# Moses Lake Water Quality: Effects and Benefits of Columbia River Dilution Water 2017-2025


**PREPARED FOR**

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# 1.0 INTRODUCTION

The improvement of water quality in Moses Lake by dilution has been a long-term process starting from the 1960s when total phosphorus (TP) concentrations in the lower lake (lower Parker Horn/South Lake) averaged 154 µg/L during spring-summer in 1969-1970. Soluble reactive phosphorus (SRP), the fraction used by algae, was also high at 38 µg/L, causing nitrogen to restrict algal growth more than phosphorus. The inflow of Columbia River water (CRW) with low TP (~8 µg/L) averaged only 4,000 acre-ft (AF) and the City's wastewater still entered the lake at 27% of the total TP load. At that time the lake was hypereutrophic (TP>100 µg/L). Blue-green algae (cyanobacteria) were 98% of total algal biomass in Parker Horn (Welch et al.,1989; Welch et al.,1992; Welch et al., 2019).

Inflow of CRW, mostly during spring, increased to an average of 109,200 AF during 1977-1983 with the Clean Lakes Project, which was funded by EPA through the Moses Lake Irrigation and Rehabilitation District (MLIRD). Average TP decreased to 85 µg/L, but wastewater still flowed into the lake. Inflow of CRW continued at an average of 100,500 AF during 1984-1988, after wastewater was diverted, and average TP decreased to 54 µg/L. Total P decreased further by 1986-1988 to 44 µg/L and SRP to 7 µg/L (Welch et al., 1992). The decrease in phosphorus doubled the ratio of TN:TP between 1969-1970 and 1986-1988 causing phosphorus to be more limiting to algal growth. While lake water quality had markedly improved, cyanobacteria were still over 50% of algal biomass and the lake was eutrophic (TP>25 µg/L) (Welch et al., 1992; Jones and Welch, 1990).

Inflow of CRW more than doubled during 1999-2016 averaging 254,000 AF, equivalent to 2 lake volumes. Total P at South Lake averaged only 19 µg/L (USBR data). The same average TP in the lower lake (lower Parker Horn/South Lake) was reported by the Washington State Department of Ecology (Ecology) from comprehensive monitoring in 2001 (Carroll, 2006). The lake had reached a mesotrophic state (<25 µg/L) through dilution with a large inflow of low-TP CRW.

Comprehensive water quality monitoring resumed in 2017 by MLIRD. Total P has averaged 28 µg/L in the lower lake since 2017 while CRW inflow averaged 160,700 AF, equivalent to about 1.3 lake volumes. That amount of dilution resulted in 71%CRW on average in the lower lake through June. Total P in the lower lake has averaged 23 µg/L in May-September during the past five years, disregarding the exceptionally high TPs in late August-September in 2024, following a breach in the East Low Canal. Total algal biomass, as chlorophyll, decreased and water transparency increased in proportion to the decrease in TP. The lower lake has been mesotrophic, despite internal loading contributing an average of 50% to TP loading during 2020-2024.

Upper and middle Rocky Ford Arm (RFA) has been regularly diluted with CRW due to wind-caused transport of lake water from Parker Horn, resulting in an average of 60%CRW through June during the past nine years. However, TP concentrations in middle and upper RFA have usually averaged higher than in the lower lake but have decreased in four of the past five years, averaging 37 µg/L, excluding 2024 (88 µg/L) due to exceptionally high and unexplained late summer TPs. Also, surface TP has decreased 35% on average, depending on the years compared and dilution effectiveness, following the sediment phosphorus inactivation treatment in 2024.

Surface TP at middle/upper RFA averaged 32 µg/L in 2025. Also, whole-lake internal loading decreased 71% in 2025, compared to 2020-2023, probably related to the treatment.

Cyanobacteria have averaged 20-28% of total algal biomass and *Microcystis* only 3-8%, at South Lake and middle RFA during the past five years, while TP averaged 21 and 31 µg/L at the two sites in four of the past five years. That is consistent with the fraction of cyanobacteria related to TP concentration in other lakes. Thus, if average TP is held at or below 30 µg/L during spring-summer, the risk of cyanobacteria exceeding 50% should be minimized.

For further information on the lake's rehabilitation and other examples of lake dilution see Welch and Brattebo (2025).

## 2.0 WATER SAMPLE COLLECTION AND ANALYSIS

Water samples were collected by MLIRD personnel with a Van Dorn bottle generally twice per month during May - September over the past nine years. Surface samples were collected at a depth of 0.5 m at nine lake sites, as well as through the water column at discrete depths during 2020 – 2025 (Figure 1). Inflows were sampled at two sites on Crab Creek (TS2 and TS3), and one each in the east low canal (TS1) and Rocky Ford Creek (TS14) (Figure 1).

Samples were shipped on ice to IEH Analytical Laboratories, Seattle, WA, for analysis of TP using the method 4500PI with detection to 2 µg/L. Chlorophyll was determined in the same lake samples on filtered residue 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 through the water column with a multi-parameter water quality 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 at TS6 and TS11 twice-monthly during July-September 2017, twice monthly in May-September 2018, twice monthly in June-September 2021, and twice monthly May-September 2022-2025. Algal abundance was determined as cell density and biovolume in $mm^3/L$ based on measured cell volumes of individual species observed and presented here as % blue-greens (cyanobacteria) and % *Microcystis*. Samples were analyzed at Western Washington University in 2017 and 2018 and Algae Analytical Services in 2021 - 2025. Samples for microcystin were collected nearshore 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 4°C and 5°C.

Specific conductance (SC), as μS/cm, was used to traceCRW in the lake and determine % lake water or %CRW according to Welch and Patmont (1980). Specific conductance is composed of conservative substances, like salinity in sea water, and not affected by biological processes. Specific conductance was consistently much lower in CRW at 142 μS/cm than in Crab Creek at 491 μS/cm and Rocky Ford Creek at 371 μS/cm. Specific conductance in Crab Creek was used to calculate %CRW in lower Parker Horn (TS5) and South Lake (TS6) and an average of Crab Creek and Rocky Ford Creek for %CRW in Rocky Ford Arm (TS11, TS12 and TS15). The equation for tracing low-SC CRW is:

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

Water and TP budgets were determined for May–September 2020 through 2025. Data from a USGS real-time gaging station on Crab Creek (#12467000), which is upstream of the lake near Road 7NE, were used to determine mean daily flow. For the 2020 water budget, an average May–September constant flow of 1.78 $m^3/s$ (62.8 cfs) measured in Rocky Ford Creek during 2008–2017 was used in the budget, because discrete or real-time flow measurements were unavailable. For water budgets determined for 2021 – 2025, discrete flow measurements determined by USGS at station #12470500 were used with linear interpolation to develop a constant flow record. Daily flows were increased by 25% in 2024 and 2025 after comparing flow rates recorded by Eutrophix just upstream of Drumheller Dam. A base flow for Rocky Coulee Wasteway of 0.68 $m^3/s$ was determined from USGS historical data. A groundwater flow of 2.1 $m^3/s$ was determined in 2001 by Ecology (Carroll, 2006). An average evaporation rate was taken from the Western Regional Climate Center and precipitation from the Grant County airport at Moses Lake. Lake levels were gauged by USGS in cooperation with USBR (USGS station #12471000). Outflow from the lake was not directly measured and was assumed as total inflow minus evaporation, because data from the 2 outflow structures were unavailable. Total P concentrations were regularly determined in Crab Creek (TS2), Rocky Ford Creek (TS14), and CRW (TS1). During the EutroSorbWC phosphorus sequestration treatments on Rocky Ford Creek during 2024 and 2025, the TP concentration at TS14 was reduced by 15%, on average, as observed in samples collected by Eutrophix (data provided by Ryan Van Goetham, pers. comm.). Rocky Coulee Wasteway baseflow TP was assumed as 87 μg/L and groundwater TP as 59 μg/L, determined in 2001 by Ecology (Carroll, 2006). Total P in precipitation of 107 μg/L was assumed from budgets determined in the 1980s (Welch et al. 1989, Jones and Welch 1990).

