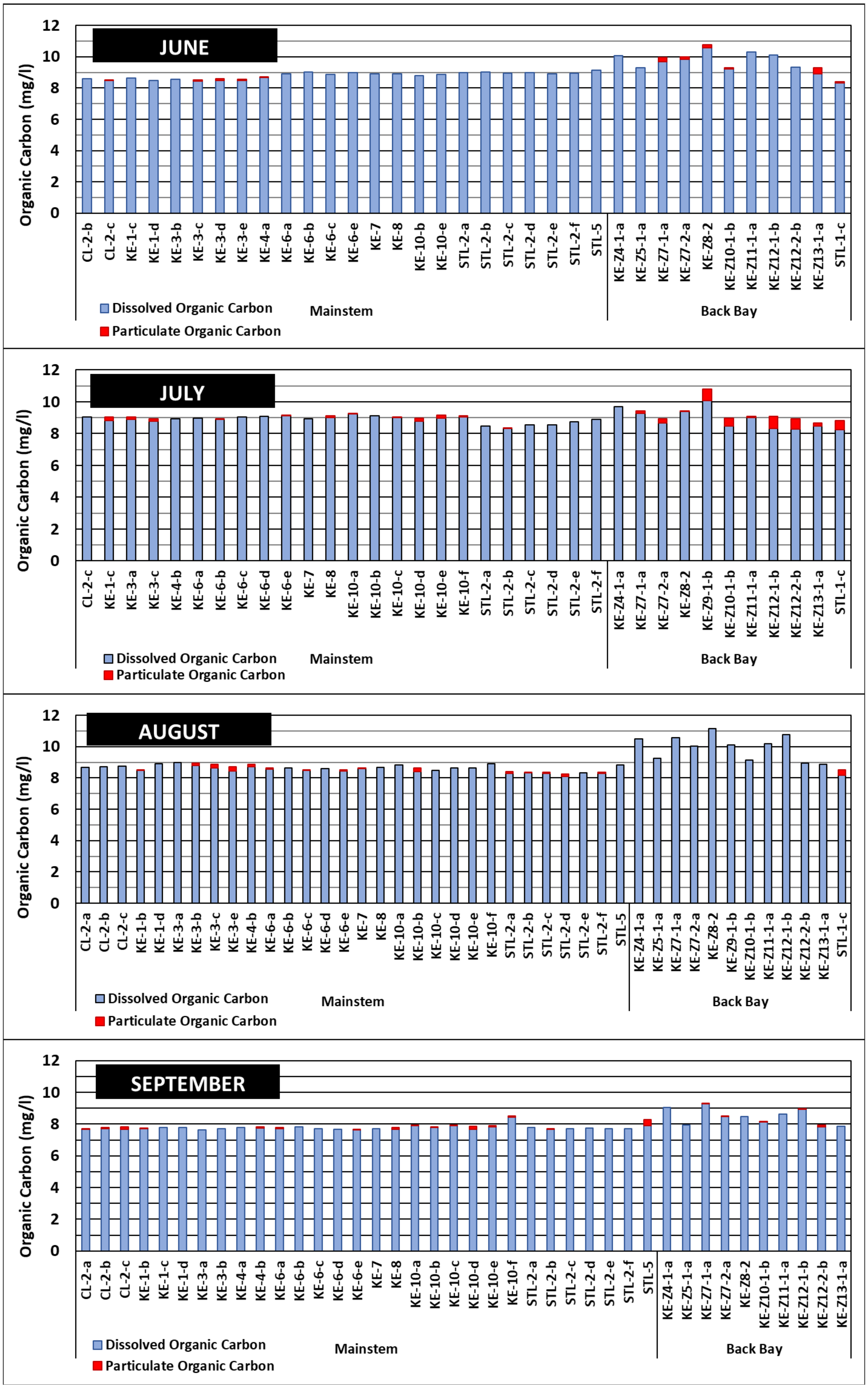


Figure 31: DOC, POC and TOC in summer 2023

6.0 DISSOLVED OXYGEN

Dissolved oxygen (DO) and water temperature (T) monitoring was performed using electronic sondes to collect in-situ measurements of these parameters along with percent saturation calculated based on ambient conditions. The monitoring included collection of discrete measurements in both winter (Dec 2021 – Apr 2022) and summer open water period (Jun-Sep), as well as continuous monitoring at several sites in both seasons. Discrete monitoring involved obtaining measurements through the depth of the water column to identify vertical variability, particularly to see if DO is reduced near the bottom in water overlying flooded peat. Continuous monitoring involved placing one or two sondes at each monitoring site for several months. Two sondes were used at some locations, with one sonde placed near the water surface and the other just above the bed, to identify if DO concentrations differ between the surface and bottom. The discrete and continuous data sets were reviewed for data quality and erroneous and inconsistent data were filtered out. For the continuous data sets, the review tended to err on the side of leaving data in rather than remove potentially suspect data.

6.1 2023 WINTER DISCRETE & CONTINUOUS DO

6.1.1 WINTER DISCRETE DO

The Keeyask PEMP (KHLP 2015a) committed to discrete DO sampling in the first winter of operation, which was the 2020/21 winter, at sites within the mainstem and various back bay locations. The discrete monitoring, however, was performed at back bay sites in the first three winter seasons (2020/21, 21/22, and 22/23) to provide a more complete representation of DO conditions in these flooded areas. The discrete back bay monitoring was discontinued for the 2022/23 season, the fourth winter of operation.

Although winter discrete DO monitoring is not required by the PEMP at the mainstem monitoring sites, discrete measurements were obtained in the 2022/23 season. The monitoring was continued because the sampling locations the same sites where continuous turbidity is measured in the winter. These sites need to be visited for maintenance checks, water sampling, and discrete turbidity monitoring. There is no additional effort required to obtain the DO data because the sonde with the in-situ turbidity probe also carries the in-situ DO probe so the DO readings are collected at the same time as turbidity.

In winter 2022/23 (Jan-Apr), discrete DO and T monitoring was performed at 4 sites along the mainstem of the Nelson River as in previous years: Clark L upstream (site CL-1), the entrance of Gull Lake (site KE-5), just upstream of Keeyask (site KE-10-c), and just downstream of Keeyask

GS in Stephens Lake (STL-4). Charts showing the measured depth profiles of DO concentration, % saturation[1] and T are provided in Appendix 2.

Monitoring results for the mainstem sites showed that DO was high through the winter at these locations and T was just above 0°C (Appx. 2). At each site, the DO was about 14-15 mg/l with a percent saturation between 97%-104%. This is consistent with results observed in previous years and with expectations in the Keeyask EIS.

6.1.2 WINTER CONTINUOUS DO

Continuous DO sensors were placed near the surface below the ice at 4 mainstem locations between mid-January to mid-April at monitoring sites CL-1, KE-5, KE-10-c and STL-4. Monitoring results showed DO concentrations along the mainstem remained high, with all 4 sites having DO concentrations between 14-15 mg/l throughout the winter (Figure 32). These DO concentrations were at or near 100% saturation during the monitoring period. Although the spillway did pass flow for a couple of weeks during the monitoring period, elevated DO concentrations were not observed at STL-4 just downstream.

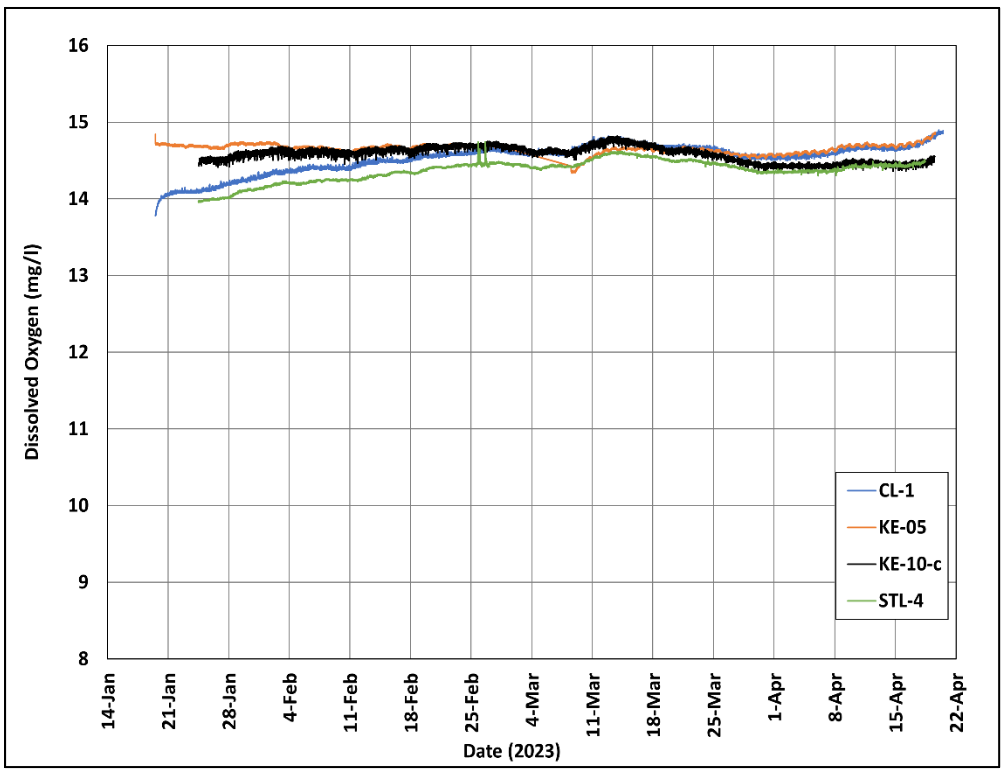


Figure 32: Winter Continuous DO at mainstem sites

[1] Saturation concentration is the DO concentration that water at a given temperature will tend to maintain in the absence of bio-chemical DO consumption, which reduces DO, or addition of excess DO from turbulent flow, which causes supersaturation.

6.1.3 SUMMER DISCRETE DO

In summer 2023 (Jun-Sep), discrete DO and T monitoring was performed at 11 sites along the mainstem of the Nelson River from Clark L upstream (site CL-2) to about 30 km downstream of the Keeyask GS in Stephens Lake (site STL-5), plus 11 sites in back bays flooded by the project and a back bay in Stephens L. Up to six sampling locations were monitored across the width of the river at the mainstem sites. In back bays, measurements were obtained at four sampling locations at each site. The sites and locations monitored were (see Appx. 1 for locations):

- Mainstem sites
  - CL-2-a to c (i.e., PE_CL-2-a, PE_CL-2-b, PE_CL-2-c); KE-1-b,c, d; KE-3-a to e; KE-4-a and b; KE-6-a to e; KE-7; KE-8; KE-10-a to e; STL-2-a to f; and STL-5
- Back bay sites (four locations measured at each identified as a, b, c, d, except KE-Z8 which has locations 1, 2, 3, 4)
  - KE-Z4-1; KE-Z5-1; KE-Z7-1; KE-Z7-2; KE-Z8 (2, 3, 4 only); KE-Z9-1; KE-Z10-1; KE-Z11-1; KE-Z12-1; KE-Z12-2; KE-Z13-1; and STL-1

Sampling was generally done at each site in June, July, August, and September, although some locations were sampled only 1-3 times. Site KE-2 a to d was not sampled this year as it matches CL-2 and KE-1. Sample location KE-8-1 was not sampled because floating peat mats covered the location. Charts showing the measured depth profiles of DO concentration, % saturation and T for each monitoring site are provided in Appendix 3. Depth profiles of back bay DO concentrations are also displayed together for comparison between the different monitoring sites (Figure 34).

Since the study area is aligned in a general west-east direction, the average concentrations at each location and date of sampling were plotted based on the planned easting of each sample location to identify any upstream to downstream trends that may be due to the project (Figure 33). Monitoring results showed that DO was high at all mainstem sites. Except for a few locations, the DO concentrations at mainstem sites were typically in the range of 8.5-10 mg/l, with a degree of saturation between about 95%-100%. This was for conditions where water temperature ranged from a low of about 15°C in September to 19°C in August. DO concentration was typically uniform through the water column depth at each sampling location.

The results show relatively uniform DO conditions from upstream to downstream along the mainstem, with some more variation at location KE-10 immediately upstream of the dam and at STL-2 immediately downstream. Some lower DO values were observed at location KE-10-f, which is in shallower water over flooded land near the south shore. Elevated DO concentrations were observed at sites STL-2-e and STL-2-f closer to the south shore, which resulted due to operation of the spillway, which causes excess oxygen to be entrained in the water. DO saturation level was about 89% for the low DO concentrations at KE-10-f and up to 1158% for peak levels at STL-2-d.

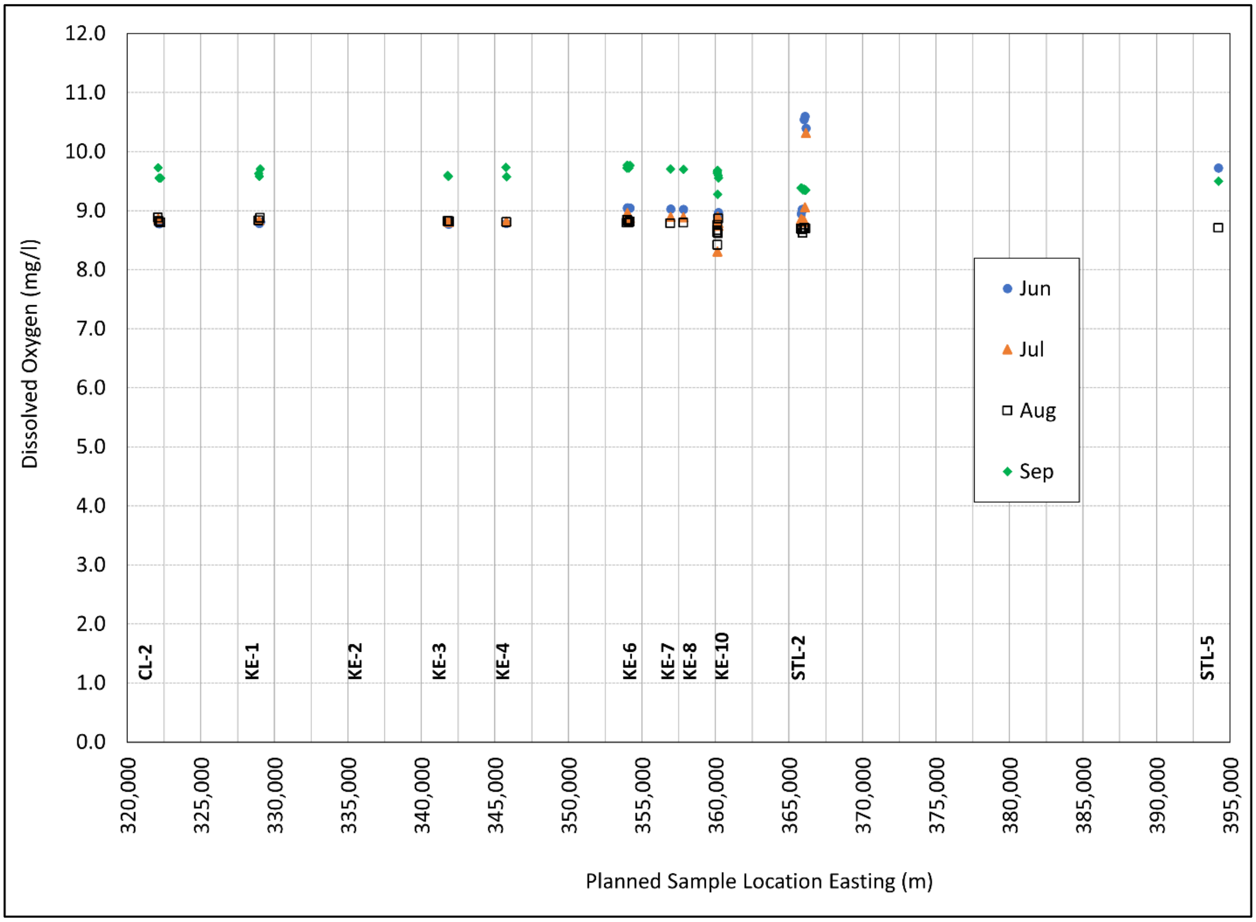


Figure 33: Average DO at mainstem sites, summer 2023

DO concentrations observed in back bays varied over a much wider range than along the mainstem (Figure 34, Appx 3). To generally summarize discrete DO concentrations observed at these sites, the DO conditions were identified as being either low, moderate, or high depending on the range of concentrations observed during the summer period. These classifications are defined based on consideration of the minimum 7-day average and instantaneous DO objectives when water temperatures are above 5°C for cool and cold aquatic species (Manitoba Water Stewardship, 2011). The 7-day average DO objectives for cool and cold-water species are 6 mg/l and 5 mg/l respectively, while the respective instantaneous minimum objectives are 5 mg/l and 4 mg/l. Based on these values, the following classifications were selected to describe the DO variation between the surface and bottom for the 48 back bay sampling locations (Table 8):

- Low < 4 mg/l < Moderate < 6 mg/l < High.

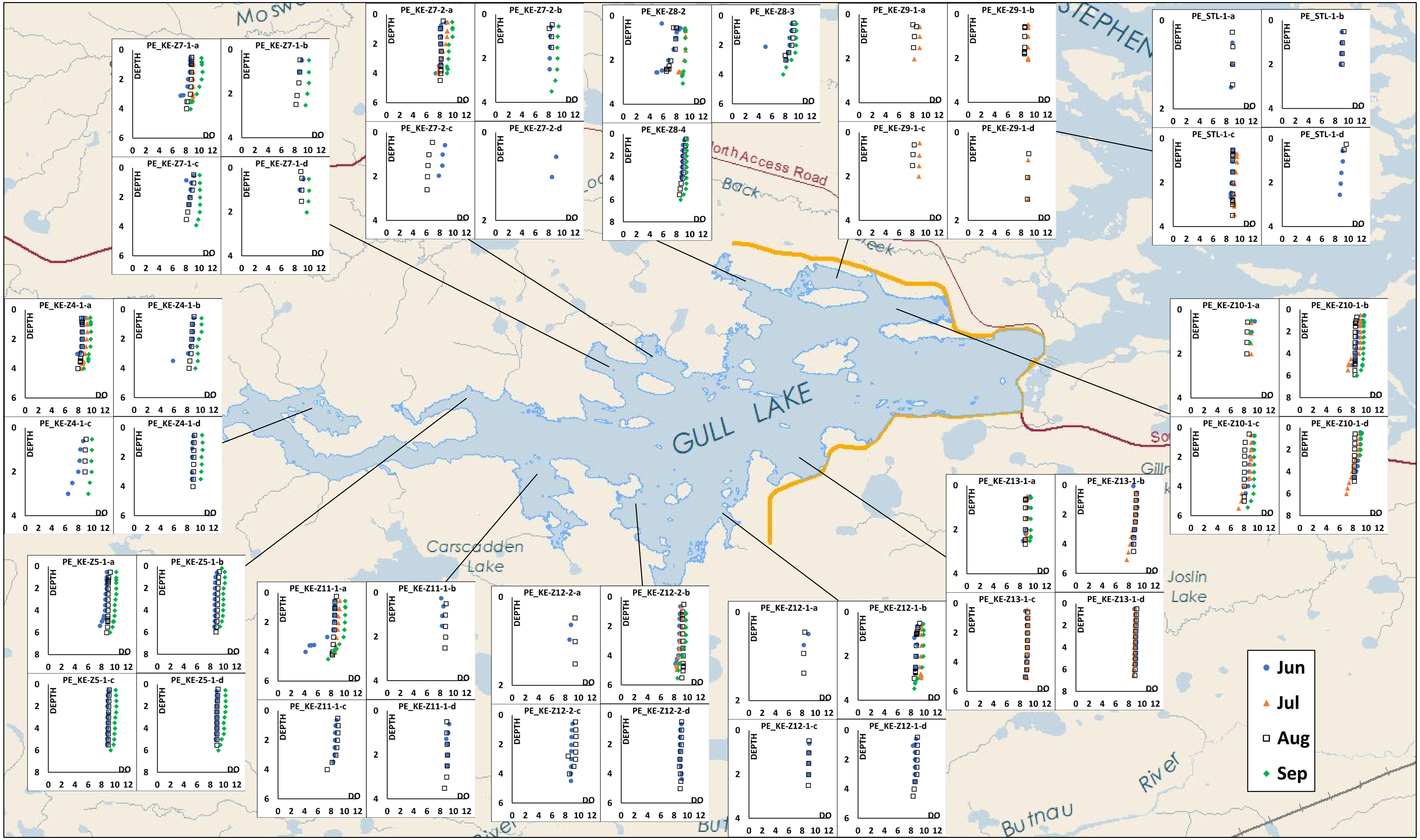


Figure 34: Summer DO depth profiles in back bays

Based on these criteria, 44 of the 47 discrete sampling sites were classified as having high DO, with concentrations that exceeded 6 mg/l (Table 8) at all depths for each sampling period. While DO concentration may have varied between about 6-10 mg/l at these locations, many locations exceeded about 8 mg/l and had DO saturation of about 80-100%. Many of these sites showed some vertical differentiation with a lower DO concentration near the bottom, even if it was only a small difference of less than 1 mg/l (Figure 34). At the 3 remaining sites, the DO concentration varied from high to moderate. However, where the DO concentration was moderate, this occurred near the bottom while the DO closer to the surface was still high. No sites had discrete observations that were low. These results are very different than the two previous summers where at multiple sites had low DO at some point in the monitoring.

Table 8: Summary of summer discrete DO conditions at back bay sites

Site/ Location[1]	a or 1	b or 2	c or 3	d or 4
KE-Z4-1	H[2, 3]	H	H	H
KE-Z5-1	H	H	H	H
KE-Z7-1	H	H	H	H
KE-Z7-2	H	H	H	H
KE-Z8	n/a	H / M	H / M	H
KE-Z9-1	H	H	H	H
KE-Z10-1	H	H	H	H
KE-Z11-1	H / M	H	H	H
KE-Z12-1	H	H	H	H
KE-Z12-2	H	H	H	H
KE-Z13-1	H	H	H	H
STL-1	H	H	H	H

Notes:

1. Site locations are designated by a, b, c or d (e.g., KE-Z4-1-a, KE-Z9-1-c, etc., except for KE-Z8 which is designated by 1, 2, 3, or 4 (i.e., KE-Z8-1, KE-Z8-2, etc.)
2. DO classified based on concentration where: low (L) < 4 mg/l < moderate (M) < 6 mg/l < high (H)
3. Single L, H or M indicates condition through depth of water column while combinations indicate variation from surface to bottom (e.g., H / L, high near surface low near bottom)

For each back bay monitoring location and sampling date, the average DO concentration was calculated from the measurements obtained through the depth of the water column. For plotting purposes, depth averaged DO was plotted based on the planned easting for the sample locations so that results are shown according to their relative position along the monitoring area, which has a west-east alignment (Figure 35). Unlike the mainstem sites, there would be no expectation that there could be an upstream to downstream trend in the results (e.g., between KE-Z11-1 and KE-Z12-2) since flow does not travel directly between them, which means they are independent. For clarity, the north and south back bays are plotted separately. Results show depth averaged DO is high, exceeding 8 mg/l at all the south backbay locations and being between 7-8 mg/l in only a few instances. Depth averaged DO concentrations at the Stephens Lake back bay site (STL-1a to f), which is unaffected by the project, were also high in 2023.

