Duncan Dam Project Water Use Plan DDMWORKS-3

Reference: DDMWORKS-3

Results of 2022 Sampling Program to Reduce Uncertainty of Phosphorus Retention in Duncan Lake Reservoir

Study Period: 2022

Ecoscape Environmental Consultants Ltd.

August 2023

Naturally, A Higher Standard

Technical Memorandum

Date: August 28, 2023
To: Teri Neighbour, Water License Requirements, Environment
BC Hydro & Power Authority
From: Jordan Akers, Heather Larratt, Mary Ann Olson-Russello
File: 20-3403 |Version 3
Subject: **Results of 2022 Sampling Program to Reduce Uncertainty of Phosphorus Retention in Duncan Lake Reservoir**

1.0 INTRODUCTION

The 2021 monthly sampling program (Apr-Oct) of the Duncan Lake Reservoir (DLR) found total phosphorus (TP) within the range found in 1994-5, although total dissolved phosphorus (TDP) was significantly lower for all samples collected (Akers et al., 2022). The purpose of the additional 2022 sampling program was to further investigate if the dominant cause for the apparent decline in TDP was genuine changes in the DLR system over the last 26 years, or whether low TDP found in the 2021 sampling program occurred because it failed to capture nutrient peaks that were observed in the original, more intensive 1994-5 study.

A recommended sampling program to reduce uncertainty regarding the 2021 phosphorus retention was summarized in a technical memo (Larratt & Olson-Russello, 2022). The 2022 sampling program aimed to clarify the phosphorus retention properties of the DLR by:

- Increased sampling frequency during the freshet (defined as the annual high flow period resulting from spring melt in a nival regime dominated watershed from April to June); sampling during the rising limb of freshet (the period of increased flow before peak flow occurs), capturing peak freshet and a sample of the falling limb of freshet (post peak flow) to replicate how freshet was captured in the 1994-5 study. Freshet on the Duncan River usually contributes about 45% of the total annual flow (45.7% ± 5.3% based on data since 1964), and introduces the most phosphorus by mass, due to higher nutrient concentrations combined with high flows (70.7% and 63.5% of annual TP and TDP respectively in the 1994-5 nutrient budget).
- Sampling both the upper Duncan River in the drawdown zone and the upper Duncan River upstream of the reservoir to determine if there are differences between the two. Drawdown zones are well-known nutrient release zones (Kaufmann et al. 2014) and within the 1994-5 study, there was increased TP and TDP inflow concentrations observed

within the drawdown zone. Determining if the drawdown zone is continuing to act as a nutrient source within the DLR further contextualizes the 2021 results.

The 2022 sampling program achieved these aims by collecting four samples, June 5th/6th, 17th, 29th & July 27th, which covered the rising limb, the peak and the falling limb of freshet. We recognize that the entirety of the rising limb was not captured within this program with elevated flows beginning in early May. Freshet timing varied among the sample years (1994/95, 2021 and 2022), with peak flow occurring as early as the first week of June or as late as the end of June. This variability complicates the planning of effective sampling programs with small sample frequency.

The 2022 sampling program could not include all recommendations proposed in the technical memo due to budgetary constraints. Recommendations that were not implemented in 2022 include increased overall sampling and frequency (weekly or biweekly), measuring nitrogen as it impacts reservoir productivity (Jin et al., 2016), and reservoir *in-situ* measurements combined with chlorophyll-a and phytoplankton samples to inform productivity estimates and nutrient consumption.

The purpose of this memo is to summarize the results of the 2022 sampling program and explain how observed TP and TDP concentrations relate to the 2021 findings. These results will be used to further inform a future sampling program to conclude the re-evaluation of DDMWORKS-3 and the role of Duncan Dam operations in TDP retention within the DLR.

2.0 METHODS

The 2022 sampling program followed the same water sample collection and transportation methodology undertaken in 2021 (Akers et al., 2022). Five sites were sampled: the Upper Duncan River, a roving site within the upper Duncan River channel at the reservoir's edge, Glacier Creek, Howser Creek and the Duncan Dam outlet gates (Table 2-1). In contrast to the 2021 sampling, the Upper Duncan River site and the roving site were both sampled during each of the four sampling events. In 2021, only the roving site was sampled when the reservoir was drawn down, and the Upper Duncan River site was sampled when the reservoir was at full pool. Sampling both Upper Duncan River sites mirrors what was done in 1994-5, and better informs the nutrient contributions of the drawdown zone. The 2021 sampling program only included the Upper Duncan River at the reservoir edge when the reservoir was drawn down, because the study was focused on understanding total nutrient inflow.

Four sampling trips were made in 2022, June 5th/6th, June 17th, June 19th, & July 27th. The low level TDP data from July 27th was not reported by ALS Laboratories, due to equipment failure. As a result, only three TDP sample dates are reported.

During each sampling event, one water sample was collected in either a triple rinsed gallon container (Glacier and Howser creeks, Duncan River Roving) or with a clean Van Dorn sampler (upper Duncan River and Duncan Dam Outlet). Within minutes of collection, the sample vessel was agitated, and water was immediately distributed into prelabeled amber glass containers and stored on ice in a cooler or in a refrigerator until they were shipped to ALS Laboratories in Burnaby, BC. Water for TDP was field filtered using a syringe and 0.45-micron filter. In addition, one duplicate, one field blank and one travel blank were analyzed for TP and TDP. A duplicate sample was randomly assigned to one of the four sites and was obtained from the same collection container as the site sample. Duplicate samples were used solely to provide quality control on nutrient analysis and values were not incorporated within subsequent analyses. Nitrile gloves were worn throughout the sample processing.

ALS Laboratories is a CALA[1] accredited lab; samples were analyzed for TP (detection limit of 2.0 µg/L in Vancouver) and TDP (detection limit of 1.0 µg/L in Edmonton), using the ultra-trace by colourimetry method APHA 4500-P E (mod), which involves persulphate digestion. All samples were shipped to ALS Laboratories in Burnaby and ALS Laboratories was responsible for the transport of samples to other processing facilities. The hold time for TP and TDP is 28 days. All TP samples were analyzed within the hold time, however, all TDP samples exceeded the hold time by 6-8 days, despite expeditious shipping of samples. For example, the samples collected on June 5/6 were received by ALS on June 9, analysis for TP occurred on June 24th, and unfortunately TDP analysis was not completed until July 11th.

Table 2-1. Import and export sampling stations in 2022.

Site Type	Station Name	Description	Latitude / Longitude	Data Obtained	Dates Sampled
Import	Station 08NH119 (upper Duncan River)	Sampled where the upper Duncan River passes under the bridge	50° 38' 19.86"N 117° 02' 58.65"W	TP, TDP and In-situ data	June 5 June 17 June 29 July 27*
Import	Upper Duncan River Roving site	Roving site near the wetted margin, but within the inflow river channel.	Site location changed depending on water levels.	TP, TDP and In-situ data	June 6 June 17 June 29 July 27*
Import	Glacier Creek	Sampled approximately 30 m upstream of the Glacier bridge crossing via a small footpath to the right bank of the creek.	50° 17' 05.18"N 116° 55'10.36"W	TP, TDP and In-situ data	June 5 June 17 June 29 July 27*
Import	Howser Creek	Sampled approximately 50 m upstream of the Howser bridge crossing via a small footpath to the left bank of the creek.	50° 27' 49.39"N 116° 54' 58.28"W	TP, TDP and In-situ data	June 5 June 17 June 29 July 27*
Export	Station 08NH126	Duncan Dam Spillway	50° 15' 05'' N 116° 56' 51'' W	TP, TDP and In-situ data	June 6 June 17 June 29 July 27*

*Due to equipment failure at ALS Laboratories, July 27 TDP data was not reported.

[1] Canadian Association for Laboratory Accreditation Inc.

3.0 RESULTS AND DISCUSSION

3.1. Duncan Lake Reservoir Hydrology

The Upper Duncan River has recorded hydrologic data starting in 1964. The mean annual discharge (MAD) across all recorded years is 62.51 ± 6.52 m^3/sec with a maximum MAD of 77.14 m^3/sec observed in 1976 and a minimum MAD of 46.69 m^3/sec observed in 2001. The MAD in 1995, 2021, and 2022 were 65.30 m^3/sec, 70.08 m^3/sec and 69.78 m^3/sec, respectively. Typically, seasonal flows increase in late March or early April, and peak flows occur in the month of June (Figure 3-1). Of the three spring sample years, 1995 and 2021 experienced peak flows at the beginning of June, whereas 2022 experienced peak flows in the 3rd week of June (Figure 3-2).

The upper Duncan River experienced unprecedented heat and flows in June 2021, but a more gradual freshet rise with peak flows above the 90th percentile of historic flows in 2022 (Figure 3-2). Despite having fewer extremes than 2021, the 2022 peak daily flow was higher than 1994 & 1995. Recent climate and hydrologic research suggest that high flows may become more frequent and intense. In coming years, the Duncan River is expected to experience increasingly higher winter flows, earlier snowmelt, higher peak flows, earlier peak flows, and lower summer/fall flows (BC Agriculture & Food Climate Action Initiative 2019).

