Moses Lake Water Quality: Effects and Benefits of Columbia River Dilution Water 2017-2024

PREPARED FOR

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1.0 INTRODUCTION

Moses Lake water quality (WQ) has been reported since the 1960s and was greatly improved with the start of increased inputs of low-phosphorus Columbia River water (CRW) starting in 1977 (Welch et al. 1989; Welch, 1992). Further improvement was shown during the 1990s through 2016 with more CRW (Welch et al. 2019; Welch and Brattebo, 2024a) and recently during 2020-2023 (Welch and Brattebo, 2024a, 2024b). The improvement in WQ resulted from a reduction of total phosphorus (TP) and chlorophyll (chl) concentrations and increased water transparency, which are indicators of lake WQ. Improved WQ between 2017-2019 and 2020-2023 was due to greater dilution with low-TP CRW, which increased by 85%.

Moses Lake WQ declined in 2024, just before and following a breach in the East Low Canal on August 5. Total P increased to unusually high concentrations, as well as specific conductance (SC) and turbidity, in lower Parker Horn and South Lake. Surface TP increased from an average of 22 µg/L during May-July to 234 µg/L during August-September at South Lake. The high TP concentrations produced predictably high chl concentrations. Yet, the fraction of blue-green algae (cyanobacteria), of total algal biovolume, remained as low as in 2021-2023. In 2024, diatoms dominated the algal crop and the few samples of near-shore algal scums had low microcystin concentrations. Nevertheless, average spring-summer WQ, indicated by TP, chl and water transparency, declined in lower Parker Horn and South Lake in 2024, compared to that in 2021-2023. Dilution was less effective in 2024 with only 58%CRW at the surface during July-September in most of the lake, compared to 76%CW during 2021-2023. Water quality and %CRW declined in 2024 despite over 200,000 AF inflow of CRW through mid-September.

Lake WQ in middle and upper Rocky Fork Arm (RFA) also declined during spring-summer 2024, compared to 2021-2023; May-September average surface TPs; 88 versus 39 µg/L. The high TPs occurred in late August. Total P in upper RFA (TS12) increased from an average of 37 µg/L during May-mid August to 292 µg/L during late August-September. Nevertheless, the blue-green algal fraction and microcystin were as low as in 2021-2023. The source(s) of late summer high TP concentrations, especially at upper RFA (TS12), is unknown, although high TPs, nitrate-nitrogen and SC occurred in Rocky Ford Creek in late summer.

The degraded state of lake water quality during spring-summer 2024, especially during August-September, interfered with the evaluation of treatment effectiveness from adding EutroSorbG to middle and upper RFA in June to inactivate mobile sediment phosphorus and reduce internal loading. However, dilution of RFA was less effective in 2024, averaging only 51%CRW – compared to the usual 60%CRW. Thus, there was an apparent benefit in lake WQ at middle (TS11) and lower (TS15) RFA in 2024 if water quality data at those sites were compared to data collected in 2020 with similar dilution effectiveness (50%CRW).

The source that produced high TP and chl in lower Parker Horn and South Lake is unknown, although TP and other constituents were unusually high in East Low Canal water just before and after the August 5 breach. After the breach, East Low Canal water was diverted to Rocky Coulee Wasteway and into the lake. The inflow was 4,165 AF between 8/7 and 8/13. Total phosphorus in CRW historically averaged 7-8 µg/L, but was 113 and 279 µg/L on 8/14 and 8/27 in 2024. Total phosphorus was also unusually high in Crab Creek (TS2) averaging 724 µg/L between 7/31 and 8/27 2024, well above the long-term average of 48 µg/L.

2.0 WATER SAMPLE COLLECTION AND ANALYSIS

Water samples were collected by the Moses Lake Irrigation and Rehabilitation District (MLIRD) personnel with a Van Dorn bottle twice per month the past seven years, at a depth of 0.5 m at nine lake sites during May-September (Figure 1). Samples were also collected through the water column at discrete depths in 2020 - 2024. Inflows were sampled at two sites on Crab Creek (TS2 and 3), and one each in the east low canal (TS1) and Rocky Ford Creek (TS14).

Samples were shipped on ice to IEH Analytical Laboratories, Seattle, WA, for analysis of total phosphorus (TP) using the method 4500PI with detection to 2 µg/L. Chlorophyll was determined in the same lake samples on residue following filtration in the laboratory with detection to 0.1 µg/L. Analytical procedures were according to standard methods (Eaton et al., 2005). Specific conductance (SC), dissolved oxygen (DO) and temperature were determined in situ with a sonde at all lake sites coincident with water sampling.

Water samples for algae identification and enumeration were also collected from the Van Dorn bottle water, coincident with the sample for other constituents. Samples for algae were collected twice-monthly during July – September in 2017, May-September in 2018, once/month in June, August, and September in 2021 and twice each of these three months in 2022 and 2024. Algal abundance was determined as biovolume in mm^3/L based on measured cell volumes of individual species observed and shown here as % blue-greens and % Microcystis. Samples were analyzed by Western Washington University algologists in 2017 and 2018 and Algae Analytical Services in 2021 - 2024. Samples for microcystin were collected at Blue Heron Park by Grant County Health personnel and at Connelly Park by MLIRD. Samples were analyzed by King County Environmental Laboratory using the ELISA method.

Water column stability was indicated by relative thermal resistance to mixing (RTRM), where

$$RTRM = (D_{bottom} - D_{surface})/(D_4 - D_5)$$

and D is water density at the surface and bottom and at 4C and 5C.

Specific conductance (SC) was used to trace CRW in the lake and determine % lake water or % CRW according to Welch and Patmont (1980). Symbols in the equation are SC, in µS/cm, which is much lower in CRW at 142 than in Crab Creek at 491 and Rocky Ford Creek at 371. Specific conductance in Crab Creek was used for lower Parker Horn and South Lake and an average of Crab Creek and Rocky Ford Creek was used for Rocky Ford Arm. The equation allows tracing of the low-SC CRW according to:

$$100\,[(LW - ELCW) / (CCW - ELCW)] = \%\,LW;\ \text{or}\ 100 - \%LW = \%CRW$$

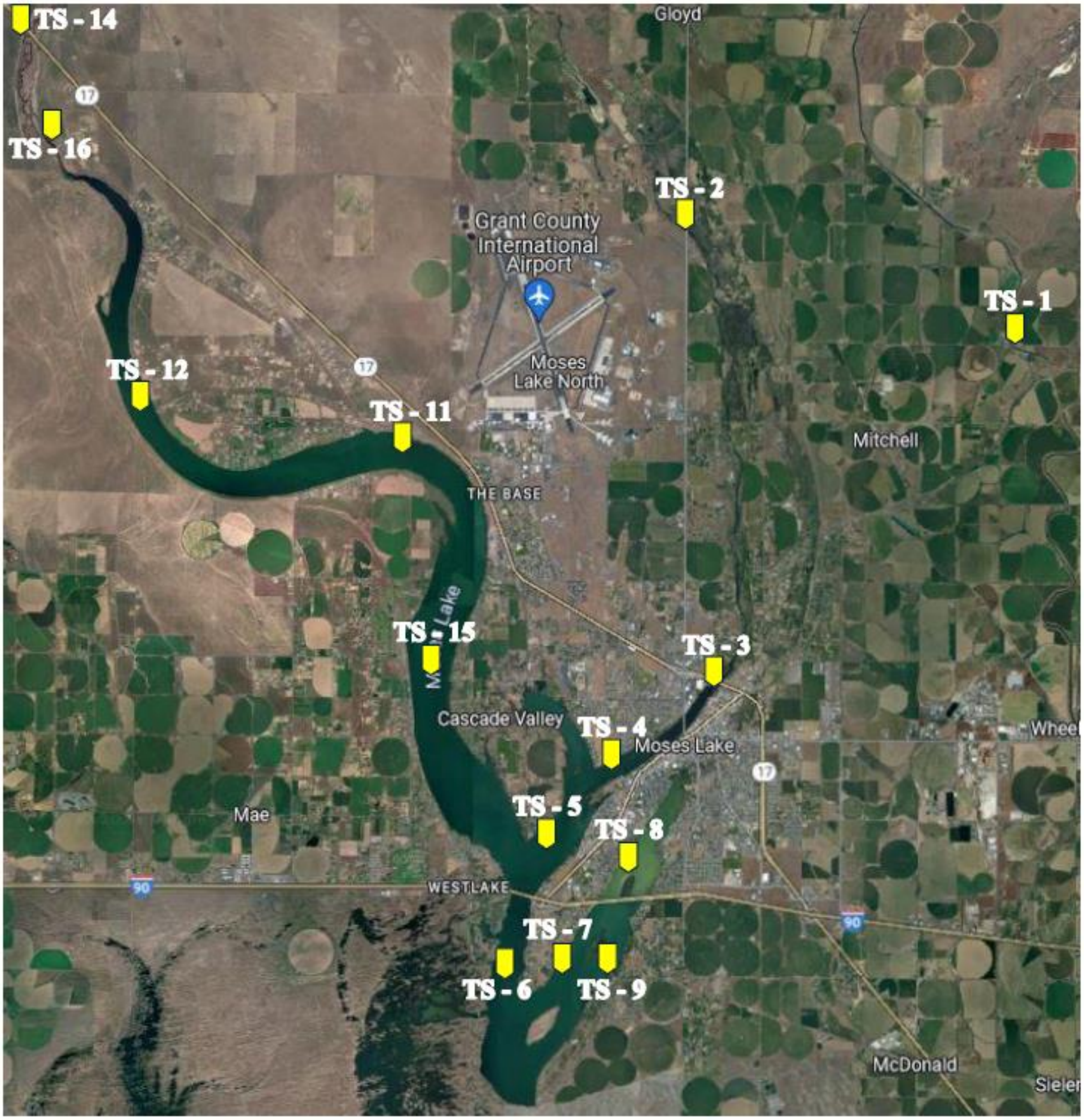

Figure 1. Sampling sites by MLIRD during 2017-2024. Most sites are similar to those sampled by UW, Civil and Environmental Engineering, during 1969-1970 and 1977-1988 (Welch et al., 1989).