While the Keeyask EIS predicted DO would typically remain relatively high (>6 mg/l), even in flooded back bays due to wind mixing, the 2023 results showed higher DO levels than observed in the previous two summers. Based on the previous two years it may have been expected that at least some low DO levels (<4 mg/l) would have been observed as well as some more moderate (4-6 mg/l) levels.

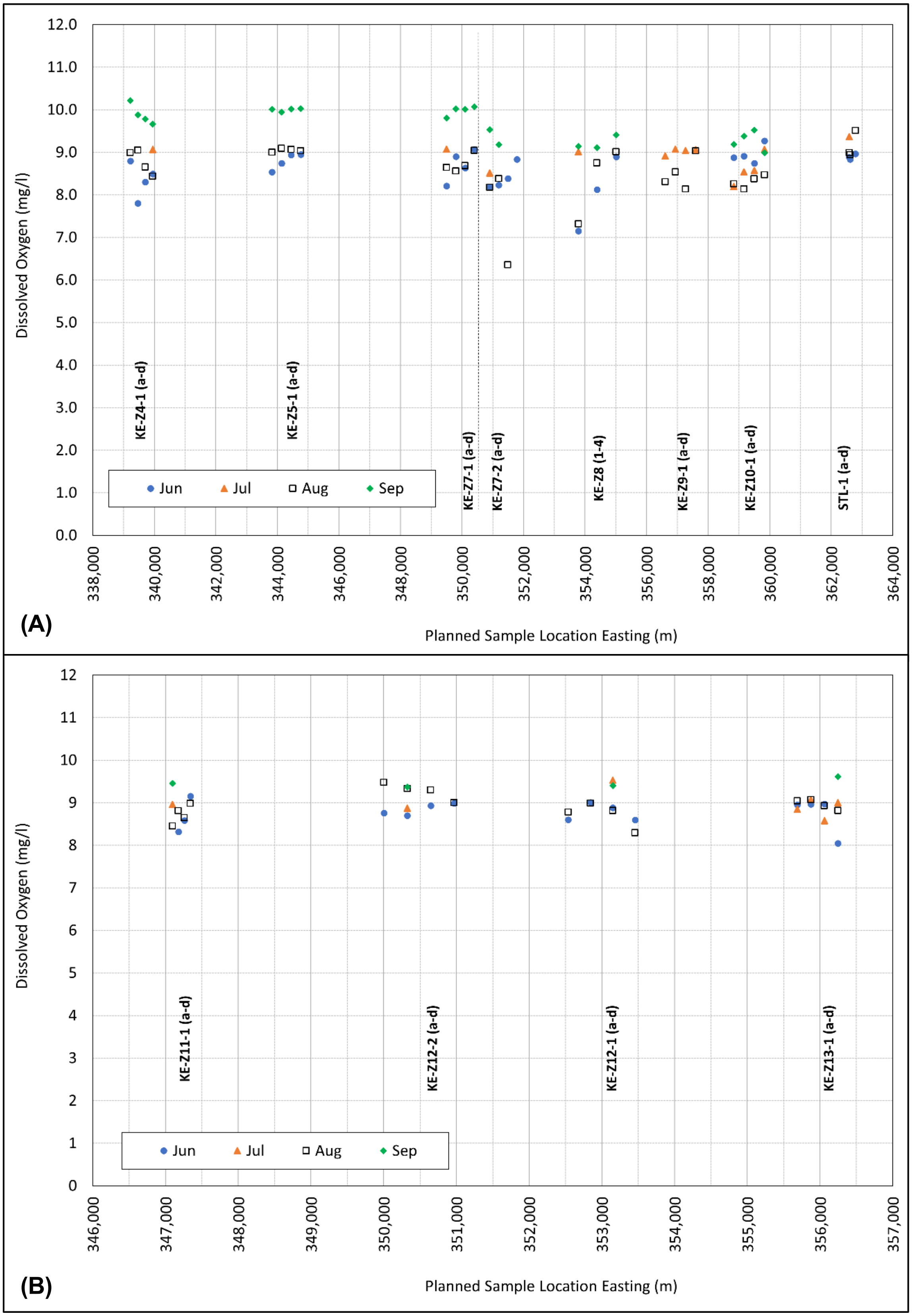


Figure 35: Average DO at north (A) and south (B) back bay sites, summer 2022

6.1.4 SUMMER CONTINUOUS DO

Continuous DO sensors were placed either near the surface (~2 m below) and bottom (~ 1m above) at the following 5 mainstem and 6 back bay locations between mid-June to the end of September:

- Mainstem:
  - CL-2-b surface
  - KE-4-b surface
  - KE-10-c surface and bottom
  - STL-2-d surface
  - STL-5 surface
- Back bay:
  - KE-Z4-1-a surface and bottom
  - KE-Z8-2 surface and bottom
  - KE-Z11-1-a surface and bottom
  - KE-Z12-1-b surface and bottom
  - KE-Z12-2-b surface and bottom
  - STL-1-c surface and bottom

Continuous DO results were reviewed to remove erroneous data and apply corrections based on discrete measurements. While some erroneous data was removed, the review generally erred on the side of leaving data in so that some deviations may not be accurate representations of actual conditions. In some cases, the results show short increases or decreases of a few milligrams-per-litre. In charts of the continuous data, some of these may look like an individual reading spiked up or down but, because the data record covers several months and readings are taken every 5 minutes, the individual event may actually occur over a few hours. Generally, spikes were removed where individual readings spike a large amount above or below adjacent readings.

Continuous monitoring results showed high levels of DO exceeding 8.5 mg/l for the mainstem sites from CL-2-b, which is upstream project effects on water levels, through to site STL-5 in Stephens Lake about 30 km downstream of the Keeyask GS (Figure 36a). DO concentrations dropped to between 8-8.5 mg/l at each site aside from STL-5 for about a week at the start of July. DO concentrations were typically within about 1 mg/l of each other between all the sites and followed the same general patterns of variation. Concentrations for the bottom DO probe at site KE-10-c were generally slightly lower than the other sites including the surface probe at that site. This may indicate a slight reduction in DO near the bottom, but there is no indication of stratification occurring at any time in the summer.

A notable exception occurs over the 3 weeks in June where DO concentrations at site STL-2-d when concentrations at the site rise to almost 11.4 mg/l at maximum and are generally above 10 mg/l, or about 2-2.5 mg/l higher than other sites (Figure 36b). These high concentrations result from operation of the spillway, which entrains DO into the water column. Comparing the spillway flow ratio (i.e., spillway flow vs total discharge) with DO concentration at STL-2-d it is apparent that when the ratio exceeds about 60%, the concentration at STL-2-d increases to a high level.

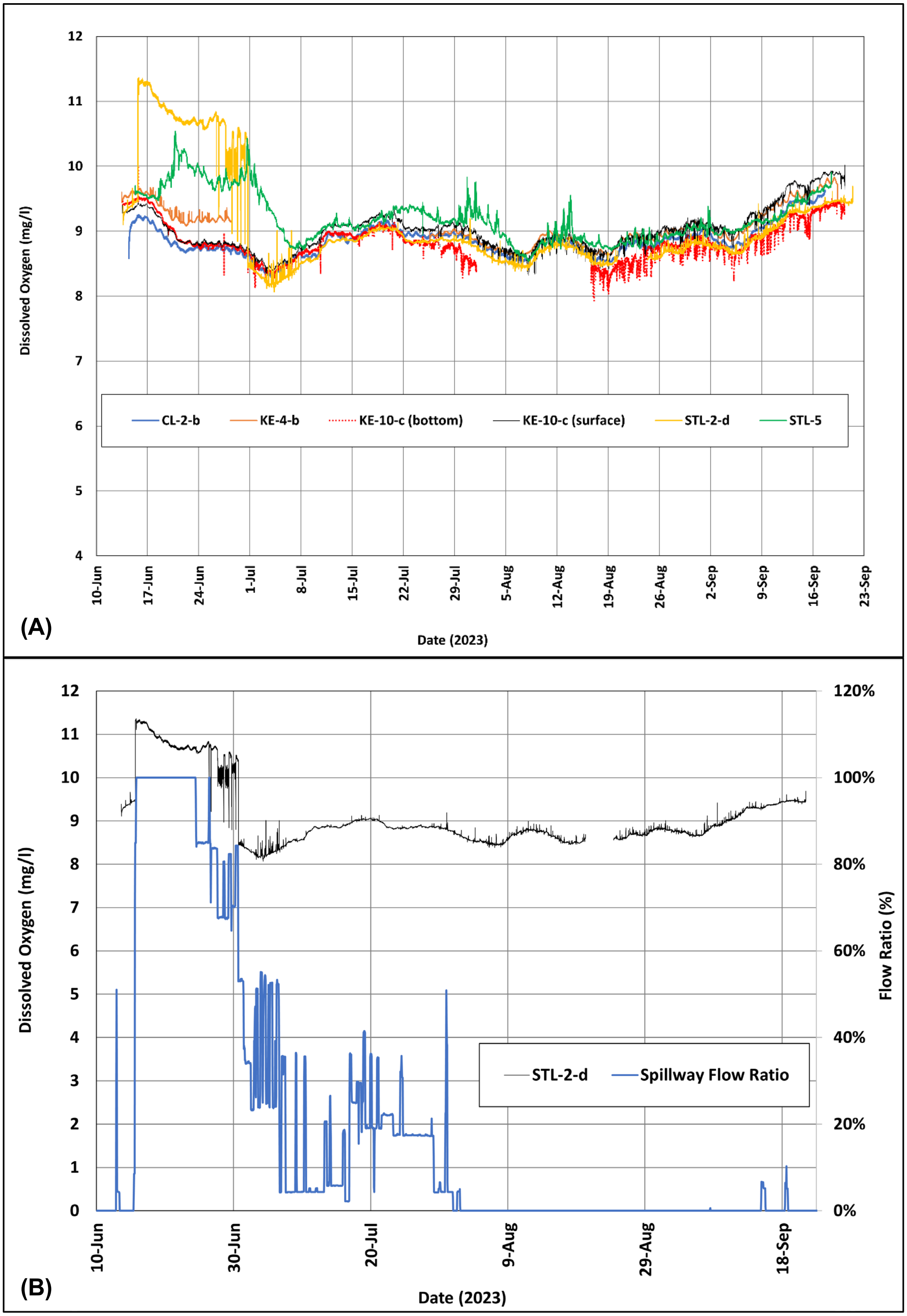


Figure 36: **Continuous DO at mainstem sites (A) and site STL-2 (B)**

Smaller changes in DO are seen when the spillway flow ratio is lower. It is likely that high DO concentrations are present in the spillway flow even at the lower flow ratios, but the effects likely are not spread far enough across the width of the river at STL-2 to be observed by the DO probe. The plume of water with higher DO would continue to mix and spread out as flow moves downstream. The increase in downstream DO appears to persist to site STL-5, which displays elevated DO concentrations coincident with the increases at STL-2 but delayed by several days (Figure 36a).

In terms of DO saturation, the mainstem sites typically had saturation levels between 90%-100%. When the spillway was in operation, the saturation levels at site STL-2 increased to about 112%-116% (Figure 37). The peak levels at STL-5 due to spillway operation in June were typically below 110% saturation, with a short peak of up to 115%. The STL-5 location also had a few peaks in DO concentration (Figure 36a) that resulted in DO saturation levels exceeding 100%, which are not associated with spillway operations and do not appear to be related to wind events. It is unclear what might cause these increases because a lacustrine site like STL-5 typically would not have supersaturated DO concentrations. It is possible these data are not accurate.

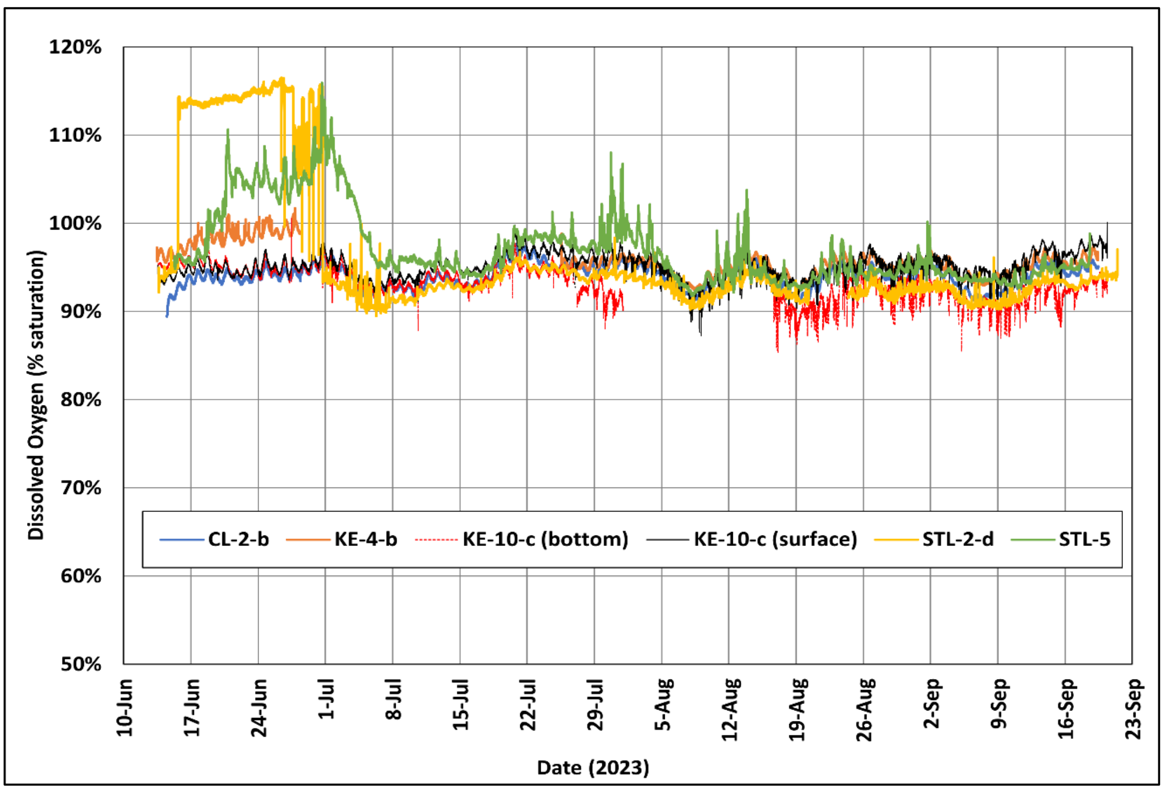


Figure 37: Continuous DO Percent Saturation at mainstem sites

At the six back bay monitoring sites, DO probes were deployed at surface and bottom positions during the summer of 2023 and for each site the reviewed results for the surface and bottom data have been plotted (Figure 38 through Figure 43). While probes were deployed throughout the summer, there were some extended periods of up to several week with missing or poor data including: a gap in bottom data at KE-Z4-1-a; gaps for both surface and bottom at site KE-Z8-2;

missing data for KE-Z11-1-a at the start for the bottom and end for the surface; missing data for the bottom at KE-Z12-1-b; a gap for the surface at KE-Z12-2-b.

Site STL-1-c had the highest observed DO overall among the back bay sites, with DO concentrations between 8-10 mg/l almost the entire summer and only a few days where it was between 6-8 mg/l (Figure 38). While this site has experienced very low DO in the past, dropping to near 0 mg/l during pre-project monitoring, it has had high DO the last 3 summers, although that would not be a result of the project.

At the remaining sites, the surface DO concentrations exceeded 6 mg/l almost the entire summer with only a few exceptions, with STL-1-c, KE-Z12-1-b, and KE-Z12-2-b exceeding 6 mg/l through the season (Figure 38, Figure 41, Figure 42). At sites KE-Z4-1-a, KE-Z11-1-a, and KE-Z8-2, the surface DO dropped to between 4-6 mg/l only a few time and for periods less than half a day (Figure 39, Figure 40, Figure 43).

Unlike surface DO concentrations, the bottom DO concentrations dropped to between 4-6 mg/l on multiple occasions at each site except STL-1-c (Figure 39 through Figure 43). The DO levels were below 6 mg/l for varying durations from less than an hour to as much as several days. All of the sites showed decreases below 6 mg/l (where data we available) in late June to early July and early August, corresponding with periods of lower wind. The sites all experience reduced DO for periods of several days at these times, with sites KE-Z4-1-a and KE-Z11-1-a having reduced DO for much of the first week of August. During this event, the DO at site KE-Z11-1-a dropped as low as 1-2 mg/l for several days (Figure 40). Site KE-Z11-1-a also dropped to low DO levels of about 3-4 mg/l for a couple days in mid-August. Among all the sites, the KE-Z11-1-a had the most events with DO below 6 mg/l, even though the first month of data was unavailable and the low DO period at the end of July was not captured. The other locations had other events with DO levels in the range of 4-6 mg/l, and a few readings below 4 mg/l, but these all tended to be short duration events of less than one day. The 2023 season was notably different than 2021 and 2022 in that none of the back bay monitoring sites had DO drop to 0 mg/l.

Overall, the continuous DO monitoring results for summer 2023 are generally consistent with expectations from predicted effects in the Keeyask EIS (KHLP 2012b). The mainstem had consistently high DO while reductions were observed in back bays, typically in association with periods of low winds.