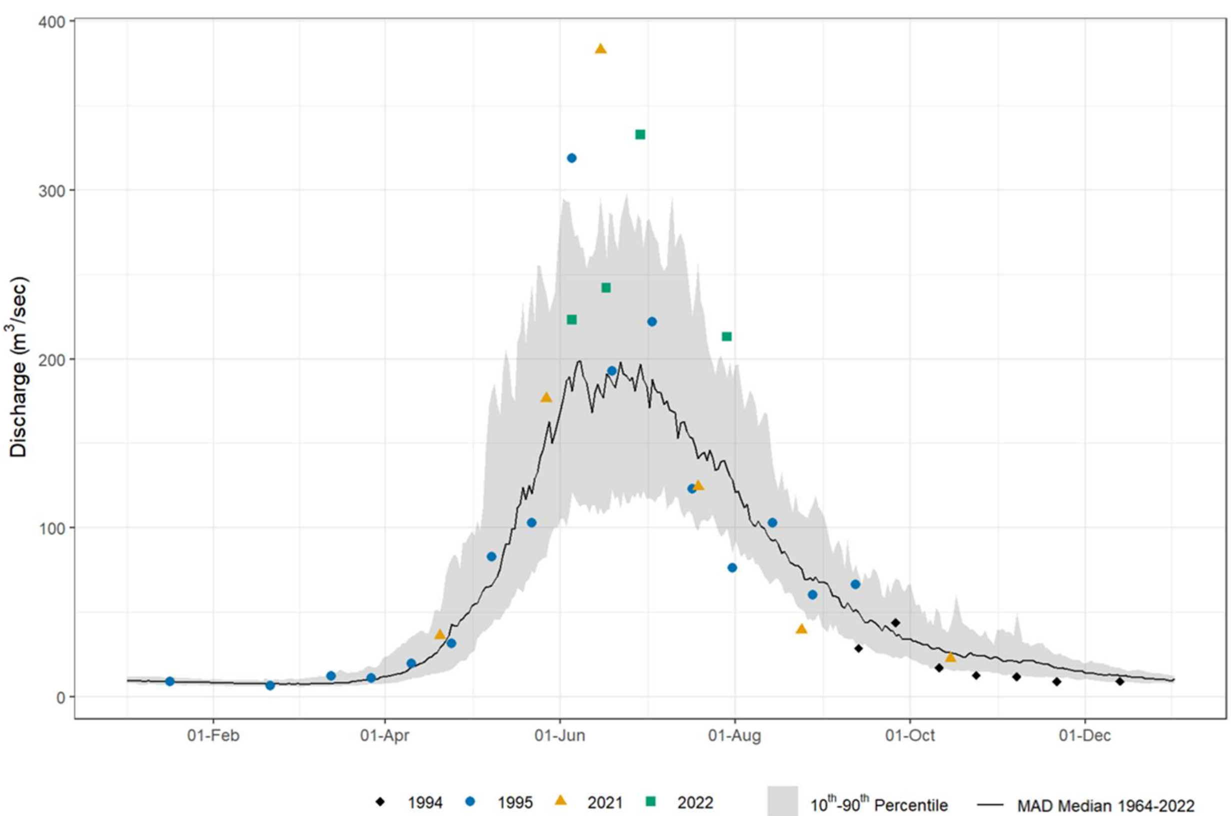

Figure 3-1. Hydrograph of the upper Duncan River, 1964-2022. Sample years 1994, 1995, 2021 & 2022 are shown with the river discharge observed on the sample day.

The first 2022 sample on June 5th occurred during the rising limb of freshet and captured the highest daily flow thus far in the season (Figure 3-2). This capture was important because increasing flows result in greater erosion and sediment transport that is associated with greater TP concentrations. The second sample, June 17th, occurred during a period of relatively consistent daily freshet flows. This sample should provide a reference for nutrient concentration values for sustained high flow events (<400% MAD for 2022). Particularly, the variability of flows around this sample may promote pulses of greater groundwater inflows that can convey TDP (Hanrahan et al. 2005; Stumm and Morgan, 1996; Slomp and Van Cappellen, 2004; Arp and Baker, 2007). Alternately, variable nutrient contribution from organic decomposition in the Duncan watershed may lead to transient spikes in TP during spring melt or reservoir turnover (Islam et al., 2013; Reddy et al., 1999). The third sample on June 29th occurred during the second highest daily flows observed in 2022. It was important to capture this event, since increasing flows are linked with high nutrient inputs that together represent a significant proportion of annual nutrient inflows.

While the 2021 sampling captured the rising limb of freshet, the sampling dates tended to follow isolated freshet peaks. We believe the 2022 samples provide a valuable insight into more typical flow events. Unfortunately, with the lack of laboratory results from the July 27th samples, we do not have TDP representation from the falling limb of the 2022 freshet.

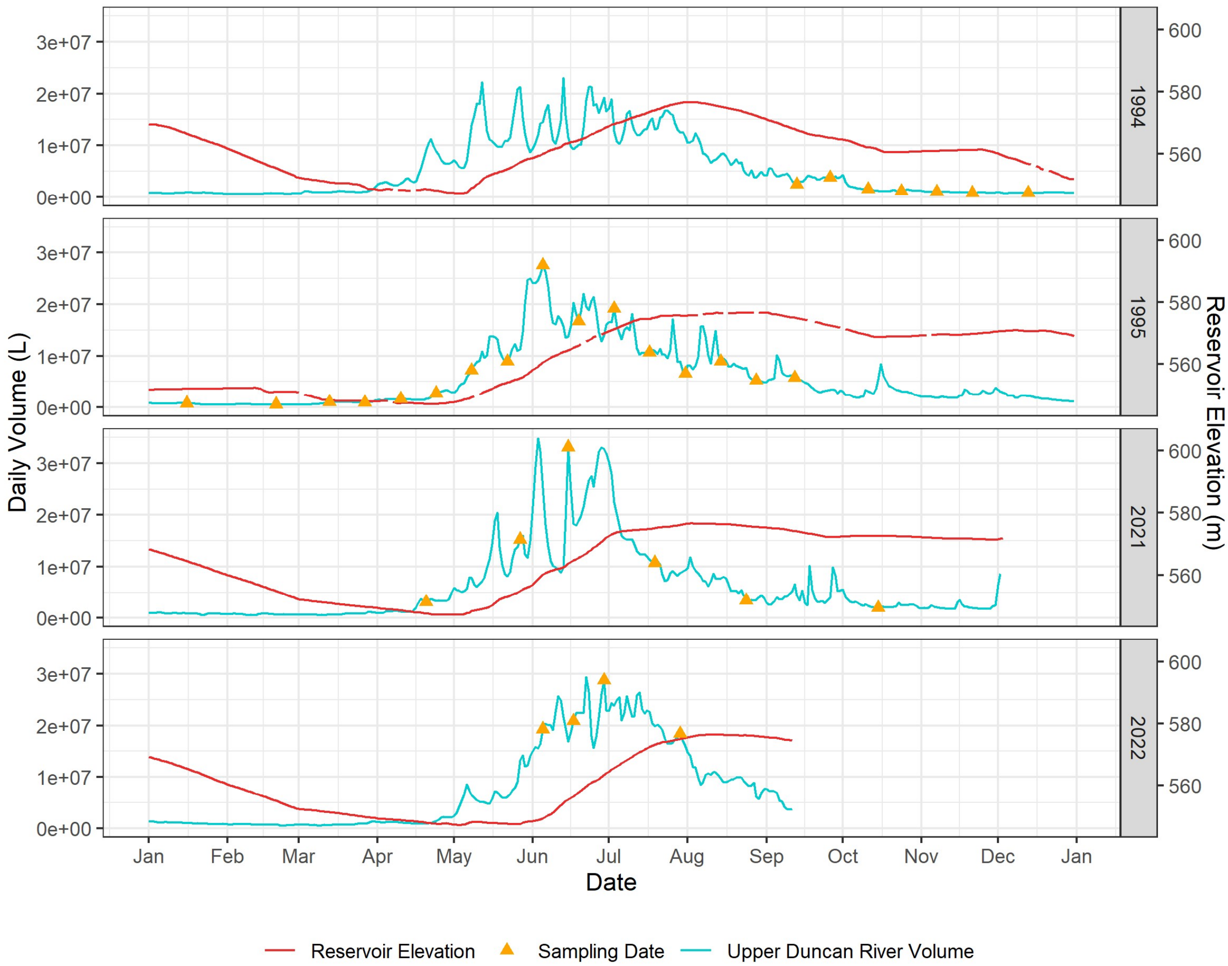

Figure 3-2. Reservoir elevation and inflow water volume from the upper Duncan River in sample years 1994, 1995, 2021 and 2022. Sample dates are indicated by orange triangles.