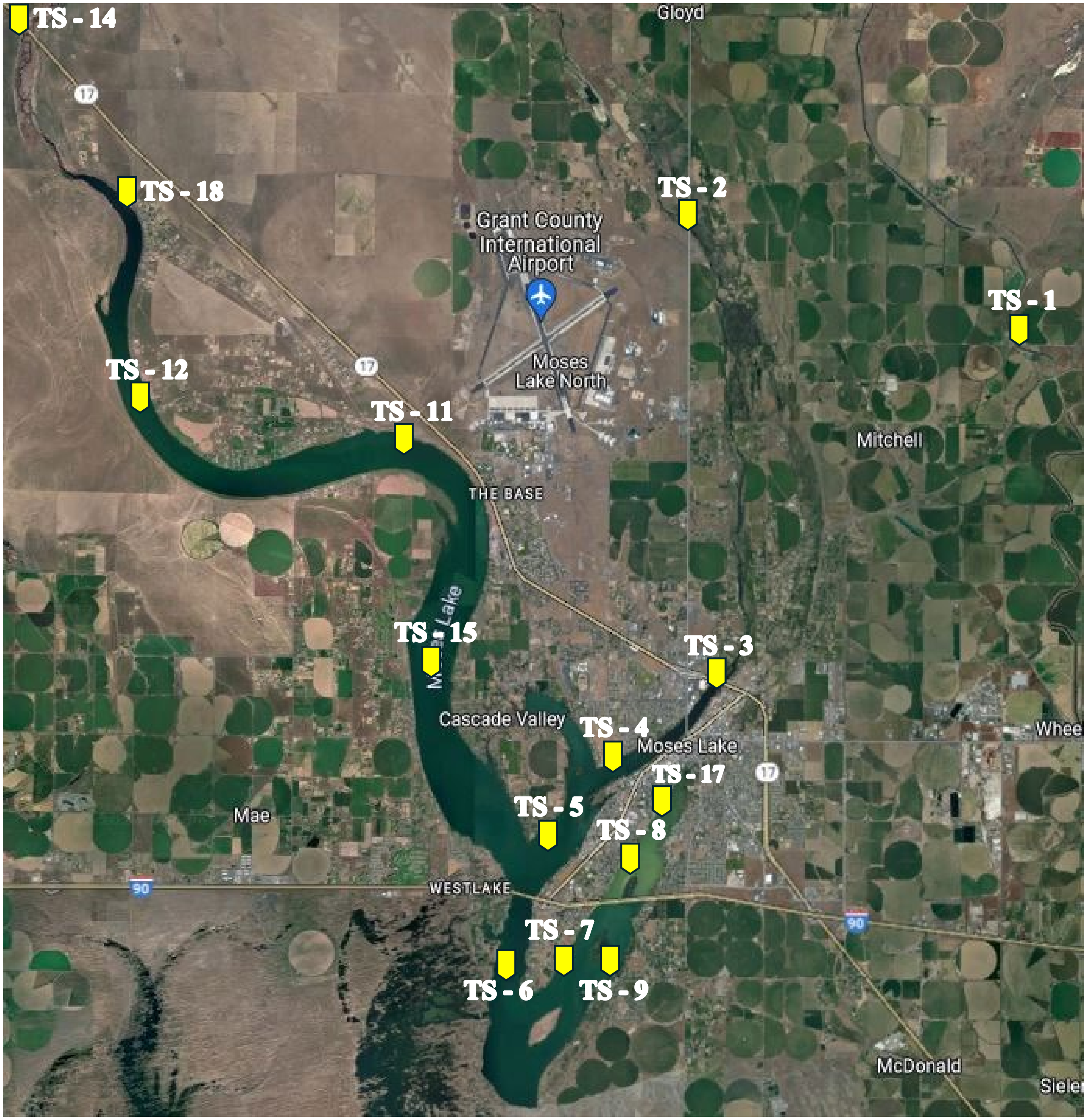


**Figure 1. Sampling sites by MLIRD during 2017-2025. Most sites are similar to those sampled by UW, Civil and Environmental Engineering, during 1969-1970 and 1977-1988 (Welch et al., 1989).**

## 3.0 WATER QUALITY MONITORING SITE COVERAGE

The six regular lake-wide monitoring sites, TS5, TS6, TS7, TS11, TS12 and TS15, cover 91% of the lake area and 95% of the lake volume. They represent the water quality in the whole lake, except for middle Pelican Horn, which has its water quality character determined more by ground water and is minimally affected by dilution, despite water pumped from Upper Pelican Horn.

### Tracing CRW

The percent of lake water that is CRW from the East Low Canal can be determined by measurements of electrical conductivity (specific conductance, SC, in µS/cm), because SC is consistently low in CRW (142 µS/cm) and high in Crab Creek (491 µS/cm), Rocky Ford Creek (431 µS/cm) and groundwater (435 µS/cm). Lake SC before CRW inflow began in 2024 reflected the inflow SCs; 394 µS/cm, 375 µS/cm, and 371 µS/cm at TS5, TS6 and TS12, respectively.

### CRW distribution in 2025

The percent CRW near the surface of the lake (0.5 m) from May through September 2025 averaged about 6% higher in South Lake (TS6), Parker Horn (TS5) and lower Pelican Horn (TS7) than in middle (TS11), upper (TS12) and lower RFA (TS15) (Table 1). That is due to slower diffusion of CRW by wind up into RFA than into South Lake (TS6) and Lower Pelican (TS7). Starting in May at 52%CRW and 40%CRW at TS11 and TS12, respectively, CRW increased to 65% and 59% in June. Thus, wind, usually from the south, effectively moved CRW water from Parker Horn into middle and upper RFA. Lower Parker Horn and South Lake probably started at around 33%CRW, as occurred in March 2024, before CRW inflow, and increased to 66%CRW and 72%CRW in June 2025. Percent CRW declined some through summer as CRW inflow declined. However, by September, CRW averaged 58% at TS5, TS6 and TS7 and 48% at TS11, TS12 and TS15. Using the average %CRWs for each of the six sites during May-September, the whole-lake, area-weighted average was 58%CRW in 2025.

These data justify using volume-weighted or area-weighted constituent concentrations from these six sites to represent whole lake conditions (*also, see Transport of Water into Rocky Ford Arm*).

**Table 1. Percent of lake area and volume represented by the six regular lake-wide monitoring sites and average %CRW during May through September 2025.**

| Site | % Area | % Volume | % CRW |
|---|---|---|---|
| **TS 5** | 8 | 6.7 | 60 |
| **TS 6** | 17 | 21.8 | 60 |
| **TS 7** | 8 | 4.4 | 66 |
| **TS 15** | 14 | 21.2 | 58 |
| **TS 11** | 27 | 30.6 | 56 |
| **TS 12** | 17 | 10.6 | 55 |

## 4.0 DILUTING EFFECT OF CRW INFLOW AND LAKE LEVEL

Lake level was, on average, 2.2 feet lower when CRW inflow started in 2020-2023 than in 2017-2019 (Figure 2, Table 2). That depth difference represents 18% of full pool volume and a greater ratio between CRW inflow and lake volume. That should have amounted to greater dilution effectiveness. That reduced volume at the start of inflow could be partly the cause for an average of 60%CRW in Parker Horn and South Lake (TS5, TS6) during June 2017-2019 versus 80%CRW during June 2020-2023.

The difference was also apparent at middle and upper RFA (TS11, TS12): average 41%CRW during June 2017-2019 versus 55%CRW during June 2020-2023. Diffusion of CRW into RFA by wind is slower than into the lower lake. Nevertheless, the lower pre-CRW lake level apparently had an effect in RFA as well.

Lake level in 2024, before CRW input, was 1043.3 ft, about a foot higher than in 2020-2023. Nevertheless, CRW was still 72% during June at TS5/TS6, and higher (61%) at TS11/TS12 than the 2020-2023 average. Pre-CRW input lake level was even higher in 2025 than in 2020-2023 by about 2 feet (Figure 2), yet CRW was 69% at TS5/TS6 and 61% at TS11/TS12 during June (Table 2).

Dilution may be more effective if lake level were lower at the start of CRW input, as indicated by comparison of %CRW for three high lake-level years (2017-2019) with four low lake-level years (2020-2023). However, the high %CRW at TS5/TS6 during June 2024 (72%) and 2025 (69%), with high starting lake levels, especially in 2025 (1044.1 feet), indicate that total CRW volume is also important for effective dilution. Thus, input of CRW during 2017-2019 averaged 88,145 AF with 60%CRW during June at TS5/TS6, versus 77%CRW during June in 2020-2025 with 156,950 AF average CRW input. The effect of CRW volume showed in RFA as well as high June %CRW occurred at TS11/TS12 (51% and 71%) in the two lowest starting lake-level years and high CRW inflows (2021 and 2022, Table 2). For most years, both low starting lake level and high CRW inflow appear to contribute to effective dilution in the lower lake as well as in middle and upper RFA. Nevertheless, %CRW was relatively high (61%) at TS11/TS12 in 2025 even with the high starting lake level (1044.1 ft) and a CRW inflow through June of 155,911 AF which was about the average for the past six years (Table 2).

Over the past 6 years, CRW inflow through September has averaged 190,168 AF, while CRW averaged 70% during June-September in lower Parker Horn/South Lake (TS5/TS6) and 60% in middle/upper RFA (TS11/TS12). Dilution is always more effective in lower Parker Horn/South Lake, but wind effectively diffuses high %CRW water from lower Parker Horn well up into RFA. Wind speed and direction were shown in 1981 to account for the diffusive transport of CRW into middle and upper RFA (Welch et al., 1982). Without wind transport of CRW, specific conductance (SC) at TS11 and TS12 would reflect the inflows from Rocky Ford Creek and groundwater (360 and 380 μS/cm). However, dilution by CRW with 142 μS/cm reduced SC at TS11/TS12 to 251 μS/cm in June 2024 and 256 μS/cm in June 2025 (*see Transport of water to RFA*).

