Grand Lake Adaptive Management Annual Report 2024

Grand Lake Adaptive Management Committee

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BACKGROUND AND PURPOSE

In January 2016, the U.S. Department of the Interior Bureau of Reclamation (Reclamation), Northern Colorado Water Conservancy District (Northern Water), Grand County Board of County Commissioners (Grand County), Northwest Colorado Council of Government (NWCCOG), and Colorado River Water Conservation District (River District) entered into the Grand Lake Clarity Stakeholders' Memorandum of Understanding (Clarity MOU) (Appendix A).

In this Clarity MOU, the parties agreed to establish an adaptive management process to implement the Water Quality Control Commission's (WQCC) narrative water quality standard for Grand Lake:

> "The highest level of clarity attainable, consistent with the exercise of established water rights, the protection of aquatic life, and protection of water quality throughout the Three Lakes system."

Further, the parties agreed to implement clarity goals to guide the adaptive management process:

> "The annual clarity goals for Grand Lake from July 1 through September 11 are an average Secchi depth of 3.8 meters and a minimum Secchi depth of 2.5 meters."

The Clarity Goals and the adaptive management approach were subsequently endorsed by the WQCC in April 2016 and the Clarity Goals were adopted as Goal Qualifiers. In the June 30, 2016, Statement of Basis and Purpose for Regulation 33 (Appendix B), the WQCC stated that "The Division [Water Quality Control Division] will assess consistency with the adopted narrative standard by monitoring whether the Proponents continue to implement the adaptive management process described in their Memorandum of Understanding and will review clarity measurements. Evaluation of the Clarity Goals will be accomplished by reviewing annual reports and summarizing progress at the Basin Issues Scoping Hearing."

The Clarity MOU established the preparation of an annual report to summarize what was learned about Colorado-Big Thompson (C-BT) Project operational approaches to meet the clarity goals, and resultant effects on water quality and clarity in Grand Lake. The MOU specifies consideration of three water quality indicator thresholds – Grand Lake Secchi depth at index sites, Shadow Mountain Reservoir dissolved oxygen (DO) at the bottom and surface, and pH in Shadow Mountain Reservoir near the surface.

This report meets the reporting requirements of Section V.C.5.d of the Clarity MOU and the Water Quality Control Commission.

2024 ADAPTIVE MANAGEMENT PROCESS

This section describes the 2024 Adaptive Management Process.

Adaptive Management Committee Representatives

The Adaptive Management Committee (AMC) comprises representatives from Reclamation, Northern Water, Grand County, NWCCOG and the River District. A list of the representatives that attended meetings in 2024 is included in Appendix C.

Section V.C. of the Clarity MOU describes the process for developing an operational plan and for the adaptive management phase during the July 1 through September 11 Grand Lake Adaptive Management (GLAM) Season. This process is illustrated in Figure 1**.**

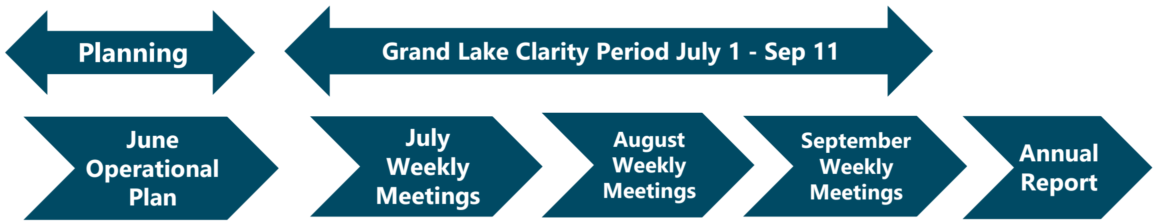

Figure 1. Adaptive Management Process

Section V.C of the Clarity MOU specifies that operational scenarios along with corresponding water quality model runs shall be presented to the AMC at a seasonal kick-off meeting by June 1 of each year.

East Troublesome Fire and 2024 GLAM Process Changes

On October 14, 2020, the East Troublesome Fire (ETF) started in Grand County. The fire burned 193,812 acres of forest and shrubland, as well as 366 residences in north-central Grand County and the Three Lakes Watershed, before it was declared contained on November 30, 2020. Some of the watersheds burned in the fire included Willow Creek, Stillwater Creek, North Fork Colorado River, and North Inlet (89, 90, 29, and 42% burned, respectively), all which flow into the Three Lakes. The most significant changes observed in the Three Lakes are increases in nutrient concentrations, specifically NO3 and NO2 as N (mg/L) and to a lesser degree Ortho Phosphorus (mg/L). Many other parameters including physical parameters and metals have not shown increasing concentrations post-fire with small median factor changes likely attributed to hydrology and other factors rather than post-fire water quality changes. Subsequent ecosystem changes, such as increased algal and cyanobacteria growth, have been observed in all post-fire years and are expected to continue.

While it is difficult to predict how long post-fire water quality changes will persist in the Three Lakes region, Figure 2 shows an example of inorganic nitrogen concentrations in Shadow Mountain Reservoir and Grand Lake from 2009-2024 with the ETF shown as a vertical dotted red line in October 2020. It is not yet known how long elevated concentrations will persist or if they have already reached a post-fire peak.

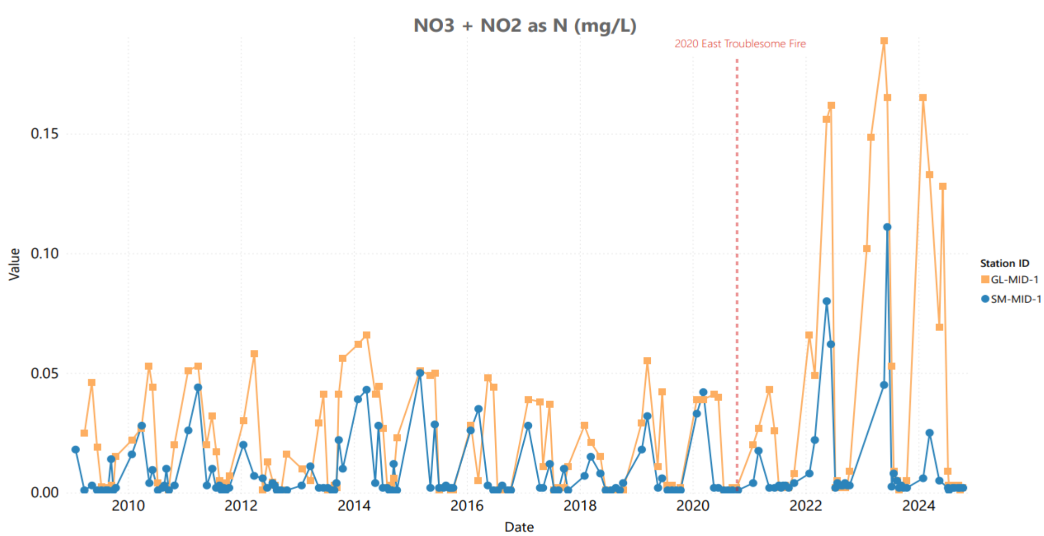

Figure 2. Inorganic nitrogen (NO3 and NO2 as N mg/L) at GL-MID surface and SM-DAM surface.