Glacier and Howser creeks do not have hydrometric information available, yet they contribute 11% and 17% of the catchment area, respectively, to the DLR (Perrin & Korman, 1997). Field observations indicate that the 2022 sampling captured both catchments in high flow periods, with higher flows on June 29th compared to June 5th, indicating that these smaller catchments behave similarly during freshet to the larger upper Duncan River (Table A-1).

3.2. *In-situ* Measurements

In-situ measurements in 2022 and 2021 demonstrated lower pH at the dam outflow site compared to 1995 (Figure 3-3, Table A-2). Average pH at the dam outflow site in June and July for 1995, 2021 and 2022 were 8.43 ± 0.30, 7.55 ± 0.21 and 7.40 ± 0.18, respectively. As presented in the 2021 report (Akers et al., 2022), the observed change of pH at the dam outflow site suggests a genuine change may have occurred within the DLR[2]. If the change in pH is genuine, the solubility and biological availability of phosphorus, nitrogen and carbon can be affected.

Turbidity in 2022 aligns with measurements in other sampling years (Figure 3-4). Above average turbidity was observed at Glacier and Howser creeks and the roving site on June 5th, which further supports our goal of capturing the rising limb of freshet that is characterized by increased sediment transport during increasing flows (Table A-2). Lastly, higher turbidity (8.2 NTU) was observed at the Dam outflow on June 5th than was observed during 2021. However, 2022 freshet turbidity was still lower than the 15-20 NTU observed during 1995. These fluctuating turbidity measurements indicate more study is needed on sediment transport within the reservoir during freshet (Gu et al., 2008). For example, creek and river plumes can transport sediments along dynamic paths and depths within a reservoir, resulting in variable turbidity and nutrient concentrations at the discharge point (Xu et al.,2018).

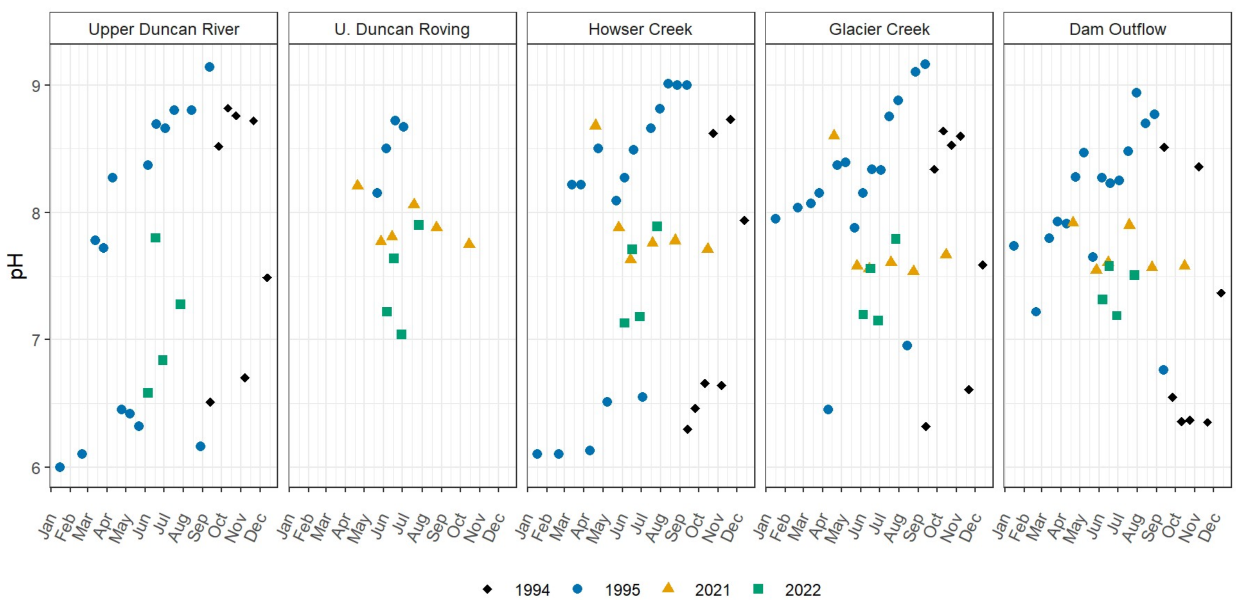

Figure 3-3. pH measured at each sample location for 1994, 1995, 2021, & 2022.

[2] However, several of the dam outflow samples collected between Oct and Dec 1994 exhibited lower pH compared to the other three sampling years, albeit no other late fall/winter data exists for comparison.

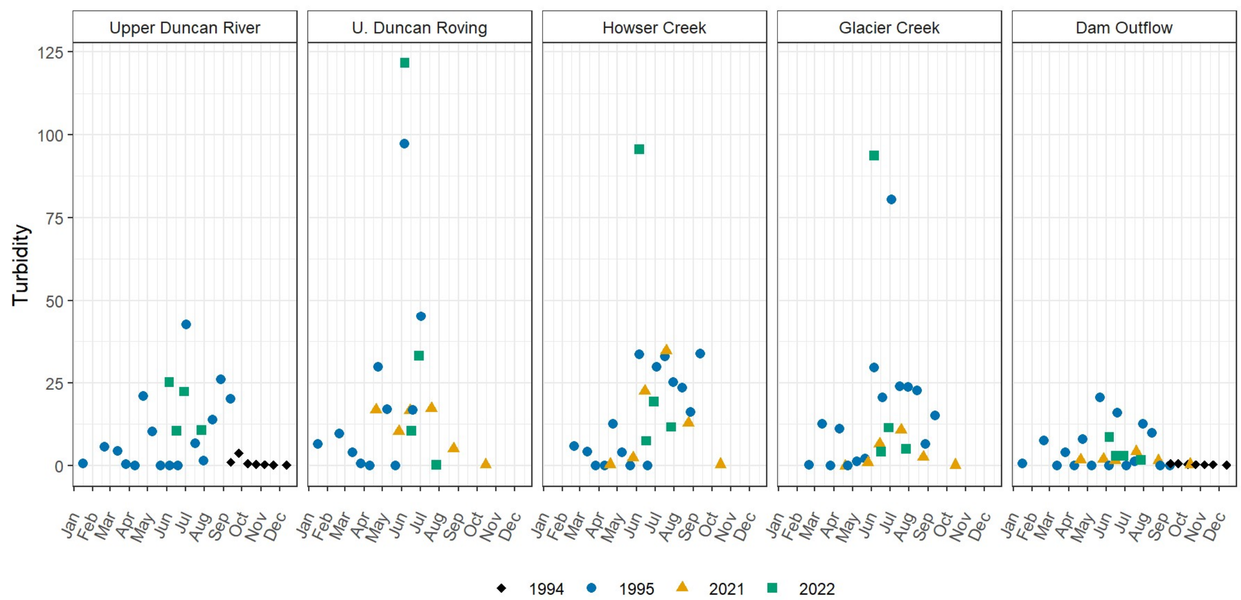

Figure 3-4. Turbidity (NTU) measured at each sample location for 1994, 1995, 2021, & 2022.

3.3. Phosphorus Concentrations

Watershed contributions of TP in freshet 2022 samples were within the upper range of concentrations observed in 1994-5 (Figure 3-5, Figure 3-6, Table A-3) which was the expected outcome of sampling during freshet. Comparing June/July freshet samples between 2021-22 & 1995 showed no significant difference ($t(38) = -0.68$, $p = 0.499$, 21/22 = 36.6 ± 27.7 µg/L, 1995 = 58.9 ± 83.4 µg/L) in the range of TP concentrations when all sites are considered together. The normality assumption was violated with this test and any statistical comparison at a smaller scale, such as the site level, was not reliable due to limited sample size.

The 2021 dam outflow samples had the most TP dissimilarity compared to previous sampling, with June and July samples of 4.1 and 2.5 µg/L, respectively, compared to the 1994-5 average of 5.68 µg/L over the June and July period. In contrast, outflow samples in June 2022 had an average of 7.6 ± 4.29 µg/L. This finding is important because it provides further indication that the 2021 sample dates may have occurred within a period of low TP concentration, which led us to hypothesize that reservoir TP mechanics may have decreased since 1995, when in fact the 2022 sampling supports the need for additional and more frequent study of not only the dam outflow, but also TP concentrations within the reservoir. As previously mentioned, these observations cannot be statistically supported due to limited sample size.

All inflow sites (Upper Duncan River, Howser & Glacier) had TP concentrations that were comparable to other samples taken during freshet in 1995 and 2021. These findings confirm the importance of freshet in contributing large amounts of TP to the DLR system. Overall, the annual and biweekly variability within the 2022 TP samples supports the need for further, frequent sampling within the DLR to better understand potential change drivers.