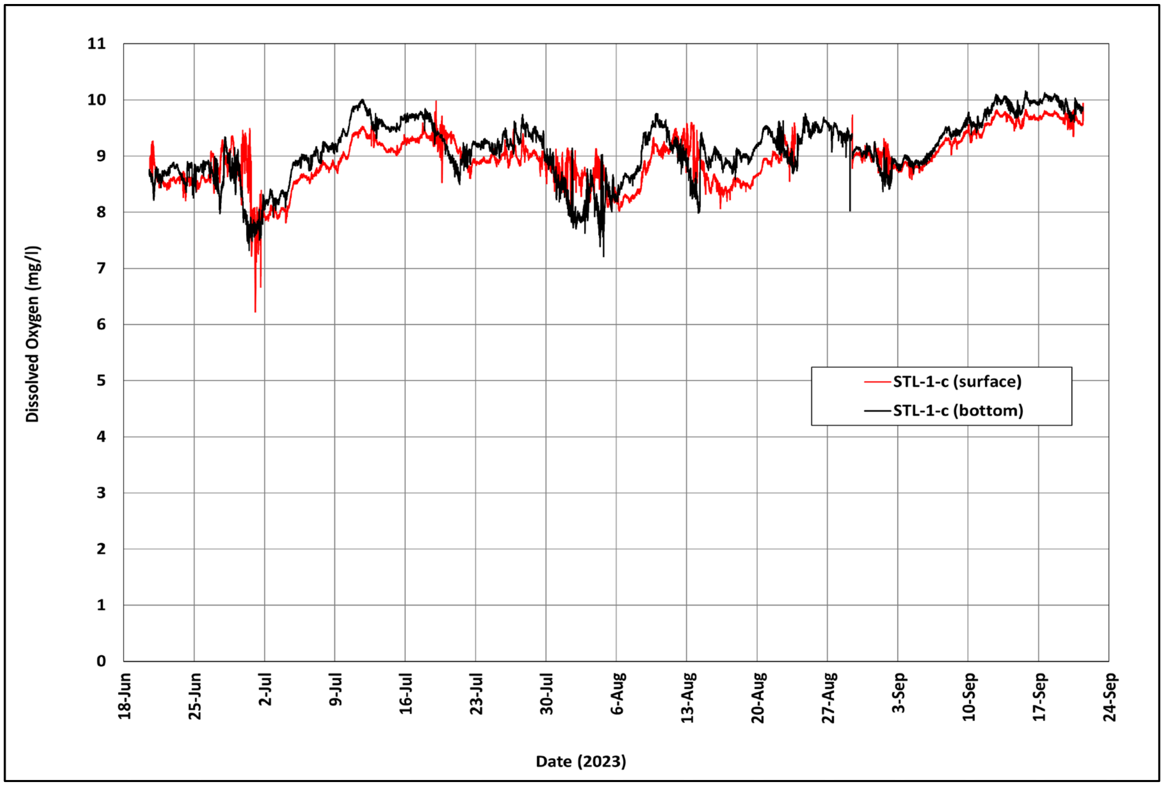


Figure 38: Continuous DO at site STL-1-c

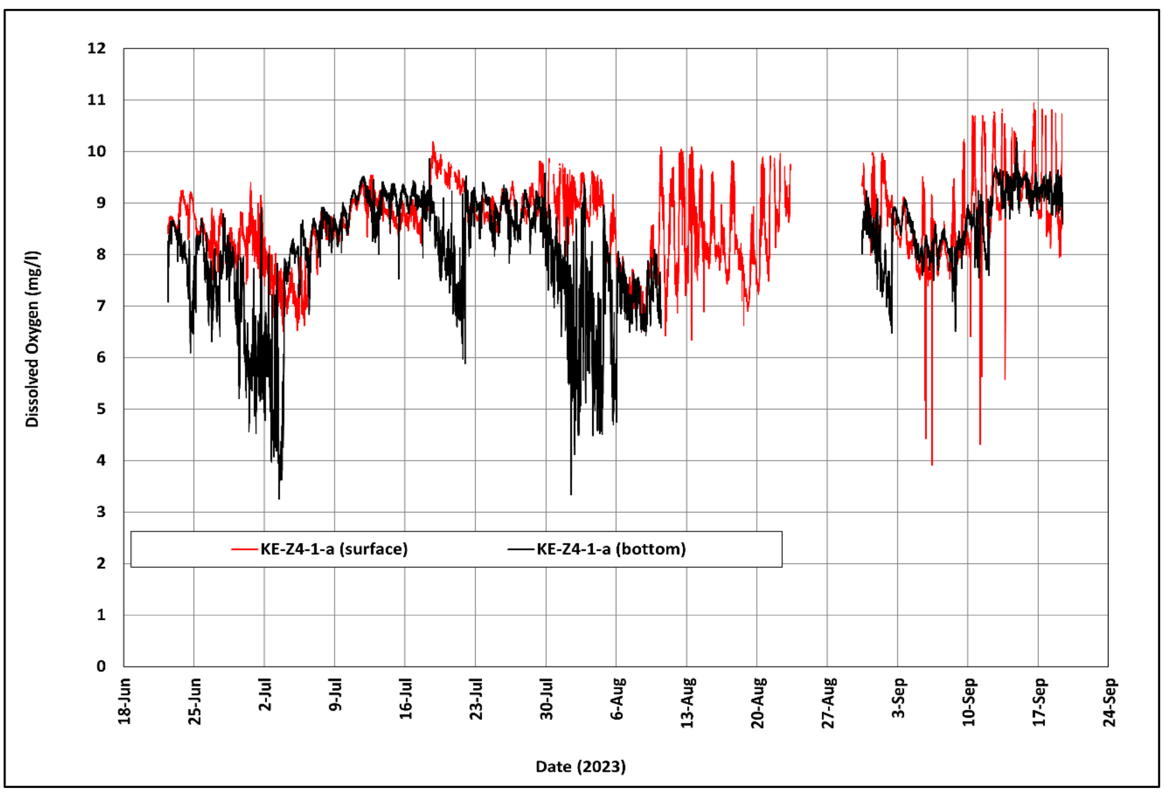


Figure 39: Continuous DO at site KE-Z4-1-a

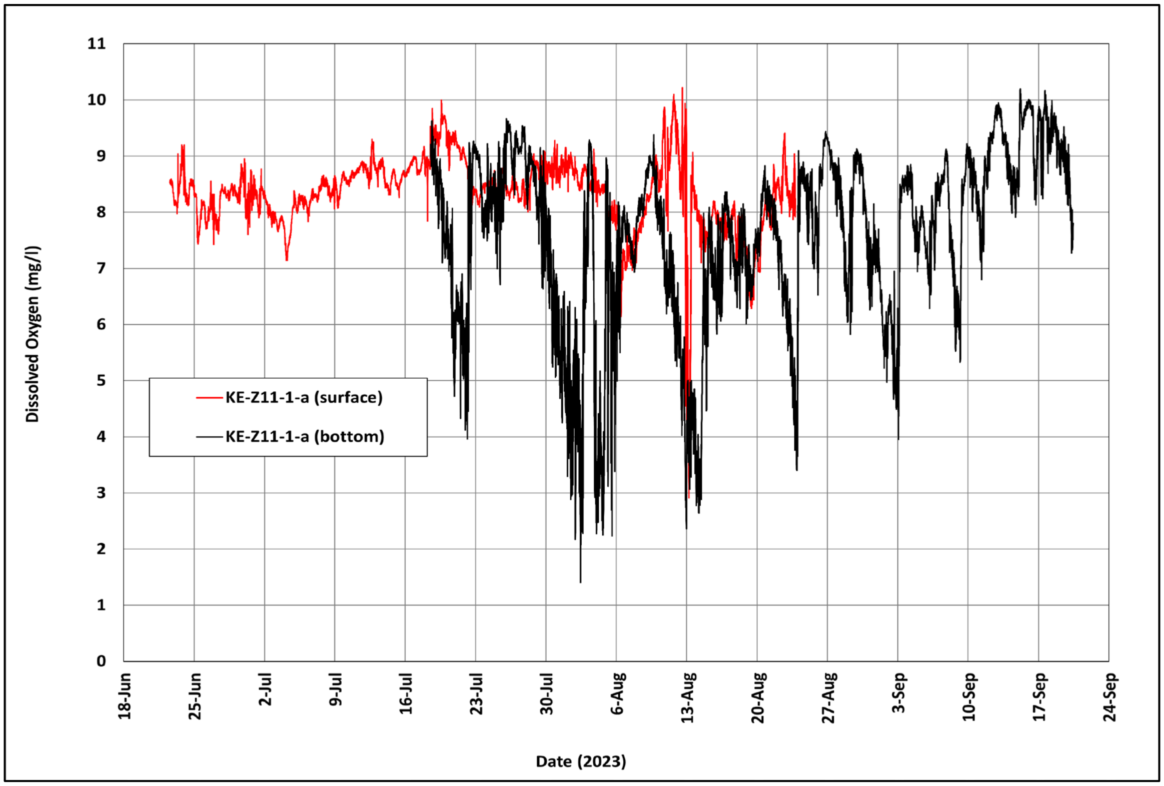


Figure 40: Continuous DO at site KE-Z11-1-a

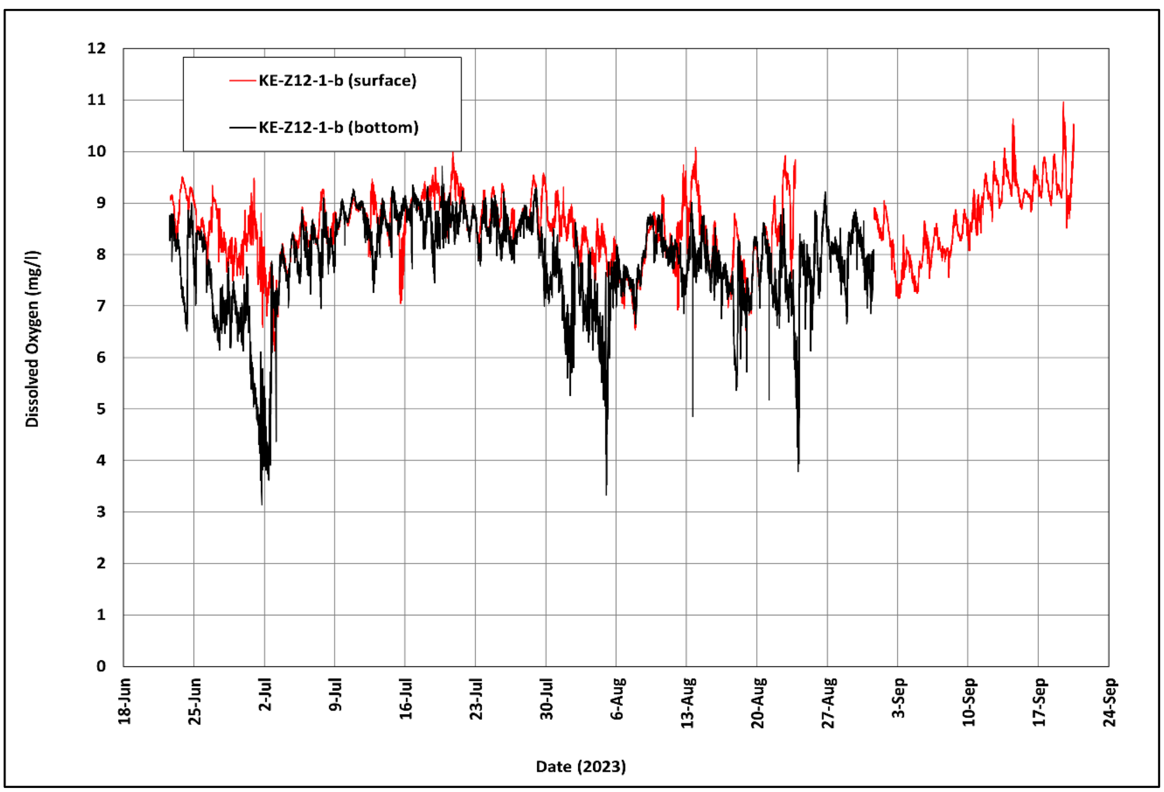


Figure 41: Continuous DO at site KE-Z12-1-b

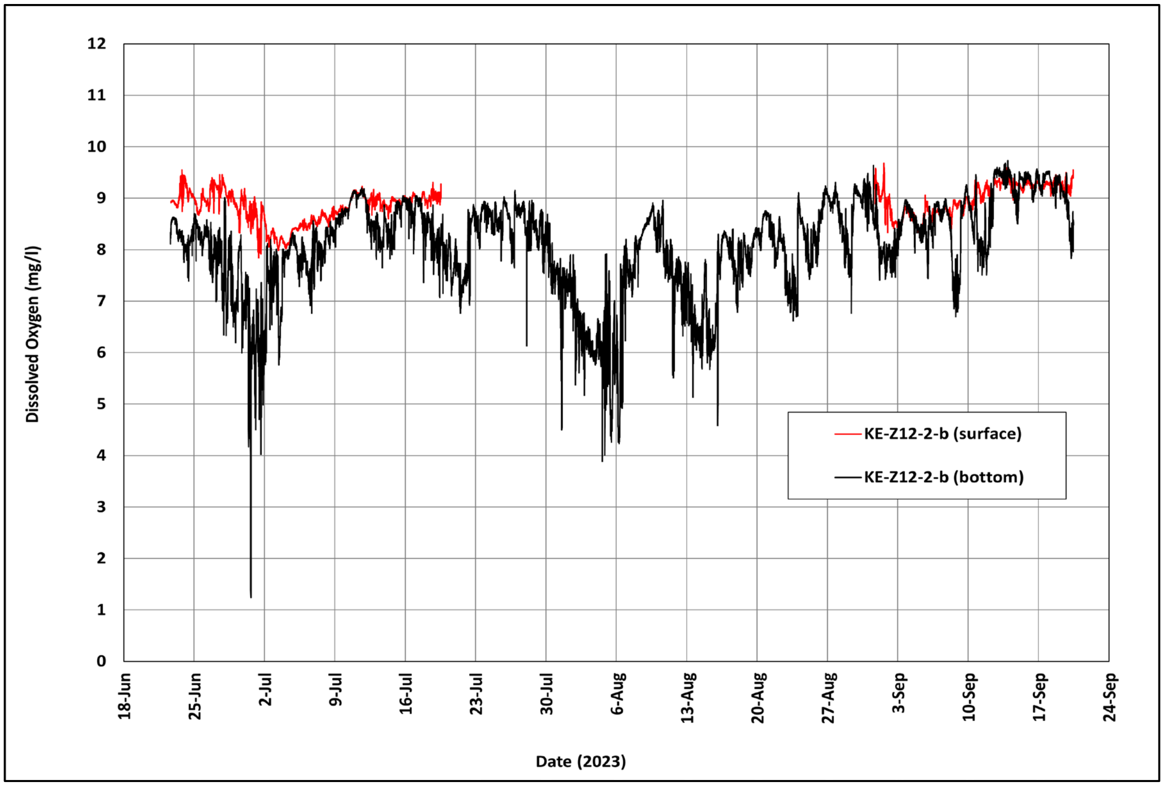


Figure 42: Continuous DO at site KE-Z12-2-b

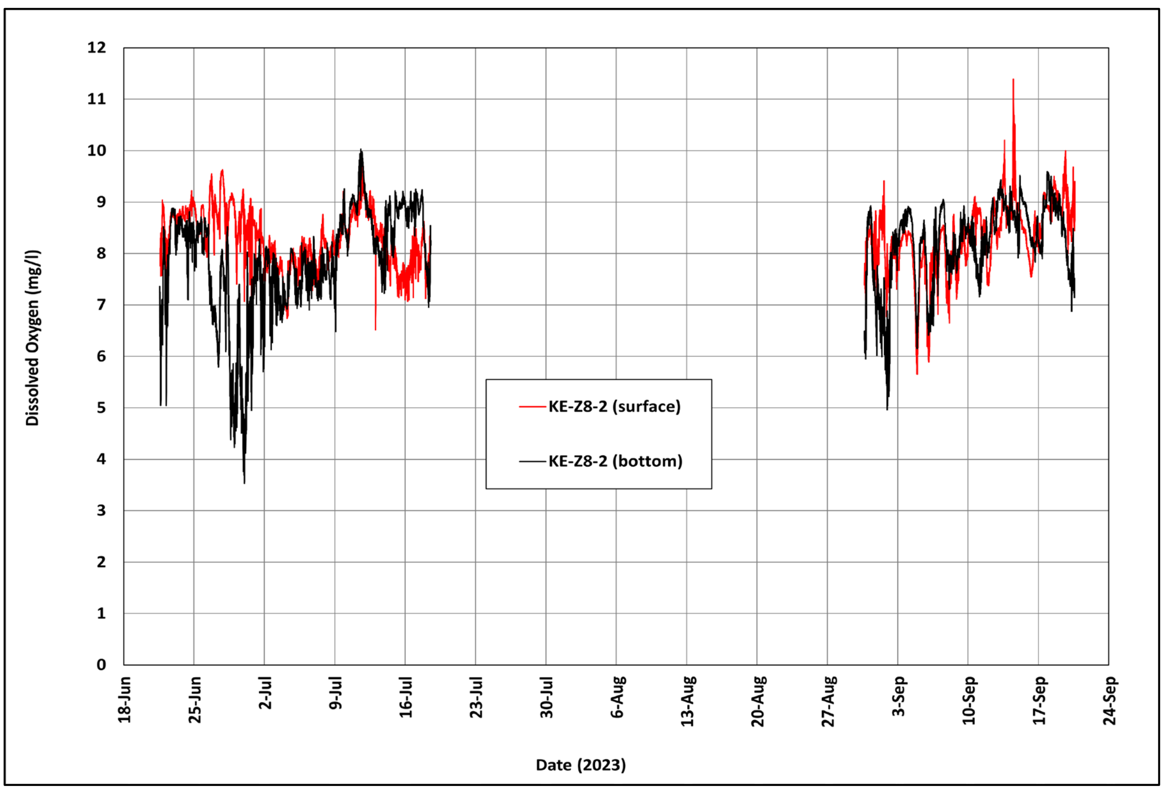


Figure 43: Continuous DO at site KE-Z8-2

6.2 LITTLE GULL LAKE AERATION SYSTEM – 2023/2024 MONITORING SUMMARY

Assessment of the aeration system operation the past year was unavailable at the time of reporting pending final monitoring data.

7.0 DEBRIS MANAGEMENT

As part of the Keeyask GS Project, in accordance with the Joint Keeyask Development Agreement (JKDA; TCN et.al. 2009), a waterways management program was started in 2015 for the Project area from Clark Lake to Gull Rapids. The JKDA indicated that up to 25 workers configured as two two-person boat patrols plus supplementary work crews would operate in the Keeyask area. One boat patrol would operate downstream to implement safety measures and inform resource users of altered water conditions due to the Project while the other would operate upstream to implement safety measures, manage hazardous debris and assist the work crews.

Boat patrols identify and remove floating woody debris (Photo 7) that may pose a safety hazard to navigation. The boat patrols previously recorded the amount of debris removed, 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, the Gull Lake area was only visited about once each week (20% of the time) by the crew that also patrolled Split Lake and the amount of debris collected in the Clark Lake to Gull Rapids area was estimated to be 20% of the total amount of debris collected by this crew. 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. In 2018 and 2019, 10 or fewer pieces of debris were removed each year (Table 9). While the patrol operated in the area in 2020 - 2024, the specific quantities of woody debris recovered have not been recorded. Except for 2003, the quantities removed after 2014 were much less than the estimated amounts of debris removed prior to 2014. This suggests that the amounts removed from the area prior to 2015 were likely much lower than estimated by the simple assumption it was 20% of the total amount collected by the Split Lake boat patrol.

In 2023, a 20-person work crew continued to focus its efforts on debris clean-up in the vicinity of the Keeyask dam, as it did in 2020-2022 (Figure 44). The work crew was primarily engaged in the collection of woody debris along the south and north dikes that accumulated between the end of the 2022 work season and the start of the 2023 season or continued to accumulate during the 2023 clean-up season. Debris collected was piled adjacent to the east end of the south dike where it was left to dry and was subsequently burned at the start of the work season.

Two boat patrols operated in the Keeyask area between Clark Lake and the Keeyask GS in summer 2023. Boat patrols marked navigation hazards like newly formed reefs created by reservoir impoundment. Weather and equipment permitting, they conducted daily patrols of the waterway to locate and remove floating woody debris. The crews were able to remove a large quantity of floating woody debris from the waterway and dispose of it on shore or in piles that could be burned in winter: however, the total quantity and type of debris removed was unavailable. The amount removed was more than previously encountered prior to Keeyask operation due to woody debris that entered the waterway when the reservoir was impounded. The boat patrols also spoke with resource users on the waterway to answer people’s questions let them know the patrols are around to provide assistance if needed.

In addition to the management of woody debris, the Project had to deal with a large peat island that was mobilized when ice on Gull Lake began to thaw and move in May 2023. During reservoir impoundment in September 2019, an island about 12 km upstream of the Keeyask GS was flooded and but part of it floated up as a peat island and remained relatively stable until spring 2023. In a Sentinel 2 image on May 13, 2023, the island could be seen within the ice as the ice on Gull L. was starting to break up (Figure 45a). Three days later, on May 15, ice had continued to break up and the island had been displaced about 2 km downstream after likely being dislodged when the ice surrounding it move (Figure 45b). By the time of the next satellite image on May 18, the peat island had made its way to the powerhouse (Figure 45c).

The island was about 1.5 ha in size when it reached the powerhouse. As it thawed, material from the island got caught up in the powerhouse trash racks, impeding flow into the turbines. To prevent damage to the powerhouse, a plan was made to use boats to push the island to the south dike near the spillway where it could be excavated and removed from the reservoir. The Keeyask EIS (KHLP 2012b) indicated an option to manage floating peat would be to use boat to push islands into off current areas or locations where it could be removed. The Waterways Programming Dept. mobilized 18 boat-patrol boats to Keeyask. Using 15 of these boats the island was pushed away from the powerhouse (Photo 8), however, they were unable to move it to the south dike due to unfavourable wind and currents, and the island ended up back at the powerhouse.

Removal of the peat island was subsequently accomplished using a crane-operated clamshell bucket working from the powerhouse deck to dig out the peat (Photo 9). The peat was loaded onto trucks and stockpiled for future use in site restoration. Flow through the powerhouse was stopped for 8 days during peat removal and all flow passed through the spillway at that time. The crane and clamshell were also used to pull peat and woody material off the trash racks to restore inflow efficiency. Clean up of the peat island and debris from the powerhouse took about a month. The Keeyask boat patrols continued to monitor for floating peat through the 2023 season and attempted to move floating peat chunks away from the powerhouse as best as possible. An amphibex, a type of floating excavator, was also tested on site to proactively remove a large, non-mobile peat island but the test program found the process to be slow and inefficient.

The Keeyask EIS (KHLP 2012b) anticipated that floating peat would need to be dealt with at the powerhouse, which was also experienced at other stations like Kettle GS downstream when they were constructed. Those other projects were able to move the peat away from the powerhouse and either pass it through the spillway or remove it from the water at a more favourable location. It was expected that similar methods would be used at Keeyask. However, moving the island proved more challenging than anticipated, resulting in a need to remove it while it was at the powerhouse and creating the need to shut down or reduce flow through the powerhouse to facilitate removal of the island and the clean resulting debris from the trash racks.

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
2020-2023	Not available				

Photo 7: Large floating debris is removed from the water by the boat patrol team

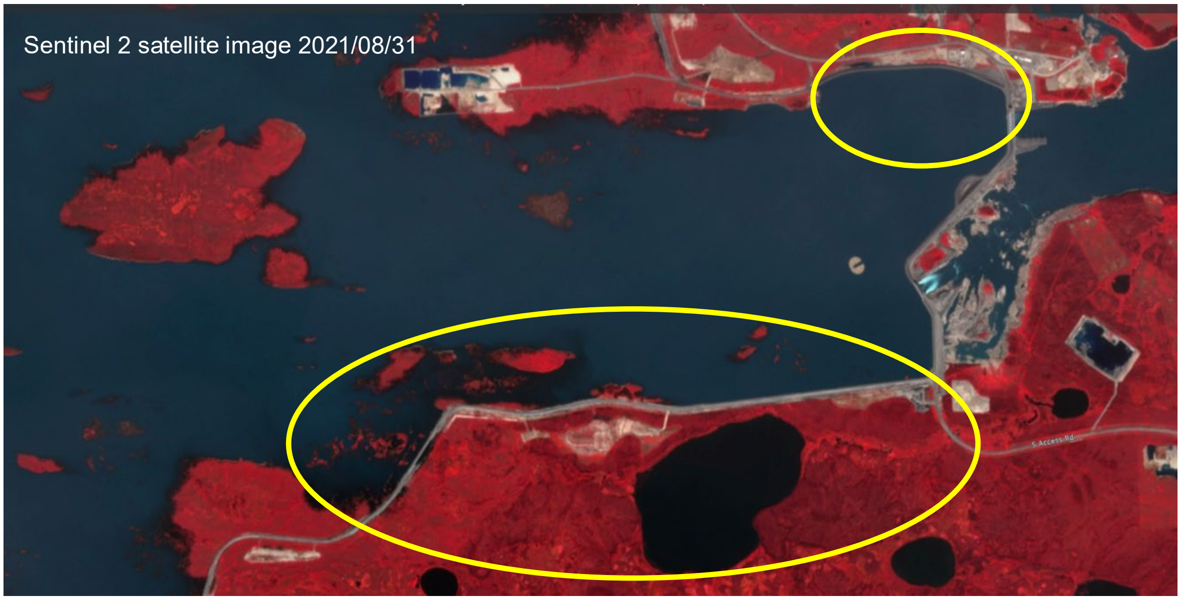


Figure 44: General work areas for work crew debris removal activities

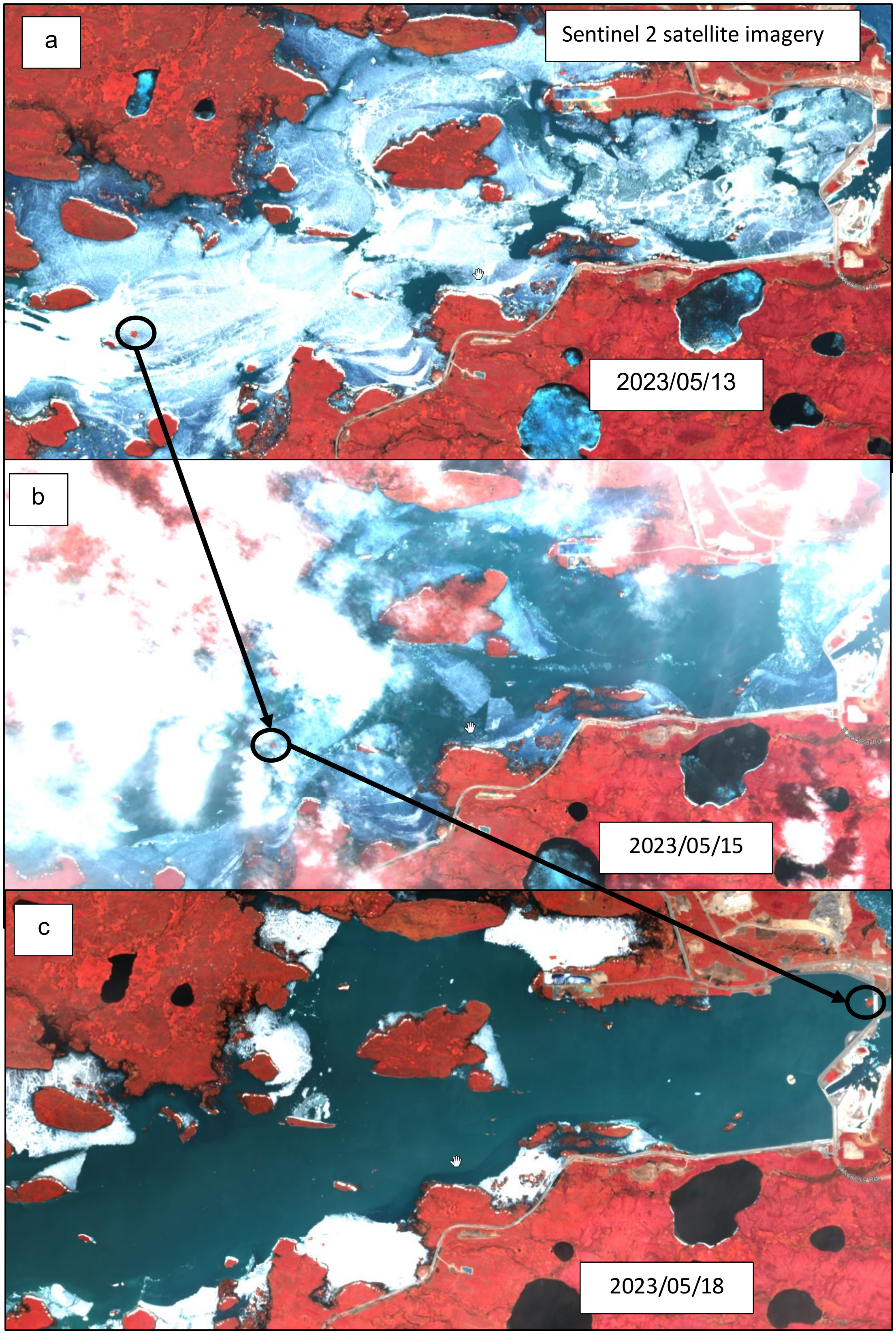


Figure 45: Origin and movement of peat island in May 2023

Photo 8: Boat-patrol boats pushing peat island away from powerhouse

Photo 9: Crane with clam shell bucket on powerhouse deck removing peat island

8.0 TOTAL DISSOLVED GAS PRESSURE

Dissolved gases such as oxygen, nitrogen, and carbon dioxide are typically present in surface waters like the Nelson River and the amount of gas present is measured as total dissolved gas pressure (TDG). These dissolved gases will attempt to maintain an equilibrium concentration that depends on factors like water temperature and air pressure. At equilibrium, the water may be referred to as being 100% saturated. When there is excess gas dissolved in the water it is said to be super-saturated, having a degree of saturation greater than 100%, and the excess gas will tend to dissipate into the atmosphere over time to bring the water back to being saturated. Conversely, if the amount of dissolved gas is low, the water is unsaturated with a degree of saturation less than 100%, and additional gas may be dissolved into the water from the atmosphere to bring the water back to being saturated. Various processes like biological activity or turbulent mixing can cause the TDG to vary between being unsaturated, saturated, or super-saturated.