Due to these effects from the ETF, the AMC met and agreed to an amended GLAM process in 2021, 2022, 2023 and 2024 which consisted of the following agreements:

- *Preseason modeling of the operation scenario to forecast water quality response will not be conducted.*
- *In lieu of modeling, pre-season data review and discussion between GLAM participants will occur regarding 2024 operations.*
- *Data collection and analysis will continue per the annual monitoring plan, including additional wildfire related monitoring programs.*
- *The AMC will meet weekly from July 1 through September 11 to discuss the data and observations on clarity.*
- *If, during the course of the GLAM season, a specific objective has been identified, and there are sufficient data to support an investigative effort, the AMC will explore the use of models and other analytical tools to understand the impacts to the Three Lakes system and how the system responds to operations.*
- *Members of the AMC may provide input to Reclamation to modify the Operation Plan as needed during the weekly conference calls. Adaptive Management may include Reclamation making changes in the C-BT Project operations or other appropriate measures. Reclamation will evaluate any input provided.*
- *A summary report of the GLAM season and process shall be produced to document the 2024 clarity season AMC efforts.*
- *A summary report on what the AMC learned about C-BT operational approaches and impacts to clarity will be produced and provided to the Commission.*
- *These modifications are necessitated by the 2020 East Troublesome Fire for an additional one-year period. Nothing in this modification alters or supersedes the other terms and conditions set forth in the 2016 MOU.*

The letter is included in Appendix D.

Planning Process

Kickoff Meeting – May 30, 2024
The AMC reviewed Reclamation's draft operational plan. The plan is described in the 2024 Operation Plan section below and the Kickoff Meeting materials are included in Appendix E. As described above, the water quality model was not used for the operational plan.

Pre-Season Weekly Meetings – June 4-24, 2024
In lieu of modeling and in accordance with the MOU modification for 2024, the AMC met weekly before the GLAM season to discuss current conditions.

GLAM Season Weekly Meetings – July 2-September 3, 2024
The AMC held weekly meetings to discuss water quality and operations in an effort to optimize clarity and gain insight about system dynamics. Meeting materials, notes and recordings are compiled in Appendix G.

Debrief Meeting – October 24, 2024
The AMC held a debrief meeting to discuss possible improvements to the process, lessons learned and recommendations for future years. Meeting materials are in Appendix H.

A schedule of all meetings is included in Appendix F.

2024 Operational Plan

The Northern Water Board of Directors sets a C-BT Project water delivery quota each year, which quantifies the amount of C-BT water available to allottees. Quotas are expressed as a percentage, in which a quota of 100% indicates that each share of C-BT receives the full allotment of 1 acre-foot, while a quota of 50% means that each share receives 0.5 acre-feet. The quota is set based on the need for supplemental water on the East Slope. The Northern Water Board set a preliminary 50% quota in November 2023 and allocated an additional 20% in April 2024. Due to a warm and dry summer, especially on the East Slope, the Board allocated an additional 10% in August 2024 for a total quota of 80%. The last time that the Northern Water Board allocated an additional quota in August or later was in 1993. The Northern Water Board also allocated 15,000 acre-feet of Regional Pool water, which comes out of unused and unclaimed quota allocations from the year prior.

Reclamation prepared an operational plan during the spring and presented it to the group for discussion at the May 30, 2024, kickoff meeting. The scenario presented sought to meet the objectives listed in Senate Document 80:

1. To preserve the vested and future rights in irrigation.
2. To preserve the fishing and recreational facilities and the scenic attractions of Grand Lake, the Colorado River, and the Rocky Mountain National Park.
3. To preserve the present surface elevations of the water in Grand Lake and to prevent a variation in these elevations greater than their normal fluctuation.
4. To so conserve and make use of these waters for irrigation, power, industrial development, and other purposes, as to create the greatest benefits.
5. To maintain conditions of river flow for the benefit of domestic and sanitary uses of this water.

The plan took into consideration the high likelihood of a spill at Lake Granby and Willow Creek Reservoir, facility outages, system maintenance, operations that help to optimize Grand Lake Clarity, power generation and East Slope water capture. The culmination of these limitations resulted in only one operational proposal with no alternatives for consideration in the 2024 season.

The 2024 Operational Plan, as outlined in an email from Reclamation on June 21, 2024, is below. This Operational Plan is a guiding document and is not prescriptive.

Operations were constrained by the following operation and maintenance projects:

1. Pole Hill Power Plant damage limiting power operations to 24 MW (~ 425 cubic feet per second (cfs)) to full load while minimizing operations between speed no-load and 24 MW. This causes Reclamation to bypass the power plant or maintain flows >425 cfs. Bypassing results in lost power opportunity.
2. Mary's Lake Power Plant maintenance that continued into this year with anticipated completion in October 2024. Flows need to be bypassed around the hydropower machinery.
3. Hansen Feeder Canal constrained to <475 cfs.
4. Outage at Flatiron Unit 3 starting on August 26 and continuing through December 2024 for a tie-in with Chimney Hollow Reservoir.

The following is an excerpt from the Bureau of Reclamation's Operational Plan in May 2024 and constitutes a "best case scenario":

1. Carter Lake

a. We try to keep Carter Lake as full as reasonable, to reduce the magnitude of West Slope spill. This requires movement of water through the Adams Tunnel.
b. We will fall short of fill at Carter in 2024, as a result of facility repairs below Pole Hill Power Plant from December through March.
c. Pumping to Carter Lake is underway. We expect to run it to August 29. This puts storage at a maximum at the end of June before July demands, met by outflow, begin to exceed pumped inflows. It preserves as-high-as-possible storage through west slope spill conditions. Demands from Carter Lake have been higher in June than were anticipated in May and June AOP simulations.
d. An outage for construction to connect Chimney Hollow facilities to the C-BT Carter Lake Interconnect runs from August 29 to December 15, 2024. The proposed operations and this outage will not adversely affect Carter Lake conditions going into 2025.