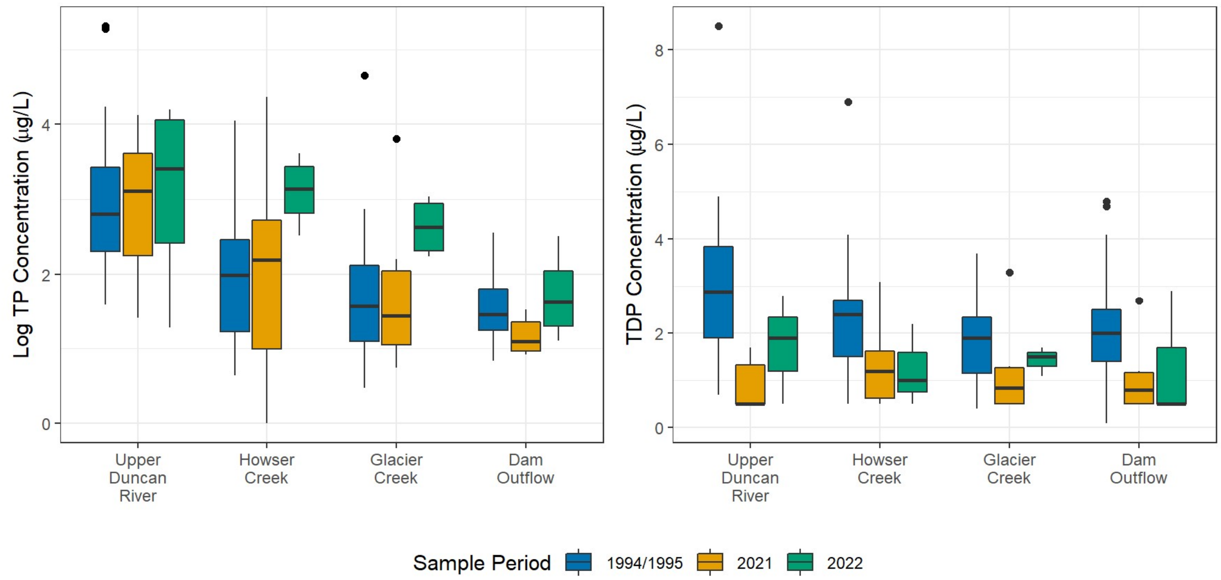

Figure 3-5. (Left) Log of total phosphorus concentration (µg/L) at inflow and outflow sites. (Right) Total dissolved phosphorus concentration (µg/L) at inflow and outflow sites. Each box represents the total number of samples during that period: 21 samples from each site in 1994-95, with bi-monthly sampling from March-November and monthly sampling from December-February; 6 samples at each site in 2021 in April-August and October; 3 samples at each site in June 2022 and 1 TP sample in July 2022. Any 2021 or 2022 TDP data below the 1 µg/L detection limit is displayed as the detection limit.

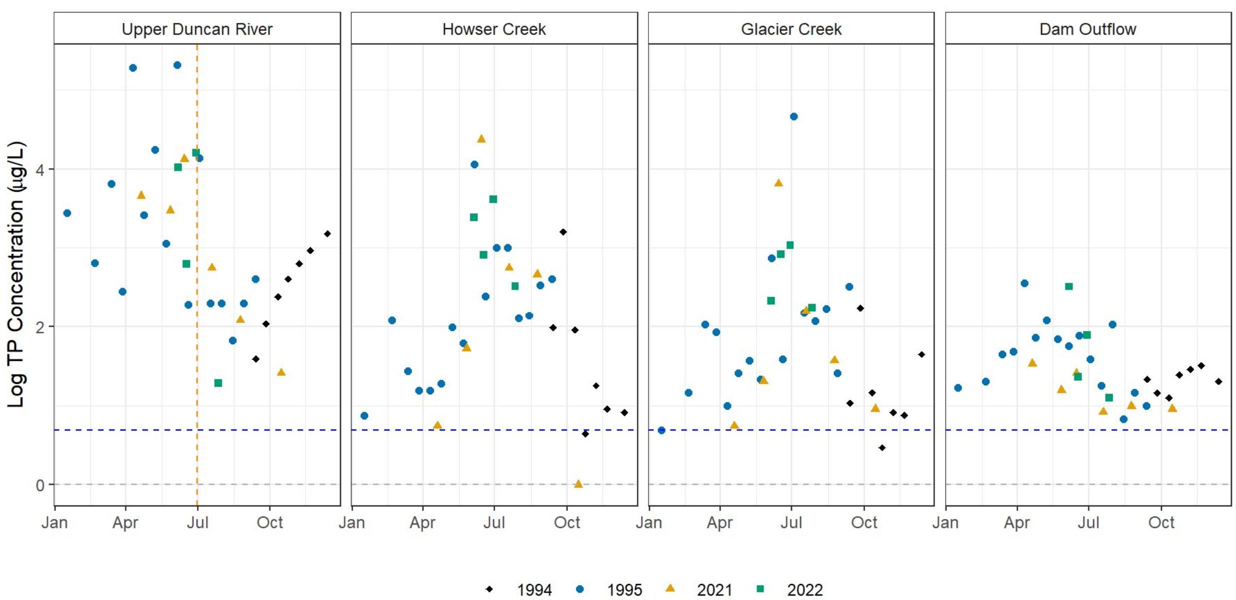

Figure 3-6. Log of total phosphorus concentration (µg/L) at inflow and outflow sites. The 1994-95 sampling effort collected 21 samples at each site. The 2021 sampling effort collected 6 samples in April-August and October. Three samples were collected at each site in June 2022 and 1 TP sample was collected in July 2022. The horizontal blue dashed line identifies the 2021/2022 detection limit for TP concentrations, and the vertical dashed orange line denotes the date where sampling transitioned from the Upper Duncan River in the drawdown zone to the upstream site during the 2021 program.

DLR June and July TDP values for 2021-22 were significantly different (*t(38) = 2.23, p = 0.032,* 21/22 = 1.9 ± 0.57 µg/L, 1995 = 3.33 ± 2.76 µg/L) than those observed in 1994-5 (Figure 3-5, Figure 3-7 & Table A-3). Four of fifteen (26.6%) TDP samples were below the ultra-low detection limit of 1.0 µg/L for June 2022, compared to 66.6% below detection limit in 2021. This detection limit is the lowest commercially available. During the 1994-5 study, Perrin & Korman reported values below 1.0 µg/L. Their lab work was conducted at a Department of Fisheries Limnology lab and as a research facility, they were able to report samples with very low limits despite increased uncertainty with reporting them (i.e., reporting 0.8 µg/L when the actual could be between 0.5-1.0 µg/L) (Pers. Comm. Chris Perrin, Oct. 31, 2022). Commercial laboratories, like those used in the 2021 & 2022, will not report a limit that they cannot provide legal confidence in. To deal with these laboratory differences, all 1994-5 samples were truncated to the 1.0 µg/L detection limit and then halved to make them comparable with the 2021 & 2022 results.

TDP samples in 2021 and 2022 were consistently lower than the 1994-5 samples across all sites. More sampling is needed to further understand the drivers of this apparent nutrient decline. TDP originates more from groundwater than erosional and sedimentary impacts like TP (Hanrahan et al., 2005; Neidhardt et al., 2018). Predicting periods of higher TDP transport in groundwater is harder than predicting TP transport in elevated surface flows. As climate change affects flow regimes, nutrient inputs will follow (Dahm et al., 2003). Continuing to build a long-term data set is the only way to comprehensively understand changes in TDP over time.

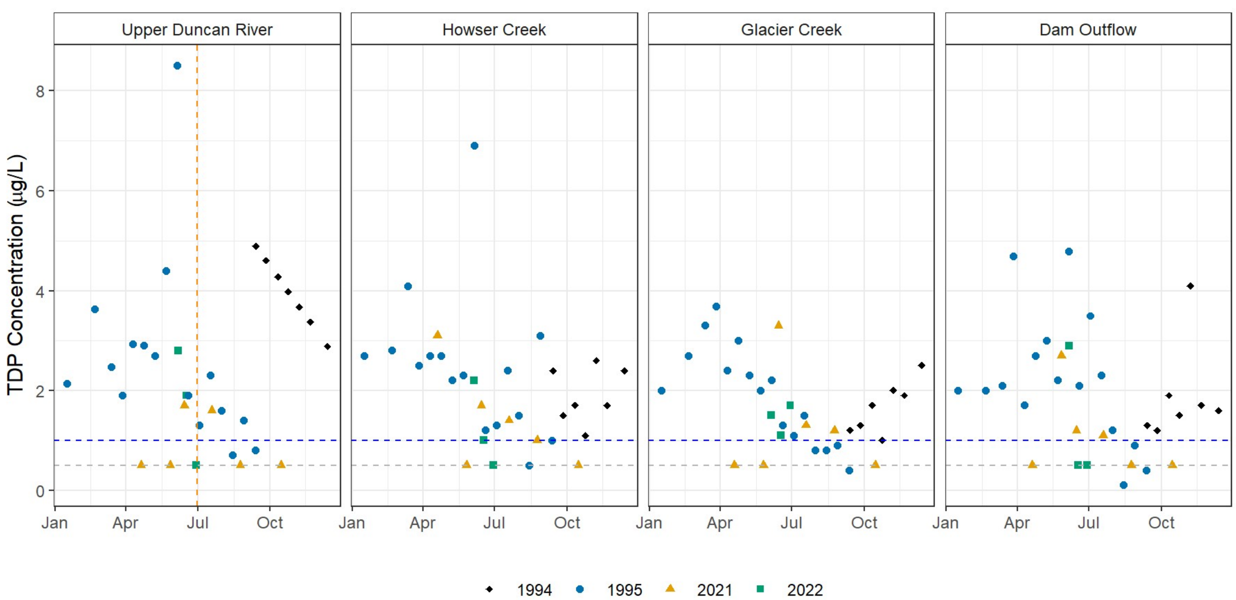

Figure 3-7. Total dissolved phosphorus concentration (µg/L) at inflow and outflow sites. Twenty-one samples at each site were taken in 1994-95. Six samples were taken in 2021, April-August & October. Three samples were taken at each site in June 2022. The horizontal blue dashed line identifies the 2021/2022 detection limit for TDP, and the vertical dashed orange line denotes the date where sampling transitioned from the roving site in the drawdown zone to the upper Duncan River site during the 2021 program.