3.0 WIND TRANSPORT OF WATER INTO ROCKY FORD ARM

Specific conductance has consistently shown that low-P Columbia River water (CRW) reaches well up into Rocky Ford Arm (RFA). Prevailing SE to SW wind was shown in a spring 1981 study to be sufficient to transport water from Lower Parker Horn several miles up RFA using a diffusion model (Welch et al., 1982). Water from Lower

Parker Horn (TS5) with 77%CRW was calculated to reach middle RFA (TS11), a distance of 5.5 miles, over a period of 100 days and produce 30%CRW at that site. That prediction agreed with observations of %CRW. Wind velocity during the study averaged 2.6 miles/hour over the 17-hour study. CRW at 8.5 miles up RFA was predicted at less than half that at middle RFA. The work was performed by Ron Nece, a hydraulics Professor at UW at the time. The effectiveness of CRW transfer up RFA was also demonstrated by observed %CRW at middle RFA (TS11) during 1977-1978 (Welch and Patmont, 1980).

The 1981 study also showed that flow from Rocky Ford Creek would have had a minimal reverse effect on CRW movement up RFA. The cross-sectional lake area of 23,000-50,000 sq. ft. and an inflow from RFC of 78 cfs would have produced a down-arm flow of only 0.001-0.002 cfs (Welch et al., 1982).

Recent data show even greater effectiveness of water transport up RFA. Wind direction was from the SE to SW 45% of the time during June-September in 2020-2024 and averaged 7.1 miles/hour. Wind was apparently adequate to account for CRW to average 70% at middle RFA (TS11) during July-August, 2020-2023. Transfer was less effective in 2024 averaging 54%CRW, even though wind direction and wind speed averaged 48% SE to SW and 7.4 miles/hour.

4.0 EFFECT OF CRW INFLOW AND LAKE LEVEL ON LAKE %CRW

Lake level averaged 2.2 feet lower in 2020-2023 than in 2017-2019 when CRW inflow started (**Table 1**). That depth difference represents 30% of full-pool volume and much less lake water to mix with the CRW inflow. That volume difference may be partly the cause for an average of 60% CRW in Lower Parker Horn and South Lake (TS5 and TS6) in June 2017-2019 versus 80% CRW in June 2020-2023.

Lake level prior to the start of CRW inflows in 2024 was 1043.3 ft, about a foot higher than in 2020-2023 (Table 1). Nevertheless, CRW was still 72% in June at TS5/6, but lower at TS11/12 (46%). CRW was higher in lower RFA at 62%, because that site is closer to the inflow.

Comparison of starting lake levels and ultimate %CRW indicates that lower lake level apparently has a benefit to dilution. Inflow volume also determines dilution effectiveness and %CRW. Inflow of CRW through June was higher in the five low lake-level years (2020-2024) at an average of 177,146 AF versus 107,140 AF in the three high lake level years (Table 1). So, there is not a straight forward comparison of years with high and low lake levels and the same inflows. Nevertheless, there are some comparisons that indicate a benefit of an initial lower lake level to dilution effectiveness (Table 1).

1. %CRW was much higher in 2023 (79%) with a starting lower lake level than in 2017 (54%) with higher lake level and with rather similar CRW inflow volumes.
2. %CRW was the same in 2020 and 2021 (82%) with similar, but lower lake levels, than previous years, despite a 70,000 AF difference in CRW inflow between 2020 and 2021.
3. %CRW was less in 2024 (72%) with a 2-foot higher lake level than in 2022 (78%) with about the same CRW inflow volume.
4. Average predicted July-September %CRW at TS5/6 was 49% for the average CRW inflow volume for the three high initial lake level years (2017-2019). Observed average lake CRW was 60% for those three years. Average predicted lake CRW was 59% for the average CRW inflow volume for the four low initial lake level years (2020-2023). Observed average lake CRW was 80% for those four years. Thus, observed CRW was 21% higher than predicted from CRW inflow volume in the four low lake level years (2020-2023), but only 11% higher than predicted from CRW inflow in the high lake level years. That indicates low initial lake level benefited dilution. Predicted %CRW from CRW inflow volume using the regression equation: %CRW = 0.11 inflow in 10^6 m^3/year + 34.79 (Welch and Brattebo, 2024a, 2024b).

Table 1. Lake level at start of CRW inflow, CRW inflow through June and surface and bottom %CRW at TS5/TS6 and TS11/TS12 in June during 2017 to 2024.

Year	Pre-CRW Lake Level (ft)	CRW Volume (AF)	%CRW at TS5/TS6	%CRW at TS11/TS12
2017	1046.8	116,779	54	44
2018	1044.0	92,290	56	39
2019	1044.0	112,349	71	41
2020	1042.4	139,828	82	32
2021	1042.2	230,000	82	51
2022	1041.4	190,404	78	71
2023	1042.9	151,929	79	63
2024	1043.3	183,570	72	43

5.0 PROGRESSION OF CRW INCREASE DURING SPRING 2024

Parker Horn and South Lake

Prior to the start of Columbia River water (CRW) inflow the end of March 2024, lower Parker Horn (TS5) and South Lake (TS6) were about one-third CRW, which was the residual from the previous year. Soon after CRW inflow started the surface in lower Parker Horn was 84% CRW, but still one-third on the bottom and at the surface and bottom at South Lake (Figure 2). By April 10, %CRW had increased markedly at the surface in lower Parker Horn (97%) and South Lake (89%), and equally as high at the bottom. By May 1, %CRW was slightly lower at the surface, but higher at the bottom (92-93%) at both sites, and temperature was 2°F lower at the South Lake bottom than surface. So, inflowing, colder (50°F) CRW was plunging to some extent, as lake level increased from 1043.3 feet before CRW started to 1046.7 feet. %CRW was determined by tracing the low specific conductance (SC) of CRW (Welch and Brattebo, 2024a, 2024b).

Temperature at TS6 increased more at the surface than at the bottom as the lake warmed in June and thermal stratification began, but %CRW was similar top to bottom; 74% and 73% on June 5 and 70% and 68% on June 19, although %CRW had decreased. The decrease in %CRW also occurred at TS4 and TS5; respectively 76% and 78% on June 5 to 62% and 66% on June 19, likely due to termination of CRW input. During July-September in 2021-2023 average %CRW at 5 sites, over 58% of the lake, was still 74-79%. So, the lake was less diluted in 2024.

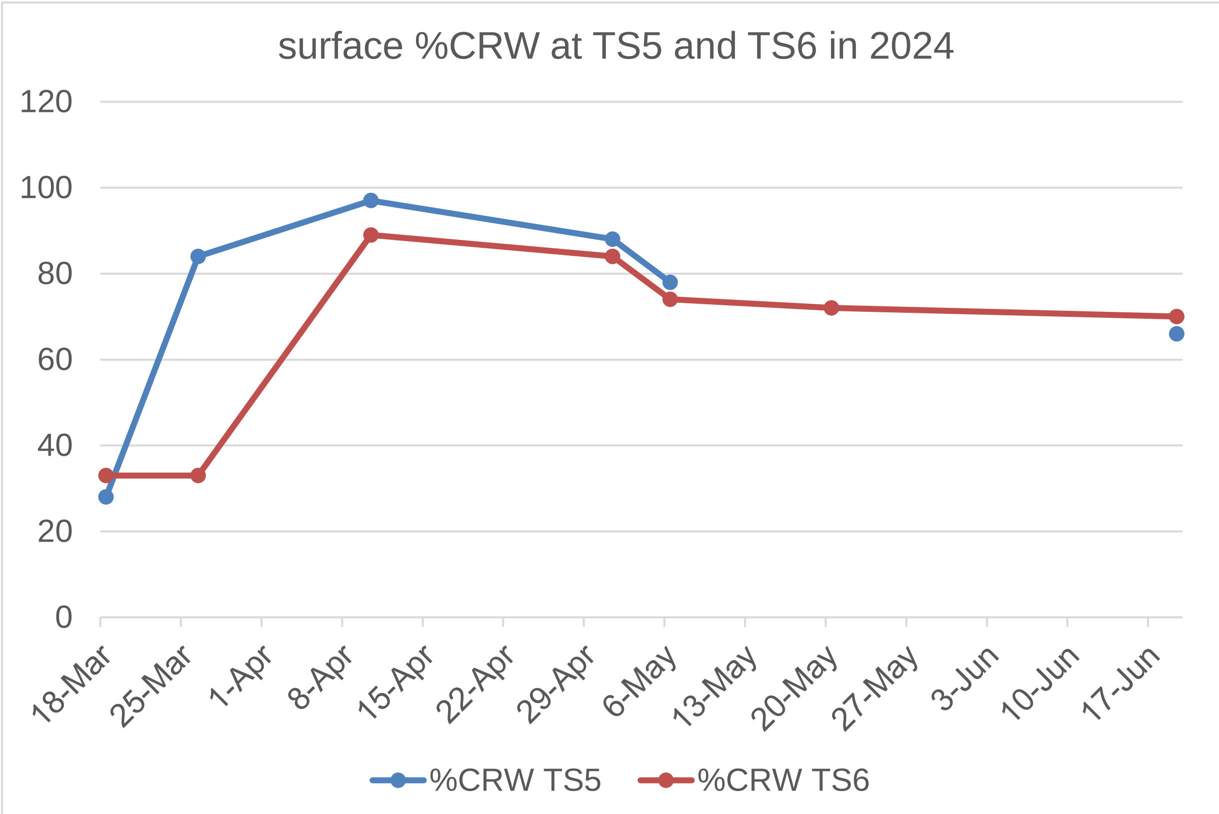

Figure 2. Progression of %CRW at the surface in lower Parker Horn and South Lake following CRW Input.