2. Horsetooth Reservoir
    a. Horsetooth Reservoir receives as much water as reasonable, to reduce the likelihood and magnitude of West Slope spill. This requires movement of water through the Adams Tunnel and has run at capacity most of the time.
    b. When East Slope priority water (project's East Slope water right comes into priority) is available and pumping to Carter Lake is occurring, diversion of this water at Dille Diversion site has been prioritized to allow storage at Carter Lake and Horsetooth Reservoir to exceed Olympus Tunnel capacity (550 cfs).
    c. Regardless of water source, deliveries to Horsetooth Reservoir cannot exceed CHFC 550 section capacity, simulated to be ~475 cfs. When pumping to Carter Lake is <u>not</u> happening, this limitation results in some marginal opportunity for east slope skim operations through Olympus Tunnel, using its remaining capacity up to 550 cfs.
    d. Horsetooth filled to 5929.5 feet on June 20, reserving a small amount of temporary storage for local storms and runoff, though this level is considered full.
    e. From its peak, the reservoir storage declines through the summer as driven primarily by demands met through delivery.
    f. Once pumping to Carter Lake ends in late August, Adams Tunnel diversions are set to maintain 430 cfs at Pole Hill Power Plant. With a portion of these flows delivered at the Big Thompson Canyon mouth, Horsetooth receives all remaining flows through September.
    g. These operations position Horsetooth Reservoir comfortably high going into refill operations in December. Without the Pole Hill constraint, we'd probably reduce flows into Horsetooth Reservoir at several points.
3. Adams Tunnel:
    a. Flow will continue through the Adams Tunnel from west to east throughout the scenario. Leading up to the beginning of the clarity period, July 1, the diversion rates may vary depending on East Slope priority water and demands out of Horsetooth. When east slope priority water exists at sufficiently high levels, it displaces the need for diversion while east slope conveyance capacities to fill Carter Lake and Horsetooth Reservoir remain maximized.
    b. In the scenario, which is highly dependent on the East Slope hydrographs used with significant uncertainty, flows through the Adams Tunnel ranged from 282 cfs in near June 10 to 500 cfs for much of the period, with 550 cfs for five days beginning June 20. Pumping at Farr Pump Plant to support this begins minimally July 1 and in earnest on July 5.

c. Weekend reductions in diversion through Adams Tunnel commence July 21, with reduced flows at ranging from 360 cfs and up. Weekday flows will work with East Slope flows to take advantage of remaining skim opportunities while keeping the system running near capacity.
d. On August 29, following shutdown of pumping to Carter Lake, diversions remain near 430 until September 29, reflecting minimum generation flows at Pole Hill.

4. Grand Lake / Shadow Mountain Connecting Channel:
    a. Highly dependent on the shape of uncertain west slope hydrographs, flows remained from Grand Lake into Shadow Mountain from mid-May through June 29, except for 2 discontinuous days in mid-June. Efforts to minimize West Slope spill do not allow for the "settling period" in late-June and early-July. Reversal of flows from Shadow Mountain Reservoir into Grand Lake begin on July 1. Lake Granby experiences a significant spill with almost complete elimination of Willow Creek pumping during the runoff period. The June AOP estimated a June to July spill of 13 kaf from Willow Creek Reservoir and 21.3 kaf from Lake Granby. Draft logs prepared on June 17 indicated 10.8 kaf had been released from Willow Creek Reservoir and 18.4 kaf had been spilled from Lake Granby.

The full operational plan and comments from GLAM entities are included in Appendix E.

2024 Adaptive Management

Discussions during the weekly GLAM meetings in 2024 addressed conditions in the connecting channel, temperature in Shadow Mountain Reservoir, power generation considerations relating to C-BT Project operations and more. Discussions emphasized that preserving water quality in Shadow Mountain Reservoir and the connecting channel could ensure that when Farr Pump Plant pumping started, water entering Grand Lake would be of higher quality, optimizing water clarity. There were discussions regarding the potential benefit of allowing a flushing flow to move through the connecting channel (from Grand Lake to Shadow Mountain Reservoir) to improve conditions within the channel prior to the start of pumping operations, but ultimately this suggestion was not acted upon due to a change in hydrology. Additionally, the AMC discussed starting Farr pumping as soon as Grand Lake inflows could no longer meet Adams Tunnel diversions, thereby preventing a period of frequent, small reversals of flow through the connecting channel that could negatively impact Grand Lake clarity. Due to changes in hydrology and operational needs, Farr Pump Plant pumping began on July 3 therefore preventing a significant duration with low flows in either direction in the connecting channel (Figure 12).

Another ongoing conversation in 2024 related to water temperatures as a control for algal growth in Shadow Mountain Reservoir. In 2022, Hydros Consulting presented an analysis of recent data showing that during July and August warmer temperatures promote cyanobacteria dominance and colder temperatures promote diatom dominance (Hydros 2022). Hydros hypothesized that there may be an optimal intermediate temperature range that minimizes the growth of both types of phytoplankton in Shadow Mountain Reservoir: 0-1 meter temperature less than 15 C and 0-5 meter temperature greater than 14 C calculated by a daily average. Because of this optimal temperature window hypothesis, the AMC discussed timing of pumping operations as a control for temperature. Reclamation included decreased Adams Tunnel diversions over the weekends in their 2024 Operational Plan to adaptively manage for clarity as has been included in previous years. In 2024, the AMC discussed a reduction of pumping on cooler days to prevent water temperatures from falling too far below the optimal range as pumped inflows to Shadow Mountain are a significant control on temperature. This discussion resulted in a conversation with Western Area Power Authority (WAPA) where the

AMC learned that power generation is often more valuable during weekdays, when residences and businesses are utilizing the most power, and less valuable on the weekends. Therefore, Reclamation retained the planned operations with decreased diversions on the weekends rather than modifying operations experimentally to target optimal temperature windows.

In 2024, both goal qualifiers: the season average and season minimum were met. The average Secchi depth in Grand Lake during the GLAM season was 4.5 meters and the minimum daily Secchi depth was 3.7 meters.