While flow through the powerhouse is not likely to cause excess gas to be dissolved into the water, turbulent flow below the spillway could cause super-saturation by entraining gas bubbles. This can be a concern if the TDG gets too high because it can cause baro-trauma in fish, which results in physiological effects such as bulging eyes and potential fish mortality.

Although the Keeyask spillway design helps reduce the potential for causing total gas pressure to get too high (KHLP 2012b), it is anticipated that some degree of supersaturation would still occur. Based on monitoring below the Limestone GS and Kelsey GS it was anticipated that TDG at Keeyask would likely be less than 110% saturation, and that this supersaturation would persist for several kilometers downstream as at the other generating stations. The degree of super-saturation decreases as the excess gases dissipate into the atmosphere and as the spillway flow mixes with the powerhouse flow.

On Aug 21, 2023, TGP monitoring was performed at one transect about 4 km upstream of the powerhouse, and at 5 transects downstream at approximately 1.5, 2.5, 3.5, 4.5, and 5.5 km downstream, with measurement obtained at a total of 35 separate locations (Figure 46). Powerhouse discharge was approximately 3,800 m3/s and there was no flow through the spillway during the monitoring. The monitoring extended further downstream than indicated in the Keeyask PEMP (KHLP 2015a) and the transect spacing was extended to 1 km instead of 500 m because it was felt that any dissipation of gases would be adequately captured with the larger spacing. TDG was monitored using a hand-held probe and measurements were obtained at depths of 1 m and 2.5 m depths, which was the depth limit for the equipment used. Monitoring to 2.5 m deep was considered adequate as previous dissolved oxygen monitoring has found that the DO concentration shows little variation through the water column depth, indicating complete mixing of the dissolved gas through the water column.

The results show TDG at all sampling points and both depths the observed values ranged between 97.9% - 100.9% saturation (Figure 46). It was generally expected that TDG saturation would be near 100% under the reservoir operating conditions at the time of testing.

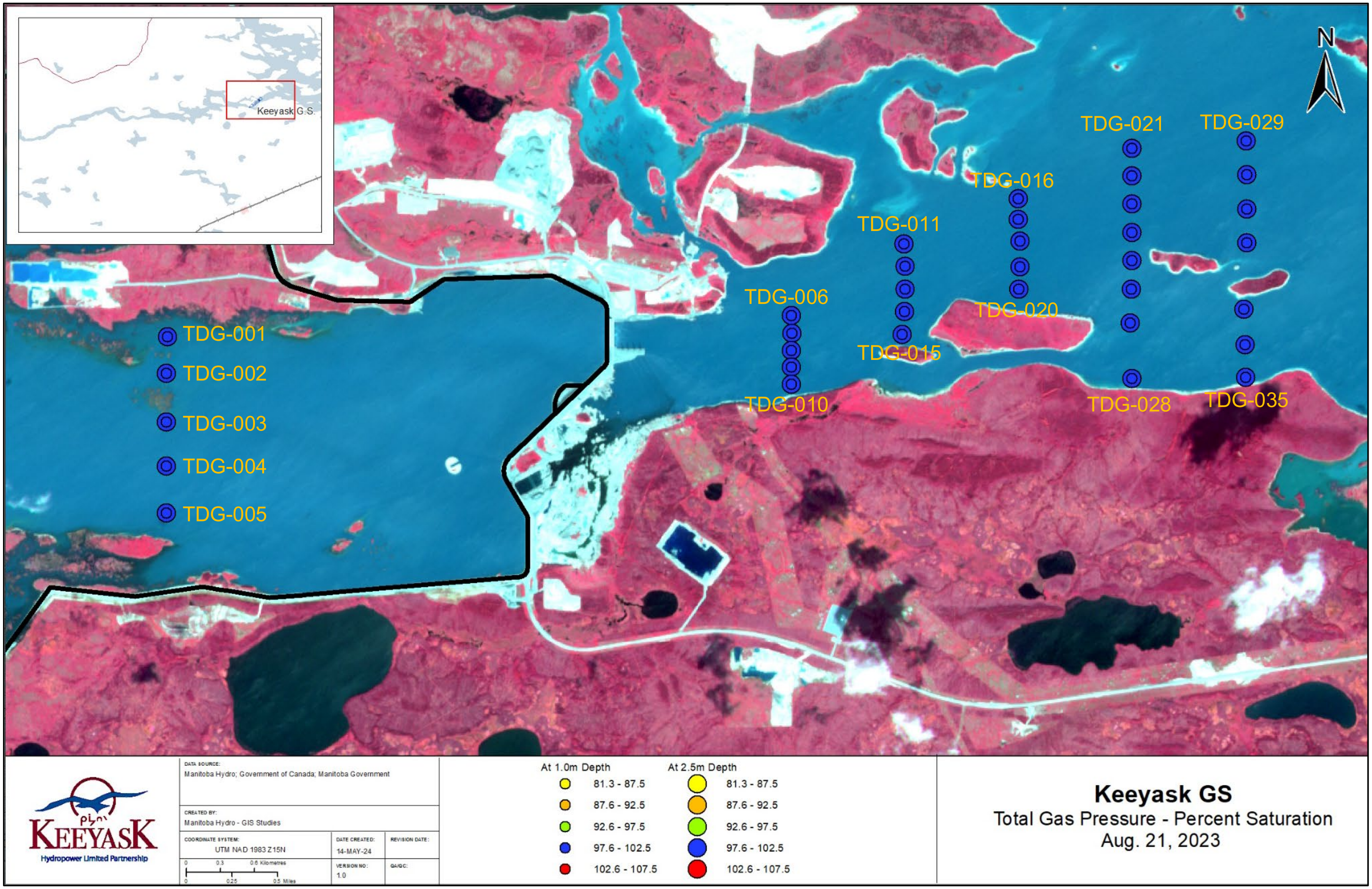


Figure 46: Total Dissolved Gas Pressure Percent Saturation at 1 m and 2.5 m depths (Aug. 21, 2023)

9.0 RESERVOIR GREENHOUSE GAS

Greenhouse gas (GHG) monitoring has been taking place at locations upstream and downstream of the Keeyask GS during both construction and operation. A comprehensive review of the monitoring results is being undertaken but was not complete at the time for submission of this annual report. The findings of the review will be presented in next year's annual report.

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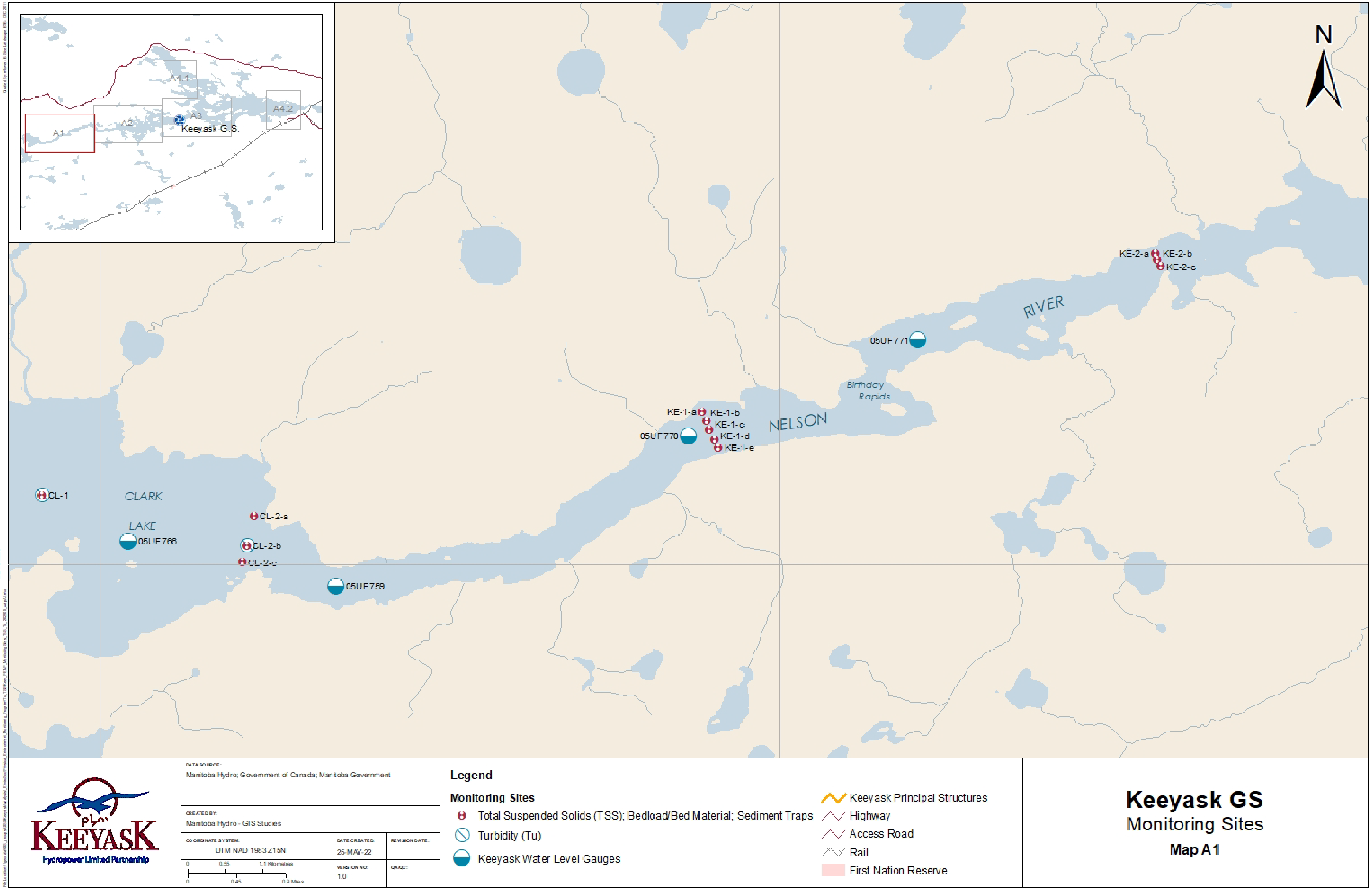
APPENDIX 1: DETAILED MAPS OF PEMP MONITORING SITES


320,000
330,000
6,240,000
N
A4-1
A4-2
A1
A2
A3
Keeyask G.S.
KE-2-a
KE-2-b
KE-2-c
RIVER
05UF771
Birthday Rapids
KE-1-a
KE-1-b
KE-1-c
KE-1-d
KE-1-e
05UF770
NELSON
CL-1
CLARK
LAKE
05UF768
CL-2-a
CL-2-b
CL-2-c
05UF769
DATA SOURCE:
Manitoba Hydro; Government of Canada; Manitoba Government
CREATED BY:
Manitoba Hydro - GIS Studies
COORDINATE SYSTEM:
UTM NAD 1983 Z15N
DATE CREATED:
25-MAY-22
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 Gauges
Keeyask Principal Structures
Highway
Access Road
Rail
First Nation Reserve
Keeyask GS
Monitoring Sites
Map A1

KEEYASK
Hydropower Limited Partnership

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

CREATED BY:
Manitoba Hydro - GIS Studies

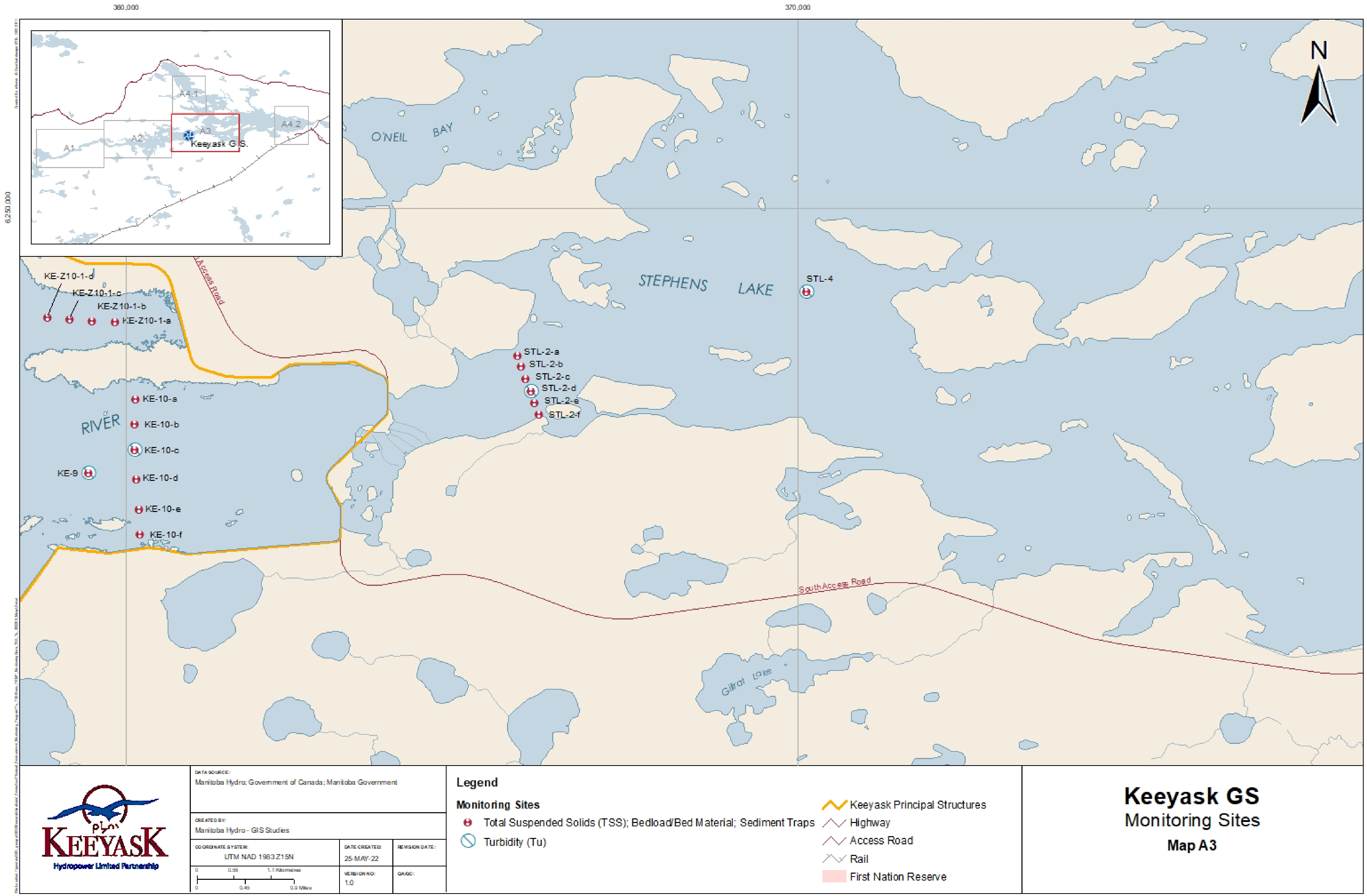
COORDINATE SYSTEM:	DATE CREATED:	REVISION DATE:
UTM NAD 1983 Z15N	25-MAY-22	
0 0.55 1.1 Kilometres / 0 0.45 0.9 Miles	VERSION NO: 1.0	QA/QC:

Legend

Monitoring Sites

- Total Suspended Solids (TSS); Bedload/Bed Material; Sediment Traps
- Turbidity (Tu)
- Keeyask Water Level Gauges
- Keeyask Principal Structures
- Highway
- Access Road
- Rail
- First Nation Reserve

Keeyask GS
Monitoring Sites
Map A2


360,000
370,000
6,250,000
A1
A2
A3
A4.1
A4.2
Keeyask G.S.
N
O'NEIL BAY
STEPHENS LAKE
RIVER
STL-4
STL-2-a
STL-2-b
STL-2-c
STL-2-d
STL-2-e
STL-2-f
KE-Z10-1-d
KE-Z10-1-c
KE-Z10-1-b
KE-Z10-1-a
KE-10-a
KE-10-b
KE-10-c
KE-10-d
KE-10-e
KE-10-f
KE-9
North Access Road
South Access Road
Gilrat Lake
KEEYASK
Hydropower Limited Partnership
DATA SOURCE:
Manitoba Hydro; Government of Canada; Manitoba Government
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Manitoba Hydro - GIS Studies
COORDINATE SYSTEM:
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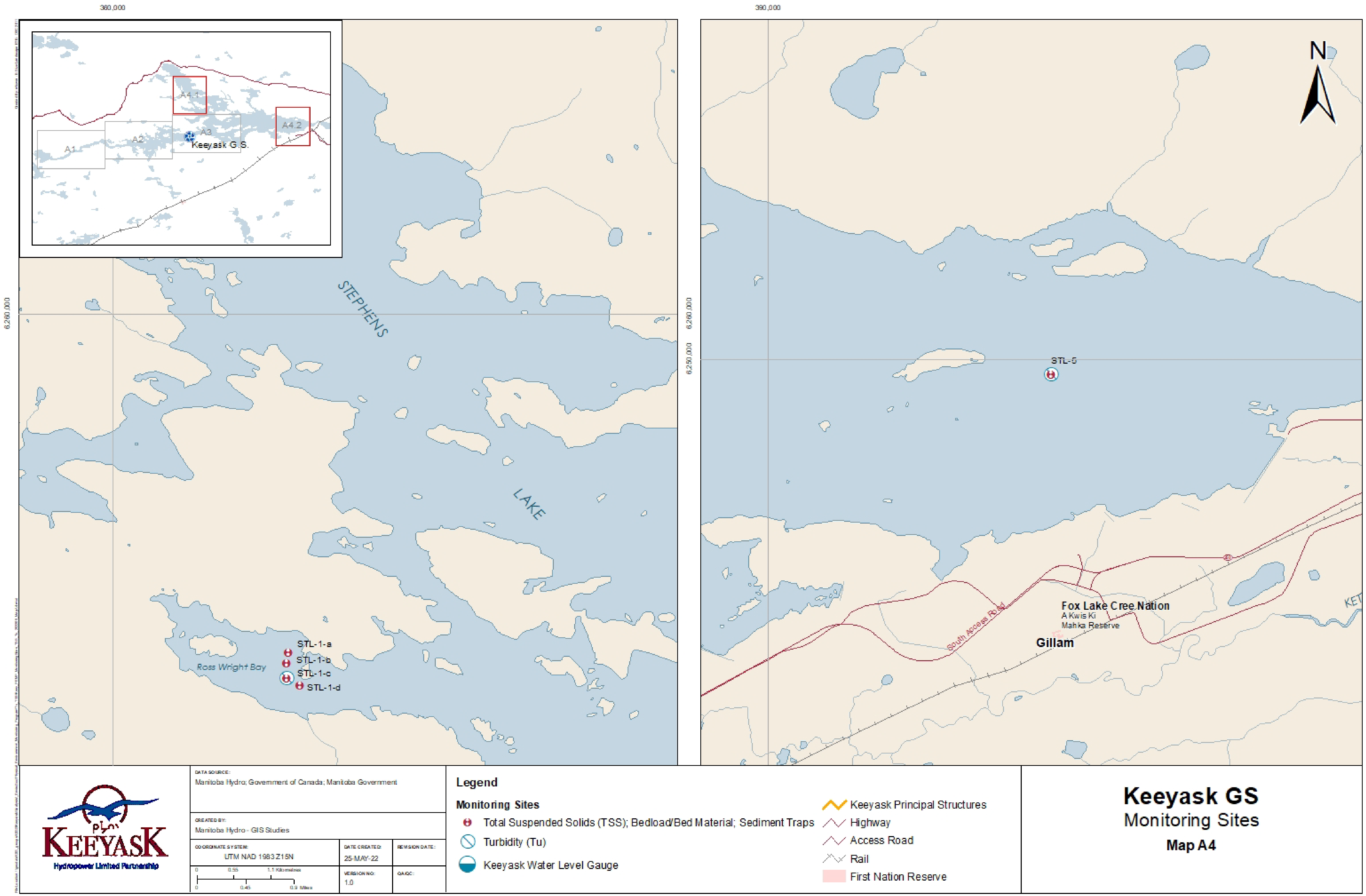
DATE CREATED:
25-MAY-22
REVISION DATE:
VERSION NO:
1.0
QA/QC:
Legend
Monitoring Sites
Total Suspended Solids (TSS); Bedload/Bed Material; Sediment Traps
Turbidity (Tu)
Keeyask Principal Structures
Highway
Access Road
Rail
First Nation Reserve
Keeyask GS
Monitoring Sites
Map A3