Rocky Ford Arm

Diffusion of CRW into RFA by wind progressed during May and June 2024, increasing from 50% to 63% in middle RFA (TS11) and from 33% to 40% in upper RFA (TS12). Percent CRW was higher at the surface than bottom, indicating that wind was more effective pushing water at the surface than at depth. Wind was determined in 1981 to be the driving force diffusing water from Parker Horn to Rocky Ford arm (Welch et al., 1982).

6.0 PATTERN OF CRW DISTRIBUTION IN THE LAKE

Entering low-TP CRW distributes throughout the lake due to wind, which is mostly from the SW, and is sufficient to transport the CRW-lake water mixture from lower Parker Horn well up into RFA (Welch and Patmont, 1980; Welch et al., 1982). However, percent CRW at the surface in the lake was always higher in lower Parker Horn and South Lake (TS5 and TS6) and occurred earlier than in middle RFA (TS11), which eventually reached around 60% CRW at 0.5 m by mid to late summer. That was the case in 2020 when CRW at South Lake (TS6), lower RFA (TS15) and middle RFA (TS11) averaged 66% at the surface (0.5 m) and 59% at 0.5 m off-bottom during July-September (Table 2). The CRW fraction was much higher at those sites and depths in 2021-2023; average 76% surface, 71% off-bottom (Table 2). Those three deep areas represent 58% of the lake area. Transport and dilution were apparently less effective in 2024 with less than 60% of CRW despite nearly 188,000 AF of CRW inputs through August.

The higher fraction of CRW throughout the lake in mid to late summer 2021 than in 2020 was probably not due to more inflow of CRW, which was 230,000 AF in 2021 versus 187,000 AF in 2020. Inputs of CRW were similar during April to June (153,000 versus 151,500 AF), while CRW at 0.5 m in June was 58% in 2020 and 71% in 2021. Also, total CRW input through June in 2022 was 156,300 AF, similar to 2021, while surface % CRW in June was even higher at the three sites in 2022 (82%) than in 2021 (71%). The CRW fraction was similar in June the previous three years, 2017-2019, at 53% with less CRW through June.

There is another process that probably enhances dilution as the summer progresses and CRW input continues. Colder and denser CRW probably tends to sink below the warming surface water. Temperature of CRW entering the lake is around 50°F in early April. The water column during July-September was more stratified in 2021 and 2022 than in 2020, 2023 and 2024, as indicated by RTRM and a greater difference in temperature between surface and bottom (Table 2). The greater stratification may have allowed colder CRW to plunge below the warmer, less dense surface water. Also, bottom water at five sites (TS 5,6,7,11 and 15) in May 2021 and 2023 had on average 14% less SC and was 5.6°F colder, indicating that colder CRW with less SC may have plunged as it entered the lake. That may indicate more effective dilution and account for the relatively high %CRW in deeper areas.

Table 2. July-September averages in 2020, 2021, 2022, 2023 and 2024 for thermal (density) resistance to water column mixing (RTRM), surface (0.5 m)-to-bottom temperature difference (°C), off bottom DO (0.5m off bottom) and surface/bottom % CRW. Averages are from South Lake (TS6), lower Rocky Ford Arm (TS15) and middle Rocky Ford Arm (TS11).

Characteristic	2020	2021	2022	2023	2024
RTRM	56	73	61	52	41
Temperature Difference	1.6	2.1	2.1	1.4	1.7
DO	4.5	3.8	4.6	5.3	3.1
% CRW	66/59	79/75	75/71	74/67	58/50

7.0 LAKE QUALITY

Average May–September surface TP was much higher in 2024 – more than double the average the past seven years at lower Parker Horn (TS5) and South Lake (TS6) and the past three years at middle and upper RFA (TS11/TS12; Table 3). The high averages were due to unusually high TPs in August and September.

Chlorophyll was proportionately much higher in 2024. Secchi transparency was less than the past seven years at TS5 and TS6 and the past four years at TS11 and TS12 (Table 3). There was 88% less transparency per unit chl at TS5 and TS6 in 2024 than in 2021-2023, indicating more non-algal turbidity.

The high TPs observed in August–September 2024 were not due to analytical error. Chlorophyll concentrations were also high in the same water samples with high TPs at typical chl:TP ratios. Average chl:TP ratio for the past seven years at TS5 and TS6 was 0.42, about the same as the ratio in 2024 of 0.40 (Table 3). The ratio at TS11 and TS12 was similar at 0.49 in 2024, including high TPs (Table 3). These high TPs occurred despite the relatively high average fraction of CRW (69%) at TS6 and TS7 during May–September. Most high TPs in 2024 were associated with high turbidity (Figure 3). Also, there was 25% less transparency than expected from chl at TS5 and TS6 in 2024 than in 2020-2023, indicating more non-algal turbidity.

The higher TP and chl, and less water transparency, at TS5 and TS6 occurred after the East Low Canal breach on August 5. Also, there was much higher TP than usual in Rocky Ford Creek (RFC), but the cause(s) for high TPs is unknown. Total Ps through July, before the breach, were similar to the past three years at 26 and 38 µg/L at TS5/TS6 and TS11/TS12, respectively. Thus, dilution with low-TP CRW was effective at maintaining low lake TP before the breach.

Table 3. May-September average TP, chlorophyll (chl), both in µg/L, and Secchi disk transparency in meters during 2017-2024 at lower Parker Horn/South Lake (TS5/TS6) and middle and upper Rocky Ford Arm (TS11/TS12). NS=not sampled. Chl* estimated from past average chl:TP ratios of 0.32 at TS5/TS6 and 0.26 at TS11/TS12, for 2 of 5 months without data during 2021.

Site	Year	TP	chl	SD
Lower Parker Horn/South Lake	2017-2019	32	13	1.4
	2020	41	22	1.6
	2021	20	7*	3.0
	2022	20	8	3.0
	2023	25	10	2.1
	2024	65	26	0.9
	8-year Average	**33**	**14**	**1.5**
Middle and Upper Rocky Ford Arm	2017-2019	81	38	NS
	2020	99	63	0.9
	2021	42	11*	1.9
	2022	30	11	1.9
	2023	45	20	1.6
	2024	88	43	0.7
	8-year Average	**68**	**33**	**1.4**