**Table 2. Lake levels in Moses Lake at start of CRW inflow, CRW inflow through June, and %CRW in Parker Horn and South Lake (TS5 and TS6) and middle and upper Rocky Ford Arm (TS11 and TS12) during June 2017-2025.**

| Year | Pre-CRW Lake Level (ft) | CRW (ac-ft) | %CRW at TS5/TS6 | %CRW at TS11/TS12 |
|---|---|---|---|---|
| **2017** | 1046.8 | 58,939 | 54 | 44 |
| **2018** | 1044.0 | 92,289 | 56 | 39 |
| **2019** | 1044.0 | 113,210 | 71 | 41 |
| **2020** | 1042.4 | 146,537 | 82 | 32 |
| **2021** | 1042.2 | 154,610 | 82 | 51 |
| **2022** | 1041.4 | 156,353 | 78 | 71 |
| **2023** | 1042.9 | 148,255 | 79 | 63 |
| **2024** | 1043.3 | 180,099 | 72 | 61 |
| **2025** | 1044.1 | 155,911 | 69 | 61 |

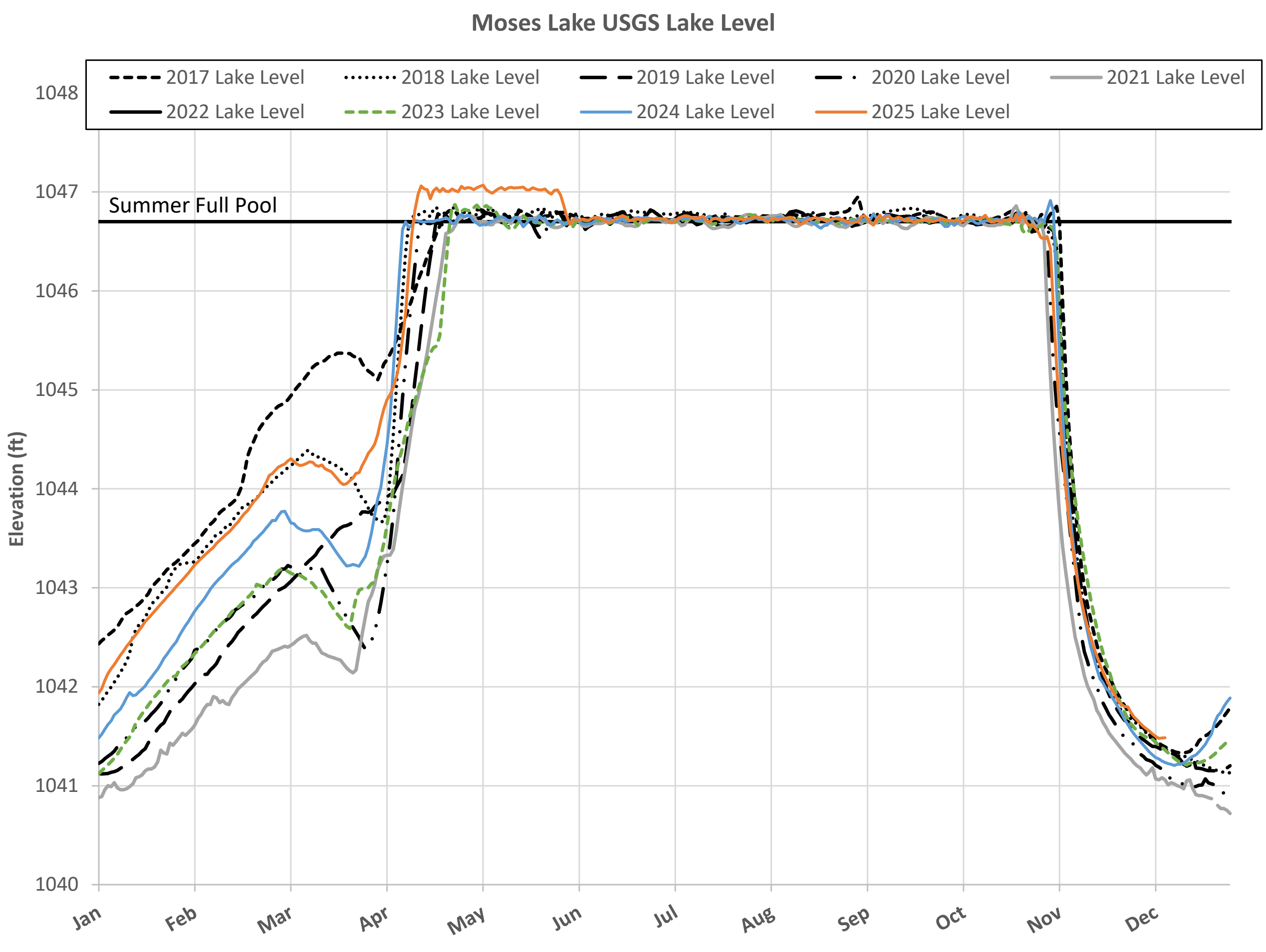


**Figure 2. Moses Lake water levels during 2017-2025.**

## 5.0 CRW DISTRIBUTION AND EFFECT OF THERMAL STRATIFICATION

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, %CRW at the surface was always higher in lower Parker Horn and South Lake (TS5 and TS6) and occurred earlier than in middle and upper RFA (TS11 and TS12), which has reached around 60%CRW in June the past three years (Table 2).

Percent CRW was usually higher at the surface than near bottom at the three deeper sites averaging 68% at the surface (0.5 m) and 62% at 0.5 m off-bottom during July-September over the past six years (Table 3). The %CRW was much higher at those sites and depths in 2021-2023; average 76% at the surface and 71% off-bottom (Table 3). Those three deep areas represent 58% of the lake area and 74% of the lake volume. Transport and dilution with CRW were apparently less effective in 2024 and 2025 with only 58% and 55%CRW at the surface during July-September, despite substantial CRW inflows of 204,218 and 171,929 AF for the two years (Table 3).

Dilution may be more effective because the colder and denser CRW most likely sinks below the warming surface water. That usually occurs in large, deep reservoirs. Temperature of CRW entering the lake is around 50°F (10°C) and denser than lake water in early April. Average bottom temperature was slightly less than at the surface at TS5 (1°C) and TS6 (3°C) during early monitoring in April through June 19, 2024. Also, specific conductance (SC) was 3% less at the bottom than surface at both sites. Those differences indicate that incoming CRW tended to sink and dilute the lake's whole water column, although some of the vertical temperature differences were due to surface warming. Nevertheless, CRW averaged 68% at the surface and nearly as high off-bottom (62%) at the deep sites (TS6, TS11 and TS15) over the past six years, indicating effective dilution through the water column (Table 3). Dilution through the water column was also determined by the large volume of entering CRW, which represented 1.4 lake volumes on average during April-June the past six years.

Dilution effectiveness, however, was not always obvious during July-September. The water column was more stratified in 2021 and 2022 than in 2020, 2023 and 2024, as indicated by higher RTRM and greater surface/bottom temperature difference (Table 3). The greater stratification may have allowed colder CRW to plunge below the warmer, less dense surface water and partly account for higher off-bottom %CRW. However, off-bottom %CRW was also high in 2023, despite less temperature difference and lower RTRM, and %CRW in 2025 at both surface and bottom was less than the previous five years, while RTRM and temperature difference were both high. Also, the input of CRW does not account for the differences in surface/bottom %CRW. Inflow CRW was lower in 2023 and 2025 than 2020-2022 and 2024, yet %CRW was high in 2023 and low in 2025.

Moses Lake is polymictic, so greater wind mixing of the water column in some years may also account for greater distribution of CRW throughout the lake at both the lake bottom and at the surface. However, wind was rather consistent during May-September over the past six years, averaging about 7 mph and mostly from the SE to SW. Thus, several factors likely determine the vertical distribution of incoming CRW (*see Transport of Water section*).

Thermal stratification, although not permanent during summer, also affects DO and TP. Off-bottom DO was usually low, averaging 4 mg/L for the six years (Table 3). That indicates anoxic (<2 mg/L) water was most likely overlying sediment at times throughout the summer allowing high rates of sediment-P release and internal loading. That effect of low off-bottom DO is supported by usually higher average off-bottom than surface TP for four of the six years.

**Table 3. July-September averages in 2020 – 2025 for thermal (density) resistance to water column mixing (RTRM), surface (0.5m)-to-bottom temperature difference (°C), off bottom DO (0.5m off bottom), surface/bottom %CRW, and surface/bottom TP difference. Averages are from South Lake (TS6), lower Rocky Ford Arm (TS15) and middle Rocky Ford Arm (TS11).**

| Characteristic | 2020 | 2021 | 2022 | 2023 | 2024 | 2025 |
|---|---|---|---|---|---|---|
| RTRM | 56 | 73 | 61 | 52 | 41 | 65 |
| Temperature Difference | 1.6 | 2.1 | 2.1 | 1.4 | 1.7 | 2.3 |
| DO off-bottom | 4.5 | 3.8 | 4.6 | 5.3 | 3.1 | 2.6 |
| %CRW | 66/59 | 79/75 | 75/71 | 74/67 | 58/50 | 55/48 |
| TP Difference | 51/77 | 35/63 | 30/35 | 32/66 | 56/47 | 26/62 |

## 6.0 TRANSPORT OF WATER TO ROCKY FORD ARM

Low-TP CRW was traced by SC to reach well up into 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 averaged 2.6 mph over the 17-hour study. Percent CRW at 8.5 miles up RFA was predicted at less than half that at middle RFA (5.5 miles). The water transport study was performed by Ron Nece, a hydraulics Professor at UW at the time. The effectiveness of CRW transfer through the whole lake was also demonstrated during 1977-1978 by comparing observed with predicted remaining %LW (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 $ft^2$ and an inflow from Rocky Ford Creek of 78 cfs would have produced a down-arm flow of only 0.001-0.002 cfs (Welch et al., 1982). Thus, CRW is transported well into RFA by wind with little down-lake flow resistance.

Recent data show even greater effectiveness of water transport well into RFA. Wind direction was from the SE to SW 45% of the time during June-September in 2020-2024 and averaged 7.1 mph (three times the experimental velocity). Wind was apparently adequate to account for CRW to average 68% at middle RFA (TS11) during June-September, 2021-2023. Transfer was less effective in 2024 and 2025 with CRW averaging 53-55%CRW in middle RFA during June-September, although CRW was 61% in June each year. Wind direction and wind speed averaged 48% and 55% of the time from the SE to SW in 2024 and 2025 and 7.4 mph during May-September (through August in 2025). Nevertheless, CRW in both middle and upper RFA together was 54% during June-September in both 2024 and 2025.