3.4. Drawdown Zone Contribution

Perrin & Korman (1997) concluded that the drawdown zone contributed 74.4% of TP and 15.9% of annual TDP loads entering the reservoir from the upper Duncan River. A similar P contribution from the drawdown zone was not observed in 2022 (Figure 3-8). Specifically, when we compare total June TP and TDP load, following similar methods to Perrin & Korman (1997), the drawdown zone contributed 77.8% TP and 28.3% TDP in 1995, while the drawdown concentrations for 2022 (Table A-3) were less than those observed in the upper Duncan River resulting in -38.4% TP and -13.9% TDP contributions using the same methods. TP and TDP concentrations were not higher at the roving site within the drawdown during June 2022 as was previously observed and theorized. These findings indicate that the influence of the drawdown zone on phosphorus loading may be decreasing over time due to prolonged erosion and repeated seasonal wet/dry cycles.

Increased turbidity through the drawdown zone indicates particulate resuspension (Perrin & Korman, 1997), but despite very high turbidity (121 NTU) observed at the roving site on June 6, 2022, the corresponding increase in phosphorus was only 24% TP and 5% TDP respectively, a dramatic decrease from increases observed during similarly turbid periods in 1995 (432% TP & 52% TDP) (Figure 3-8). This apparent decline in TP and TDP during high turbidity events aligns with the theory that changes in the phosphorus contribution from the drawdown zone occurred between 1995 and 2022.

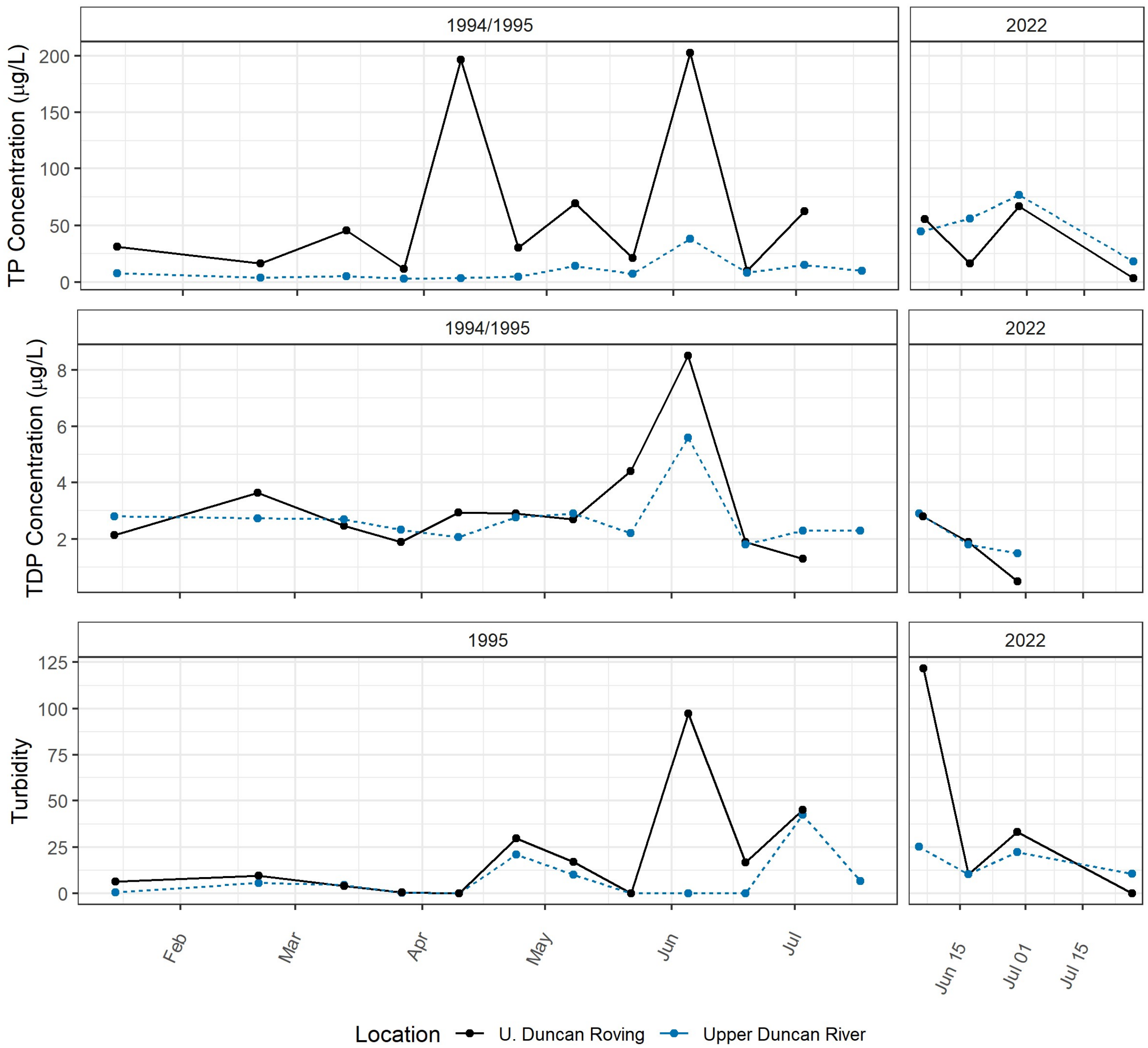

Figure 3-8. Total phosphorus (TP), total dissolved phosphorus (TDP) (µg/L) and turbidity (NTU) at the upper Duncan River and roving sites. 1994-5 sampling points represent an average concentration of one to three samples taken on the same date at the same location. In 1994-5, 44 samples of each TP & TDP, were collected from January to July compared to the six samples in June 2022. *Lines connecting points are only for a visual and do not indicate any interpolation between points.

3.5. Duplicate Samples

A duplicate sample was randomly assigned to one of the four sites and was obtained from the same collection container as the site sample. Duplicate samples were used solely to provide quality control on nutrient analysis and values were not incorporated within subsequent analyses (Table 3-1).

Table 3-1. Summary of 2022 duplicate samples.

Date	Sample Site	TP (µg/L)	TP Duplicate (µg/L)	TDP (µg/L)	TDP Duplicate (µg/L)
2022-06-05	Glacier	10.3	12.2	1.5	1.5
2022-06-17	Glacier	18.5	7.5	1.1	0.5*
2022-06-29	Glacier	20.8	20.5	1.7	1.2
2022-07-27	Glacier	9.4	8.4	—	—

* Below detection limit (value reported as half of limit); — No result due to equipment failure

TP duplicate samples from 2022 had more variation than 2021 duplicate samples; the closest 2022 pair was 20.8 µg/L and 20.5 µg/L (a 0.3 µg/L difference), and the worst pair was 18.5 µg/L and 7.5 µg/L (a 11 µg/L difference). The worst pairing, of June 17th 2022, indicates high intrasample variability. Given the suspended nature of TP, there is potential for variations between subsamples collected from the same container.

The TDP samples had less variation than TP samples in June 2022. Only one sample of six duplicate comparison samples came in below the detection limit (June 17th, 2022) compared to eight of twelve samples below the detection limit in 2021. The June 5th sample is an ideal duplicate finding, without any observed variation, whereas the June 29th sample had a variation of only a 0.5 µg/L but this does represent a 34.48 relative percent difference. By definition, percent difference will be higher in ultra-low analyses compared to standard analyses.

The 2022 travel and field blanks were all below detection limit indicating in-field and lab accuracy.