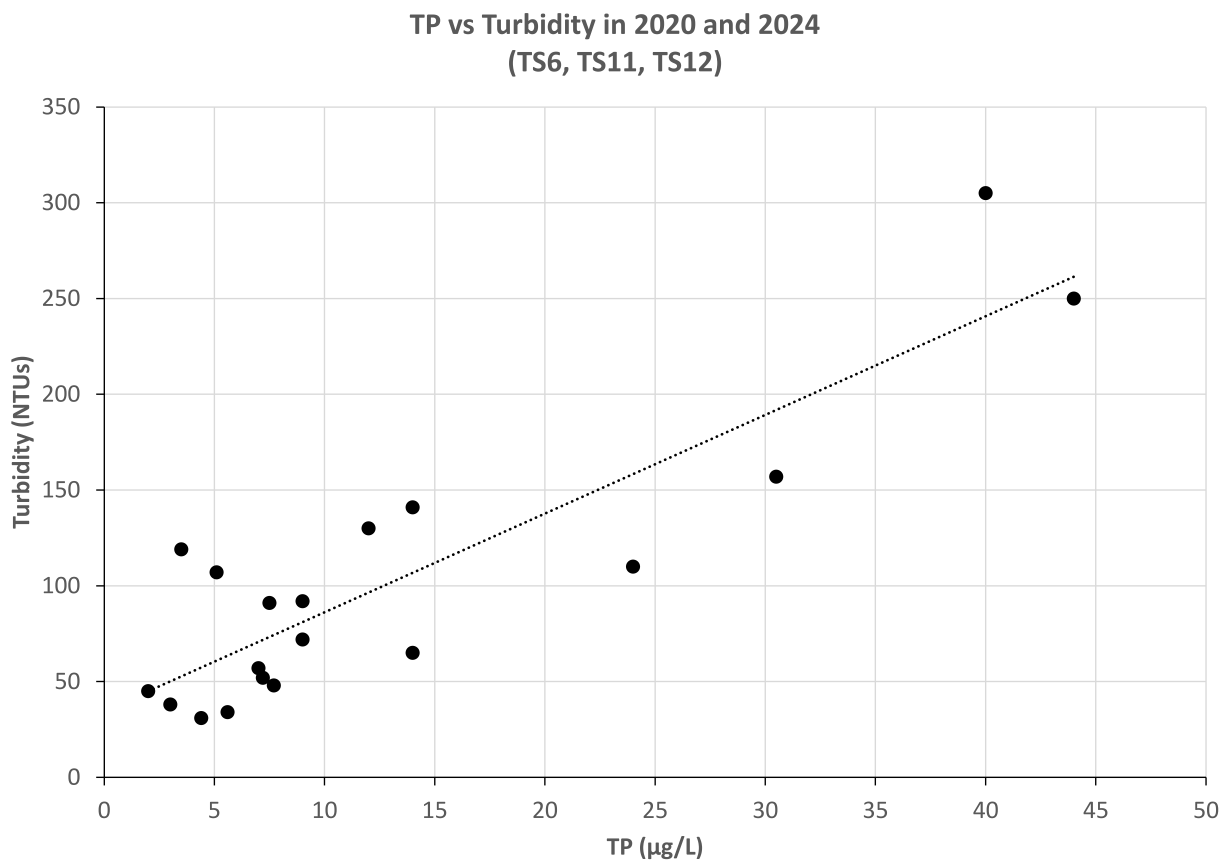

Figure 3. Total P in µg/L related to turbidity (NTU) at TS 6, 11 and 12 during 2020 (n=10) and 2024 (n=6). Some points are averages in the water column, depending on available data. Observed ranges in TP and NTU were 31-1051 µg/L TP with 4-27 NTU in 2024 and 45-305 µg/L TP with 2-40 NTU in 2020. Some high TPs that would skew the relationship minimizing the effect of lower levels were omitted from the figure.

There was apparently a large mass of TP that entered the lake through Rocky Coulee Wasteway (RCW) after the East Low Canal breach on August 5. The resulting high lake concentrations substantially raised the spring-summer averages. Average May-September surface TP in 74% of the lake was 8 times higher than in 2021-2023 (Table 4). Volume-weighted, whole-lake TP was 4 times higher. Most of the very high TPs were in lower Pelican (TS7) during August–September. If TPs at TS7 are omitted, average TPs at the other four sites were 42 and 47 µg/L – only about 50% greater than the past three years. Omitting TPs on August 27 at upper/middle RFA gives a May-September average of 44 µg/L, similar to 2021-2023 (39 µg/L).

Dilution was also less effective in 2024 at 61% CRW compared to over 70% CRW the past three years. The relatively low dilution effectiveness was despite the high CRW input (Table 4). However, 2% (4,165 AF) of the CRW input from March 22 to September 17 was during 8/7-8/13, just after the August 5 breach when East Low canal (ELC) water between 7/31 and 8/27 contained high concentrations of phosphorus (279 µg/L TP and 169 µg/L SRP), as well as high nitrate-nitrogen (3970 µg/L) and SC (683 µS/cm). Also, TP in Crab Creek (TS2) was 1900 µg/L on 7/31, which was nearly all SRP. Canal water (CRW) has been historically and consistently low in TP at only 7-8 µg/L. The high nitrate-nitrogen and SC were about 200 and 5 times the usual concentrations in ELC. The high SC may partly account for the low %CRW in the lake, because SC is a tracer for CRW (see Table 14). The source for the unusually high constituent levels entering the lake from the canal through RCW is unknown.

Table 4. May-September average total phosphorus (TP) in µg/L at 5 sites that represent 74% of the lake area (TS5, TS6, TS7, TS11, and TS15), average July-September surface %CRW, total CRW inflow, lake elevation at start of CRW input and duration of CRW input. (*42 µg/L without TS7; **44 µg/L without TS7).

	2020	2021	2022	2023	2024
Average TP (surface 0.5m)	47	24	21	29	210*
Average TP (all depths)	74	34	30	35	126**
%CRW	65	77	73	73	61
CRW (1000s AF)	187	230	190	160	204
Pre CRW elevation (ft)	1042.3	1042.2	1041.3	1042.6	1043.3
CRW input duration (days)	120	94	90	84	100

Average surface TP increased seven-fold at five sites in Parker and Pelican Horns and the lower lake during August and September (Table 5). Some TP concentrations were as high as in wastewater, which averaged 5,200 µg/L before wastewater diversion in 1984. The source for the unprecedented high TPs in these areas is unknown, although canal water that entered the lake through Rocky Coulee Wasteway had unusually high concentrations of TP and other constituents. Part of the inflow was pumped into Pelican Horn as usual at 21 cfs. This source of high-TP water to the lower lake did not reach into lower RFA. Average May – September TP in lower RFA (TS15) was 47 µg/L, which was not unusual. There were also high TPs at depth on 9/30; 9420 µg/L at TS6b, 735 µg/L at TS7b, and 1820 µg/L at TS8d.

Table 5. Average and range of inflow and surface TP concentrations (µg/L) during August and September 2023 and 2024, for Crab Creek inflow (TS2), Upper Parker Horn (TS4), Middle and Lower Park Horn (TS8 and TS7) and the lower lake (TS6).

Year	TS2	TS4	TS6	TS8	TS7
2023	35 (31-41)	32 (24-38)	23 (16-31)	26 (22-33)	26 (16-36)
2024	96 (18-157)	117 (33-265)	198 (32-343)	251 (21-700)	2704 (28, 5380)

Dilution of high TP

The August-September volume-weighted TP in the lower lake area (TS5, TS6, TS7) was 557 µg/L. The highest TP was in lower Pelican Horn (TS7; 1563 µg/L). The high TPs will be diluted some during winter due to inflow from Crab Creek and groundwater at 20 and 10 cfs, respectively, from September through March, as in 2024, the exchange rate for that lake volume (1/3 of total lake) would be about 0.1% per day and the final calculated lake TP would be 424 µg/L by the end of March, using an inflow TP of 45 µg/L. If CRW inflow in 2025 is similar to that in 2024 during April through June at 1216 cfs, producing an exchange rate of 1% per day, with a CRW TP of 8 µg/L, the calculated lake TP would be 15 µg/L. Whole-lake, volume-weighted TP at TS5 and TS6 in May 2024 was 11 µg/L (no data at TS7). Average TP at the three sites through June 2024 was 27 µg/L, the increase being due to internal loading. Thus, the late season high TPs due to the canal breach will likely be mostly diluted by June 2025.

Total P in inflow streams

Total P concentrations in the two surface streams entering the lake remained rather constant through 2023 (Table 6). Total P concentrations in Rocky Ford Creek (RFC) over the past 30 years averaged 158 µg/L. Total P was less at the source spring to RFC over a shorter period. Total P in Crab Creek markedly declined by the 1980s, largely due to a change from till to spray irrigation in the watershed, resulting in less erosion. Average TP has remained rather constant since the 1980s at 48 µg/L.

These stream inflows are not the major source of mass TP loading to the lake. Their contributions in 2020 and 2021 averaged 5.8% for Crab Creek and 21.8% for Rocky Ford Creek. The major contributor was internal recycling of P from bottom sediments at 52.6% of the total (Tetra Tech, 2022a and 2022b). So, input of TP from the major portion of the watershed is a minor contributor to the lake.

Table 6. Total P concentrations (µg/L) averaged (±%deviation from average) over indicated periods during mostly spring-summer in Rocky Ford Creek at two sites and Crab Creek. USBR sites, RFC spring CBP114, CC CBP161, RFC Hwy 17 CBP060. MLIRD sites: RFC TS14, CC TS2.

	UW 1968-1970	UW 1977-1979	UW 1986-1988	Recent Years
Rocky Ford Spring				115±30% (n=39, 2010-2020 USBR)
Rocky Ford Spring				103±17% (n=5, 2001 DOE)
Rocky Ford Hwy 17	172	167	165	157±28% (n=116, 1995-2020 USBR)
Rocky Ford Hwy 17				130 (n=2, 2001 DOE)
Rocky Ford Hwy 17				161±8% (n=39, 2019-2023 MLIRD)
Crab Hwy 17	111	92	47	48±107 (n=82, 2003-2018 USBR)
Crab Hwy 17				52±30% (n=39, 2017-2023 MLIRD)

8.0 CYANOBACTERIA, MICROCYSTIN, AND WATER QUALITY

Microcystin concentrations were relatively low near shore at Connelly Park in middle Rocky Ford Arm (RFA, near TS11) in 2018 and 2019 (20 and 13 µg/L). Yet, May-September average TP and chl concentrations in open water (TS11) were very high averaging 92 and 50 µg/L, respectively (Table 7). On the other hand, microcystins were relatively high at Blue Heron Park in 2018 (606 µg/L) with open-water TP and chl concentrations at nearby lower Parker Horn and South Lake (TS5 and TS6) less than half the levels at middle RFA (Table 7). The alga *Microcystis* (MA), producer of microcystin, was the dominant cyanobacteria at both open water sites in 2018, despite the large difference in near-shore microcystin (Table 7). Total cyanobacteria (blue-green algae) also dominated algal biovolume in RFA (82%) and lower Parker/South Lake (43%) during July-September 2017, but microcystin was not sampled.