The fraction of CRW in middle and upper RFA increased on average from the previous year's residual of 44% in May to 64% in July during the past six years (2020-2025). That increase in %CRW represents about 10,400 AF of the volume in middle/upper RFA containing CRW diffused from lower Parker Horn**.** That is roughly equal to the usual May-September inflow from Rocky Ford Creek of about 11,600 AF during. Thus, a substantial volume of CRW was transported consistently from lower Parker Horn to middle and upper RFA during May-September over the past six years. The 44%CRW in May was a residual from the previous year and accounts for the low TP of 31 µg/L.

## 7.0 LAKE QUALITY

Lake water quality is usually represented by summer or spring-summer average TP, chlorophyll (chl), and transparency. The average May-September TP in Moses Lake over the past nine years is directly related to chl (Figure 3). That is consistent with the frequently used relation from 99 lakes and reservoirs (Jones and Bachmann, 1976). Also, Secchi transparency is inversely related to chl (Figure 4), which is consistent with the equation form Carlson (1977). Thus, lake water quality, which is reflected by chl concentration and resulting water transparency, is managed by measures to control TP.

Dilution with large quantities of CRW has effectively reduced lake surface TP from levels that existed prior to the Clean Water Project in 1977. Lake TP was typically low throughout the lake for five of the past six years with area-weighted, lake-wide average May-September TP at six sites that ranged from 23 to 70 µg/L. The lake-wide average in 2025 was 23 µg/L, and 26 µg/L for 2021-2023 and 2025. That 26 µg/L is a reduction of 85% from the pre-dilution TP concentration of 154 µg/L at TS5 and TS6 in 1969-1970 (Welch et al., 1992). The lake is now borderline mesotrophic (<25 µg/L) from hypereutrophic (>100 µg/L) conditions before the start of regular inputs of low-TP CRW began in 1977.

Average May–September surface TP was the highest in 2024, due to unusually high TPs measured in late August and September, following a breach in the East Low Canal. Average area-weighted TP at six sites from May through mid-August in 2024 was low at 30 µg/L, as in other recent years, but increased to 70 µg/L if late August-September data were included. Total P was unusually high at lower Parker Horn and South Lake (TS5 and TS6) and middle and upper RFA (TS11 and TS12) in 2024 – more than double the average of four of the last five years (2021-2023 and 2025, Table 4).

Chlorophyll was also proportionately much higher in 2024, and Secchi transparency was much less than the past nine years at TS5 and TS6 and the past six years at TS11 and TS12 (Table 4). There was 88% less transparency per unit chl at TS5 and TS6 in 2024 than in 2021-2023, indicating the presence of non-algal turbidity.

The high TPs observed in late August and September in 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. The average chl:TP ratio during 2017-2023 and 2025 at TS5 and TS6 was 0.41 and 0.40 in 2024 (Table 4). The ratio at TS11 and TS12 was even slightly higher at 0.49 in 2024, including the high TPs (Table 4). These high TPs occurred in 2024 despite the relatively high average fraction of CRW (69%) at TS6 and TS7 during May–September. Also, there was 25% less transparency than expected from chl at TS5 and TS6 in 2024 than in 2020-2023 and 2025, indicating the presence of non-algal turbidity. See Welch and Brattebo (2025) for further explanation for the high TPs in 2024.

**Table 4. May-September average TP, chlorophyll (chl), both in µg/L, and Secchi disk transparency in meters during 2017-2025 at lower Parker Horn/South Lake (TS5/TS6) and middle/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 |
| | 2025 | 19 | 7 | 2.4 |
| | **9-year Average** | **32** | **13** | **1.9** |
| 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 |
| | 2025 | 32 | 13 | 1.2 |
| | **9-year Average** | **64** | **31** | **1.4** |

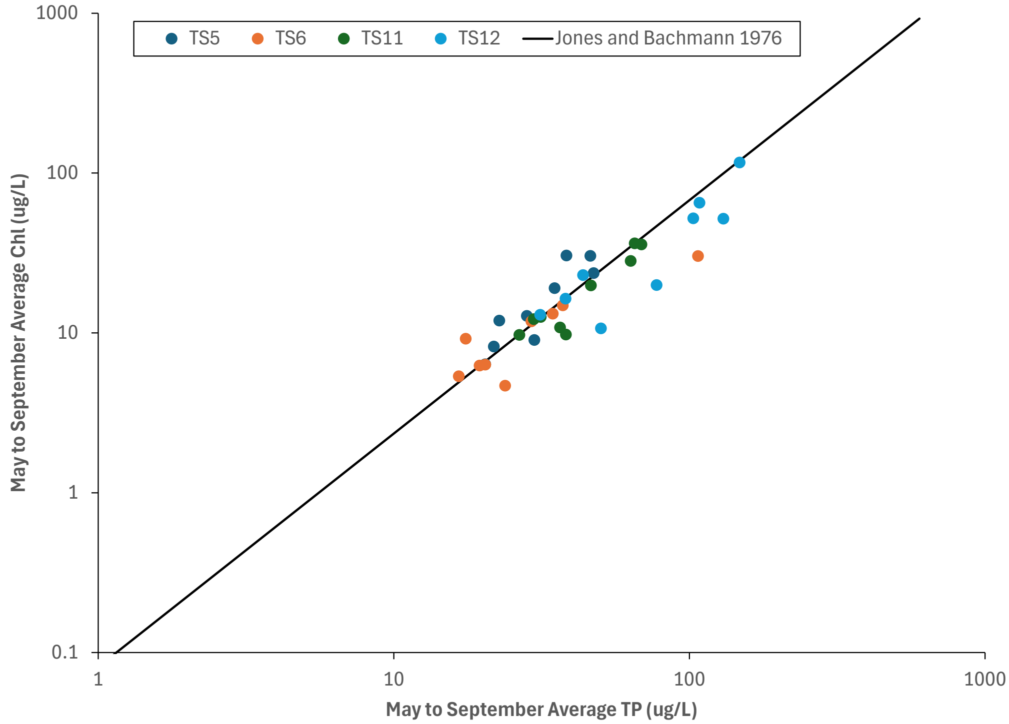


**Figure 3. May to September Average TP and chl at Lower Parker Horn (TS5), South Lake (TS6), Middle RFA (TS11), and Upper RFA (TS12) during 2017 – 2025, related to the Jones and Bachman TP-chl relationship (1976).**

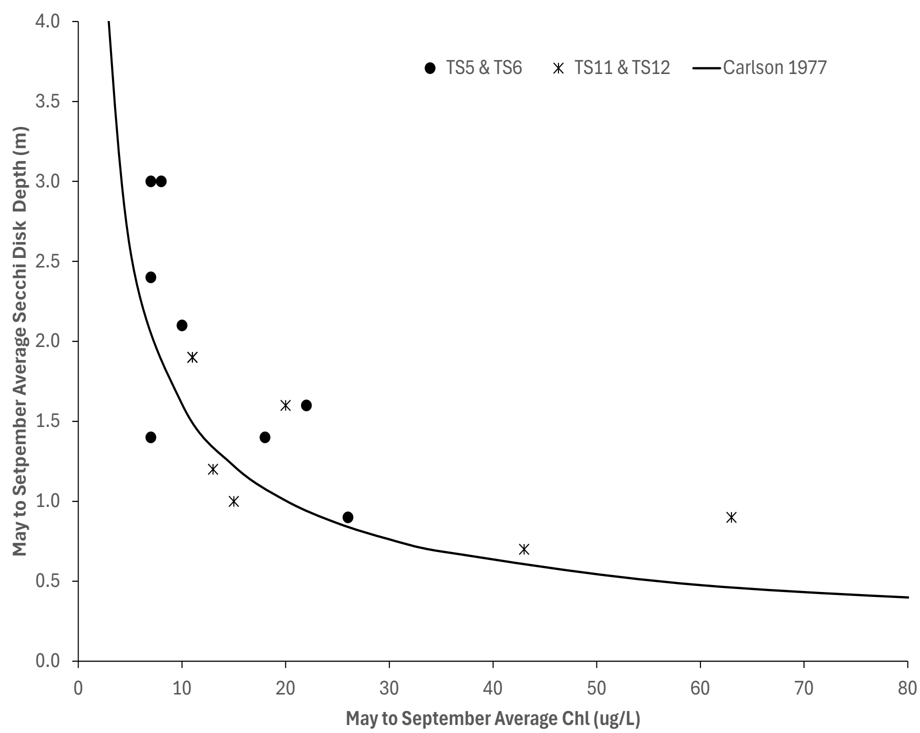


**Figure 4. May to September Average chl and Secchi Disk Depth at Lower Parker Horn (TS5), South Lake (TS6), and Middle/Upper RFA during 2017-2025, related to the Carlson chl-SD relationship (Carlson, 1977).**

## 8.0 CYANOBACTERIA, MICROCYSTIN AND WATER QUALITY

Nearshore average concentrations of microcystin have varied over 100-fold the past eight years at Blue Heron and Connelly Parks (Table 5). In contrast, percent cyanobacteria and *Microcystis*, of total algal biomass, have varied much less (3-11% of average) at both the open water sites (TS11, TS6), over the past 5 years with algae data (Table 5). Moreover, there was no difference in open water % cyanobacteria and % *Microcystis* between the two sites, with the past 5-year average of 28% and 20% cyanobacteria and 3% and 4% *Microcystis* at TS11 and TS6, respectively. Also, average TP and chl were similar at the two sites during the past five years; 34 and 30 µg/L TP and 13 and 12 µg/L chl. Thus, the occurrence of nearshore scums of cyanobacteria and the presence of microcystin were not reflected in open water TP, chl and algae data. Also, the presence of scums and concentrations of microcystin were widely different between the two sites in 2018 with little difference among open water TP, % cyanobacteria and % *Microcystis* (Table 5).