4.0 CONCLUSIONS

This memo summarized the findings of the 2022 sampling program and how observed TP and TDP in 2022 relate to the 2021 and 1994-5 findings. These results will inform the future sampling program to finalize the re-evaluation of DDMWORKS-3 and the role of the Duncan Dam operations in TDP retention within the DLR. The following are high level conclusions based on the work to-date:

1. Capturing multiple stages of freshet (rising limb and peak) demonstrated that high nutrient concentrations align with freshet's high flows, resulting in maximum daily load. Samples collected during this period are vital to clarifying the total DLR nutrient regime.
2. 2022 TDP loading was lower during peak freshet compared to the rising limb samples. This aligns with research on the relationship between TDP and groundwater influx (Stumm and Morgan, 1996; Arp and Baker, 2007), versus TP associated with particle transport in surface flows (Jones et al., 2010).
3. Sample variability was high throughout all sampling years (1994-5, 2021, & 2022). Increased sampling frequency within freshet could improve the accuracy of overall nutrient loading estimates and clarify the annual phosphorus budget of DLR.
4. 2022 samples comparing the Upper Duncan River upstream of the DLR and the Upper Duncan within the drawdown zone found reduced nutrient loading from the drawdown zone compared to the contributions observed in 1995. This may indicate that the drawdown zone is no longer acting as a high nutrient source.
5. Dam outflow sampling in 2021 & 2022 found decreased pH in DLR samples compared to 1995 samples collected within a similar season. This indicates a change may have occurred within the DLR system. However, the results are further complicated as 1994 samples collected between Oct and Dec at the dam outflow site had the lowest pH values among all years, and there is no late fall/winter data for comparison in other years. The apparent scope of pH change merits further investigation due to its broad influence on biogeochemical reservoir processes including phosphate adsorption and Fe, Mn, Al, Ca to P dynamics.
6. Dam outflow turbidity was lower in both 2021 and 2022 during the freshet period compared to 1994-5. This finding may indicate a change in the transport of particulate phosphorus, sediment sorption of P and reservoir dynamics generally.
7. This sampling program further addressed the inconsistent detection limits between the 1994-5 study and more recent analyses. Since current commercial sampling methods cannot provide similar resolution, truncating analyses at a 1 μg/L detection limit maintains consistency in analysis across different sampling years.

8. Continuing to build a long-term data set is the only way to comprehensively understand changes in TDP over time.

5.0 RECOMMENDATIONS

The 2022 sampling program highlighted important characteristics of the DLR and provided valuable insights for future sampling to clarify the operational component of nutrient supply lost to the Lower Duncan River and Kootenay Lake through retention in the DLR. The following recommendations are intended to inform a future sampling program to holistically determine nutrient retention in DLR due to dam operations:

1. Since high nutrient concentrations align with freshet's high flows resulting in maximum daily load, freshet should be prioritized in future sampling. Further, since 2022 TDP loading was lower during peak freshet compared to the rising limb samples, more sampling during the rising limb of freshet is needed to address the phosphorus loading question. Without increased sampling during the rising limb of freshet, there is a potential to underestimate nutrients entering the reservoir.
2. Sample variability was high throughout all sampling years (1994-5, 2021, & 2022), therefore increased sampling frequency from monthly to weekly within freshet could improve the accuracy of overall nutrient loading estimates.
3. Sampling for comparison of the Upper Duncan River upstream of the DLR and the Upper Duncan within the drawdown zone found reduced nutrient loading from the drawdown zone compared to contributions observed in 1995. Future sampling should include both locations to further understand the current contributions of the drawdown zone.
4. The apparent scope of pH change between 1995 and 2021/2022 merits further investigation and sampling due to its broad influence on biogeochemical reservoir processes which may influence the retention of nutrients in DLR.
5. Dam outflow turbidity was lower in both 2021 and 2022 during the freshet period compared to 1994-5. Further investigation of DLR dynamics is needed to understand sediment transportation, as it plays a role in the retention of nutrients. Sediment transport is critical to TP and water column turbidity measurements are one means of sediment travel within the reservoir.

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Table A-1. Field photographs from sampling trips demonstrating water level & intensity in ungauged Howser & Glacier creeks.

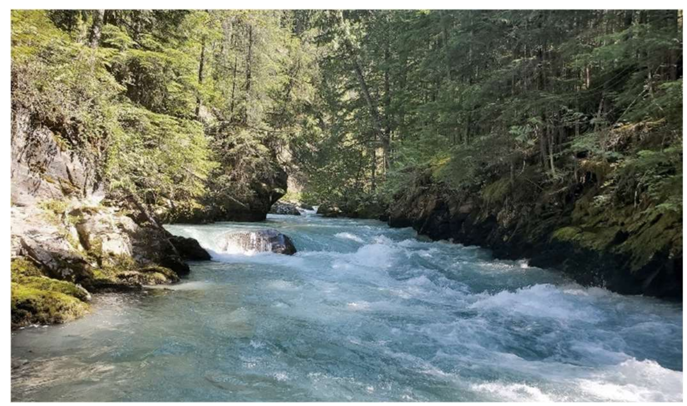
	Howser Creek	Glacier Creek
June 5		
June 29		
July 29		

Table A-2. I*n-situ* results of 1994/95, 2021, and 2022 field measurements at sample locations by date.

Sampling Location	Date	Latitude	Longitude	Temperature	pH	Dissolved Oxygen (%)	Dissolved Oxygen (mg/L)	Conductivity (µS/cm)	Total Dissolved Solids (mg/L)	Salinity (psu)	Turbidity (NTU)	Oxidation Reduction Potential (mV)
Dam Outflow	2022-07-27	50.1515	116.5707	14.8	7.51	97.8	9.90	147.40	119.000	0.090	1.6	39.4
Dam Outflow	2022-06-29	50.1515	116.5707	11.8	7.19	90.5	9.80	138.60	120.497	0.090	2.8	110.8
Dam Outflow	2022-06-17	50.1515	116.5707	11.99	7.58	94.6	10.20	133.60	115.571	0.080	2.8	220.3
Dam Outflow	2022-06-06	50.1515	116.5707	8.8	7.32	93.7	10.88	75.80	71.353	0.050	8.5	170.2
Dam Outflow	2021-10-15	50.1515	116.5708	11.1	7.58	88.2	9.70	85.50	75.620	0.050	0.3	108.3
Dam Outflow	2021-08-24	50.1515	116.5708	11.2	7.57	90.5	9.94	71.90	63.481	0.050	1.4	76.8
Dam Outflow	2021-07-19	50.1515	116.5708	11.2	7.90	73.3	8.05	NA	NA	0.075	4.2	61.5
Dam Outflow	2021-06-15	50.1515	116.5707	12.3	7.61	98.4	10.53	80.00	68.733	0.050	1.4	79.7
Dam Outflow	2021-05-27	50.1515	116.5707	11.6	7.55	99.4	10.81	71.10	62.147	0.040	1.9	94.2
Dam Outflow	2021-04-20	50.1515	116.5707	8.7	7.92	103.9	12.09	80.08	76.207	0.060	1.7	115.2
Dam Outflow	1995-09-12			11.42	6.76						0	
Dam Outflow	1995-08-28			10.42	8.77						0	
Dam Outflow	1995-08-14			10.78	8.7						9.8	
Dam Outflow	1995-07-31			16.16	8.94						12.6	
Dam Outflow	1995-07-17			10.74	8.48						1.1	
Dam Outflow	1995-07-03			9.66	8.25						0	
Dam Outflow	1995-06-19			10.89	8.23						15.9	
Dam Outflow	1995-06-05			12.07	8.27						0	
Dam Outflow	1995-05-22			11.34	7.65						20.5	
Dam Outflow	1995-05-08			11.04	8.47						0	
Dam Outflow	1995-04-24			7.97	8.28						7.9	
Dam Outflow	1995-04-10			4.05	7.91						0	
Dam Outflow	1995-03-27			3.97	7.93						3.9	
Dam Outflow	1995-03-13			2.58	7.8						0	
Dam Outflow	1995-02-20			1.63	7.22						7.5	
Dam Outflow	1995-01-16			2.19	7.74						0.53	
Dam Outflow	1994-12-13			4.03	7.37						0.22	
Dam Outflow	1994-11-21			6.06	6.35						0.25	
Dam Outflow	1994-11-07			8.49	8.36						0.26	
Dam Outflow	1994-10-24			9.8	6.37						0.26	