GRAND LAKE & SHADOW MOUNTAIN RESERVOIR CLARITY

This section describes observed water quality and clarity in Shadow Mountain Reservoir and Grand Lake during the 2024 GLAM season (July 1 - September 11). Figure 3 shows the monitoring sites where data were collected. Grand County Water Information Network (GCWIN) is contracted to manage the Secchi Program for the GLAM process and the summary of this program is attached in Appendix I. Secchi measurements were recorded at all reservoir sites, and two buoys equipped with real-time sensors collected profile data every four hours at SM-MID and SM-DAM Real-time data collection also occurred at GR-PUMP, CR-SMU, SM-CMK (USGS site) and NI-SP (USGS site). Farr pump flows are measured at Farr Pump Plant.

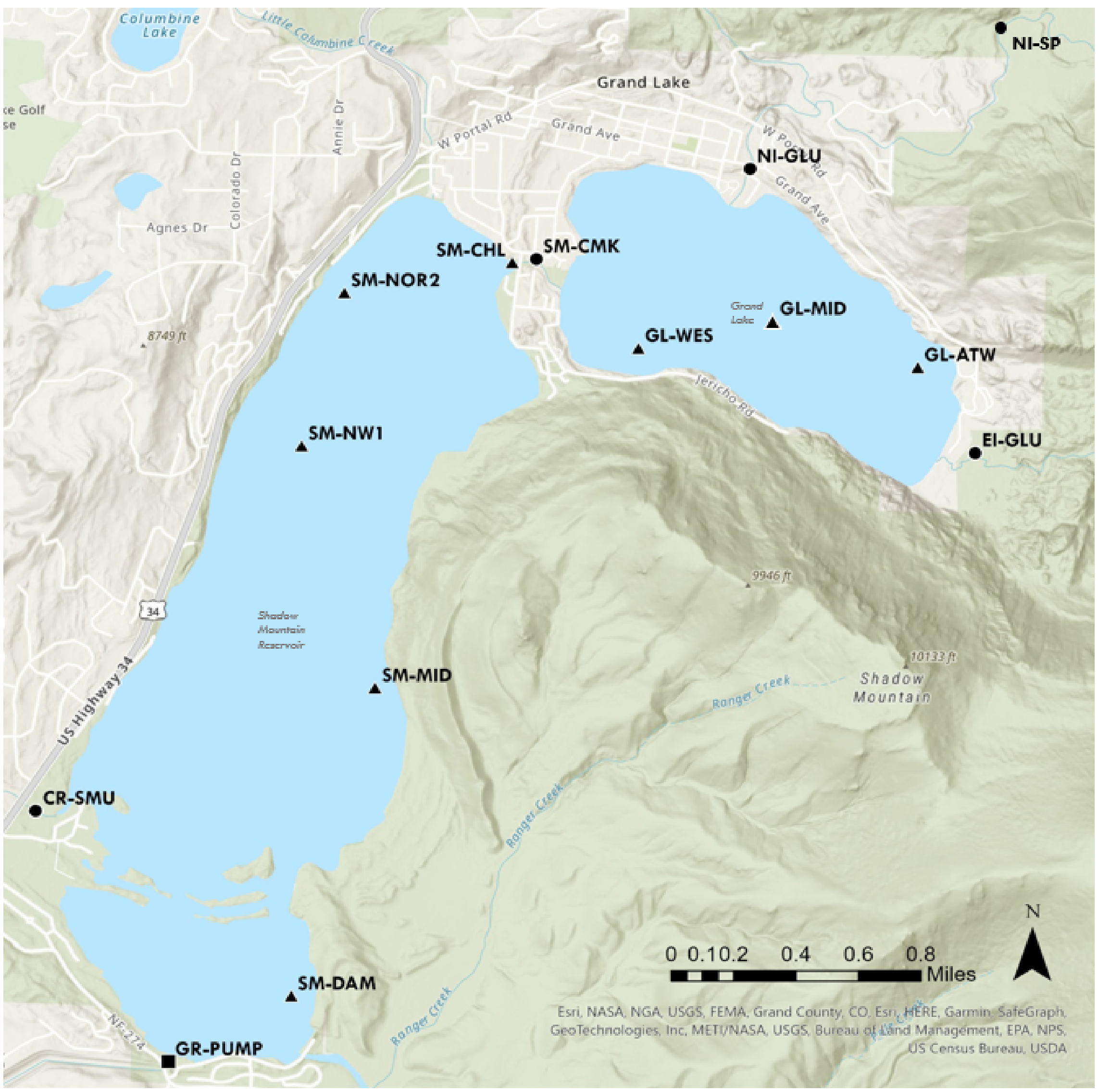

Figure 3. Map of Sampling and Monitoring Locations used during the GLAM season and Weekly GLAM Meetings

Operations and Water Quality Summary Results

Operations Summary

Peak naturalized (undepleted) runoff into the Three Lakes in 2024 was reached on June 8 at a daily average of 3,277 cfs (Figure 4). The total April through July runoff volume of 243 thousand acre-feet (KAF) was greater than but close to the Northern Water May most probable forecast of 220 KAF and well within the bounds of the maximum forecast of 267 KAF. The C-BT Project's East Slope Big Thompson water right was in priority from late April through mid-June. A total of 14.2 KAF of East Slope priority water was collected and placed into storage in Carter Lake and Horsetooth Reservoir.

Due to a planned outage over the winter to connect Chimney Hollow Reservoir to the C-BT system that delayed water movement to Carter Lake, combined with an unplanned maintenance outage on the East Slope conveyance system, Carter Lake did not fill during the runoff season. Because of the above-average runoff, above-average system storage after water year 2023, and unused space in Carter Lake, the C-BT Collection System spilled at both Willow Creek Reservoir and Lake Granby. The spill at Willow Creek Reservoir totaled 39.8 KAF, while 44.4 KAF spilled from Lake Granby for a total C-BT Collection System spill of 84.2 KAF. Weather during the clarity season was slightly warmer than average with slightly below average precipitation (Figure 5, Figure 6). Precipitation was distributed relatively evenly throughout the GLAM season (Figure 6, Figure 7). While there were a few precipitation events upstream of the Three Lakes during the 2024 GLAM season, none caused notable impacts to water clarity (Figure 7).