Lake water quality improved in 2025 at both TS6 and TS11 with lower average TP concentrations than the past six years (Table 5). Percent cyanobacteria were as low or lower in 2025 than any of the past five years with data on algae and % *Microcystis* remained low (Table 5). There were nearshore algal scums on only two occasions at each site in 2025, but average microcystin in the scums was above the 8 µg/L standard at Blue Heron Park (Table 5). Thus, the low % *Microcystis* and % cyanobacteria were consistent with low TP at both sites in 2025.

The cyanobacteria and *Microcystis* (MA) fractions of biovolume were also low at the two open-water sites in 2024, despite higher May-September average TP and chl than any of the past several years (Table 5). Also, diatoms were the dominant algal group at both open-water sites during the summer of 2024. However, 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 scums 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* 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 in the water column 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 several hundred-fold range in the near-shore microcystin concentrations over the past eight years (Table 5).

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 less than 30 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). Total P averaged 27 µg/L over the past five years at the two sites (TS6 and TS11), if late August-September data in 2024 were excluded, while cyanobacteria averaged 24% of total algae, and microcystin averaged only 6.6 µg/L, less than the state standard. Thus, effective dilution with CRW has improved water quality, held TP below 30 µg/L and kept cyanobacteria and microcystin relatively low the past five years.

**Table 5. Average microcystin concentrations in µg/L from near-shore samples at Connelly Park and Blue Heron Park, near TS11 and TS5/TS6, 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 usually during June-September. Average 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. NA = no algae data.**

| 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 | 36 | 10 | NS | 43 | 35 | 25 | 7 |
| **2018** | 20 (4) | 79 | 67 | 48 | 28 | 606 (8) | 87 | 64 | 41 | 18 |
| **2019** | 13 (11) | NA | NA | 69 | 24 | 78 (15) | NA | NA | 30 | 14 |
| **2020** | 220 (33) | NA | NA | 65 | 40 | 197 (11) | NA | NA | 41 | 22 |
| **2021** | 1098 (8) | 23 | 6 | 36 | 11 | No Scums | 22 | 10 | 20 | 7 |
| **2022** | 2 (9) | 30 | 1 | 30 | 12 | 575 (2) | 12 | 1 | 20 | 8 |
| **2023** | 2 (1) | 45 | 1 | 31 | 12 | 7 (3) | 27 | 1 | 25 | 10 |
| **2024** | 1.4 (1) | 26 | 2 | 48 | 20 | 2.1 (3) | 26 | 6 | 65 | 26 |
| **2025** | 5.5 (2) | 14 | 6 | 27 | 9 | 33 (2) | 12 | 3 | 19 | 7 |

## 9.0 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 (TS14) over the past 30 years averaged 158 µg/L. Total P was less at the source spring to Rocky Ford Creek over a shorter period. Total P in Crab Creek (TS2) markedly declined by the 1980s, largely due to a change from rill to spray irrigation in the watershed, resulting in less erosion (Welch et al., 1992). Average TP has remained rather constant since the 1980s at 48 µg/L. Total P concentrations in 2025 were close to the long-term averages: 164 µg/L in Rocky Ford Creek (TS14) and 47 µg/L in Crab Creek (TS2).

Stream inflow TPs in both stream inflows were unusually low and high in late summer 2024 with concentrations ranging from 18-1900 µg/L in Crab Creek (average 326 µg/L) and 12-761 µg/L in Rocky Ford Creek (average 245 µg/L). Reasons for the unusual stream TP concentrations in 2024 are unknown.

These stream inflows are not the major source of mass TP loading to the lake. Their contributions in 2020-2023 and 2025 averaged 8.5% for Crab Creek and 8.6% for Rocky Ford Creek. The major contributor was internal recycling of P from bottom sediments averaging 42% of the total TP loading during May – September in 2020-2023 and 2025 (Table 7) (Tetra Tech, 2022a, 2022b, and 2026). So, stream input of TP from the major portion of the watershed is a minor contributor to the lake, compared with internal recycling.

**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) |

# 10.0 INTERNAL LOADING

Total P in the lake has usually increased as the summer progressed (Welch and Brattebo, 2024). Average June-September TP was 2.2 times the May concentrations during 2020-2025 at the six sites representing 91% of the major lake area. Internal loading of TP to the whole lake volume averaged 7,067 kg during May-September in 2020-2023 and only 2,037 kg in 2025 (Table 7). Internal loading in 2025 was 21.1% of the total and about 29% of the 2020-2023 average of 7,067 kg (Table 8). Also, internal loading in 2020-2023 was less than the average during 1984-1988 of 9,346 kg, following wastewater diversion (Jones and Welch, 1990).

Total loading and internal recycling were unusually high in 2024 due to late August-September high lake TP concentrations following the canal breach. Average whole-lake, area-wide weighted surface (0.5 m) TP during May-September in 2024 was 70 µg/L, but only 30 µg/L through mid-August (see Welch and Brattebo, 2025).

The reduced internal loading in 2025 was not due to increased dilution with CRW inflow, which would have produced higher %CRW in the lake. Inflow of CRW was 191,268 AF, which was less than the average of the past six years. Also, off-bottom DO at the three deep sites (TS6, TS11 and TS15) averaged lower in 2025 (2.6 mg/L) than the past six years and CRW averaged less at 55% (Table 3). Thus, there was less dilution and lower off-bottom DO, which would have tended to increase lake TP and internal loading in 2025. However, results from the TP mass balance show the opposite with a substantial decrease of 71% in internal loading in 2025 compared with 2020-2023 (Tables 7 and 8).

**Table 7. Total Phosphorus mass balances during May – September 2020-2025.**

| | 2020 | 2021 | 2022 | 2023 | 2024 | 2025 |
|---|---|---|---|---|---|---|
| **Phosphorus Inflows (kg)** | | | | | | |
| Direct Precipitation | 216 | 96 | 263 | 149 | 25 | 58 |
| Crab Creek | 975 | 1,064 | 1,045 | 996 | 7,771 | 1,249 |
| Rocky Ford Creek | 4,017 | 2,623 | 2,673 | 2,319 | 3,281 | 3,646 |
| Rocky Coulee Wasteway (Baseflow) | 786 | 786 | 786 | 786 | 786 | 786 |
| Rocky Coulee Wasteway (CRW Dilution) | 1,186 | 1,599 | 1,878 | 453 | 4,600 | 704 |
| Groundwater | 1,163 | 1,163 | 1,163 | 1,163 | 1,163 | 1,163 |
| Internal | 8,318 | 10,740 | 4,167 | 5,044 | 25,937 | 2,037 |
| **Total Phosphorus Load** | **16,662** | **18,072** | **11,975** | **10,911** | **43,563** | **9,644** |
| | | | | | | |
| **Phosphorus Outflows (kg)** | | | | | | |
| Combined Outflow (Groundwater, MLIRD Dam, USBR Dam) | 6,643 | 4,845 | 3,101 | 1,692 | 10,327 | 2,896 |
| Sedimentation | 8,693 | 7,155 | 7,091 | 5,815 | 19,688 | 4,777 |
| **Total Phosphorus Loss** | **15,336** | **12,000** | **10,192** | **7,507** | **30,015** | **7,673** |

**Table 8. Total internal phosphorus loading during May – September 2020-2025 (calculated as the positive residual in the phosphorus mass balance).**

| Year | Total Internal P Load (kg) | Percent of Total Load | Time Period |
|---|---|---|---|
| 2020 | 8,318 | 49.9% | May 1 - Jul 9 |
| 2021 | 10,740 | 59.4% | May 15 - Jun 25; Jul 24 - Aug 20; Sep 18 - Oct 1 |
| 2022 | 4,167 | 34.8% | Sep 4 - 17 |
| 2023 | 5,044 | 46.2% | May 29 - Jun 11; Jun 12 - 25; Sep 18 - Oct 1 |
| 2024 | 25,937 | 59.5% | May 29 – Jun 11; Aug 7 – Sep 3 |
| 2025 | 2,037 | 21.1% | Jun 12 - 25; Aug 29 - Sep 3; Sep 4 - 17 |

# 11.0 WATER TEMPERATURE

Surface water temperature has increased on average about 2°F (71.5 to 73.5°F) during July-September, or any group of months by 1.5 to 2.5°F, at lower Parker Horn and South Lake since the 1970s and 1980s (Table 9). The increase was nearly 3°F during May-September from the slightly cooler 1980s. The 2°F is less than half the temperature increase recorded for 245 world lakes from 1985 to 2019 and extrapolated by the decadal rate of increase to 2025. Lake Washington was among the group and its temperature has increased 2°F.

The water temperature increase since 2017 is not related to CRW inflow, which should have had a cooling effect. The highest July-August temperature of 79°F in 2021 occurred during the highest CRW inflow (Table 9). However, the lowest water temperatures for any combination of months were in 2024 with the second highest CRW inflow. Nevertheless, average daily maximum air temperatures recorded at the Moses Lake airport have increased on average of 4.3°F in May-September and 5.1°F in July-August between 1957-1965 and 2017-2025. There are no data available during 1970s-1980s from the Moses Lake airport.