Keeyask G.S.
A1
A2
A3
A4.1
A4.2
STEPHENS
LAKE
Ross Wright Bay
STL-1-a
STL-1-b
STL-1-c
STL-1-d
STL-5
Fox Lake Cree Nation
A Kwis Ki
Mahka Reserve
Gillam
South Access Road
N
DATA SOURCE:
Manitoba Hydro; Government of Canada; Manitoba Government
CREATED BY:
Manitoba Hydro - GIS Studies
COORDINATE SYSTEM:
UTM NAD 1983 Z15N
DATE CREATED:
25-MAY-22
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VERSION NO:
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QA/QC:
Legend
Monitoring Sites
Total Suspended Solids (TSS); Bedload/Bed Material; Sediment Traps
Turbidity (Tu)
Keeyask Water Level Gauge
Keeyask Principal Structures
Highway
Access Road
Rail
First Nation Reserve
KEEYASK
Hydropower Limited Partnership
Keeyask GS
Monitoring Sites
Map A4

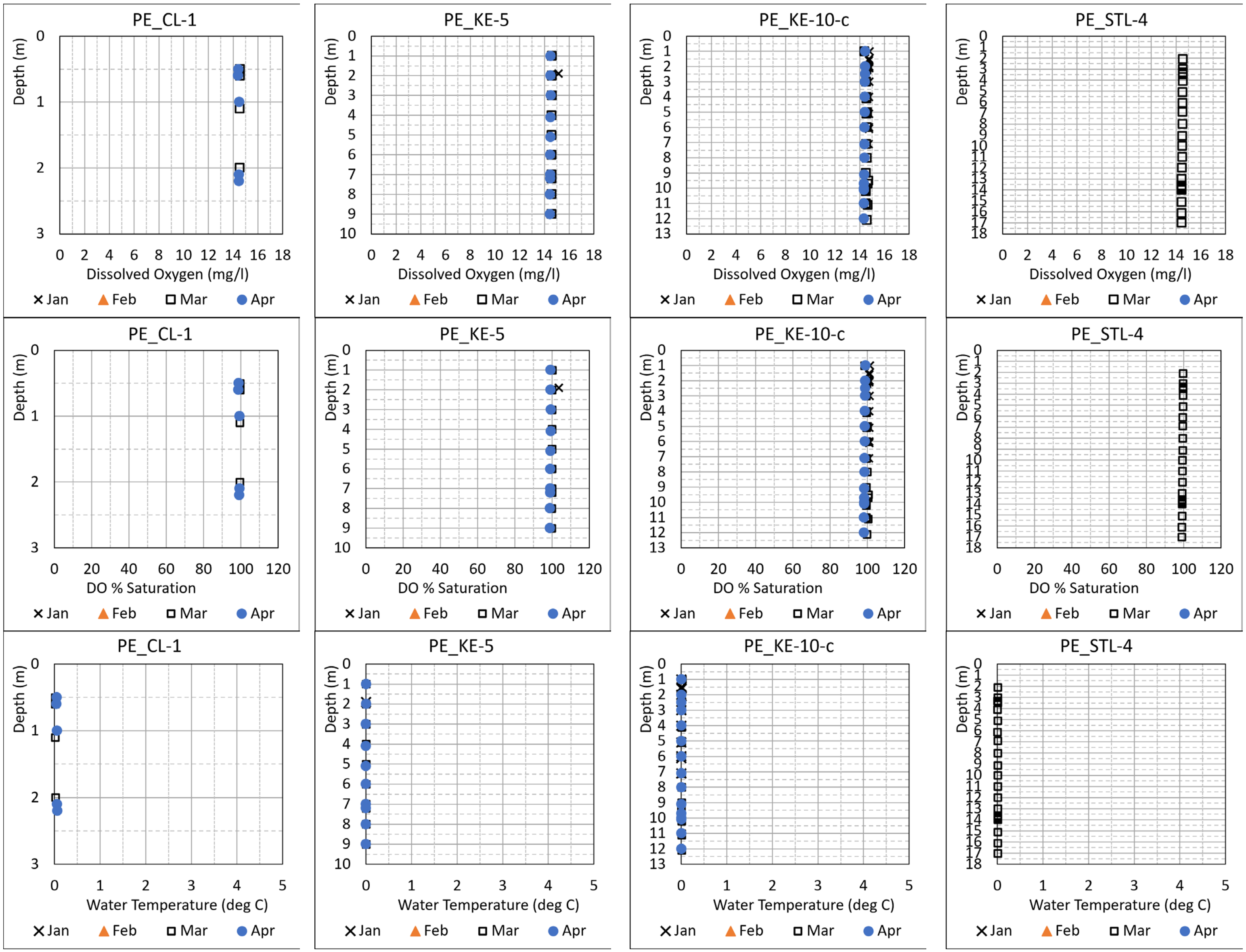
APPENDIX 2: WINTER DEPTH PROFILE CHARTS OF DISSOLVED OXYGEN CONCENTRATION, PERCENT SATURATION, AND WATER TEMPERATURE

Site Listing in order of presentation in Appendix 2:

Note that site names on charts all include the “PE_” prefix that is an internal designation used to identify the monitoring site as part of the physical environment program.

Mainstem sites (upstream to downstream):

- PE_CL-1
- PE_KE-5
- PE_KE-10-c
- PE_STL-4


PE_CL-1
PE_KE-5
PE_KE-10-c
PE_STL-4
Depth (m)
Dissolved Oxygen (mg/l)
DO % Saturation
Water Temperature (deg C)
Jan
Feb
Mar
Apr

APPENDIX 3: SUMMER DEPTH PROFILE CHARTS OF DISSOLVED OXYGEN CONCENTRATION & PERCENT SATURATION, AND WATER TEMPERATURE

Site Listing in order of presentation in Appendix 3:

Note that site names on charts all include the "PE_" prefix that is an internal designation used to identify the monitoring site as part of the physical environment program.

Mainstem sites (upstream to downstream):

- PE_CL-2-a, b, c (i.e, PE_CL-2-a, PE_CL-2-b, PE_CL-2-c)
- PE_KE-1- b, c, d
- PE_KE-3-a, b, c, d, e
- PE_KE-4-a, b
- PE_KE-6-a, b, c, d, e
- PE_KE-7
- PE_KE-8
- PE_KE-10-a, b, c, d, e, f
- PE_STL-2-a, b, c, d, e, f
- PE_STL-5

North back bay sites:

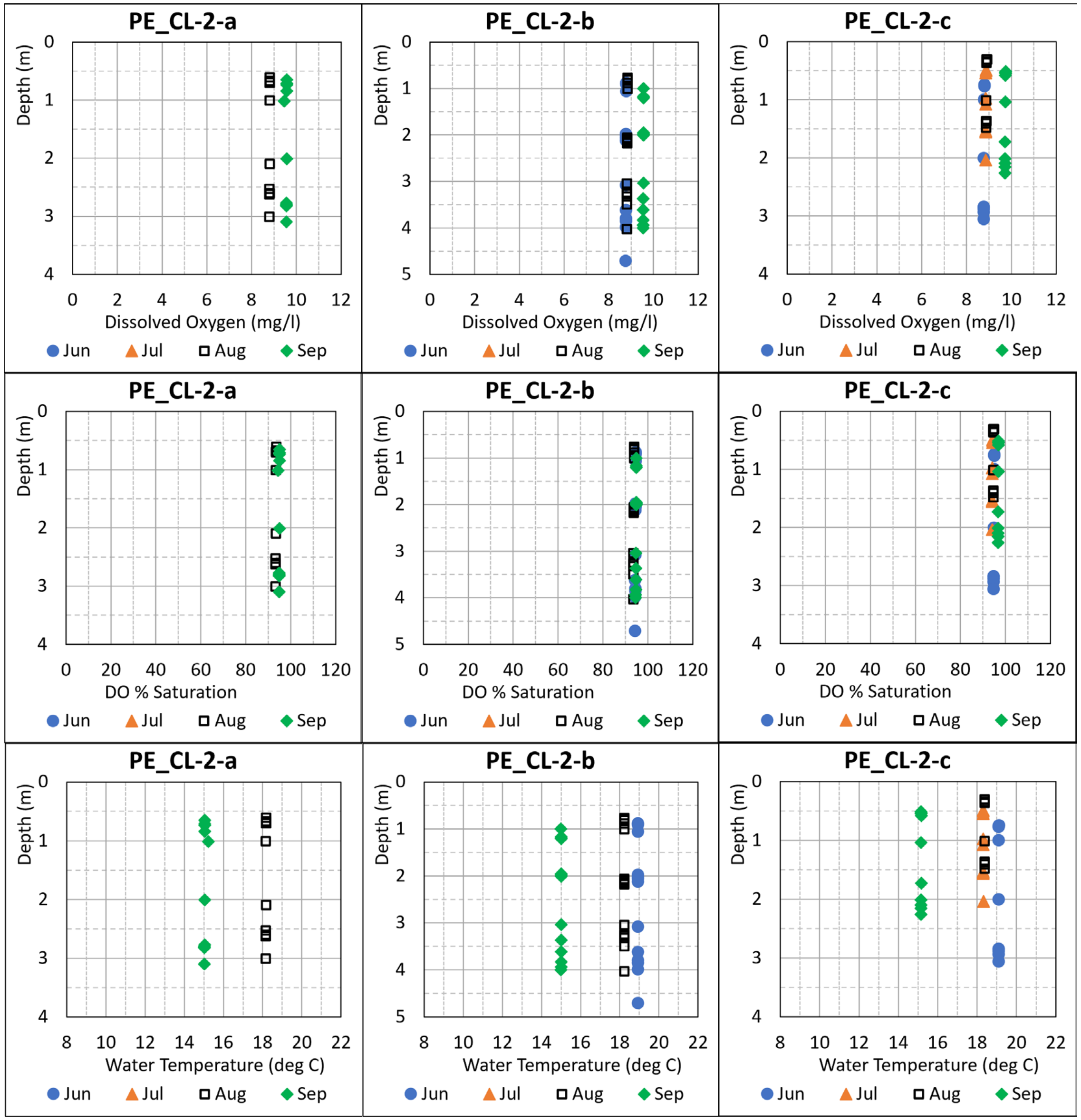
- PE_KE-Z4-1-a, b, c, d
- PE_KE-Z5-1-a, b, c, d
- PE_KE-Z7-1-a, b, c, d
- PE_KE-Z7-2-a, b, c, d
- PE_KE-Z8-2, 3, 4
- PE_KE-Z9-1-a, b, c, d
- PE_KE-Z10-1-a, b, c, d

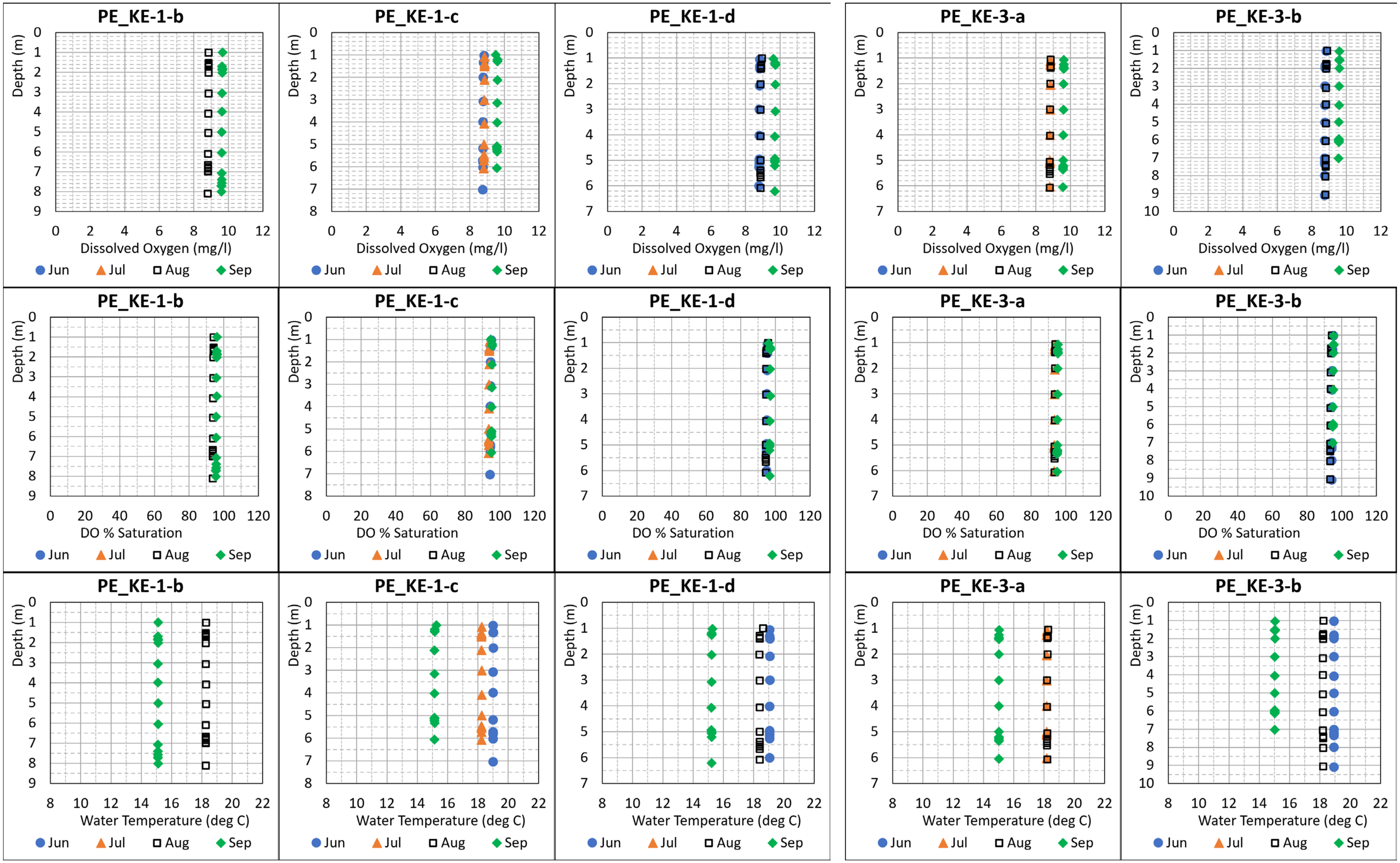
South back bay sites:

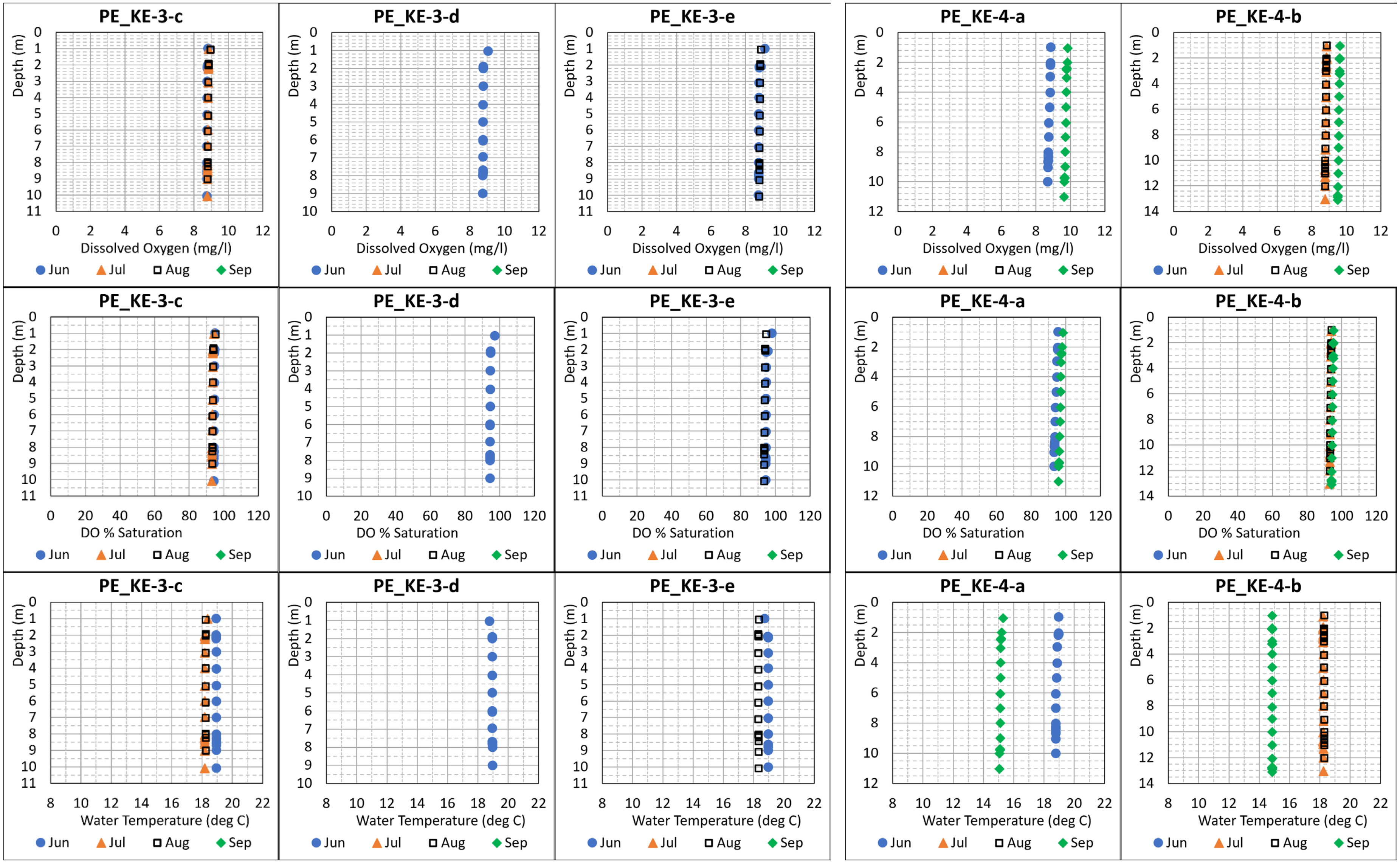
- PE_KE-Z11-1-a, b, c, d
- PE_KE-Z12-1-a, b, c, d
- PE_KE-Z12-2-a, b, c, d
- PE_KE-Z13-1-a, b, c, d

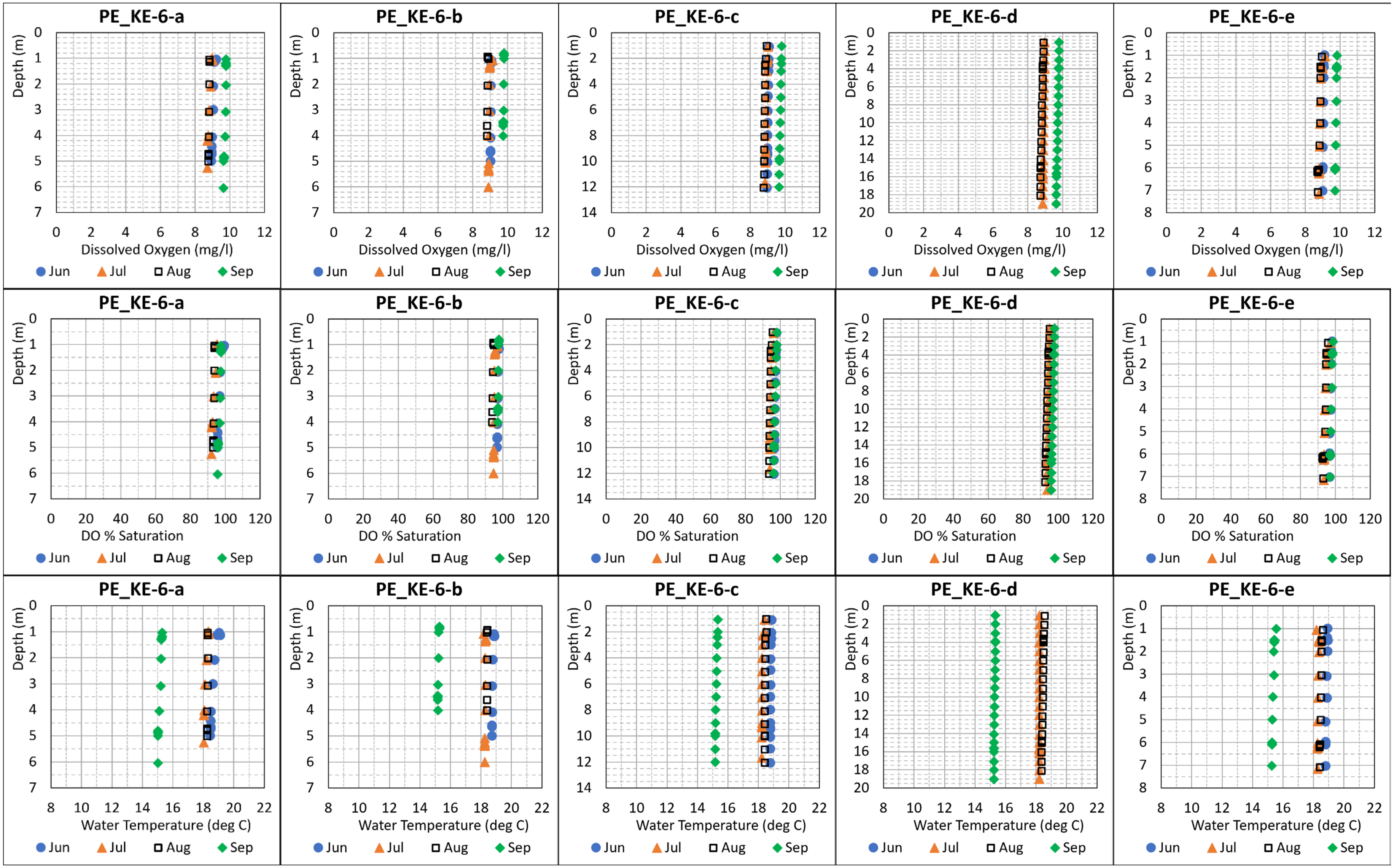
Stephens Lake back bay site:

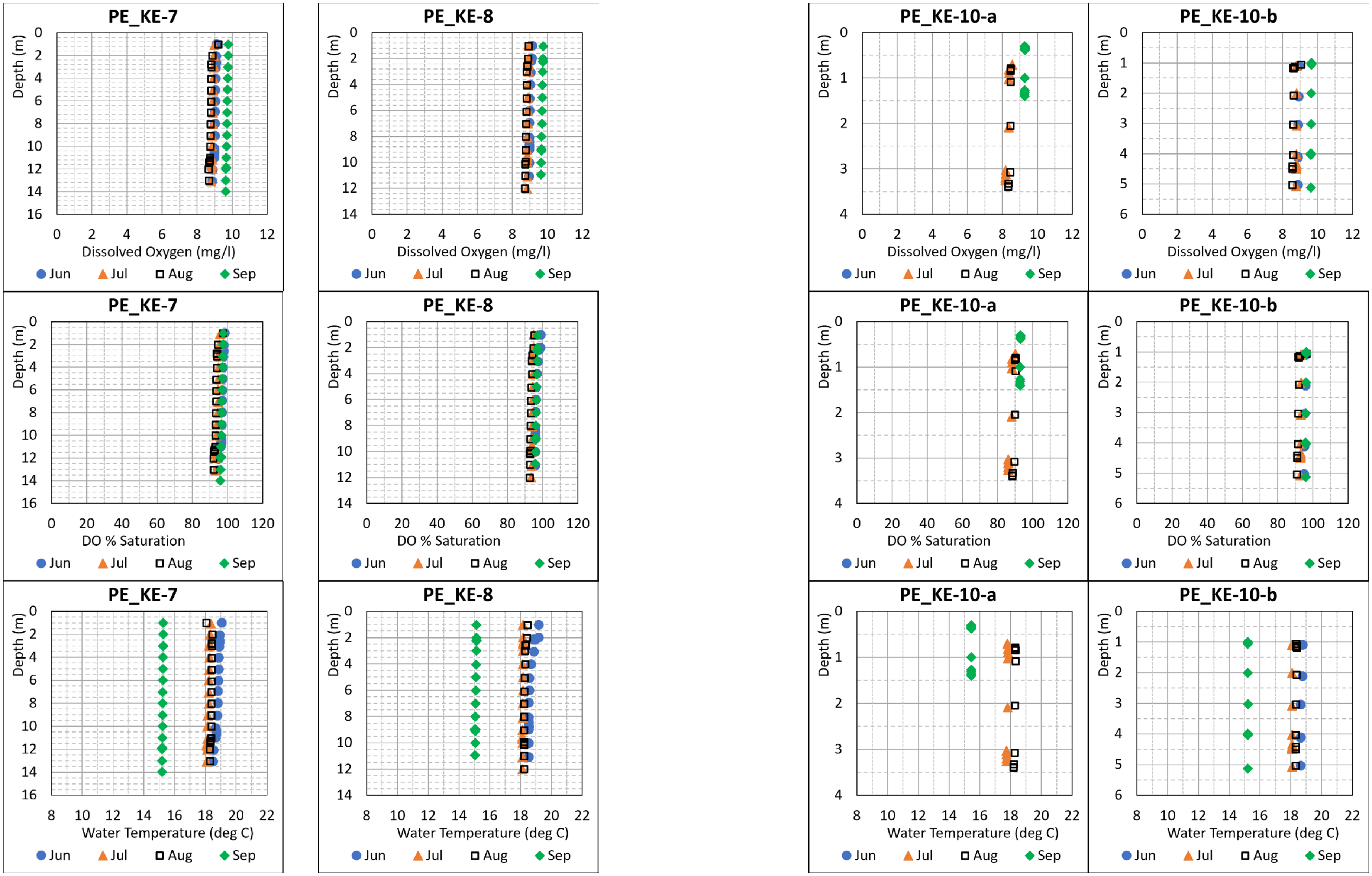
- PE_STL-1-a, b, c, d

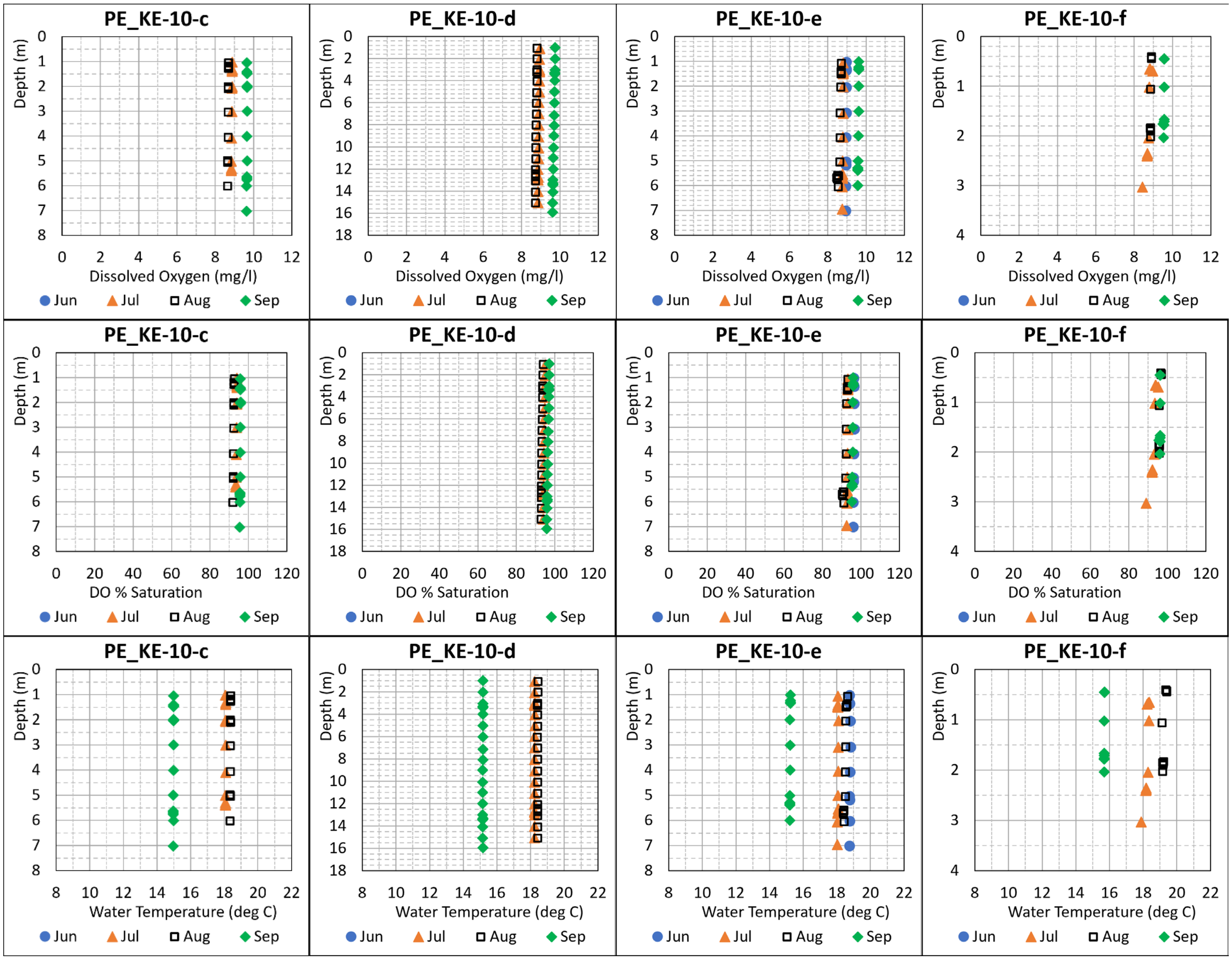

PE_CL-2-a
PE_CL-2-b
PE_CL-2-c
Depth (m)
Dissolved Oxygen (mg/l)
DO % Saturation
Water Temperature (deg C)
Jun
Jul
Aug
Sep

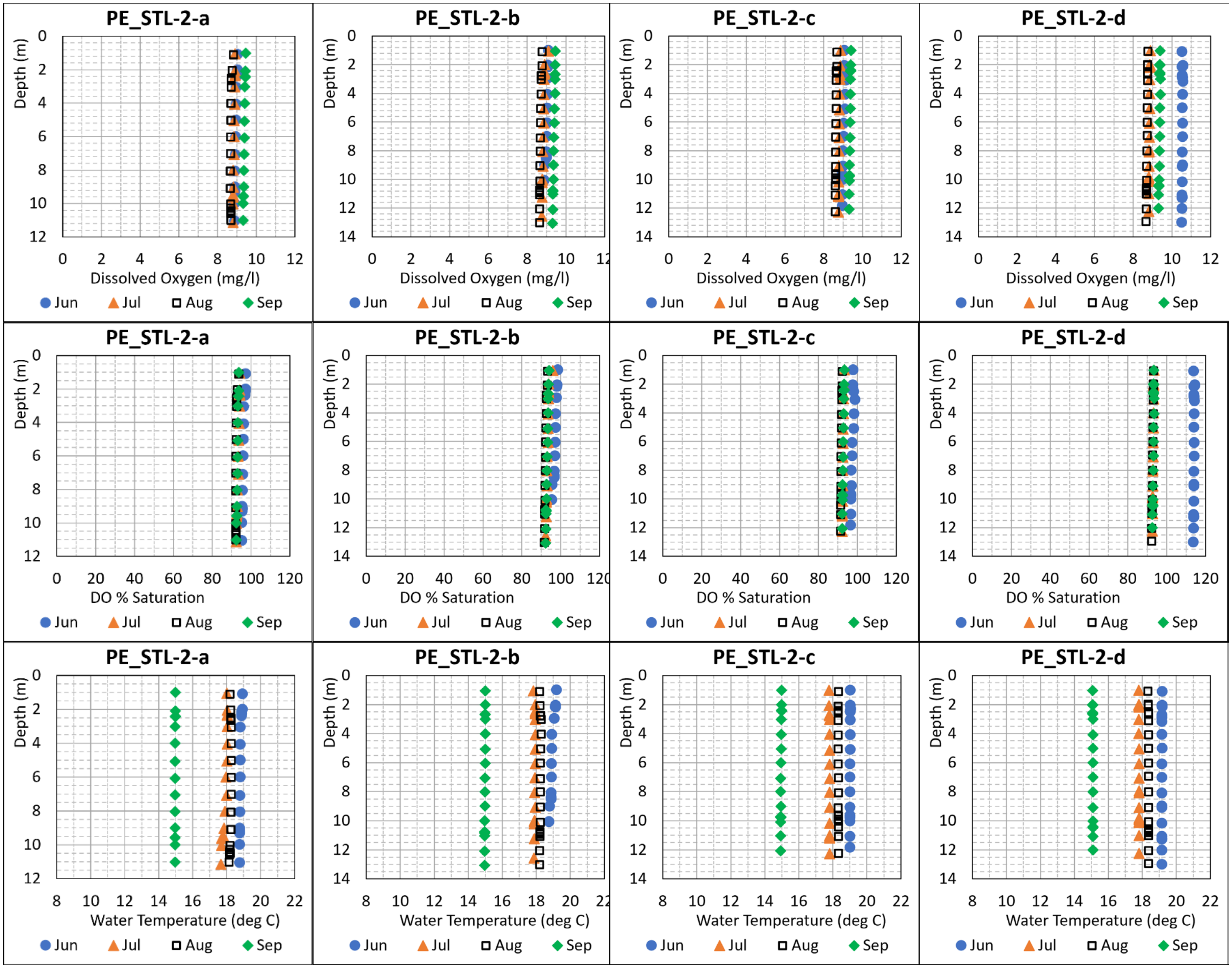

PE_KE-1-b
PE_KE-1-c
PE_KE-1-d
PE_KE-3-a
PE_KE-3-b
Depth (m)
Dissolved Oxygen (mg/l)
DO % Saturation
Water Temperature (deg C)
Jun
Jul
Aug
Sep

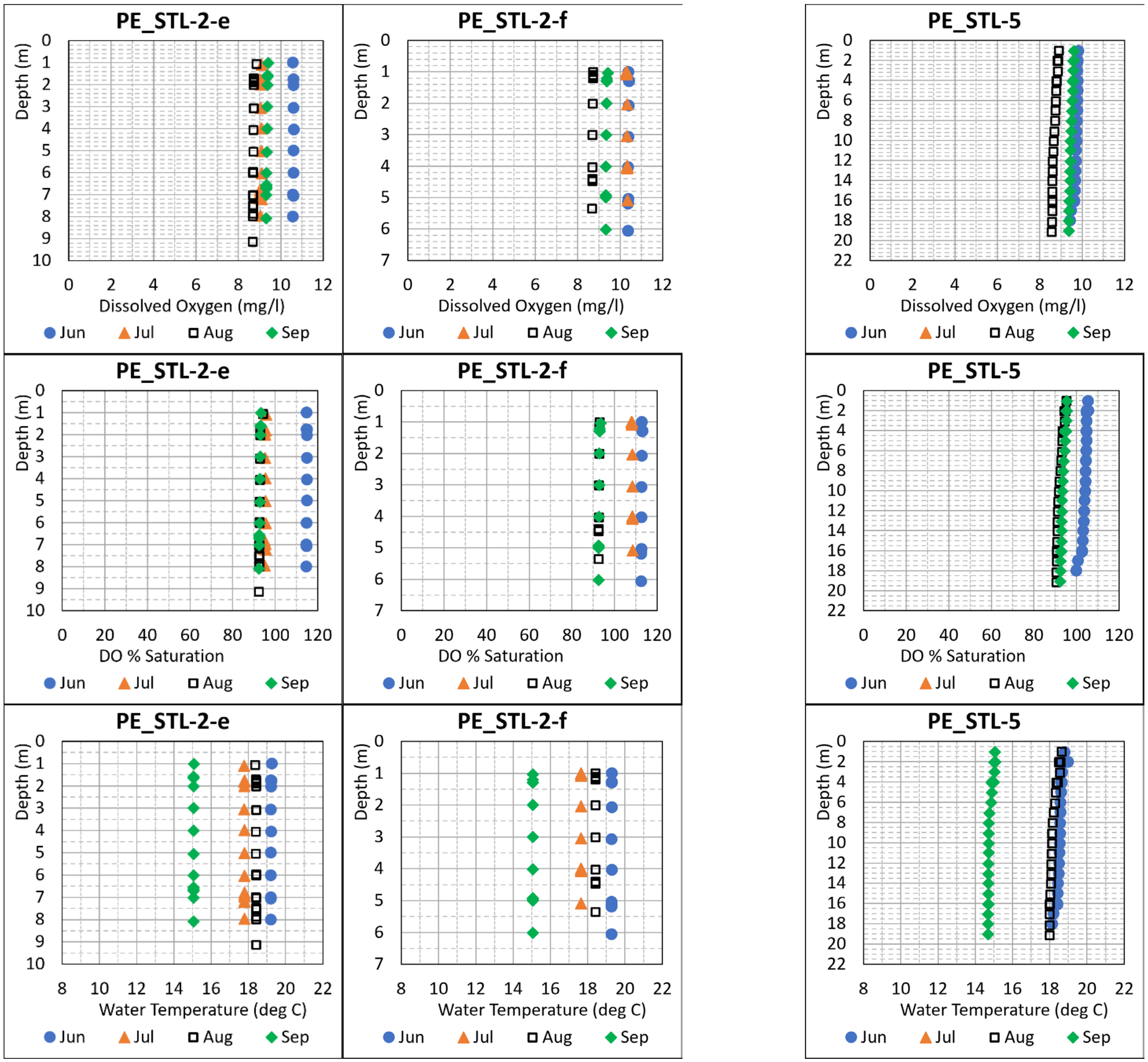

PE_KE-3-c
PE_KE-3-d
PE_KE-3-e
PE_KE-4-a
PE_KE-4-b
Depth (m)
Dissolved Oxygen (mg/l)
DO % Saturation
Water Temperature (deg C)
Jun
Jul
Aug
Sep

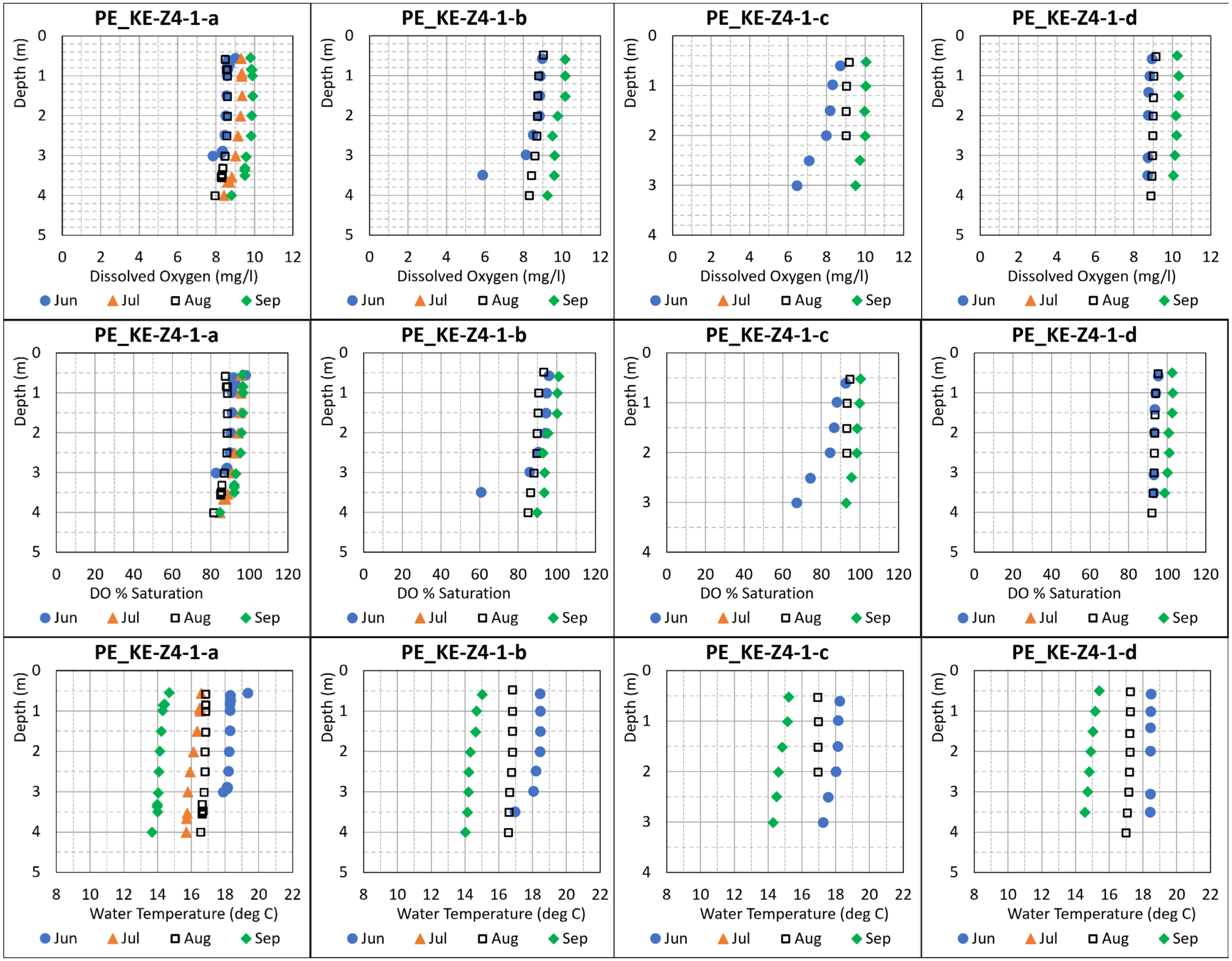

PE_KE-6-a
PE_KE-6-b
PE_KE-6-c
PE_KE-6-d
PE_KE-6-e
Depth (m)
Dissolved Oxygen (mg/l)
DO % Saturation
Water Temperature (deg C)
Jun
Jul
Aug
Sep


PE_KE-7
PE_KE-8
PE_KE-10-a
PE_KE-10-b
Depth (m)
Dissolved Oxygen (mg/l)
DO % Saturation
Water Temperature (deg C)
Jun
Jul
Aug
Sep

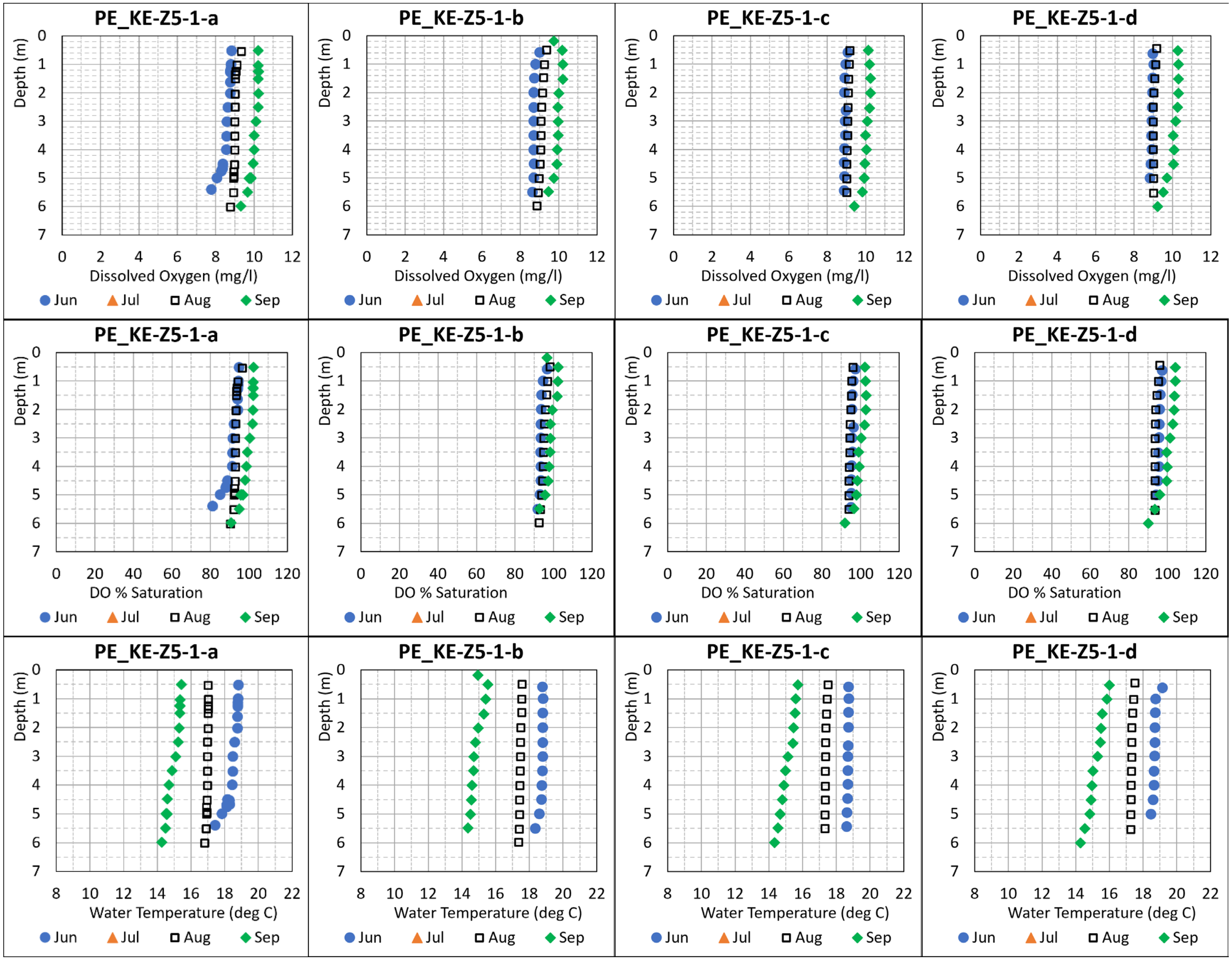

PE_KE-10-c
PE_KE-10-d
PE_KE-10-e
PE_KE-10-f
Depth (m)
Dissolved Oxygen (mg/l)
DO % Saturation
Water Temperature (deg C)
Jun
Jul
Aug
Sep