Flow direction in the connecting channel is important for understanding clarity responses to changing flows in both Grand Lake and Shadow Mountain Reservoir. During runoff, water flows from Grand Lake into Shadow Mountain Reservoir and is shown as negative flow in Figure 8. Once Adams Tunnel diversions exceed Grand Lake inflows, the flow reverses, moving water from Shadow Mountain Reservoir into Grand Lake, shown as positive flow in Figure 8. Farr Pump Plant pumping operations began on July 3, just two days after Reclamation's forecasted date of flow reversal on July 1 (Figure 8, Appendix E). The decision to start pumping was based on several factors including available storage on the East Slope, minimizing spill out of Granby Reservoir, maximizing the length of the settling period in Grand Lake, and the availability of skim water for East Slope power generation. Skim water is native Big Thompson River water that is diverted into the C-BT Project system for power generation and then returned to the river shortly thereafter. Water was pumped at Farr Pump Plant at an average daily rate of between 330 and 570 cfs, and when possible, during off-peak power cost hours. Reclamation reduced diversions at the Adams Tunnel during the GLAM season in 2024 limiting flows through the West Portal to 400 cfs on weekends. This approach has been used in previous years with the intention of improving clarity. While these modified operations highlight the adaptive management process working to achieve the best clarity possible, no definitive effects are attributable to varying weekend/weekday pumping rates.

Finally, two fires (Alexander Mountain Fire and Stone Canyon Fire) near East Slope C-BT infrastructure temporarily affected operations during July as water could not be moved north from Flatiron Reservoir into Horsetooth Reservoir. These fires did not cause significant impacts to infrastructure or water quality in 2024. The effects will continue to be monitored as fire recovery is ongoing.

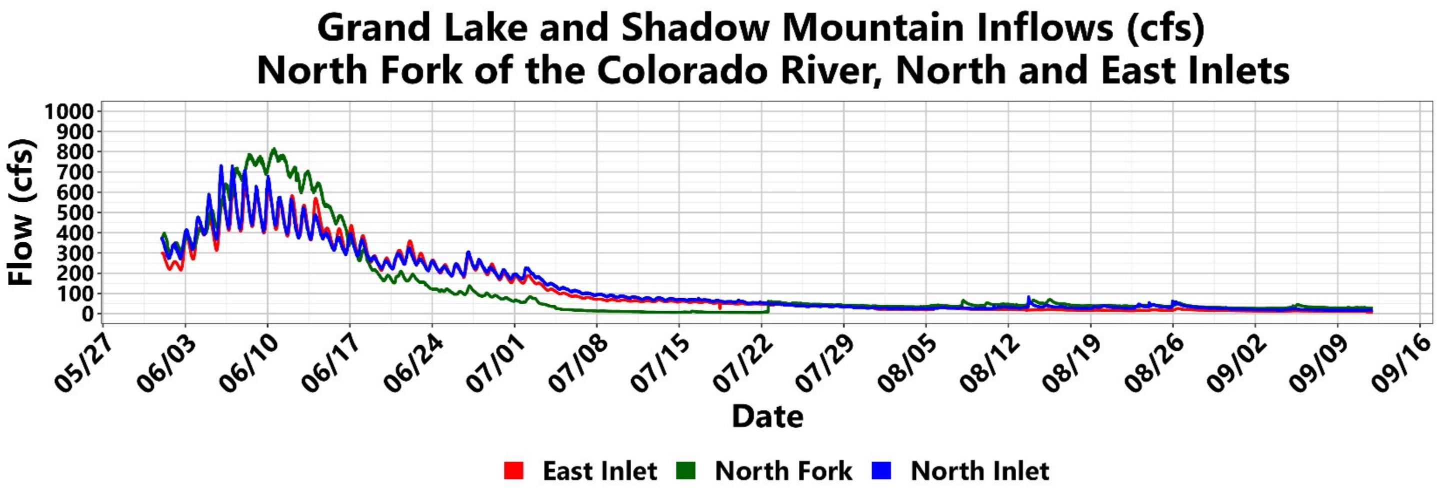

Figure 4. Inflows (cfs) into Grand Lake and Shadow Mountain Reservoir including the North Fork, North and East Inlets.

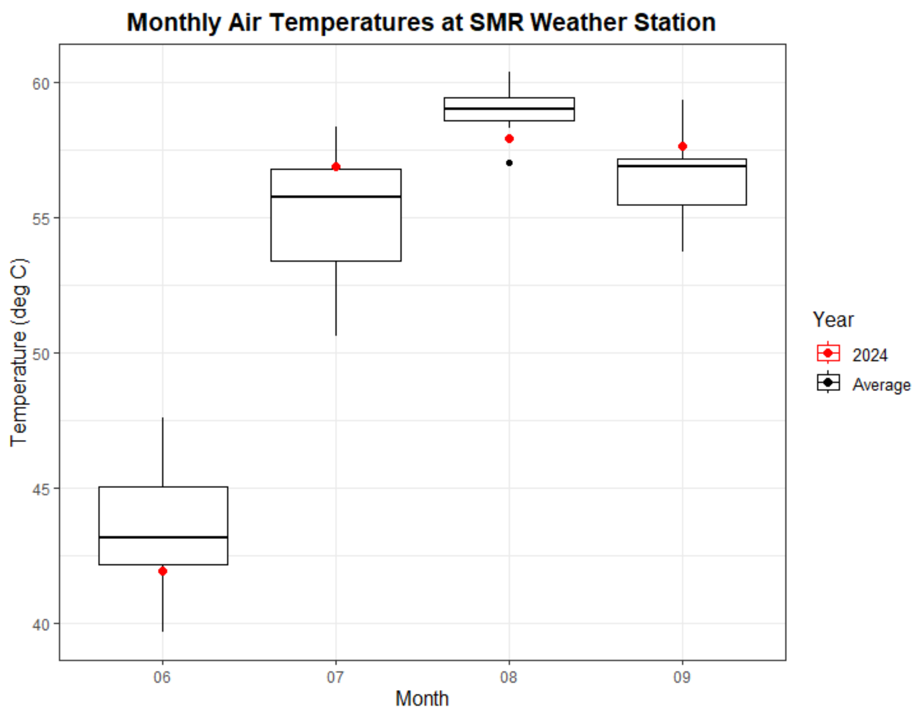

Figure 5. June- September Average Air Temperatures by month at Shadow Mountain Reservoir Weather Station with 2012-2023 average in black and 2024 monthly averages in red.