### Algae

Blue-green algae (cyanobacteria) tend to be favored by increased temperature. However, the dominance of blue-greens in Moses Lake has been rather closely related to TP concentration, with low fractions of total algal biovolume during 2021-2023 and 2025 associated with TPs of 20-30 µg/L, which resulted from large inputs of low-P CRW. That is consistent with the risk of cyanobacteria fractions of algal biomass over 50% that was shown to decrease as TP declined below around 30 µg/L (Downing et al., 2001). Also, the increase of blue-greens in Moses Lake was shown in the 1980s to start when lake temperature reached about 68°F (20°C). The average water temperature in May-June, 67.2°F, has increased 2.5°F since the 1970s-1980s, but has not increased over the past nine years (Table 9).

### Fish

The species in Moses Lake that are least tolerant of increased temperature are walleye and smallmouth bass. Those populations increased several-fold in the 1980s and 1990s as lake trophic state changed from hypereutrophic (>100 µg/L) to borderline mesotrophic (25-50 µg/L) (Welch, 2009). Also, those two species prefer temperature below 77 and 79°F, respectively. Thus far, surface temperature at lower Parker Horn (TS5) and South Lake (TS6) has averaged 73.4°F during July-September, well below their preferred temperatures (Table 9). Moreover, average July-September temperature at the 4.5 m depth at those two sites and middle and lower RFA (TS11 and TS15) averaged 74°F during 2025, while DO averaged 6.5 mg/L (2.2-10.7 mg/L). Those conditions usually allowed those species to avoid higher surface temperatures and still have enough DO. Fish would probably avoid greater depths with lower temperature, because of lower DO, which averaged only 3.1 mg/L at 0.5 m off-bottom at South Lake and middle and lower RF Arm in 2025 (Table 3). *see CRW distribution section*

**Table 9. Average surface temperature in lower Parker Horn and South Lake for different periods during spring-summer over a range of Columbia River dilution water during 1977 and 1979 (164,760 to 209,150 AF) and 1986-1988 (66,020 to 207,280 AF) and 2017-2025 (75,456 to 230,005 AF). Sampling frequency during 1977-1988 was usually twice-monthly as well as during the past 8 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** | 113,210 | 71.0 | 75.3 | 64.5 | 70.3 |
| **2020** | 185,103 | 66.7 | 74.5 | 67.2 | 69.5 |
| **2021** | 230,005 | 67.2 | 79.0 | 67.8 | 72.0 |
| **2022** | 190,459 | 68.2 | 74.3 | 76.8 | 73.1 |
| **2023** | 159,293 | 68.9 | 77.3 | 66.3 | 71.7 |
| **2024** | 204,218 | 59.7 | 73.4 | 63.8 | 66.8 |
| **2025** | 171,929 | 70.1 | 75.4 | 74.5 | 73.1 |
| **Nine-year Average** | | 67.1 | 75.8 | 68.7 | 70.9 |
| **1977/1979** | 186,950 | 64.9 | 75.9 | 65.8 | 69.5 |
| **1986-1988** | 114,500 | 64.5 | 72.6 | 66.5 | 68.1 |

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

The middle and upper sections of RFA were treated with 250 tons of EutrosorbG containing 10% lanthanum (La) and 90% clay during the first two weeks of June 2024. The treatment area was 2,910 acres (43% of total lake area) with a volume of 51,880 AF (63.99 x $10^6$ $m^3$). The treated area is 49% of the total lake area, minus middle and upper Pelican Horn. Thus, the treated area was about half of that regularly diluted with CRW and represented as whole-lake water quality.

The resulting La concentration of the treatment was about 0.5 mg/L. Lanthanum sorbs mobile phosphorus in bottom sediments thus reducing sediment phosphorus release and internal loading. The treatment removes 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 (SRP and particular P) from the water column and inactivating sediment mobile phosphorus with alum. Eutrosorb-G was expected to have a similar effect on internal loading from bottom sediment.

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 stratify resulting in low DO near the bottom; e.g., 6.6 mg/L (55% saturation) on 7/19/2020 and 0.8

mg/L (12% saturation) on 7/22/2020, both after 8:00AM. Anoxia (zero DO) probably existed at the sediment-water interface during the night on those dates. Dissolved oxygen at 5.5 m averaged 2.8 mg/L (0.9-5.5) around 8:00AM on six dates in 2025. Thus, anoxia likely existed near the sediment-water interface, especially at night in 2025 as well. The anoxic 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, which entrains high-TP bottom water (Jones and Welch, 1990). The total P mass balance model for RFA was calibrated with an oxic and anoxic release rate of 4 mg/m$^2$ per day, which was similar to the laboratory-experimental rate of 3.5 mg/m$^2$ per day (Okereke, 1987; Tetra Tech, 2020).

### Treatment Effectiveness – Phosphorus

The data show that the treatment had a positive effect on surface (0.5 m) TP at middle RFA (TS11), at middle and upper RFA (TS11/TS12) together, as well as, at middle and lower RFA (TS11/TS15) together, for a total of 10 comparisons. Average May-September TP decreased 10-67% (average 37%), depending on the years compared and if corrected for dilution effectiveness (Table 10). Late-summer TP was exceptionally high in 2024, especially at TS12. That was probably unrelated to the treatment, because high TPs occurred in the lower lake as well.

Average TP at TS11 was 26% less after (2024) than before (2020) treatment with similar dilution effectiveness; 57%CRW in 2020 versus 53%CRW in 2024 at TS11 and 52%CRW both years at TS11/12 (Table 10). The treatment effect was much less at TS11 and TS12 together (10%), due to unusually high, late summer TPs at TS12 in 2024 (Table 10).

Total P was slightly lower in 2025 than in 2021-2023 (before treatment) at both TS11 and TS11/TS12 (Table 10). Total P in parentheses was estimated for 2021-2023 from the long-term %CRW–TP relation at TS5 and TS6, to correct for less dilution effectiveness in 2025 versus 2021-2023 (Figure 5). However, %CRW was usually less in middle and upper RFA than in the lower lake (TS5/TS6). For example, the %CRW-TP relation for TS5/TS6 predicts lower TPs by 23-35% than observed at TS11 in 1987-1988 (60 vs 74 µg/L). Also, TPs in 2020 at TS11 and TS11/TS12 were 30% and 71% higher than predicted at TS5 and TS6. Thus, the predicted TPs in 2021-2023, which corrected for the lower dilution effectiveness in 2025 (68 and 67%CRW versus 55%CRW and 56%CRW in 2025), may exaggerate the resulting higher treatment effectiveness (49% and 37%) shown in Table 10.

Determining treatment effectiveness was complicated by the unusually high TPs throughout the lake in late summer 2024. Excluding the high TP concentration of 129 µg/L at TS11 on 8/27/24 reduced the May-September average TP to 39 µg/L and increased the treatment reduction of TP to 40% instead of 26%, shown in Table 10. However, the TP of 129 µg/L is considered valid because chl was also relatively high at 33 µg/L for a chl:TP ratio of 0.26, which is not unusual; the chl:TP ratio in four of the last nine years at TS11 averaged 0.32. The chl:TP average for the last nine years at TS11 was 0.41.

Total P concentrations were exceptionally high in August 2024, after the East Low Canal breach. Excluding the high TP concentrations of 129 and 932 µg/L on 8/27/24 at TS11 and TS12 reduced the average concentration at

TS11/TS12 to 40 µg/L, giving a reduction in TP of 60% from 2020 with the same treatment effectiveness (52%CRW). However, chl was also high at TS12 on 8/27 (345 µg/L), giving a chl:TP ratio of 0.37, which is close to the usual ratio of 0.4.Therefore, excluding the high TP at TS11 of 129 µg/L and 932 µg/L at TS12 to assess the treatment effect is not justified, because, 1) chl was also high giving the usual chl:TP ratios, 2) all other TP results in 2024 were consistent with previous data at those sites, and 3) TPs over 100 µg/L occurred at TS11 and TS12 in 2020.

The observed reduction in TP in 2024 versus 2020 at TS11 (29%) and TS11/TS12 (10%) contrasts with the change in TP in the lower lake at TS5/TS6, which was not treated with Eutrosorb-G. Average May-September TP was actually higher at TS5/TS6 in 2024 than in 2020 by 58% with similar dilution effectiveness (66%CRW in 2020 and 63%CRW in 2024). That increase in TP between 2020 and 2024 in the lower lake, without treatment, indicates that the observed decrease in TP in middle and upper RFA was probably due to the treatment. However, average TP in the lower lake (TS5/TS6) was 9% less in 2025 than in 2021-2023 (20 versus 22 µg/L) and 54% less if corrected for dilution effectiveness (20 versus 43 µg/L), which was 77%CRW in 2021-2023 versus only 61%CRW in 2025 during July-September. Those corrected percent reductions in TP in the lower lake, without treatment, are similar to the reductions in middle and upper RFA with treatment. That indicates TP was lower throughout the lake in 2025, and that the treatment in RFA may have affected the lower lake quality as well.