Sampling Location	Date	Latitude	Longitude	Temperature	pH	Dissolved Oxygen (%)	Dissolved Oxygen (mg/L)	Conductivity (µS/cm)	Total Dissolved Solids (mg/L)	Salinity (psu)	Turbidity (NTU)	Oxidation Reduction Potential (mV)
Dam Outflow	1994-10-11			14.18	6.36						0.3	
Dam Outflow	1994-09-26			13.74	6.55						0.58	
Dam Outflow	1994-09-13			14.42	8.51						0.52	
Glacier Creek	2022-07-27	50.1706	116.5512	9.7	7.15	101.4	11.52	67.90	62.285	0.040	11.4	170.1
Glacier Creek	2022-06-29	50.1706	116.5512	9.55	7.56	99.2	11.31	76.10	70.144	0.050	4.1	223.3
Glacier Creek	2022-06-17	50.1706	116.5512	13.118	7.79	103.1	10.83	65.30	55.000	0.040	4.9	26.8
Glacier Creek	2022-06-05	50.1706	116.5512	5.3	7.20	95.7	12.13	67.60	70.492	0.050	93.7	170
Glacier Creek	2021-10-15	50.1706	116.5512	5.8	7.67	97.7	12.24	63.10	64.852	0.050	0.1	104.6
Glacier Creek	2021-08-24	50.1706	116.5512	9.8	7.54	102.0	11.57	48.60	44.496	0.030	2.5	100.1
Glacier Creek	2021-07-19	50.1706	116.5512	13.1	7.61	79.8	8.40	NA	NA	0.034	10.8	30.6
Glacier Creek	2021-06-14	50.1706	116.5512	14.7	7.56	106.5	10.81	59.50	48.132	0.030	6.6	76.8
Glacier Creek	2021-05-26	50.1706	116.5512	10.3	7.58	104.2	11.69	45.00	40.699	0.030	0.8	71.3
Glacier Creek	2021-04-19	50.1706	116.5512	8.7	8.60	102.8	11.97	69.10	65.202	0.050	-0.2	103.6
Glacier Creek	1995-09-12			7.15	9.16						15.1	
Glacier Creek	1995-08-28			6.84	9.1						6.4	
Glacier Creek	1995-08-14			7.67	6.95						22.7	
Glacier Creek	1995-07-31			7.67	8.88						23.7	
Glacier Creek	1995-07-17			7.65	8.75						23.9	
Glacier Creek	1995-07-03			7.35	8.33						80.4	
Glacier Creek	1995-06-19			7.13	8.34						20.6	
Glacier Creek	1995-06-05			5.86	8.15						29.5	
Glacier Creek	1995-05-22			4.04	7.88						2	
Glacier Creek	1995-05-08			5.15	8.39						1.11	
Glacier Creek	1995-04-24			4.71	8.37						0	
Glacier Creek	1995-04-10			3.55	6.45						11.1	
Glacier Creek	1995-03-27			0.65	8.15						0	
Glacier Creek	1995-03-13			1.99	8.07						12.6	
Glacier Creek	1995-02-20			1.19	8.04						0.2	
Glacier Creek	1995-01-16			1.13	7.95							
Glacier Creek	1994-12-13			0.06	7.59							
Glacier Creek	1994-11-21			-0.27	6.61							
Glacier Creek	1994-11-07			1.06	8.6							

Sampling Location	Date	Latitude	Longitude	Temperature	pH	Dissolved Oxygen (%)	Dissolved Oxygen (mg/L)	Conductivity (µS/cm)	Total Dissolved Solids (mg/L)	Salinity (psu)	Turbidity (NTU)	Oxidation Reduction Potential (mV)
Glacier Creek	1994-10-24			3.01	8.53							
Glacier Creek	1994-10-11			6.63	8.64							
Glacier Creek	1994-09-26			8.11	8.34							
Glacier Creek	1994-09-13			9.5	6.32							
Howser Creek	2022-07-27	50.2749	116.5460	9.1	7.18	101.6	11.72	112.60	105.196	0.080	19.3	185.1
Howser Creek	2022-06-29	50.2749	116.5460	8.75	7.71	102.5	11.92	122.20	115.208	0.080	7.4	209.9
Howser Creek	2022-06-17	50.2749	116.5460	13.932	7.89	106.3	10.96	141.60	117.000	0.090	11.6	29.4
Howser Creek	2022-06-05	50.2749	116.5460	5.4	7.13	94.3	11.91	119.20	123.779	0.090	95.6	181
Howser Creek	2021-10-15	50.2749	116.5460	5.6	7.71	98.7	12.39	99.90	102.962	0.070	0.3	108.7
Howser Creek	2021-08-24	50.2749	116.5460	9.7	7.78	103.4	11.75	97.50	89.570	0.070	12.8	96.4
Howser Creek	2021-07-19	50.2749	116.5460	12.7	7.76	98.7	10.47	NA	NA	0.079	34.7	93.6
Howser Creek	2021-06-14	50.2749	116.5460	12.2	7.63	110.0	11.81	60.70	52.310	0.040	22.5	84.6
Howser Creek	2021-05-26	50.2749	116.5460	11.1	7.88	109.3	12.01	77.20	68.239	0.050	2.3	67.6
Howser Creek	2021-04-19	50.2749	116.5460	9.1	8.68	107.4	12.37	130.00	121.243	0.090	0.3	97.2
Howser Creek	1995-09-12			8.07	9						33.8	
Howser Creek	1995-08-28			7.6	9						16.2	
Howser Creek	1995-08-14			8.09	9.01						23.5	
Howser Creek	1995-07-31			8.46	8.81						25.2	
Howser Creek	1995-07-17			8.12	8.66						32.9	
Howser Creek	1995-07-03			7.54	6.55						29.8	
Howser Creek	1995-06-19			6.79	8.49						0	
Howser Creek	1995-06-05			6.14	8.27						33.5	
Howser Creek	1995-05-22			4.52	8.09						0	
Howser Creek	1995-05-08			5.6	6.51						3.9	
Howser Creek	1995-04-24			4.65	8.5						12.5	
Howser Creek	1995-04-10			2.99	6.13						0	
Howser Creek	1995-03-27			1.93	8.22						0	
Howser Creek	1995-03-13			2.66	8.22						4.2	
Howser Creek	1995-02-20			-0.01	6.1						5.8	
Howser Creek	1995-01-16			1.69	6.1							
Howser Creek	1994-12-13			0.9	7.94							
Howser Creek	1994-11-21			-0.12	8.73							

Sampling Location	Date	Latitude	Longitude	Temperature	pH	Dissolved Oxygen (%)	Dissolved Oxygen (mg/L)	Conductivity (µS/cm)	Total Dissolved Solids (mg/L)	Salinity (psu)	Turbidity (NTU)	Oxidation Reduction Potential (mV)
Howser Creek	1994-11-07			2.02	6.64							
Howser Creek	1994-10-24			3.91	8.62							
Howser Creek	1994-10-11			7.47	6.66							
Howser Creek	1994-09-26			8.03	6.46							
Howser Creek	1994-09-13			8.08	6.3							
U. Duncan Roving	2022-07-27			20.8	7.90	99.3	8.88	162.50	115.000	0.080	0.1	14.8
U. Duncan Roving	2022-06-29			9.97	7.64	97.8	11.04	173.30	157.934	0.120	10.4	172.7
U. Duncan Roving	2022-06-17			9.9	7.04	98.3	11.13	99.70	91.144	0.070	33.2	131.7
U. Duncan Roving	2022-06-06	50.4387	116.9340	6.8	7.22	96.1	11.73	13.00	12.904	0.010	121.6	174.9
U. Duncan Roving	2021-06-14	50.3614	117.0127	12.9	7.81	101.4	10.70	55.20	46.658	0.030	16.6	86.4
U. Duncan Roving	2021-05-27	50.3208	116.5850	9.9	7.77	99.9	11.30	75.10	68.591	0.050	10.3	104.7
U. Duncan Roving	2021-04-20	50.2540	116.5555	5.7	8.21	98.6	12.37	89.10	91.786	0.070	16.9	124.3
U. Duncan Roving	1995-07-03			7.61	8.67						45.1	
U. Duncan Roving	1995-06-19			7.59	8.72						16.7	
U. Duncan Roving	1995-06-05			5.95	8.5						97.3	
U. Duncan Roving	1995-05-22			6.11	8.15						0	
U. Duncan Roving	1995-04-24			5.65	6.45						20.9	
U. Duncan Roving	1995-04-10			4.09	8.27						0	
U. Duncan Roving	1995-03-27			3.53	7.72						0.3	
U. Duncan Roving	1995-03-13			2.32	7.78						4.4	
U. Duncan Roving	1995-02-20			0.36	6.1						5.7	
Upper Duncan River	2022-07-27	50.6388	117.0499	10.6	6.84	98.7	11.00	106.00	95.155	0.070	22.3	179.7
Upper Duncan River	2022-06-29	50.6388	117.0499	7.52	7.80	96.7	11.59	97.40	95.001	0.070	10.4	247.8
Upper Duncan River	2022-06-17	50.6388	117.0499	11.59	7.28	98.1	10.67	93.00	81.000	0.060	10.6	43.1
Upper Duncan River	2022-06-05	50.6388	117.0499	6	6.58	95.3	11.84	102.30	104.272	0.080	25.1	192.7
Upper Duncan River	2021-10-15	50.3818	117.0302	5.8	7.75	96.2	12.03	71.08	73.650	0.050	0.2	102.8
Upper Duncan River	2021-08-24	50.3818	117.0302	10.3	7.88	102.1	11.44	64.80	58.550	0.040	5.0	85.3
Upper Duncan River	2021-07-19	50.3818	117.0302	13.1	8.06	91.9	9.66	NA	NA	0.058	17.2	5.4
Upper Duncan River	1995-09-12			9.21	9.14						20.1	
Upper Duncan River	1995-08-28			9.14	6.16						26	
Upper Duncan River	1995-08-14			8.06	8.8						13.7	
Upper Duncan River	1995-07-31			9.56							1.3	