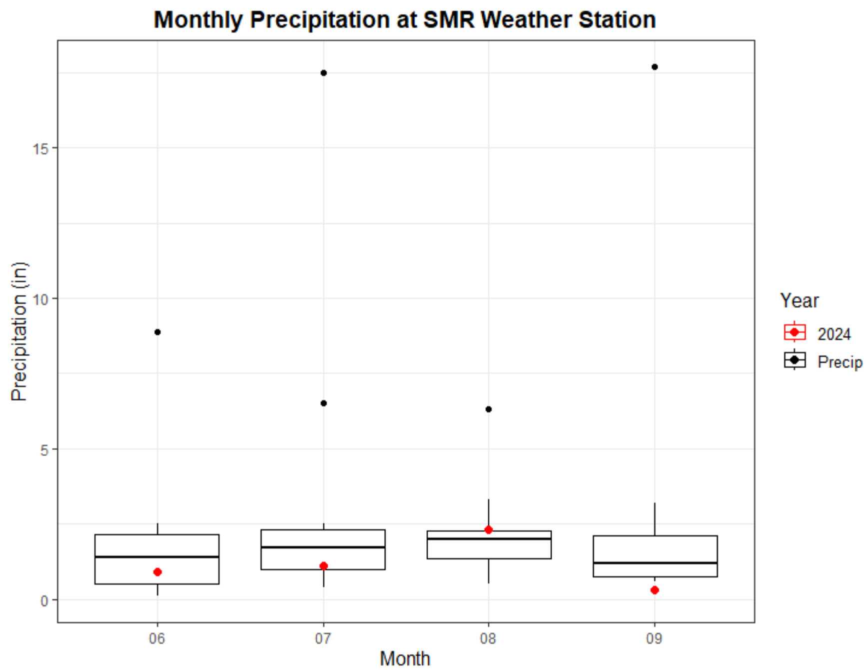

Figure 6. Monthly precipitation (in) (June-September) at Shadow Mountain Reservoir Weather Station. 2012-2023 shown in black boxplot, 2024 average monthly precipitation indicated in red.

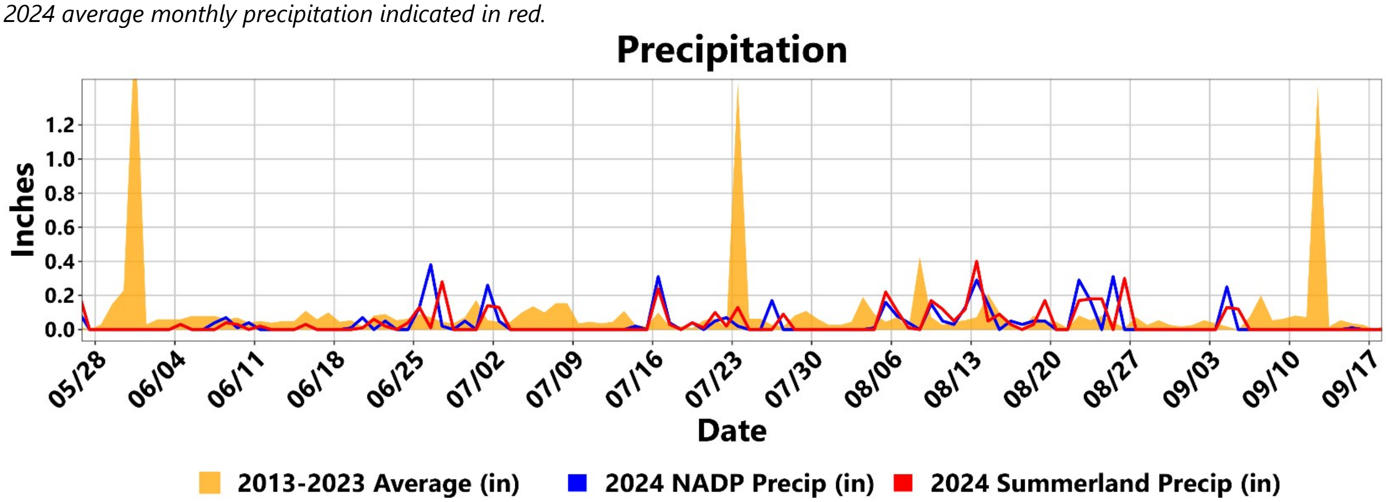

Figure 7. Precipitation (in) at the NADP Precipitation Station and Summerland Park with 2013-2023 average precipitation in orange.

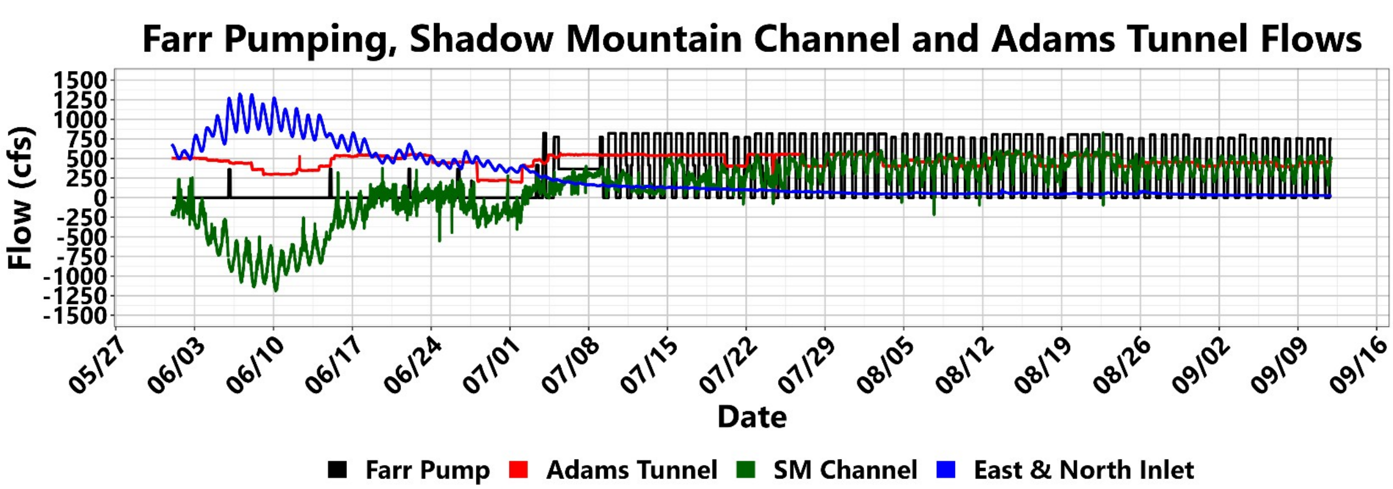

Figure 8. Farr Pumping, Shadow Mountain Channel, North and East Inlet flows, and Adams Tunnel Flows

Clarity and Water Quality Summary

Both Grand Lake and Shadow Mountain Reservoir saw improvement in average daily clarity occurring between peak runoff and the beginning of the GLAM season (Figure 9). Clarity in Grand Lake was greater than clarity in Shadow Mountain Reservoir on all but two days: July 10 and 12. Daily average clarity in both water bodies was greater than 3 meters from July 8 through the end of the GLAM season with a significant percentage of days in both water bodies with clarity greater than 4 m.