**Table 10. Average May-September TP (µg/L) at 0.5 m for TS11 (middle RFA) and TS11/TS12 (middle/upper RFA) in 2020 and 2021-2023 before the EutrosorbG treatment in June 2024, and in 2024 and 2025 after the treatment. Total P and % decrease in parentheses estimated by the percent increase in TP that would have occurred in 2021-2023 from the observed decrease in %CRW in 2025 using the %CRW-TP relation in Figure 5. Note that the relation in Figure 5 was based on the long-term dataset for the Lower Lake (TS5/TS6).**

| | 2020 | 2024 | % decrease | 2021-2023 | 2025 | % decrease |
|---|---|---|---|---|---|---|
| **TS11 TP** | 65 | 48 | 26% | 32 (53) | 27 | 16% (49%) |
| **TS11 and TS12 TP** | 99 | 89 | 10% | 39 (52) | 33 | 13% (37%) |
| **TS11 TP** | 65 | | | | 27 | 59% |
| **TS11 and TS12 TP** | 99 | | | | 33 | 67% |
| **TS11 CRW** | 57% | 53% | | 68% | 55% | |
| **TS11 and TS12 CRW** | 52% | 52% | | 67% | 56% | |

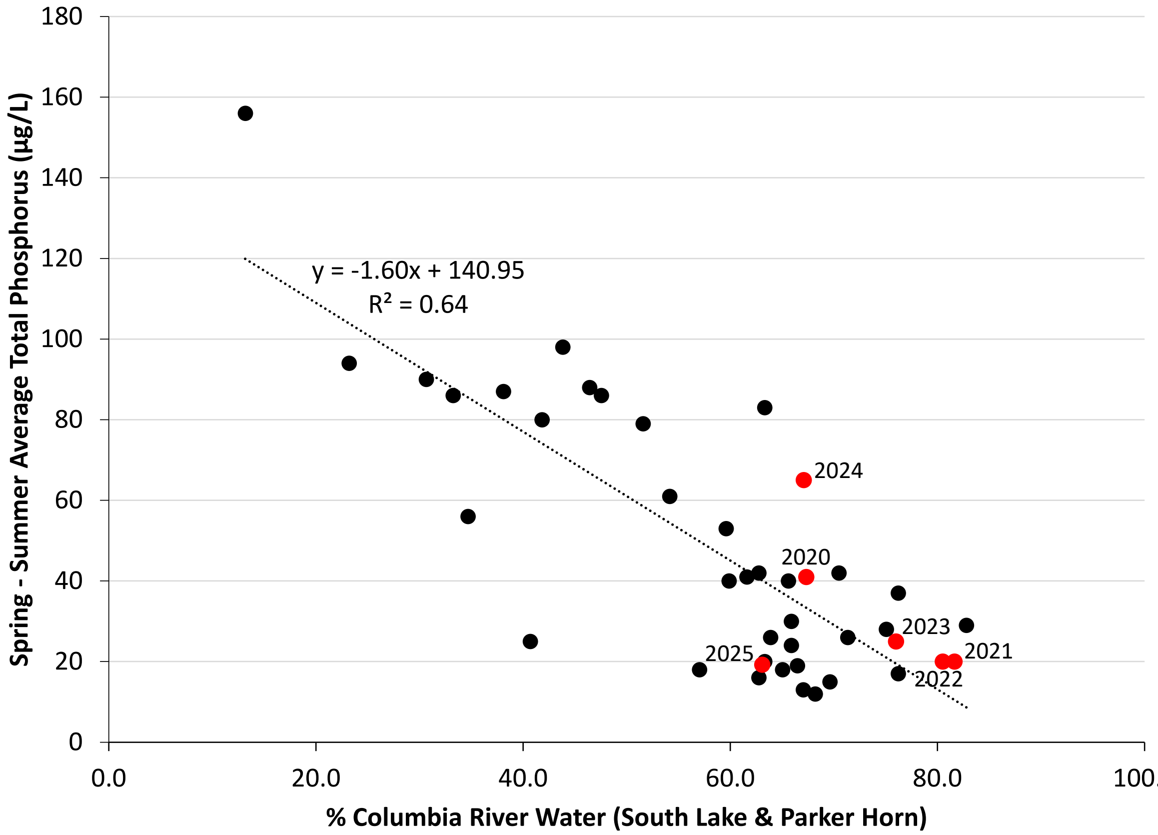


**Figure 5. Relation between average May-September TP and % Columbia River Water at TS5 and TS6.**

Average May-September volume-weighted TP in 2024, after the June treatment, was 15% less than in 2020 at similar dilution effectiveness (57%CRW versus 53%CRW) and only 6% less in 2025 than in 2021-2023 (Table 11). However, volume-weighted TP in 2025 was 52% less than in 2020 with similar dilution effectiveness (57%CRW versus 55%CRW), showing positive treatment effectiveness.

The treatment of middle and upper RFA had no apparent effect on surface (0.5 m) TP in 91% of the major lake area. Post-treatment average May-September TP was higher in 2024-2025 (46 µg/L) than in 2020-2023 (36 µg/L) (Table 12). However, post-treatment average surface TP was reduced by 25% compared to the 2020-2023 average TP by omitting the exceptionally high TPs in late August-September 2024, after the canal breach, resulting in a May-mid August average of 27 µg/L (Table 12).

Internal phosphorus loading, determined by whole-lake mass balance, was 71% less in 2025 than the 4-year average in 2020-2023 (Tables 7 and 8). The low internal loading in 2025 was not due to increased dilution or high %CRW in the lake (*see Internal Loading and CRW distribution*). Rather, the reduced internal loading in 2025 was likely due to the treatment of upper and middle RFA with EutroSorbG in the summer of 2024. The treated area in middle and upper RFA was nearly half the lake area that represents whole-lake water quality.

**Table 11. Average May–September volume weighted TP (µg/L) at TS11 (middle RFA) in 2020 and 2021-2023, before the EutrosorbG treatment in June 2024, and in 2024 and 2025 after the treatment, and % decrease in TP. Average %CRW was during June – September.**

| | 2020 | 2024 | % decrease | 2021-2023 | 2025 | % decrease |
|---|---|---|---|---|---|---|
| **TS 11 TP** | 65 | 55 | 15% | 33 | 31 | 6% |
| **TS 11 TP** | 65 | | | | 31 | 52% |
| **CRW** | 57% | 53% | | 68% | 55% | |

**Table 12. Average May–September area-weighted surface (0.5 m) TP in 91% of the lake area (TS5, TS6, TS7, TS11, TS12, and TS15). Omitting late August-September TPs, after canal breach in 2024, resulted in 27 µg/L in 2024-2025 versus 36 µg/L in 2020-2023.**

| TP (µg/L) | Pre-Treatment | | | | Post-Treatment | |
|---|---|---|---|---|---|---|
| | 2020 | 2021 | 2022 | 2023 | 2024 | 2025 |
| **Surface (0.5 m)** | 63 | 29 | 24 | 28 | 68 | 23 |
| **Average** | 36 | | | | 46 | |
| **Average without late August-September 2024 data** | | | | | 27 | |

### Treatment Effectiveness – Chlorophyll

Average May-September chl concentrations decreased in 2024 at both middle RFA (TS11) and middle and upper RFA together (TS11/TS12) after the treatment, compared to chl in 2020 (Table 13). Dilution effectiveness at TS11 was similar for those two years (57%CRW and 53%CRW; Table 10). Chl was much less in 2025 than in 2024, and slightly less than in 2021-2023, which had much higher dilution effectiveness (68%CRW) than in 2025 (55%CRW). Using the dilution effectiveness correction for TP in Table 10, and using a chl:TP ratio of 0.4, gives an expected chl of 21 µg/L for 2021-2023 for both TS11 and TS11/TS12 and treatment effectiveness of 57% and 38%, respectively. The maximum reduction was 81% and 78% between the equal dilution effectiveness years 2020 and 2025.

**Table 13. Average May–September chl (µg/L) at 0.5 m for TS 11 (middle RFA) and TS11 and TS12 (middle/upper RFA) in 2020 and 2021-2023, before the EutrosorbG treatment in June 2024, and in 2024 and 2025 after the treatment.**

| | 2020 | 2024 | % decrease | 2021-2023 | 2025 | % decrease |
|---|---|---|---|---|---|---|
| **TS 11 chl** | 42 | 20 | 52 | 12 | 9 | 25 |
| **TS11 & TS12 chl** | 69 | 43 | 38 | 14 | 13 | 7 |

### Treatment Effectiveness – Algae

Blue-green algae (cyanobacteria) at TS11 comprised a lower percent of total algal cell volume in 2025 than in any of the past nine years; 58% less than in 2021-2023 and 83% less than in 2017-2018 (Table 14). Blue-greens were even a lesser percent of total cell volume in 2024 despite much higher TP, especially compared with 2017-2018 (68%) and at similar TP concentrations (48 vs 51 µg/L, Table 14). The *Microcystis* fraction in 2025 was only one-tenth of that in 2017-2018 (no algal data in 2019-2020), although slightly more at only 1-2% in 2022-2024.

Thus, the response of blue-green algae in 2025, and the continued low *Microcystis* fraction, compared with that in 2017-2018, was likely due to the sediment phosphorus inactivation treatment in 2024, although TP in 2024 was similar to that in 2017-2018 (Table 14). Some of the reduction of blue-greens in 2025, and in 2024 despite higher TP, may have been due to the bentonite clay in Eutrosorb-G interfering with the recruitment of blue-greens from bottom sediment.