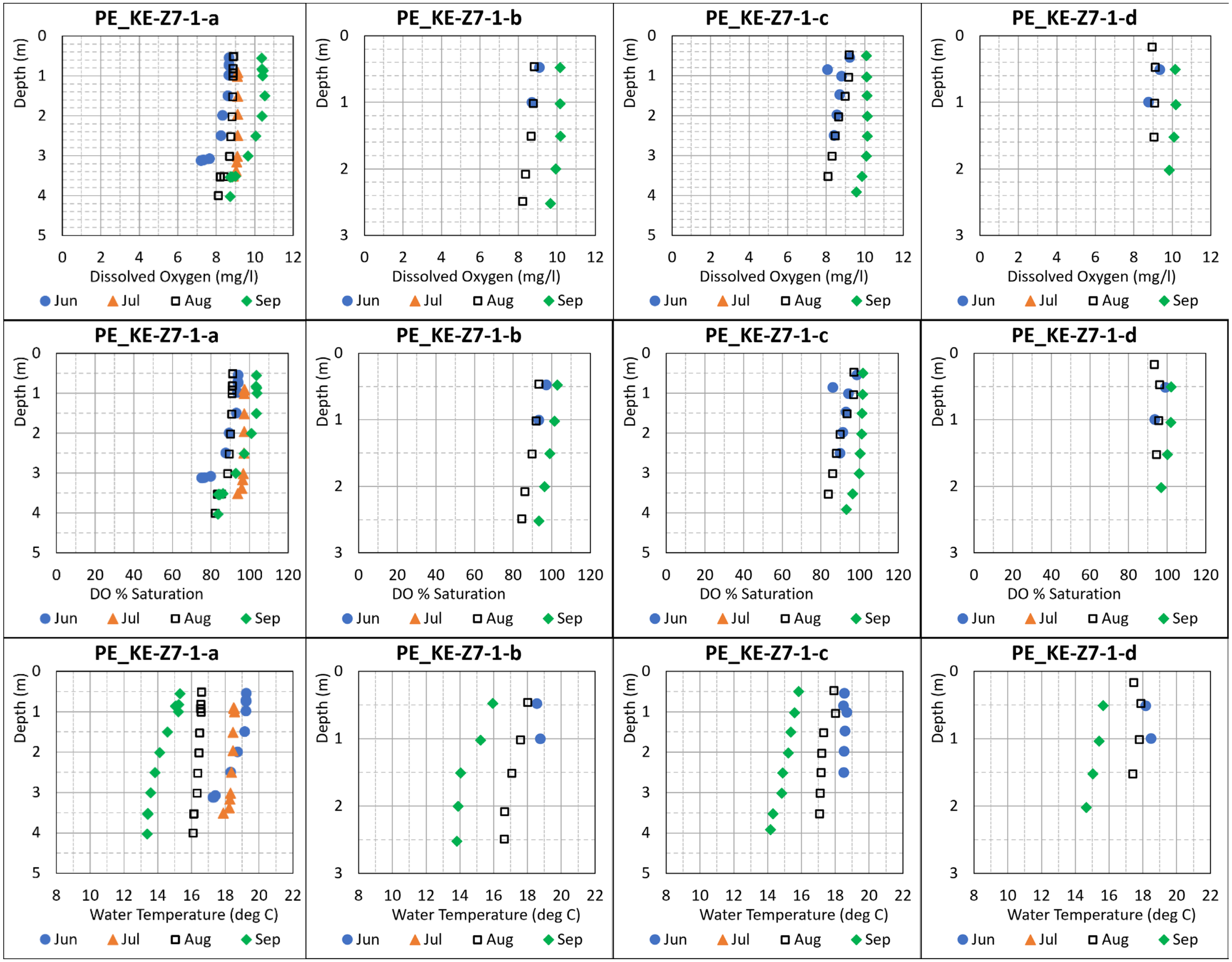

PE_STL-2-a
PE_STL-2-b
PE_STL-2-c
PE_STL-2-d
Depth (m)
Dissolved Oxygen (mg/l)
DO % Saturation
Water Temperature (deg C)
Jun
Jul
Aug
Sep

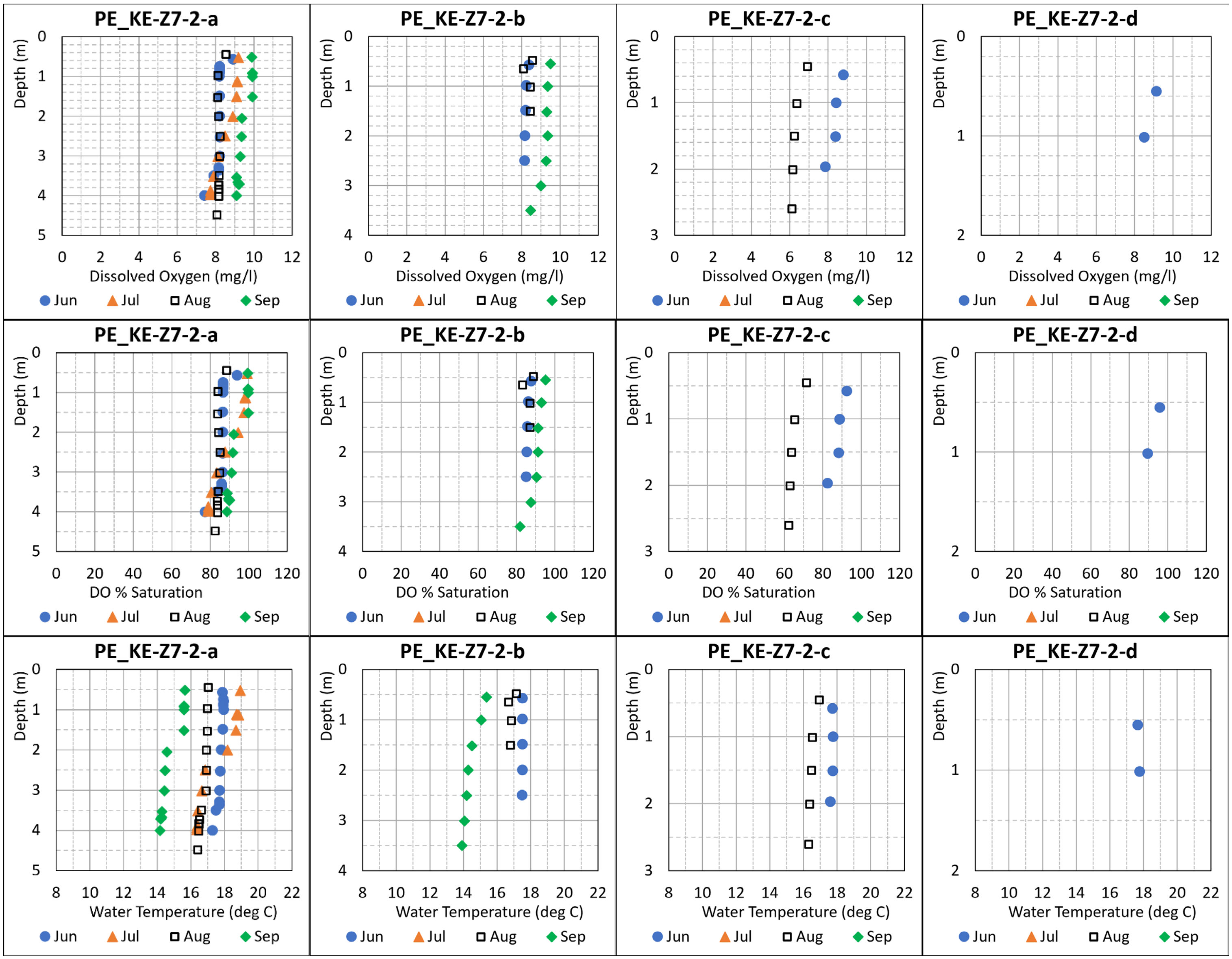

PE_STL-2-e
Depth (m)
Dissolved Oxygen (mg/l)
Jun Jul Aug Sep
PE_STL-2-f
Depth (m)
Dissolved Oxygen (mg/l)
Jun Jul Aug Sep
PE_STL-5
Depth (m)
Dissolved Oxygen (mg/l)
Jun Jul Aug Sep
PE_STL-2-e
Depth (m)
DO % Saturation
Jun Jul Aug Sep
PE_STL-2-f
Depth (m)
DO % Saturation
Jun Jul Aug Sep
PE_STL-5
Depth (m)
DO % Saturation
Jun Jul Aug Sep
PE_STL-2-e
Depth (m)
Water Temperature (deg C)
Jun Jul Aug Sep
PE_STL-2-f
Depth (m)
Water Temperature (deg C)
Jun Jul Aug Sep
PE_STL-5
Depth (m)
Water Temperature (deg C)
Jun Jul Aug Sep

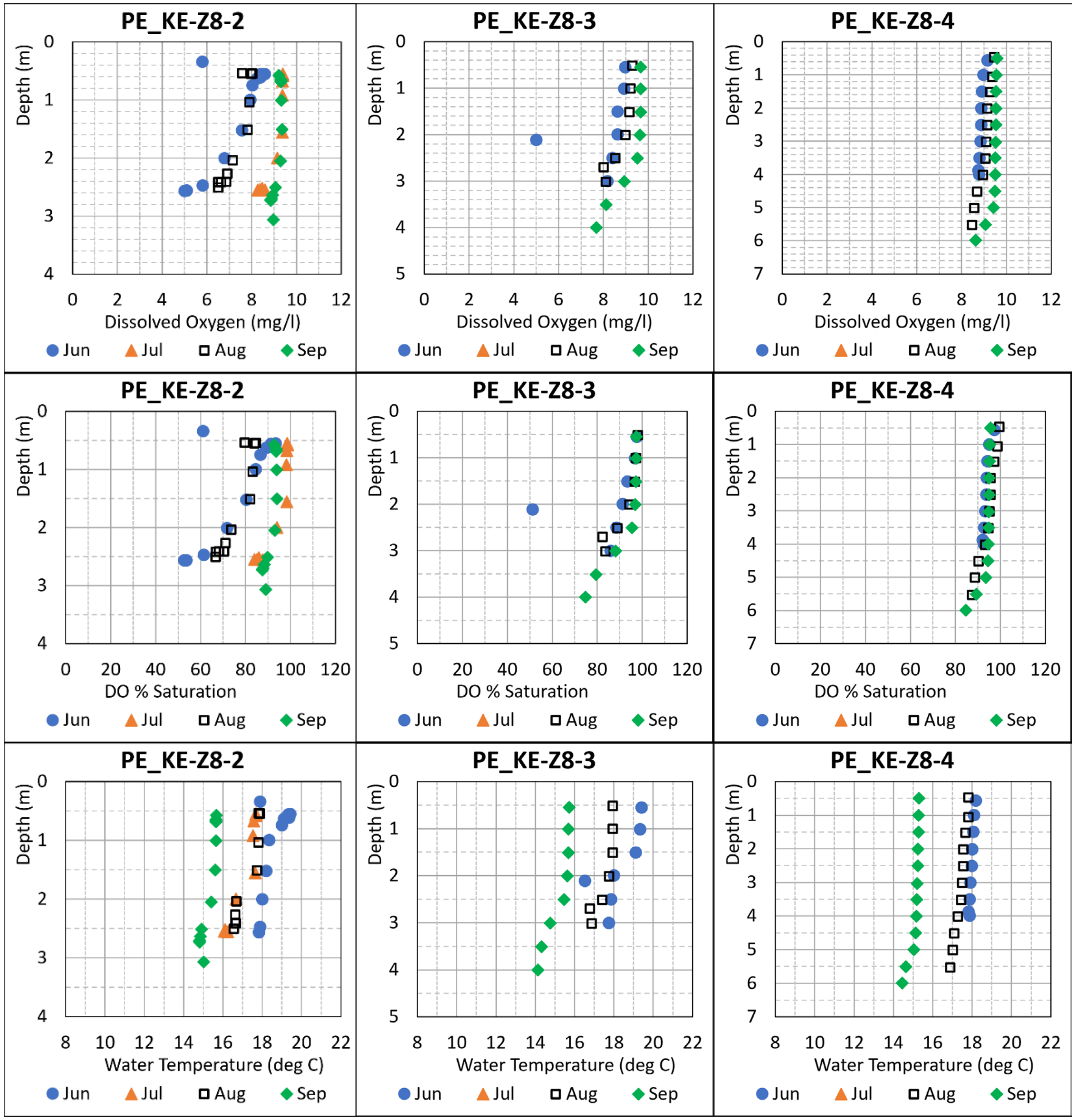


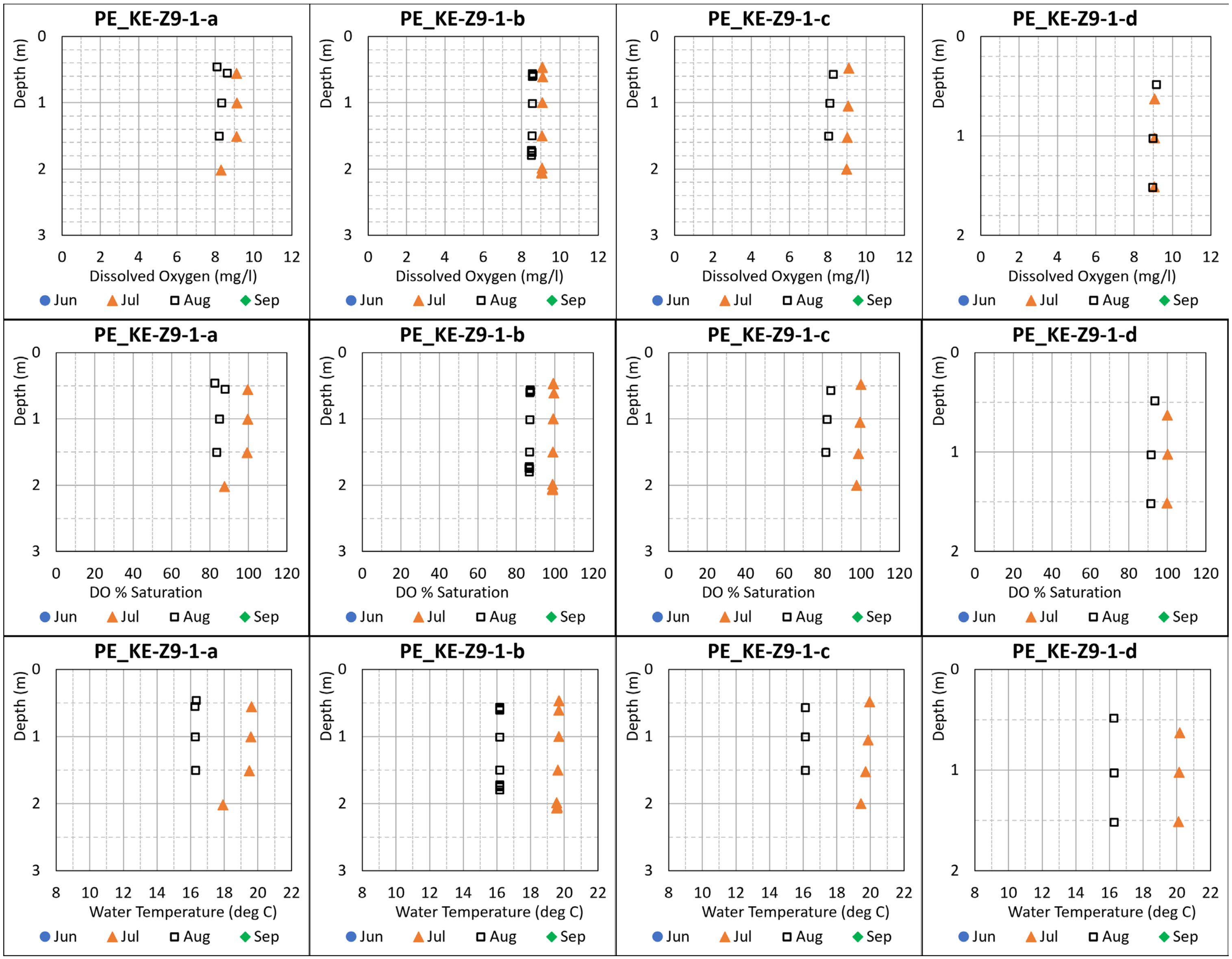
PE_KE-Z4-1-a
PE_KE-Z4-1-b
PE_KE-Z4-1-c
PE_KE-Z4-1-d
Depth (m)
Dissolved Oxygen (mg/l)
DO % Saturation
Water Temperature (deg C)
Jun
Jul
Aug
Sep

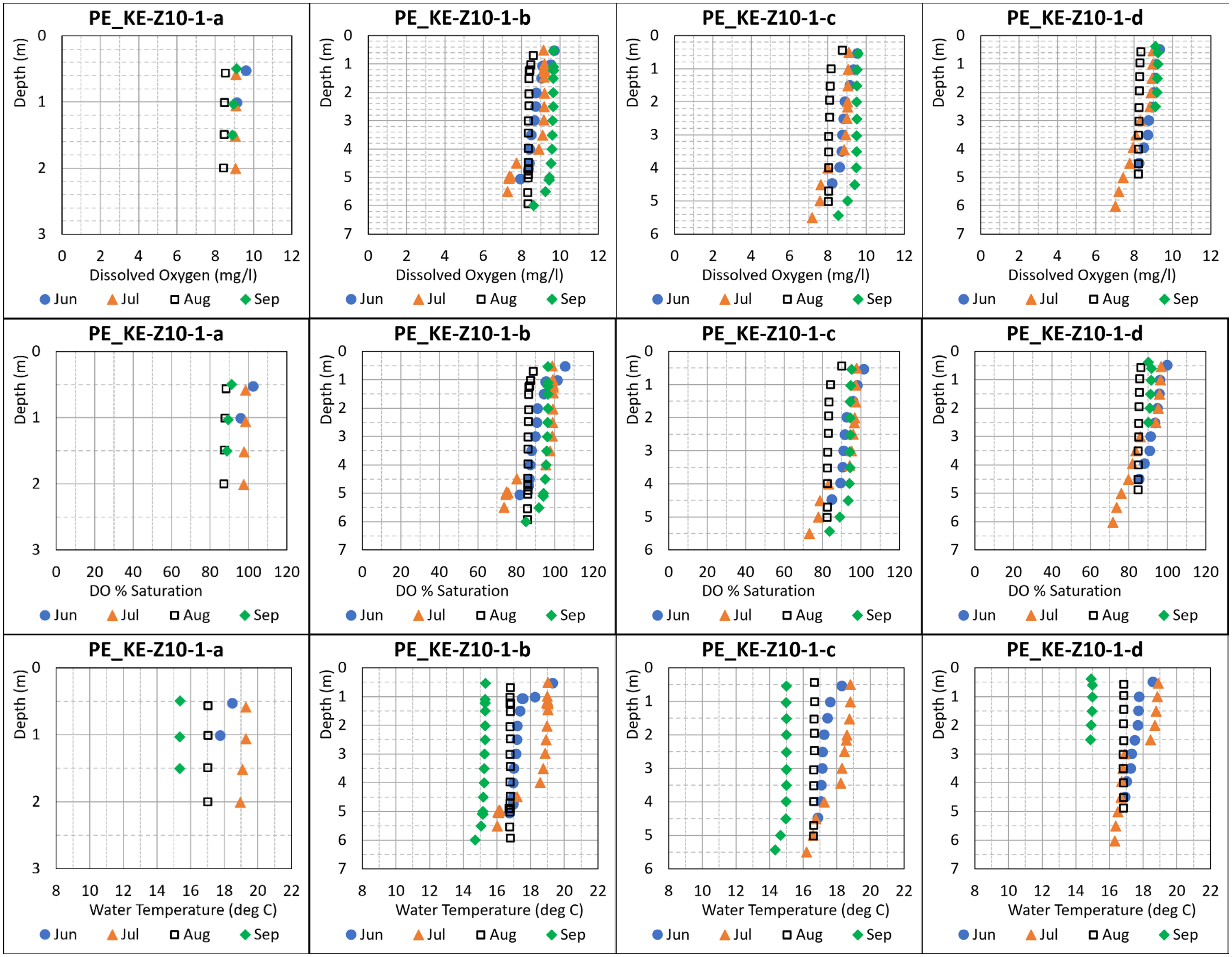

PE_KE-Z5-1-a
PE_KE-Z5-1-b
PE_KE-Z5-1-c
PE_KE-Z5-1-d
Depth (m)
0 1 2 3 4 5 6 7
0 2 4 6 8 10 12
Dissolved Oxygen (mg/l)
Jun Jul Aug Sep
PE_KE-Z5-1-a
PE_KE-Z5-1-b
PE_KE-Z5-1-c
PE_KE-Z5-1-d
Depth (m)
0 20 40 60 80 100 120
DO % Saturation
Jun Jul Aug Sep
PE_KE-Z5-1-a
PE_KE-Z5-1-b
PE_KE-Z5-1-c
PE_KE-Z5-1-d
Depth (m)
8 10 12 14 16 18 20 22
Water Temperature (deg C)
Jun Jul Aug Sep