There was less microcystin at Blue Heron in 2019, and much less open water TP, than at Connelly Park (Table 7). Microcystin was similarly high at both sites in 2020, but TP and chl in open water at middle RFA (TS11) were more than double levels at lower Parker Horn and South Lake in both years. Also, the high average microcystin concentrations at Connelly Park in 2021 (1098 µg/L) were inconsistent with the low *Microcystis* fraction (6%) of total algal biovolume and relatively lower TP (42 µg/L) in open water at middle RFA (Table 7).

Water quality and levels of cyanobacteria improved during 2021-2023. Total P was unusually low throughout the lake in spring and early summer 2021, especially at lower Parker Horn and South Lake (average 14 µg/L; Table 7). There was no *Microcystis* (MA) at middle RFA (TS11) or at lower Parker Horn and South Lake (TS5 and TS6) in June, and that alga was only 0.4 and 3.4 % of total biovolume at those sites, respectively, in August. Microcystin was not observed at Blue Heron Park in 2021 due to no obvious scum formations that usually prompted sampling. That was consistent with the low % *Microcystis* and TP and chl concentrations in open water at lower Parker/South Lake (TS5/6; Table 7).

Cyanobacteria and *Microcystis* (MA) were low at both open-water sites (TS6 and TS11) in 2022, consistent with low TP and chl (Table 7). There were two small scums at Blue Heron in September 2022 that produced high microcystin concentrations, which was inconsistent with low TP, chl, cyanobacteria and *Microcystis* in open water at lower Parker Horn and South Lake. Microcystins were usually present at low, less than state standard concentrations (8 µg/L) in the nearshore at Connelly Park, but were absent at Blue Heron except for two small scums in September. Total P and chl, as well as the cyanobacteria fraction of total algal biovolume, were higher at the open water sites in 2023 than the previous two years. Yet microcystins were as low as in 2022 (Table 7).

The cyanobacteria and *Microcystis* (MA) fractions of biovolume were also low at the two open water sites in 2024, yet May-September average TP and chl were higher than any of the past several years (Table 7). Diatoms were the dominant algal group at both sites during the summer. The low cyanobacteria, *Microcystis* and microcystin were consistent with relatively low average TP during May to mid-August at TS11 (35 µg/L) and May-July at TS6 (22 µg/L).

For most of the observations, there is no obvious relationship between concentrations of the toxin microcystin in algal accumulations from near-shore samples and algal composition or TP and chl in open water at the two sites. The inconsistent association between microcystin in near-shore water and open water TP, chl, % cyanobacteria and % *Microcystis* (MA) indicates that other factors besides open water conditions determine the accumulation of cyanobacteria, *Microcystis* and associated microcystin in near-shore areas. Wind is important in distributing buoyant cyanobacteria throughout the lake. They tend to accumulate at the surface in open water due to their buoyancy as the day progresses and are distributed to nearby shores as wind typically increases in the afternoon. Thus, relatively low concentrations of cyanobacteria can accumulate in large clumps on the surface in open water and those clumps can be transported downwind to shore. Microcystins have occurred in near-shore areas of other lakes with very low chl concentrations in open water (Jacoby et al. 2000; 2015). Also, *Microcystis* is usually in bottom sediment at high concentrations and can migrate vertically into and through the water column, as do other buoyant cyanobacteria (Barbiero and Welch, 1992). Those processes can account for the high variability observed in these data - nearly 100% of averages in the near-shore microcystin concentrations.

These observations also indicate that clumps of *Microcystis*, and its associated microcystin, could still accumulate in near-shore areas even if the spring-summer average open water TP were 20 -30 µg/L. Those accumulations would be expected to diminish eventually if an average TP of 20 µg/L were regularly attained, because the risk of cyanobacteria fractions of algal biomass over 50% is known to decrease as TP declines below around 30 µg/L (Downing et al., 2001). Nevertheless, open water TP averaged 22 µg/L at lower Parker Horn and South Lake in 2021-2023, and while the nearby Blue Heron Park shoreline was not sampled in 2021 because algal scums were not obvious, there were relatively small scums with high microcystins there in late 2022, and three samples with low microcystins in 2023 (Table 7).

Cyanobacteria averaged 71% of total algal biovolume at four sites during 2017-2018 (TS5, TS6, TS11 and TS12). *Microcystis* dominated at 78% of maximum cyanobacteria biovolume, while *Aphanizomenon* averaged only 3%. In 2021, cyanobacteria did not dominate averaging 22 and 23% at two sites (TS11 and TS6) and *Microcystis* averaged only 8% and *Apanizomenon* averaged 5%. In 2022, cyanobacteria were again low averaging 21%, as were *Microcystis* at 1% and *Aphanizomenon* at 15%. Cyanobacteria were more prevalent in 2023 at 27 and 45% of total biomass, but *Microcysits* was again low at only 1% and *Aphanizomenon* was 7 and 24%. These low concentrations of cyanobacteria were consistent with the low TP concentrations, especially in 2022. However, the exceptionally high TP and chl at the two open-water sites in 2024, along with low cyanobacteria and *Microcystis* (MA) fraction, associated with low near-shore microcystin concentrations, illustrate the inconsistency between open-water WQ and near-shore scum accumulations. Also, the low TP and chl observed in 2021-2023, due to effective dilution, may not always result in low or no near-shore scums and microcystin, as was the case at Connelly Park in 2021 and Blue Heron in 2022 (Table 7).

Table 7. Average microcystin concentrations in µg/L from near-shore samples at Connelly Park and Blue Heron Park, near TS11 and 5, respectively, usually during mid to late summer with sample no. in (); NS = no samples taken. Open-water average percent cyanobacteria (CY%) and Microcystis (MA %) fractions of total biomass at TS 6 and TS11. TP and chl at 0.5 m depth in µg/L at middle RFA (TS11) and lower Parker Horn/South Lake (TS5/6) during May-September. NS = microcystin not sampled. No scums = no accumulations observed to sample.

Year	Connelly Park	Rocky Ford Arm				Blue Heron Park	Lower Parker Horn/South Lake			
	Microcystin	CY%	MA%	TP	Chl	Microcystin	CY%	MA%	TP	Chl
2017	NS	82	57	37	10	NS	43	35	25	7
2018	20 (4)	79	67	83	49	606 (8)	87	64	41	18
2019	13 (11)	NS	NS	101	51	78 (15)	NS	NS	30	14
2020	220 (33)	NS	NS	99	63	197 (11)	NS	NS	41	22
2021	1098 (8)	23	6	42	11	No Scums	22	10	20	7
2022	2 (9)	30	1	27	11	575 (2)	12	1	20	8
2023	2 (1)	45	1	45	15	7 (3)	27	1	25	10
2024	1.4 (1)	26	2	88	43	2.1 (3)	26	6	65	26

9.0 WATER TEMPERATURE

Surface water temperature has increased on average about 2°F during May-September at lower Parker Horn and South Lake since the 1980s. The increase was about 3°F for mid-summer or the whole summer (Table 8). The increase was only about 1°F during spring-summer from the slightly warmer 1970s. The 2°F is less than half the temperature increase recorded in 2019 for 245 world lakes from 1985 extrapolated by decadal increase to 2025. Water temperature was much less in 2024, probably due in part to more CRW throughout the summer at a total of over 204,000 AF.

Blue-green algae tend to be favored by increased temperature. However, the dominance of blue-greens has been rather closely related to TP concentration, with low fractions of total algal biovolume during 2021-2023 associated with TPs of 20-30 µg/L resulting from large inputs of low-P CRW. That is consistent with the risk that cyanobacteria fractions of algal biomass over 50% was shown to decrease as TP declined below around 30 µg/L (Downing et al., 2001). Also, the start of blue-greens in Moses Lake was shown in the 1980s to occur when lake temperature reached about 68°F (20°C). The average for May-June has not increased much above that recently. The lower surface temperatures during 2024 may account for the dominance of diatoms throughout the summer.

Table 8. Average surface temperature in lower Parker Horn and South Lake for different periods during spring-summer over a range of Columbia River dilution water (CRW) during 1977 and 1979 (164,760 to 209,150 AF) and 1986-1988 (66,020 to 207,280 AF) and 2017-2024 (75,456 to 230,000AF). Sampling frequency during 1977-1988 was usually twice-monthly as well as during the past 7 years.

Year	CRW (AF)	Average Surface (0.5 m) Temperature at TS5/TS6			
		May-June	July-August	September	May-September
2017	75,456	67.2	77.6	70.5	70.5
2018	105,758	66.2	75.4	67.0	69.5
2019	119,077	71.0	75.3	64.5	70.3
2020	186,813	66.7	74.5	67.2	69.5
2021	230,003	67.2	79.0	67.8	72.0
2022	190,304	68.2	74.3	76.8	73.1
2023	159,300	68.9	77.3	66.3	71.7
2024	204,218	59.7	73.4	63.8	66.8
Water Column Average		66.9	75.9	68.0	70.4
1977/1979	186,950	64.9	75.9	65.8	69.5
1986-1988	114,500	64.5	72.6	66.5	68.1

10.0 EFFECTIVENESS OF INACTIVATING SEDIMENT PHOSPHORUS IN MIDDLE AND UPPER ROCKY FORD ARM

Treatment

The middle and upper sections of Rocky Ford Arm (RFA) were treated with 250 tons of EutrosorbG containing 10% lanthanum (La) and 90% clay during the first two weeks of June, 2024 (Figure 4). The treatment area was 2910 acres with a volume of 51,880 AF (63.99 x 10^6 m^3). The resulting La concentration was about 0.5 mg/L. Lanthanum sorbs mobile phosphorus in bottom sediments thus reducing sediment phosphorus release and internal loading. The treatment strips soluble phosphorus (SRP) from the water column, but not particulate phosphorus, which is usually most of the total phosphorus (TP) in the water column (95% in 2023).