**Table 14. Average May – September TP (µg/L) and % blue-green algae (BG) and *Microcystis* (MA) of total algal volume at 0.5 m for TS11 in 2017-2018 and 2021-2023 before treatment and in 2024 and 2025 after the EutrosorbG treatment in June 2024.**

| | 2017-2018 | 2021-2023 | 2024 | 2025 |
|---|---|---|---|---|
| **TP (µg/L)** | 51 | 32 | 48 | 27 |
| **% BG** | 81 | 33 | 26 | 14 |
| **% MA** | 62 | 3 | 2 | 6 |

## 13.0 SUMMARY AND CONCLUSIONS

1. The six regularly sampled sites, TS5, TS6, TS7, TS11, TS12 and TS15, cover 91% of the major lake area and 95% of the volume. Determining %CRW by SC showed that starting at 40-52%CRW at TS11 and TS12, and around 30%CRW at TS5 and TS6 before CRW input, CRW increased to 65% and 59% in middle and upper Rocky Ford Arm and 66% and 72% in lower Parker Horn and South Lake, respectively, in June, 2025. Percent CRW in the lake declined some by September 2025, but the six-site, May-September area-weighted average for 2025 was 58%CRW. These results show that wind distributes CRW rather quickly through the lake and data from these six sites represent whole-lake conditions.

2. A lower lake level at the start of CRW inflow should increase dilution effectiveness because there is less lake volume to dilute. Lake level averaged 2.2 feet lower when inflow started in 2020-2023 than in 2017-2019. That lake level difference may have accounted for more effective dilution by June at TS5/TS6 (80% CRW) than in 2017-2019 (60% CRW). The difference in dilution effectiveness was apparent in RFA as well with 55%CRW and 41%CRW, respectively. The starting lake level difference of 2.2 feet represents 18% of full pool volume for an increased ratio between inflow volume and lake volume, which should increase dilution effectiveness. However, CRW inflow volume also affects dilution. Lake water at TS5/TS6 was 72%CRW and 69%CRW in June 2024 and 2025, respectively, following 1-2 feet higher starting lake levels than in 2020-2023. The effective diluiton in 2024-2025, despite higher starting lake levels was partly due to higher CRW inflows that averaged 65% higher in 2024-2025 than in 2017-2019. Over the past six years CRW inflows averaged slightly over 190,000 AF through September, while June-September CRW averaged 70% in lower Parker Horn/South Lake and 60% in middle/upper RFA,

demonstrating the dilution effectiveness of high CRW inflows, as well as diffusive transport of CRW well into RFA by wind.

3. Percent CRW is usually higher in Parker Horn/South Lake but reached 55-60% at TS11 and averaged slightly higher (68%) if two other deep sites (TS6 and TS15) were included. The three sites represent 58% of the lake area and 74% of the volume. Incoming colder (50°F) and denser CRW tended to sink in Parker Horn/South Lake indicated by slightly colder bottom water with slightly higher SC. Thus, CRW averaged 62% off-bottom at the deep sites indicating effective dilution through the water column. However, the degree of stratification over the past six years was unrelated to observed dilution (%CRW) through the water column. The large inflows of CRW during April-June during the past six years, representing 1.25 lake volumes, enhanced dilution through the water column. Also, the lake is polymictic, so wind affects water column mixing, although wind speed and direction were rather consistent the past six years (*see #4 below*). Periodic stratification affects off-bottom DO, which averaged 4 mg/L, well below saturation, over the past six years, probably causing the higher off-bottom TP.

4. Inflow of CRW was transported into RFA by prevailing wind, which was usually from the SE and SW at an average of 7 mph during May-September over the past six years. An experiment in 1981 demonstrated that process by comparing predicted with observed %CRW in middle RFA. Also, inflow from Rocky Ford Creek was shown to have a minimal counter effect of transporting RFA water toward the lower lake. That process was effective in transporting water from lower Parker Horn to middle and upper RFA, which contained an average of 67%CRW during June-September in 2021-2023 and 54%CRW in 2024-2025. The average increase of 20%CRW from May to July (44% to 64%) in middle/upper RFA during the past six years represents a transport of about 10,400 AF of CRW, which was about the averaged May-September inflw from Rocky Ford Creek. Thus, transport of diluted lake water well into RFA is a consistent process.

5. Lake water quality at lower Parker Horn/South Lake (TS5/TS6) was much improved in 2025 with the lowest May-September average TP over the past nine years at 19 µg/L and an average chl of 7 µg/L. Total P was also low in middle/upper RFA (TS11/TS12) with an average TP of 32 µg/L. Chlorophyll concentrations at those sites were directly related to TP, consistent with data from a large group of lakes, as was Secchi transparency related to chl. Total P at six sites throughout the lake averaged 26 µg/L during 2021-2023 and 2025. That respresents an 85% reduction from the pre-dilution average of 154 µg/L at lower Parker Horn/South Lake in 1969-1970. Total P was unusually high in 2024 during late August-September at all sites following a breach in the East Low Canal. Much less observed water transparency for the concentration of chl (algae) present indicated unusually high non-algal turbidity. The high TPs were not due to analytical error because chl was consistent with TP.

6. Inputs to the lake from Crab Creek and Rocky Ford Creek contributed an average of only 17% of total TP loading to the lake during May-September in 2020-2023 and 2025. Total P inflow concentrations have been consistently averaging 48 µg/L in Crab Creek and 158 µg/L in Rocky Ford Creek during May-September. Total P concentrations in those inflow streams were exceptionally high in 2024 for unknown reasons.Those two streams drain a large portion of the watershed. Internal loading was the major contributor to May-September TP loading at an average of 49% in 2020-2024.

7. Internal loading was unusually low in 2025 at 2,037 kg, which was only 21% of the 2020-2023 average. Internal loading in 2024 was almost 26,000 kg, three times the average for 2020-2023 and 1984-1988, due to exceptionally high lake TP concentratrations in late August-September after a breach in the East Low Canal. The low internal load in 2025 was likely due in part to the sediment phosphorus inactivation treatment in middle and upper RFA. The low internal loading in 2025 was not due to increased CRW inflow or to higher off-bottom DO, which were less than averages for the past several years.

8. The occurrence of near-shore scums of cyanobacteria and concentrations of microcystin varied over 100-fold the past eight years at Blue Heron and Connelly Parks while percent cyanobacteria and *Microcystis* in open water (TS6 and TS11) varied by only 3-11% on average. These open-water algae fractions were similarly low during the past five years, averaging 20% and 28% cyanobacteria and 3% and 4% *Microxystis,* respectively. Average TP and chl were also low at 30-34µg/L and 12-13 µg/L, respectively the past five years. Cyanobacteria and *Microcystis* fractions of total algal biomass were even low at both open-water sites in 2024 despite unusually high late summer TP and chl concentrations. While the occurrence of cyanobacteria scums and microcystin were unrelated to open water algal and TP data, the relatively low TP of around 30 µg/L or less should minimize the fractions of cyanobacteria and *Microcystis* of total algae. Near-shore accumulations of scums with microcystin above the standard (8 µg/L) may still occur due to their buoyancy and the effect of wind concentrating surface scums nearshore.

9. Surface water temperature has increased 1.5-2.0°F since the 1970s-1980s, but only 1°F compared to the 1970s. The increase is not related to CRW inflow, which should have a cooling effect. However, average daily maximum air temperature has increased 4.3°F on average during May-September between 1957-1965 and 2017-2025, and 5.1°F in July-August. Cyanobacteria are usually favored by increased temperature but are dependent on phosphorus to produce biomass. Cyanobacteria have usually started to increase in Moses Lake when surface temperature has reached about 68°F, and spring water temperatures have not changed (May-June average 67°F). The two most sensitive fish species are walleye and smallmouth bass, with preferred temperatures of 77°F and 79°F, respectively. Surface temperature during July-September averaged 73.4°F during the past eight years, well below their preferred temperature. They may be restricted from deeper, cooler water at times due to low DO.

10. The EutrosorbG treatment to 2,910 acres of middle and upper RFA covered nearly half the lake's routinely monitored area. The treatment's active ingredient is lanthanum, which binds mobile phosphorus in the bottom sediment. A mass balance with 2019 data showed that 64% of the TP loading to RFA was internally recycled from bottom sediment as internal loading. While middle RFA mean depth is only 6.6 m, anoxia probably exists in the sediment overlying water at times, as evidenced by low off-bottom DO concentrations, which result in high rates of sediment P release as internal loading. Determining effects of the 2024 treatment depended to some extent on year-to-year dilution effectiveness. Also, late August-September TP concentrations were exceptionally high in 2024 following a breach in the East Low Canal, although the actual source is unknown. Comparing average May-September surface (0.5 m) TP concentrations between 2020 and 2025, with similar dilution effectiveness, and comparing 2025 TP (corrected for dilution effectiveness) with 2021-2023, resulted in 10 observations of treatment effectiveness that ranged from 10% to 67%, with an average of 37%. Volume-weighted TP in middle RFA decreased slightly in 2024, following treatment, compared with 2020, but by 51% in 2025 versus 2020 with similar dilution effectiveness. Whole-lake, area-weighted, TP decreased by 25% in 2024-2025, compared with 2020-2023, if late August-September high TPs in 2024 were ignored. Internal loading, determined by whole-lake mass balance, decreased by 71% in 2025 compared to the average for 2020-2023 – likely related to the treatment. Internal loading in 2024 was exceptionally high due to high TP throughout the lake following the East Low Canal breach. Chl decreased following the treatment by 7% to 81% (average 47%), depending on which years were compared, with the largest decrease between 2020 and 2025, and equal dilution effectiveness. Percent cyanobacteria was much reduced in 2025 and *Microcystis* continued at a low fraction of total algal biomass, likely related to the sediment inactivation treatment.

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