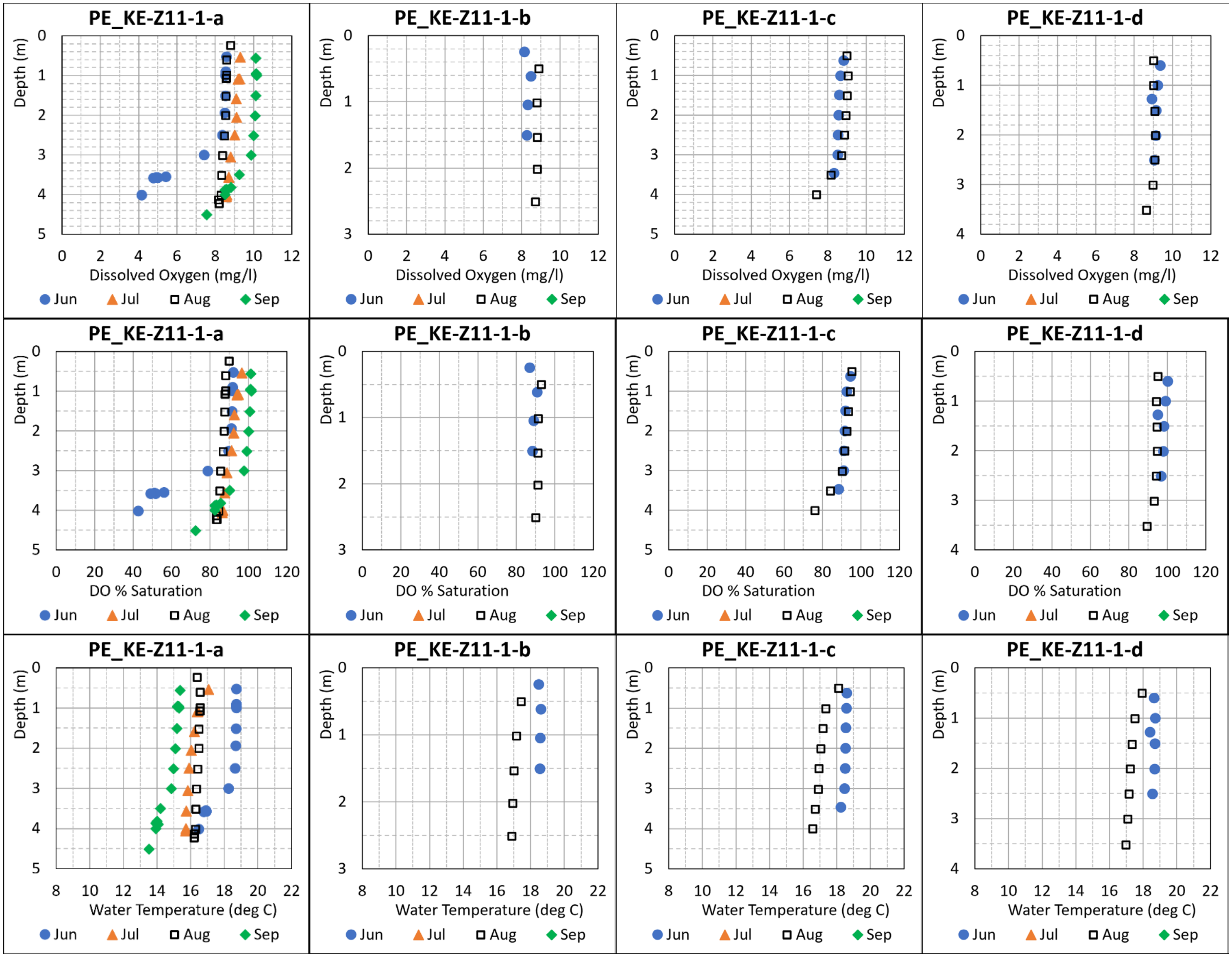

PE_KE-Z7-1-a
PE_KE-Z7-1-b
PE_KE-Z7-1-c
PE_KE-Z7-1-d
Depth (m)
Dissolved Oxygen (mg/l)
DO % Saturation
Water Temperature (deg C)
Jun
Jul
Aug
Sep

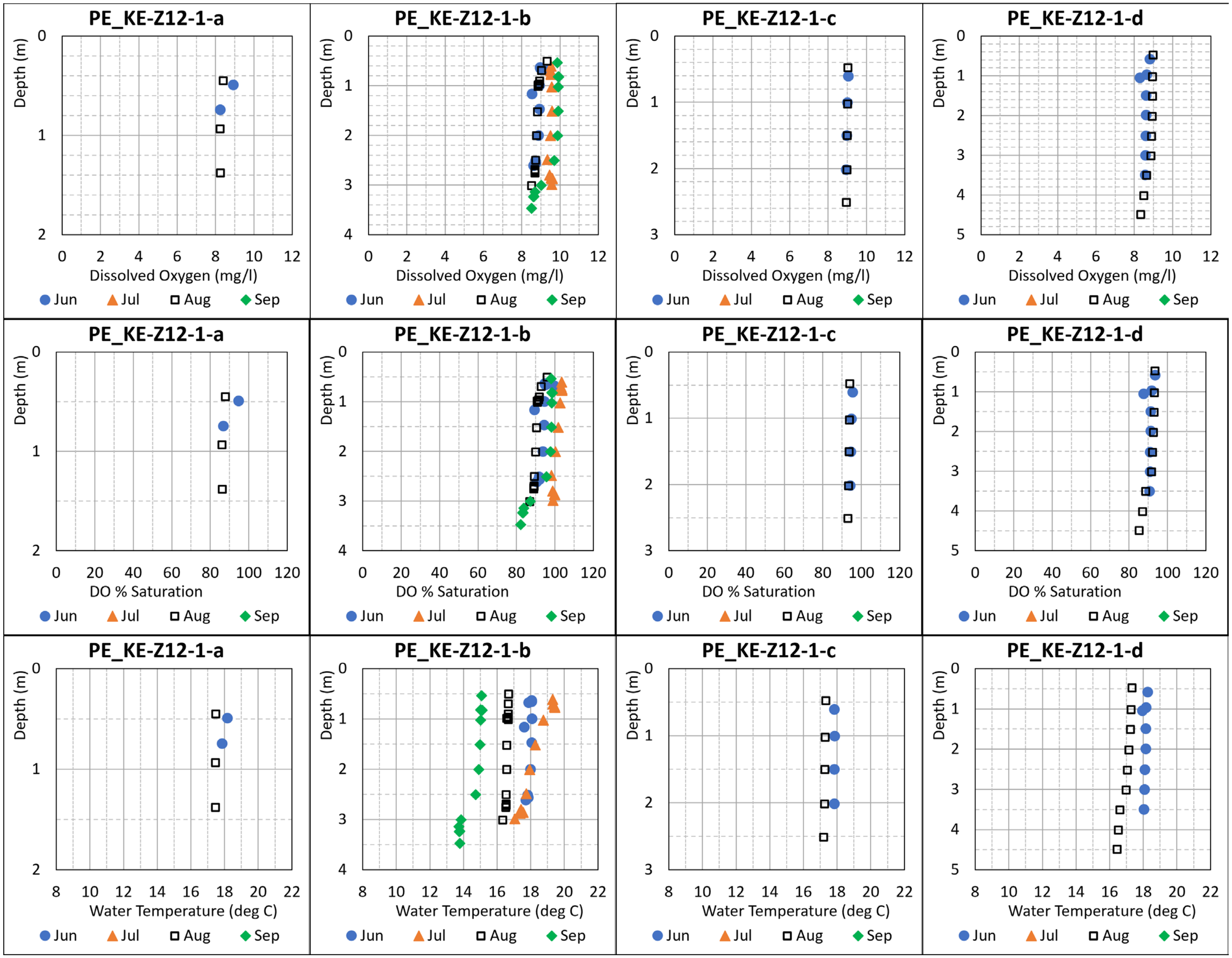

PE_KE-Z7-2-a
PE_KE-Z7-2-b
PE_KE-Z7-2-c
PE_KE-Z7-2-d
Depth (m)
Dissolved Oxygen (mg/l)
DO % Saturation
Water Temperature (deg C)
Jun
Jul
Aug
Sep

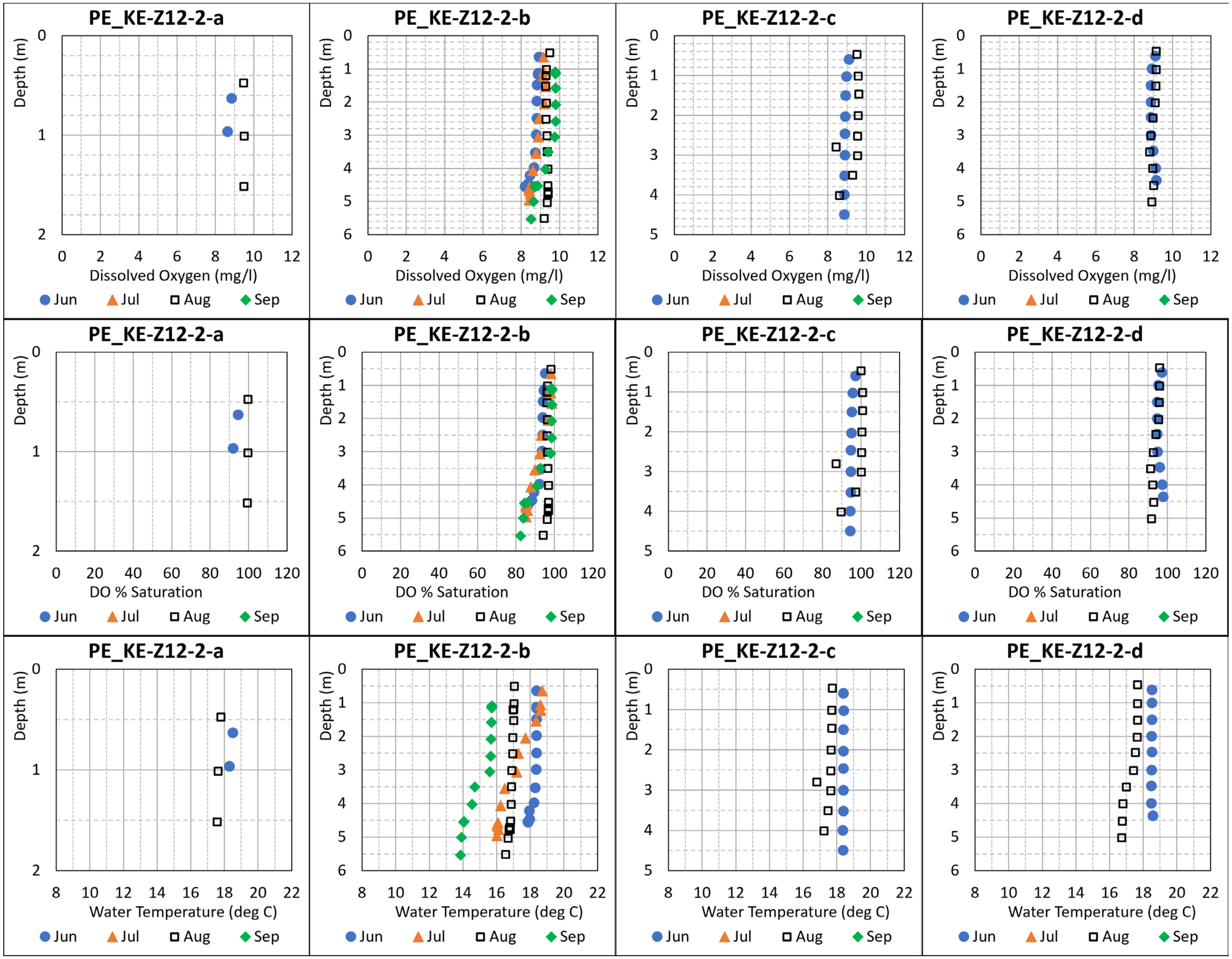

PE_KE-Z8-2
PE_KE-Z8-3
PE_KE-Z8-4
Depth (m)
Dissolved Oxygen (mg/l)
DO % Saturation
Water Temperature (deg C)
Jun
Jul
Aug
Sep

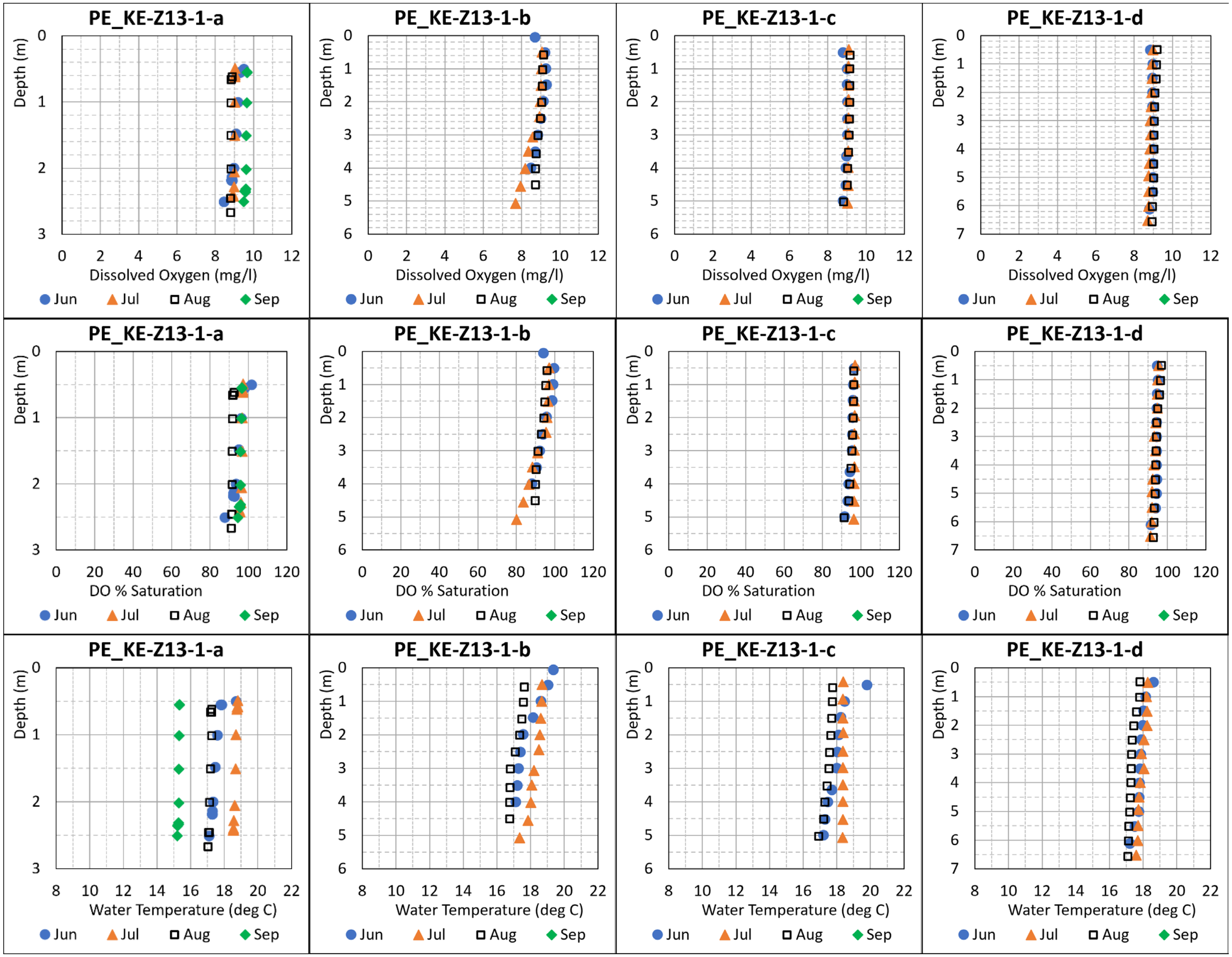

PE_KE-Z9-1-a
Depth (m)
Dissolved Oxygen (mg/l)
Jun Jul Aug Sep
PE_KE-Z9-1-b
Depth (m)
Dissolved Oxygen (mg/l)
Jun Jul Aug Sep
PE_KE-Z9-1-c
Depth (m)
Dissolved Oxygen (mg/l)
Jun Jul Aug Sep
PE_KE-Z9-1-d
Depth (m)
Dissolved Oxygen (mg/l)
Jun Jul Aug Sep
PE_KE-Z9-1-a
Depth (m)
DO % Saturation
Jun Jul Aug Sep
PE_KE-Z9-1-b
Depth (m)
DO % Saturation
Jun Jul Aug Sep
PE_KE-Z9-1-c
Depth (m)
DO % Saturation
Jun Jul Aug Sep
PE_KE-Z9-1-d
Depth (m)
DO % Saturation
Jun Jul Aug Sep
PE_KE-Z9-1-a
Depth (m)
Water Temperature (deg C)
Jun Jul Aug Sep
PE_KE-Z9-1-b
Depth (m)
Water Temperature (deg C)
Jun Jul Aug Sep
PE_KE-Z9-1-c
Depth (m)
Water Temperature (deg C)
Jun Jul Aug Sep
PE_KE-Z9-1-d
Depth (m)
Water Temperature (deg C)
Jun Jul Aug Sep

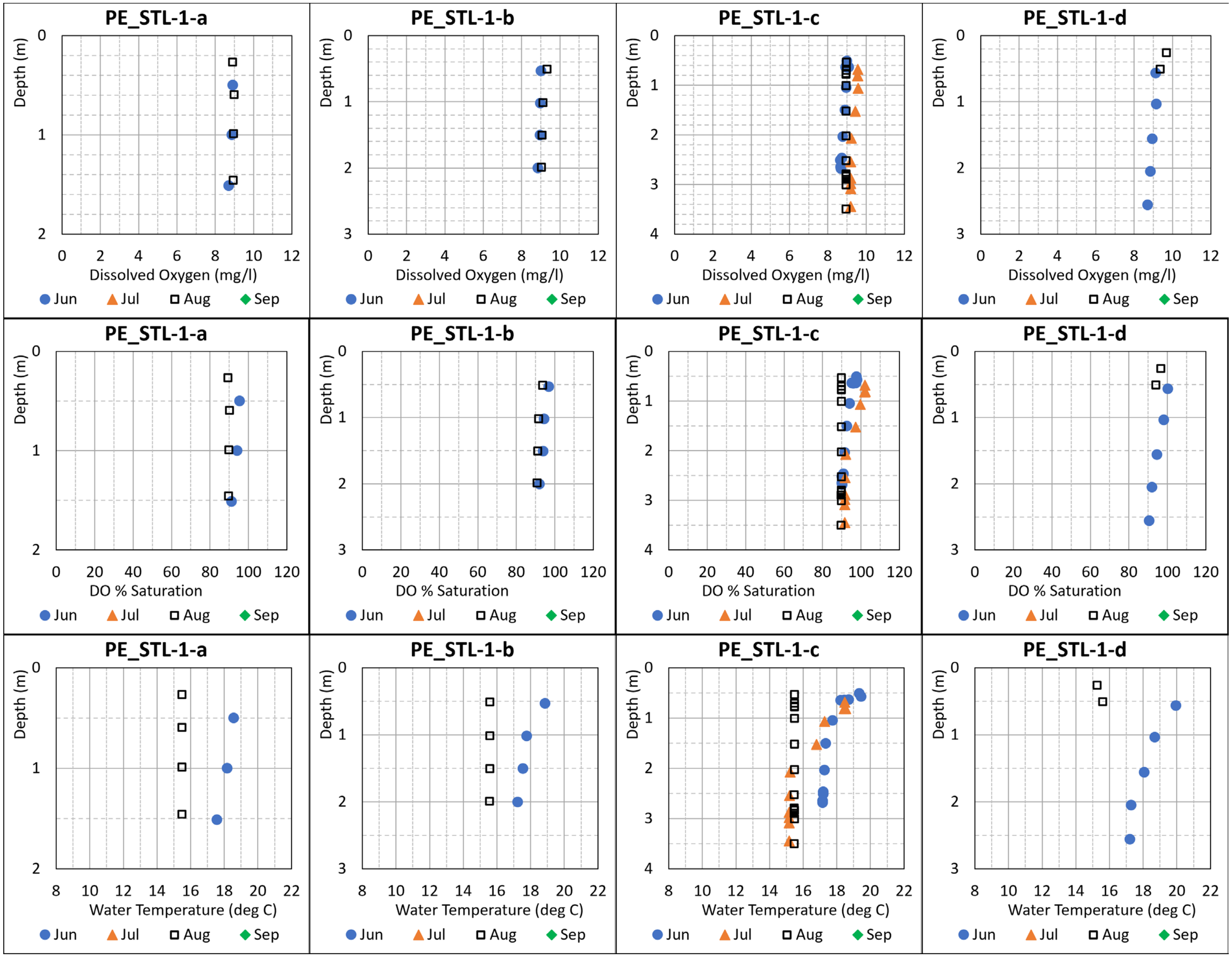

PE_KE-Z10-1-a
Depth (m)
Dissolved Oxygen (mg/l)
Jun Jul Aug Sep
PE_KE-Z10-1-b
Depth (m)
Dissolved Oxygen (mg/l)
Jun Jul Aug Sep
PE_KE-Z10-1-c
Depth (m)
Dissolved Oxygen (mg/l)
Jun Jul Aug Sep
PE_KE-Z10-1-d
Depth (m)
Dissolved Oxygen (mg/l)
Jun Jul Aug Sep
PE_KE-Z10-1-a
Depth (m)
DO % Saturation
Jun Jul Aug Sep
PE_KE-Z10-1-b
Depth (m)
DO % Saturation
Jun Jul Aug Sep
PE_KE-Z10-1-c
Depth (m)
DO % Saturation
Jun Jul Aug Sep
PE_KE-Z10-1-d
Depth (m)
DO % Saturation
Jun Jul Aug Sep
PE_KE-Z10-1-a
Depth (m)
Water Temperature (deg C)
Jun Jul Aug Sep
PE_KE-Z10-1-b
Depth (m)
Water Temperature (deg C)
Jun Jul Aug Sep
PE_KE-Z10-1-c
Depth (m)
Water Temperature (deg C)
Jun Jul Aug Sep
PE_KE-Z10-1-d
Depth (m)
Water Temperature (deg C)
Jun Jul Aug Sep


PE_KE-Z11-1-a
PE_KE-Z11-1-b
PE_KE-Z11-1-c
PE_KE-Z11-1-d
Depth (m)
Dissolved Oxygen (mg/l)
DO % Saturation
Water Temperature (deg C)
Jun
Jul
Aug
Sep


PE_KE-Z12-1-a
PE_KE-Z12-1-b
PE_KE-Z12-1-c
PE_KE-Z12-1-d
Depth (m)
Dissolved Oxygen (mg/l)
DO % Saturation
Water Temperature (deg C)
Jun
Jul
Aug
Sep


PE_KE-Z12-2-a
PE_KE-Z12-2-b
PE_KE-Z12-2-c
PE_KE-Z12-2-d
Depth (m)
Dissolved Oxygen (mg/l)
Jun
Jul
Aug
Sep
PE_KE-Z12-2-a
PE_KE-Z12-2-b
PE_KE-Z12-2-c
PE_KE-Z12-2-d
Depth (m)
DO % Saturation
Jun
Jul
Aug
Sep
PE_KE-Z12-2-a
PE_KE-Z12-2-b
PE_KE-Z12-2-c
PE_KE-Z12-2-d
Depth (m)
Water Temperature (deg C)
Jun
Jul
Aug
Sep


PE_KE-Z13-1-a
PE_KE-Z13-1-b
PE_KE-Z13-1-c
PE_KE-Z13-1-d
Depth (m)
Dissolved Oxygen (mg/l)
DO % Saturation
Water Temperature (deg C)
Jun
Jul
Aug
Sep


PE_STL-1-a
PE_STL-1-b
PE_STL-1-c
PE_STL-1-d
Depth (m)
Dissolved Oxygen (mg/l)
DO % Saturation
Water Temperature (deg C)
Jun
Jul
Aug
Sep