A mass balance TP model calibrated for the whole RFA showed that 64% of phosphorus loading was from internal release of sediment phosphorus (Tetra Tech, 2020). Whole-lake TP was predicted to decrease from 63 µg/L to 31 µg/L (50%) through stripping TP from the water column and inactivating sediment mobile phosphorus with alum. EutrosorbG was expected to have a similar effect on internal loading from bottom sediment but not a similar reduction in water column TP.

Middle RFA is the largest section in the lake at 27% of total area with a mean depth of 21.7 ft (6.6 m). The area can temporarily thermally stratify resulting in low dissolved oxygen (DO) near the bottom; 6.6 mg/L (55% saturation) on 7/19/2020 and 0.8 mg/L (12% saturation) on 7/22, both after 8:00 am. Anoxia (zero DO) probably existed at the sediment-water interface during the night on those dates. Sediment-P release rate was observed at ten times the oxic rate in Moses Lake sediment cores (Okereke, 1987). Also, internal loading has increased after wind mixing (Jones and Welch, 1990). The total P mass balance model calibration for RFA produced an oxic and anoxic release rate of 4 mg/m^2 per day, similar to the laboratory-experimental rate of 3.5 mg/m^2 per day (Okereke, 1987; Tetra Tech, 2020).

Figure 4. Barge transporting EutroSorbG to treat sediments in Rocky Ford Arm, 2024.

Phosphorus and Chlorophyll

Seasonal, May–September, average TP and chl have been used to indicate water quality conditions in the lake since before and after the Clean Water Project started in 1977. Columbia River water (CRW) inputs have usually started in April, so dilution has occurred in some lake areas by May, as occurred in 2024 (see Lake Level Effect). Average, May-September, surface (0.5 m) TP at TS 11 and TS12 did not decrease in 2024, as expected, compared to averages in 2021–2023, or to the average in 2020-2023, but was less than the average in 2020 (Table 9). The high average TP in 2024 was largely due to an unusually high surface TP on August 27 of 932 µg/L at TS12 (0.5 m off-bottom TP was 1,170 µg/L). Surface TP at TS11 was also high at 129 µg/L, but TP concentrations around 100 µg/L have occurred previously, especially in 2020 (Table 9). Chlorophyll was also higher in 2024 than in either 2021, 2022, or 2023, but less than in 2020 (Table 9).

The high TP concentrations in 2024 at TS11 and TS12 were not due to analytical error, as explained in the WQ section. Chlorophyll (chl) concentrations were also high in the same water samples with typical chl/TP ratios. The average chl/TP ratio in samples at TS11 and TS12 from May-September in 2024 was 0.40 (Table 9). The average chl/TP ratio for the other four years was 0.46. Total P was 932 µg/L at TS12 in the late August sample with chl of 345 µg/L for a chl/TP ratio of 0.37. Thus, chl, in the same water sample, was consistent with the high TP concentrations.

The source of the unusually high TP at TS12 in 2024; (932 µg/L at 0.5 m and 1,170 µg/L 0.5 m off-bottom on 8/27 and 3,890 µg/L on 9/30) is unknown. There were also unprecedented high TP concentrations in the lower lake on 9/30; 343 µg/L (chl of 120 µg/L) and 9,420 µg/L and 5,380 µg/L at TS6 a, b and 737 µg/L at TS7 a, b. These high levels occurred after the breach in the East Low Canal on August 5, with canal water upstream of the breach diverted to Rocky Coulee Wasteway. The diverted flow during 8/7-8/13 was 4,166 AF. Although there were no spikes in Crab Creek flow, TP was 1,900 µg/L on 7/31 and 114 µg/L on 8/14, before and after the canal breach in contrast to the long-term average TP in Crab Creek (TS2) of 48 µg/L. Also, TP at Upper Parker Horn (TS4), where Crab Creek flows into Parker Horn, was 165 µg/L on 8/14, well above usual levels. Average flow in Crab Creek during May-September, at 63 cfs, was not unusual.

The source for high TPs at TS12 was unlikely connected to the source of high TPs in the lower lake, because TP at TS15, between the lower lake and upper RFA (TS12), averaged only 46 ± 29% µg/L (maximum 66 µg/L). However, there were high TPs in upper (TS14) and lower (TS16) Rocky Ford Creek on 7/30 and 8/27 of 194 and 761 µg/L at TS 14 and 560 and 690 µg/L at TS16. Rocky Ford Creek has a long-term average TP of 158 µg/L (Table 6). Although Rocky Ford Creek inflows with TPs of 100s of µg/L do not account for TPs in 1000s of µg/L in the lake at TS12, particulate phosphorus could accumulate on the lake bottom and be resuspended with wind mixing producing higher concentrations in the water column than in the inflow. Internal loading can also raise lake TP well above inflow concentrations. Total P in Rocky Ford Creek was unusually lower than the long-term average in September at 53 and 44 µg/L at the two sites.

Given the unusually high TPs at TS12 in 2024, data at TS11 and TS15 were used to evaluate effectiveness of the sediment treatment to reduce TP and chl in middle and lower RFA. Surface (0.5 m) and volume-weighted water column TP and surface chl in 2024 were compared with similar data in 2020, because dilution effectiveness was similar, 50% CRW during June–August in 2020 and 51% in 2024. Dilution in upper/middle RFA was more effective during those months in 2023 at 86% CRW and the 2021 – 2023 average was 73%. Inputs of CRW into Parker Horn were not that different; 139,820 AF in 2020, 153,929 AP in 2023, and 183,670 AF in 2024. Wind speed and direction was shown to transport the mix of CRW and lake water from lower Parker Horn to and through RFA and wind speed and direction have been similar the past eight years. Although there was more CRW in 2024 than in 2020, %CRW were essentially the same. Total P is related to % CRW from long-term data in the lower lake (Welch and Brattebo, 2024a). May–September average TP during 2021–2023 at TS11 and TS12 was lower than in earlier years at 37 µg/L with an average of 65% CRW, which is predicted by the regression equation.

With these constraints, the treatment was apparently effective at reducing internal loading. Average surface (0.5 m) TP during June–September at TS11 decreased from 68 µg/L in 2020 to 52 µg/L in 2024 or by 24%, while chl decreased 36% (Table 10). The decrease was less for average volume-weighted TP for four depths. Surface TP exceeded 100 µg/L only once in 2024 (129 µg/L on 8/27) and twice in 2020 (105 and 128 µg/L). Average surface TP at TS12 showed no change; 158 µg/L in 2020 and 154 µg/L in 2024. All surface TP concentrations at TS12 were over 100 µg/L in 2020, but only one in 2024 at 932 µg/L.

Off-bottom (0.5 m) TP concentrations at TS12 in 2024 included 1,170 and 3,890 µg/L on 8/27 and 9/30, respectively, which were 4 to 5 times higher than in any previous samples. They were not considered for treatment effectiveness because off-bottom was not sampled at TS12 in 2020. There were no off-bottom TP concentrations over 67 µg/L in 2023.

High surface (0.5 m) TP concentrations over 100 µg/L were included for treatment effectiveness because such high TPs greater than 100 µg/L in RFA were not that unusual and analytical error was not suspected. Chlorophyll was consistent with TP and seven years of TP analyses of Moses Lake water samples by the IEH Analytical Laboratory have been highly reliable.

Algal composition

Green algae and diatoms tend to dominate in May and early June, then blue-greens (cyanobacteria) increase later when the water warms in June. Blue-greens usually start when water temperature reaches about 20°C (68°F). The blue-green alga *Anabaena* was more dominant in 2024 in May and early June than the past two years (Table 11). The blue-greens *Anabaena* (Ana) and *Aphanizomenon* (Aph) were the dominant taxa through early July in 2024 as in the previous two years. However, diatoms were dominant by the end of July through August in 2024, which is unusual, although they typically dominate by September, as occurred in 2022-2024. *Microcystis*, the producer of microcystin, began to show up in July 2024, but at only 1% of total algal biovolume and averaged only 6% later in July through September. Diatoms continued to dominate algal biovolume through September in 2024 as in previous years. The unusual dominance by diatoms starting in mid-summer and lower fraction of blue-greens, especially *Microcysis*, may indicate a positive effect of the sediment treatment.

Table 9. Total P and chlorophyll (TP/chl) in µg/L at 0.5 m in upper and middle Rocky Ford Arm (average for TS11/12) during spring-summer 2024 compared to data from the previous four years with May-September averages in the bottom column. Sample timing represents 2024, and approximate times for other years. TPs for missed sampling dates in quotes are assumed as an average of previous and next sample dates for time weighting. Missed samples for chl in quotes are estimated using an average chl:TP ratio of 0.39 for 2020-2023 data. Average chl:TP for 2024 was 0.40.