Sampling Location	Date	Latitude	Longitude	Temperature	pH	Dissolved Oxygen (%)	Dissolved Oxygen (mg/L)	Conductivity (µS/cm)	Total Dissolved Solids (mg/L)	Salinity (psu)	Turbidity (NTU)	Oxidation Reduction Potential (mV)
Upper Duncan River	1995-07-17			10.55	8.8						6.7	
Upper Duncan River	1995-07-03			7.4	8.66						42.5	
Upper Duncan River	1995-06-19			8.23	8.69						0	
Upper Duncan River	1995-06-05			5.9	8.37						0	
Upper Duncan River	1995-05-22			6.74	6.32						0	
Upper Duncan River	1995-05-08			6.26	6.42						10.2	
Upper Duncan River	1995-01-16			0.46	6						0.52	
Upper Duncan River	1994-12-13			0.24	7.49						0.21	
Upper Duncan River	1994-11-21			-0.07	8.72						0.19	
Upper Duncan River	1994-11-07			1.37	6.7						0.26	
Upper Duncan River	1994-10-24			5.17	8.76						0.39	
Upper Duncan River	1994-10-11			8.62	8.82						0.62	
Upper Duncan River	1994-09-26			8.7	8.52						3.8	
Upper Duncan River	1994-09-13			8.81	6.51						0.96	

Table A-3. Lab results of 1994/95, 2021, and 2022 TDP and TP concentrations by date.

Sample Date	Variable	Upper Duncan River (µg/L)	Upper Duncan Roving (µg/L)	Howser Creek (µg/L)	Glacier Creek (µg/L)	Duncan Dam (µg/L)	Duplicate (µg/L)	Field Blank (µg/L)	Travel Blank (µg/L)
2022-06-05	TDP	2.9	--	2.2	1.5	--	1.5	0.5**	--
2022-06-06	TDP	--	2.8	--	--	2.9	--	--	--
2022-06-17	TDP	1.8	1.9	1	1.1	0.5**	0.5**	0.5**	--
2022-06-29	TDP	1.5	0.5**	0.5**	1.7	0.5**	1.2	0.5**	--
2021-04-19	TDP	--	--	3.1	0.5**	--	0.5**	0.5**	--
2021-04-20	TDP	--	0.5**	--	--	0.5**	--	--	--
2021-05-26	TDP	--	--	0.5**	0.5**	--	0.5**	0.5**	--
2021-05-27	TDP	--	0.5**	--	--	2.7	--	--	--
2021-06-14	TDP	--	1.7	1.7	3.3	--	--	0.5**	--
2021-06-15	TDP	--	--	--	--	0.5**	1.2	--	--
2021-07-19	TDP	--	1.6	1.4	1.3	1.1	1.9	0.5**	--
2021-08-24	TDP	--	0.5**	1	1.2	0.5**	0.5**	0.5**	--
2021-10-15	TDP	--	0.5**	0.5**	0.5**	0.5**	0.5**	0.5**	--
1994-09-13	TDP	4.9	--	2.4	1.2	1.3	--	--	--
1994-09-26	TDP	7.5	--	1.5	1.3	1.2	--	--	--
1994-10-11	TDP	1.8	--	1.7	1.7	1.9	--	--	--
1994-10-24	TDP	1.1	--	1.1	1	1.5	--	--	--
1994-11-07	TDP	1.8	--	2.6	2	4.1	--	--	--
1994-11-21	TDP	2	--	1.7	1.9	1.7	--	--	--
1994-12-13	TDP	2.3	--	2.4	2.5	1.6	--	--	--
1995-01-16	TDP	2.8	--	2.7	2	2	--	--	--
1995-02-20	TDP	2.5	3.2	2.8	2.7	2	--	--	--
1995-03-13	TDP	2.6	2.7	4.1	3.3	2.1	--	--	--
1995-03-27	TDP	2.2	2.1	2.5	3.7	4.7	--	--	--
1995-04-10	TDP	2	2.2	2.7	2.4	1.7	--	--	--
1995-04-24	TDP	3.1	2.6	2.7	3	2.7	--	--	--
1995-05-08	TDP	2.9	--	2.2	2.3	3	--	--	--
1995-05-22	TDP	2.2	4.4	2.3	2	2.2	--	--	--
1995-06-05	TDP	5.6	8.5	6.9	2.2	4.8	--	--	--
1995-06-19	TDP	1.8	1.9	1.2	1.3	2.1	--	--	--
1995-07-03	TDP	2.3	1.3	1.3	1.1	3.5	--	--	--
1995-07-17	TDP	2.3	--	2.4	1.5	2.3	--	--	--

Highlighted cells indicate duplicate sample pairings.

** Indicate sample was below detection limit & reported as half the detection limit.

Sample Date	Variable	Upper Duncan River (µg/L)	Upper Duncan Roving (µg/L)	Howser Creek (µg/L)	Glacier Creek (µg/L)	Duncan Dam (µg/L)	Duplicate (µg/L)	Field Blank (µg/L)	Travel Blank (µg/L)
1995-07-31	TDP	1.6	--	1.5	0.8	1.2	--	--	--
1995-08-14	TDP	0.7	--	0.5	0.8	0.1	--	--	--
1995-08-28	TDP	1.4	--	3.1	0.9	0.9	--	--	--
1995-09-12	TDP	0.8	--	1	0.4	0.4	--	--	--
2022-06-05	TP	44.8	--	29.4	10.3	--	12.2	1**	1**
2022-06-06	TP	--	55.6	--	--	12.3	--	--	--
2022-06-17	TP	56	16.4	18.3	18.5	3.9	7.5	1**	1**
2022-06-29	TP	76.5	66.9	37.2	20.8	6.6	20.5	1**	1**
2022-07-27	TP	18.1	3.6	12.4	9.4	3	8.6	1**	1**
2021-04-19	TP	--	--	2.1	2.1	--	1**	1**	1**
2021-04-20	TP	--	38.7	--	--	4.6	--	--	--
2021-05-26	TP	--	--	5.6	3.7	--	3	1**	1**
2021-05-27	TP	--	32.1	--	--	3.3	--	--	--
2021-06-14	TP	--	61.7	78.9	45.1	--	--	1**	1**
2021-06-15	TP	--	--	--	--	4.1	3.9	--	--
2021-07-19	TP	--	15.6	15.6	9	2.5	5.2	1**	1**
2021-08-24	TP	--	8	14.3	4.8	2.7	11.3	1**	--
2021-10-15	TP	--	4.1	1**	2.6	2.6	2.2	1**	1**
1994-09-13	TP	4.9	--	7.3	2.8	3.8	--	--	--
1994-09-26	TP	20.4	--	24.6	9.4	3.2	--	--	--
1994-10-11	TP	3.3	--	7.1	3.2	3	--	--	--
1994-10-24	TP	1.8	--	1.9	1.6	4	--	--	--
1994-11-07	TP	2.8	--	3.5	2.5	4.3	--	--	--
1994-11-21	TP	3.3	--	2.6	2.4	4.5	--	--	--
1994-12-13	TP	4	--	2.5	5.2	3.7	--	--	--
1995-01-16	TP	7.8	--	2.4	2	3.4	--	--	--
1995-02-20	TP	4	3.4	8	3.2	3.7	--	--	--
1995-03-13	TP	5.7	4.7	4.2	7.6	5.2	--	--	--
1995-03-27	TP	3.4	2.5	3.3	6.9	5.4	--	--	--
1995-04-10	TP	3.2	4	3.3	2.7	12.9	--	--	--
1995-04-24	TP	5.1	4.9	3.6	4.1	6.4	--	--	--
1995-05-08	TP	14.1	--	7.3	4.8	8	--	--	--
1995-05-22	TP	7.3	21.3	6	3.8	6.3	--	--	--

Highlighted cells indicate duplicate sample pairings.

** Indicate sample was below detection limit & reported as half the detection limit.

Sample Date	Variable	Upper Duncan River (µg/L)	Upper Duncan Roving (µg/L)	Howser Creek (µg/L)	Glacier Creek (µg/L)	Duncan Dam (µg/L)	Duplicate (µg/L)	Field Blank (µg/L)	Travel Blank (µg/L)
1995-06-05	TP	38.3	202.5	57.6	17.7	5.8	--	--	--
1995-06-19	TP	8.2	9.8	10.9	4.9	6.6	--	--	--
1995-07-03	TP	14.9	62.5	20.2	105.6	4.9	--	--	--
1995-07-17	TP	10	--	--	8.8	3.5	--	--	--
1995-07-31	TP	10	--	8.2	7.9	7.6	--	--	--
1995-08-14	TP	6.2	--	8.5	9.3	2.3	--	--	--
1995-08-28	TP	10	--	12.5	4.1	3.2	--	--	--
1995-09-12	TP	13.6	--	13.6	12.3	2.7	--	--	--

Highlighted cells indicate duplicate sample pairings.

** Indicate sample was below detection limit & reported as half the detection limit.