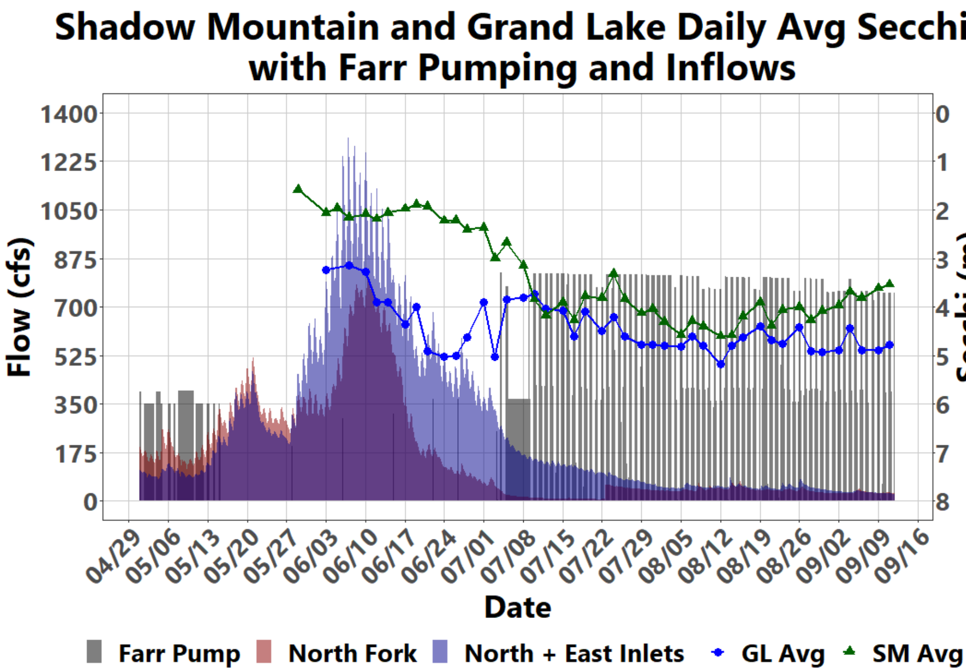

Figure 9. Shadow Mountain Reservoir and Grand Lake daily average Secchi with Farr pumping inflows. Note exclusion of hit-bottom measurements in SM Avg calculation.

Clarity in Grand Lake began with Secchi depths around 3 meters in early June during peak runoff and increased as runoff tapered off with a Grand Lake average Secchi depth of 3.9 meters on July 1, the first day of the clarity season (Figure 10). The daily average Secchi depth calculated from averaging two viewscope readings from each site: GL-WES, GL-ATW and GL-MID. In Grand Lake and SM-MID, SM-DAM, SM-NOR2, and SM-NW1 in Shadow Mountain Reservoir. The daily average Secchi depth in Grand Lake exceeded 5 meters on two occasions: July 3 and August 12 with 74% of daily average Secchi depths in Grand Lake exceeding 4.5 m. The final average clarity in Grand Lake during the GLAM Period was 4.5 meters.

Clarity in Grand Lake remained relatively consistent throughout the GLAM season with the minimum clarity of 3.7 meters set on July 10; all following average clarity observations exceeded this minimum value. Farr pumping in the off-peak hours began on July 3 just a few days into the GLAM season and continued with a generally consistent pattern through the end of the GLAM season.

One day with notable clarity differences across the three index locations in Grand Lake was on July 5 with clarity measurements ranging from 3.0 to 4.7 meters from GL-WES to GL-ATW (from west to east, or from Shadow Mountain Reservoir, toward the Adams Tunnel) respectively. This variance across the water body follows the onset of pumping and movement of pumped flows through Shadow Mountain Reservoir and into Grand Lake. Clarity measurements improved over the following weeks with minimal variation between monitoring locations.

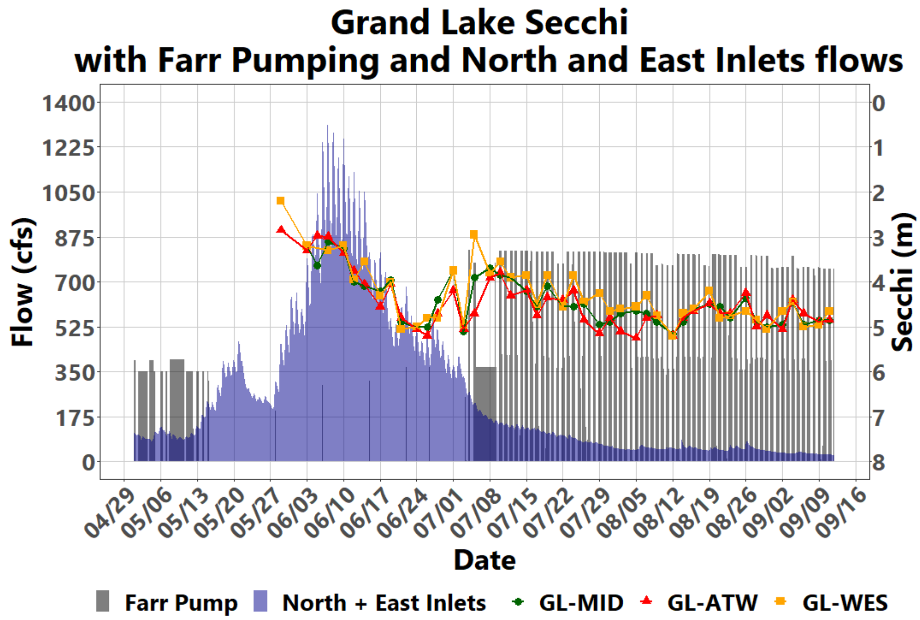

Figure 10. Grand Lake Secchi depth with Farr pumping and North and East Inlet flows

Shadow Mountain Reservoir had a GLAM season Secchi depth average of 3.9 meters and a maximum daily average Secchi depth of 4.6 meters (Figure 11). Note that the bottom of Shadow Mountain Reservoir was hit during several sampling events at SM-NOR2 indicating high clarity in the shallow areas of the reservoir; per the monitoring protocol (Appendix I), those measurements are disqualified and are excluded from figures and calculations. Clarity in Shadow Mountain Reservoir was less than 2 meters in early June prior to the start of the GLAM season but increased through the first few weeks of July, with no measurements lower than 3 meters from mid-July through the end of the GLAM season on September 11. Clarity was generally highest at SM-MID and lowest at SM-NOR2.