Sample Date	2024	2023	2022	2021	2020	2020 - 2023
May	30/13	15/5	"15/6"	14/1	75/"29"	30/5
June week 1	53/16	24/3	30/8	25/2	106/17	22/8
June week 3	47/18	53/24	19/5	66/12	135/25	68/17
July week 1	29/8	58/36	27/13	32/8	158/110	69/58
July week 4	38/8	50/18	"24/10"	26/"9"	175/198	34/13
August week 2	32/9	35/13	21/4	33/NS	"143/56"	30/9
August week 4	530/189	49/23	22/7	88/NS	111/88	53/15
September week 1	NS	39/21	61/10	46/14	86/34	49/15
September week 2	48/43	60/57	40/42	77/27	36/55	59/42
May-Sept	89/36	40/21	28/13	42/9	110/69	55/28

Table 10. Average surface (0.5 m) TP and chl concentrations and volume-weighted TP concentrations at TS11 and TS15 during June to September before (2020) and after (2024) treatment of upper and middle RFA with EutrosorbG. Dilution effectiveness as % CRW and CRW volume (AF) during June – August at TS11/TS12.

Station	Parameter	2020	2024	%Decrease
TS 11	Surface TP (µg/L)	68	52	24%
	Surface Chl (µg/L)	36	23	36%
	V-W TP (µg/L)	69	64	8%
TS15	Surface TP (µg/L)	69	47	32%
	Surface Chl (µg/L)	32	16	50%
	V-W TP (µg/L)	67	48	28%
%CRW		50	51	--
CRW Volume (AF)		139,828	204	--
CRW Days		120	100	--

Table 11. Dominance of algal groups at 0.5 m at middle Rocky Ford Arm (TS11) in % of total algal cell volume. Blue-greens (BG), or cyanobacteria, were usually *Microcystis, Anabaena, Oscillatoria* and *Aphanizomenon*. Green algae (G) and Diatoms (D) included several taxa. Other non-nuisance taxa usually contributing small volume fractions were not included. NS = not sampled. Sample timing represents 2024, and approximate for other years. Sample week 2 Sept 2024 was Oct 1.

Sample Date	2024	2023	2022
May week 3	G 83% D 15%	NS	NS
June week 1	G 72% BG 19%	G 74% D 20%	G 91% D 5%
June week 3	BG 85% D 11%	G 74% D 28%	G 52% D 32%
July week 1	BG 79% D 14%	BG 86% D 9%	BG 81% G 15%
July week 4	D 81% BG 9%	BG 75% D 20%	NS
August week 2	D 76% BG 11%	BG 79% D 17%	BG 37% D 20%
August week 4	D 75% BG 19%	BG 60% D 34%	G 27% BG 5% D 7%
September week 1	NS	D 50% BG 46%	D 46% BG 10%
September week 2	D 79% BG 19%	D 94% BG 3%	D 80% BG 9%

11.0 TREATMENT OF ROCKY FORD CREEK

A soluble-phosphorus binding agent, EutrosorbWC, was added to lower Rocky Ford Creek (RFC) at Drumheller Dam starting in June 2024. Soluble reactive phosphorus (SRP) has been usually high in RFC. Total-P and SRP data from TS14, downstream from the Trout Lodge hatchery at Highway 17, was compared with data from a new site (TS16) downstream from the SRP binding agent addition at Drumheller Dam (Table 12).

The average TP and %SRP (164 µg/L, 66% at TS14) during 2020-2023 was consistent with earlier data from that site during 1995-2023 (158 µg/L, Table 6). However, the magnitude of some TP concentrations and range in 2024 were unusual and unprecedented.

Similar wide ranges in other constituents (TN and SC) at TS14 were unusual as well (Table 13). Average TN in 2024 was similar to the level in 2023, but the range was six times greater in 2024. The range in SC was ten times greater in 2024 than **in** 2023. Average TN and range at TS16 were similar to those at TS14 (Table 13). The high TN (4130 µg/L) occurred on 8/14 after the canal breach, as well as the highest TN (4510 µg/L) at TS16 on 8/27. Also, the low SC (67 µS/cm) occurred on 8/27. However, there was likely no connection between the canal breach and the unusually high and low TPs and TNs at TS14 and TS16, and low SC at TS14. The distance between the breach site and RFC is about 13 miles.

Average TP and SRP concentrations at the downstream site (TS16) were actually higher than at TS14, which is upstream of the EutrosorbWC addition, with a similar range in TP and even greater range in SRP (Table 12). The unusually large variation upstream and downstream of the EutrosorbWC addition site, in both TP and SRP, greatly reduced the prospect of any meaningful assessment of treatment effectiveness.

Table 12. Average and range of TP and SRP in Rocky Ford Creek at TS14 (Hwy 17) and TS16 (near lake) during May – September in 2024 and previous years.

Site	Parameter	2024	2020-2023
TS14	TP (µg/L)	188 (12 – 761)	164 (132 – 296)
	SRP (µg/L)	28 (<1 – 83)	109 (80 – 122)
TS16	TP (µg/L)	313 (34 – 690)	--
	SRP (µg/L)	81 (<1 – 277)	--

Table 13. Average and range of Total N (µg/L) and specific conductance (µS/cm; SC) at TS 14 (Hwy 17) and TS 16 (near lake) during May – September 2023 and 2024.

Site	Parameter	2024	2023
TS14	TN (µg/L)	1854 (626 – 4130)	2099 (1860 – 2710)
	SC (µS/cm)	319 (67 – 613)	362 (350 – 384)
TS16	TN (µg/L)	2312 (640 – 4510)	--
	SC (µS/cm)	334 (302 – 360)	--

The East Low Canal breached on August 5 and CRW flows were diverted to Rocky Coulee Wasteway, upstream of the breach, and into Moses Lake. Nevertheless, unusually high concentrations of constituents occurred in inflow streams before and after the breach.

Specific conductance (SC), nitrate-N, and TP concentrations were much higher than usual in inflows just before (7/31) and the August 5 canal breach than during June and early July (Table 14). Maximum concentrations in the East Low Canal, Crab Creek, and Rocky Ford Creek during June-July were typical, but subsequent maximums were much higher than unusual (Table 14). However, a connection between the high levels in the two inflow streams and the breach site, as well as high levels in the canal at TS1, was unlikely given the distance involved.

Table 14. Change in maximums of specific conductance (SC, µS/cm), nitrate (µg/L) and total phosphorus (TP, µg/L) in the East Low Canal (TS1), Crab Creek (TS2) and Rock Ford Creek (TS14) during June 19 – July 9 and July 31 – August 14, 2024 (no SC data for Crab Creek).

Location	June 19 – July 9			July 31 – August 14		
	SC	Nitrate	TP	SC	Nitrate	TP
East Low Canal	173	42	11	683	5440	279
Crab Creek	No data	159	80	No data	13200	1900
Rocky Ford Creek	309	908	161	613	4120	761

12.0 SUMMARY AND CONCLUSIONS

1. Lake water quality markedly deteriorated in 2024, compared to water quality in 2021-2023. Total P increased to unusually high concentrations in late summer 2024 from an average of 22 µg/L during May-July to 234 µg/L in August-September at South Lake (TS6). The high late summer TPs raised the May-September average at lower Parker Horn and South Lake to 65 µg/L from the 2021-2023 average of 22 µg/L. The May-September average at five sites, lower Parker Horn (TS5), South Lake (TS6), Middle Rocky Ford Arm (TS11), Lower Pelican Horn (TS7) and lower RFA (TS15) was 210 µg/L. August-September average TP at TS4 (upper Parker Horn), TS6, and TS7 was 1000 µg/L, nearly 40 times higher than in 2023 (27 µg/L). The high TP in lower Pelican Horn (TS7) was 5380 µg/L, slightly higher than the average in wastewater before diversion in 1984. These high, late-summer TPs were not due to analytical error, because chl concentrations were proportionally higher, with chl to TP ratios consistently around 0.40.

2. The source(s) for the late-summer TPs in the lower lake is unknown, but they occurred just before and after a breach in the East Low Canal on August 5, which necessitated diverting canal water to Rocky Coulee Wasteway (RCW) and into the lake. Canal water contained 113 and 279 µg/L TP on 8/14 and 8/27, respectively, 14 and 35 times the long-term average of 8 µg/L. Also, TP in Crab Creek, upstream from RCW, averaged 724 µg/L between 7/31 and 8/27, 15 times the usual average of 48 µg/L. These increased TPs were accompanied by large increases in nitrate-N and specific conductance. While the original source for these unusually high concentrations is unknown, the high canal TPs occurred in August after the breach when 4,165 AF of canal water entered the lake through RCW. The high volume-weighted TP of 557 µg/L at TS5, 6 and 7 in August-September should be diluted to 15 µg/L in spring 2025 if CRW inflow is similar to the 1216 cfs during April-June as in 2024.

3. Water quality in upper/middle RFA (TS12 and TS11) also declined markedly in late summer 2024 compared to water quality in 2021-2023, with respective average TPs of 88 versus 39 µg/L during May-September. Similar to the seasonal change in the lower lake, average TP increased from 37 µg/L during May-mid August to 292 µg/L during late August-September. There were high TPs (761 and 690 µg/L) in upper and lower Rocky Ford Creek (TS14, TS16) in August, as well as high nitrate-N and specific conductance, but stream TPs were not as high as at TS12 (932 µg/L surface and 3890 µg/L off-bottom). However, if TPs from August 27 were omitted, the May-September average TP at TS11/TS12 was 44 µg/L, similar to 2021-2023 (39 µg/L). Thus, the high TPs occurred in late summer as in the lower lake and the source is unknown.

4. Blue-green algae (cyanobacteria) and microcystin-producing *Microcystis*, remained at low fractions of total algal biovolume at both middle RFA (TS11) and South Lake (TS6) in 2024, as in 2021-2023, despite the high average May-September TPs at both sites. That may have been due to low average May to mid-August TP concentrations of 35 µg/L at TS11 and 22 µg/L at TS6, which were similar to average May-September TPs in 2021-2023. Non-nuisance causing diatoms were unusually the dominant algal fraction through the summer. Diatoms often dominate in late summer, due to decreased water temperature. Surface water temperature was nearly 4F lower in September 2024 than the 2017-2023 average (63.8 versus 70.4F). The fraction of cyanobacteria to total algal biovolume was relatively low in open water at TS6 and TS11 in 2021-2023, averaging 20% and 33%, while TP at the two sites averaged 22 and 33 µg/L, respectively. Thus, the cyanobacteria fraction was generally less than 50% of total algal biovolume if TP were less than 30 µg/L, as shown for a large group of lakes by Downing et al (2001). Yet, 2024 was unusual with the cyanobacteria fraction averaging less than 30% at both sites (26%), while TPs were over 60 µg/L. Also, the near-shore scum accumulations of cyanobacteria and their microcystin content have been unrelated to TP and % cyanobacteria in open water during the past six years. Cyanobacteria can be buoyant, accumulate on the surface and be wind-blown to shore. Thus, near-shore scums with microcystin above the state standard (8 µg/L) can still occur even if open water TP were 30 µg/L or less.

5. Incoming CRW mixes with lake water and that mixture distributes throughout the lake, even well up into RFA. That was demonstrated with a hydraulic experiment in 1981. Tracing CRW throughout the lake is possible with conservative specific conductance (SC), because CRW has much lower SC than the lake. The fraction of CRW during July-September was higher in the three deep areas (TS6, TS15 and TS11) in 2021-2023 than in 2020 and 2024; average 76% CRW versus 62% CRW. The CRW fraction was less at the bottom, but incoming colder CRW tends to sink below warmer surface water diluting usually higher TP concentrations at depth. Calculated CRW% was lower during July-September 2024, possibly due to higher SC in the inflows (CC, RFC, and ELC) during July 31-August 26 than during June 19-July 9. The CRW fraction should have been higher from the large CRW inflow through September of 204,218 AF, because % CRW is directly related to CRW inflow. Lower lake level at the start of CRW inflow probably increased %CRW throughout the lake, as well. A 2.2-foot lower lake level (2020-2023) than in 2017-2019 represented 30% of full-pool volume, resulting in June %CRWs of, respectively, 80% and 60% in lower Parker Horn and South Lake (TS5/TS6) and 55% and 41% in middle and upper RFA (TS11/TS12). Lake level was a foot higher at the start of CRW input in 2024, yet CRW was still 72% in June at TS5/TS6, although lower at TS11/TS12 (46%). However, CRW inflow was 65% higher in the three high lake-level years. So, inflow volume likely affected %CRW as well.

6. Surface summer temperature has increased 3°F since the 1980s, but only 1°F compared to the 1970s. Blue-green algae (cyanobacteria) are usually favored by increased temperature but are dependent on phosphorus to produce biomass. Blue-greens usually start in Moses Lake when surface temperature reaches 68°F, and spring water temperatures have not changed.

7. Unusually high TP, as well as TN and SC, occurred in Rocky Ford Creek (RFC) at both the upstream (TS14) and downstream sites (TS16) in August 2024. Total P was usually consistent year-to-year in RFC, averaging 158 µg/L during 1995-2023, with the SRP fraction usually around 2/3 of TP. Causes for the unusually high (761 µg/L) and low (12 µg/L) TPs in RFC is unknown. Thus, evaluating effectiveness of the EutrosorbWC treatment to reduce the soluble fraction of TP is not possible given the unusually high variability in phosphorus concentrations both upstream and downstream of the treatment site.

8. The EutrosorbG treatment to upper and middle RFA in June 2024 was expected to reduce phosphorus internal loading, which has been the major source of TP. However, average TP and chl concentrations at the two monitoring sites (TS11 and TS12) did not decrease from the previous three years (2021-2023).

Rather, average May-September TP increased from 37 to 89 µg/L and chl from 14 to 36 µg/L. High average TPs in 2024 were due to an unusually high TP of 932 µg/L at TS 12 in late August. Average TP from May to mid-August was 37 µg/L, similar to 2023. The source for high TPs in upper RFA is unknown, but were likely not associated with high TPs in the lower lake because TPs in lower RFA (TS15) averaged only 46 µg/L. However, there were unusually high TPs in upper and lower RFC, but not as high as in upper RFA. The higher TPs in the lake may have been due partly to less effective dilution with CRW; 51% CRW at TS11 during June-August 2024 versus 73% CRW in 2021-2023. Thus, TP and chl in 2024 at TS11 and TS15 were compared with levels at those sites in 2020 with similar lake dilution effectiveness (50%CRW). As a result, average June-September surface TP and chl decreased by 24% and 32% at the two sites, respectively, and chl by 36% and 50%. CRW inflow and duration were similar; about 140,000 AF over 120 days in 2020 and 184,000 AF over 100 days in 2024. Thus, the treatment apparently had some benefit to surface WQ by reducing internal phosphorus loading. However, another year of data are needed without the unusually high TP concentrations in upper RFA and in RFC to fully evaluate treatment effectiveness.

13.0 REFERENCES

Barbiero RP, Welch EB. 1992. Contribution of benthic blue-green algal recruitment to lake populations and phosphorus translocation. Freshwater Biol. 27(2):249–260.

Downing JA, Watson SB, & McCauley E. (2001). Predicting cyanobacteria dominance in lakes. Canadian Journal of Fisheries and Aquatic Science, 58, 1905–1908.

Eaton AD, Clesceri LS, Rice EW, Greenberg AE, Franson MAH. 2005. Standard methods for the examination of water and wastewater. 21st ed. American Public Health Association, Water Environment Federation and American Water Works Association.

Jacoby JM, Collier DC, Welch EB, Hardy FJ, Crayton M. 2000. Environmental factors associated with a toxic bloom of Microcystis aeruginosa. Can J Fish Aquat Sci. 57(1):231–240.

Jacoby J, M Burghdoff, G Williams, L Read and FJ Hardy (2015). Dominant factors associated with microcystins in nine midlatitude, maritime lakes. Inland Waters 5:187-202.

Jones, C.A., EB Welch. 1990. Internal phosphorus loading related to mixing and dilution in a dendritic, shallow prairie lake. Water Environment Research. 62(7):847-852.

Okereke VO. 1987. Internal phosphorus loading and water quality projections in Moses Lake. MSE Thesis, Civil and Environmental Engineering, University of Washington, Seattle, WA

Tetra Tech, Inc. 2020. Technical Memorandum: TP Mass Balance Model Results and Treatment Alternative Evaluation for the Rocky Ford Arm of Moses Lake, WA. Prepared for Moses Lake Irrigation and Rehabilitation District. June 2020.

Tetra Tech, Inc. 2022a. Technical Memorandum: Moses Lake – Whole Lake Mass Balance Model & Management Alternatives Evaluation. Prepared for Moses Lake Irrigation and Rehabilitation District. March 2022.

Tetra Tech, Inc. 2022b. Draft Technical Memorandum: Moses Lake Water and Total Phosphorus Budget for 2021. Prepared for Moses Lake Irrigation and Rehabilitation District. April 2022.

Welch EB, CR Patmont. 1980. Lake restoration by dilution: Moses Lake, Washington. Water Res. 14:1317-1325.

Welch EB, KL Carlson, RE Nece and MV Brenner. 1982. Evaluation of Moses Lake Dilution. Water Resources. Series Tech. Rep. No. 77, Dept. of Civil Engr., University of Washington.

Welch, EB, CA Jones and RP Barbiero. 1989. Moses Lake quality: results of dilution, sewage diversion and BMPs – 1977 through 1988. Water Res. Ser. Tech. Rep. 118, Dept Civil & Environ. Eng., Univ. of Washington, Seattle, WA, 65 pp. http://mlird.org/cleanlakeproject.html

Welch EB, Barbiero RP, Bouchard D, Jones CA. 1992. Lake trophic state change and constant algal composition following dilution and diversion. Ecol Eng. 1(3):173–197.

Welch EB and SK Brattebo and C Overland. 2019. Four decades of diluting phosphorus to maintain lake quality. Water Environment Research 92:26-34.

Welch EB and SK Brattebo. 2024a. Effectiveness of diluting Moses Lake, Washington, with low phosphorus Columbia River water. Lake and Reservoir Management 40:339-353.

Welch EB and SK Brattebo. 2024b. Moses Lake Water Quality: Effects and Benefits of Columbia River Dilution Water, 2017-2023. Moses Lake Irrigation and Rehabilitation District.