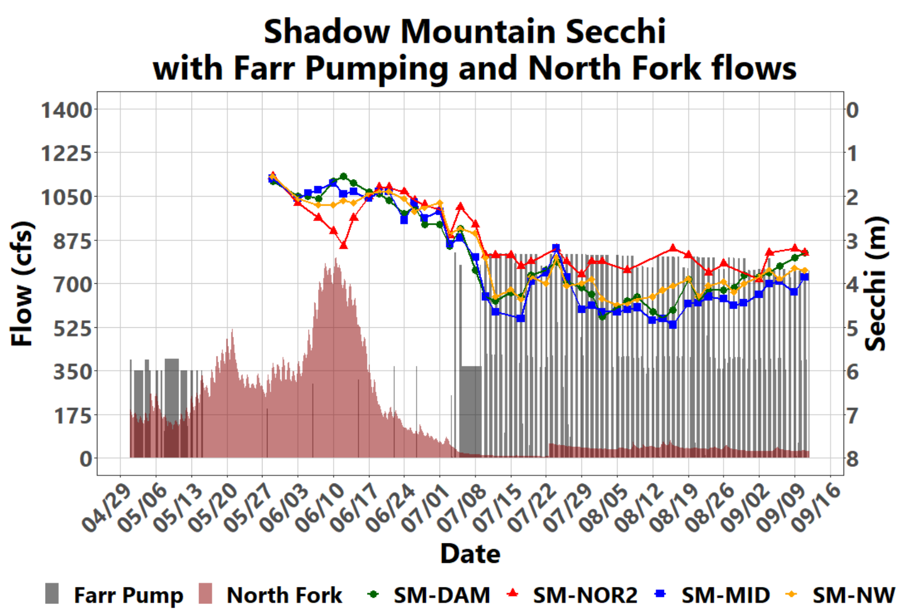

Figure 11. Shadow Mountain Reservoir Secchi depth with Farr Pumping and North Fork flows. Missing points indicate a measurement that hit bottom.

Conditions in the connecting channel between Grand Lake and Shadow Mountain Reservoir were a focus of several discussions during the 2024 GLAM season with the intention of avoiding warm stagnant water and conditions promoting algal growth. As shown in Figure 12 the chlorophyll *a* relative fluorescence units (RFU) timeseries in the connecting channel indicated some algal growth in mid-June prior to the start of the GLAM season as well as some in mid-July that are paired with some high turbidity events (Figure 13). Specific Conductivity (SpC) is also a good indicator of flow direction in the connecting channel; increases in SpC correlate closely with direction of flow from Shadow Mountain Reservoir to Grand Lake (Figure 13). Discussions during the early GLAM season addressed a target start to Farr pumping before flow in the connecting channel tapered off significantly resulting in conditions favoring poor clarity. This "clean switch" concept aims to keep enough water flowing through the connecting channel in either direction to avoid oscillation of flow and degraded clarity. The orange rectangle in Figure 12 highlights a period of near-zero flow in the connecting channel and the subsequent chlorophyll *a* and phycocyanin increases.

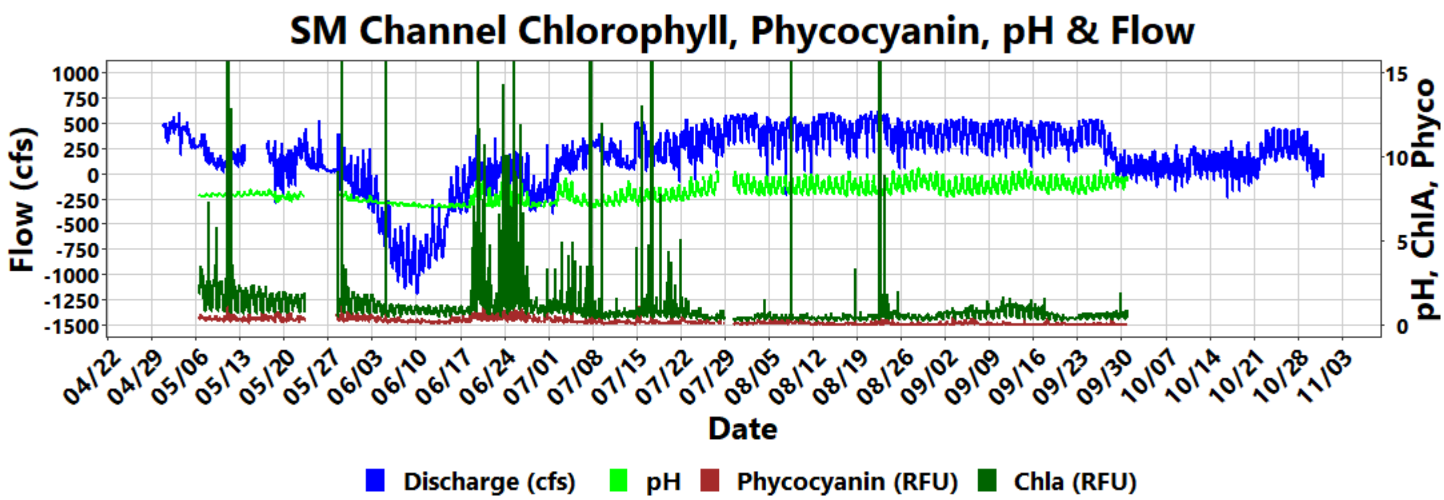

Figure 12. Water quality in the connecting channel between Grand Lake and Shadow Mountain Reservoir showing flow, pH, phycocyanin and chlorophyll a.

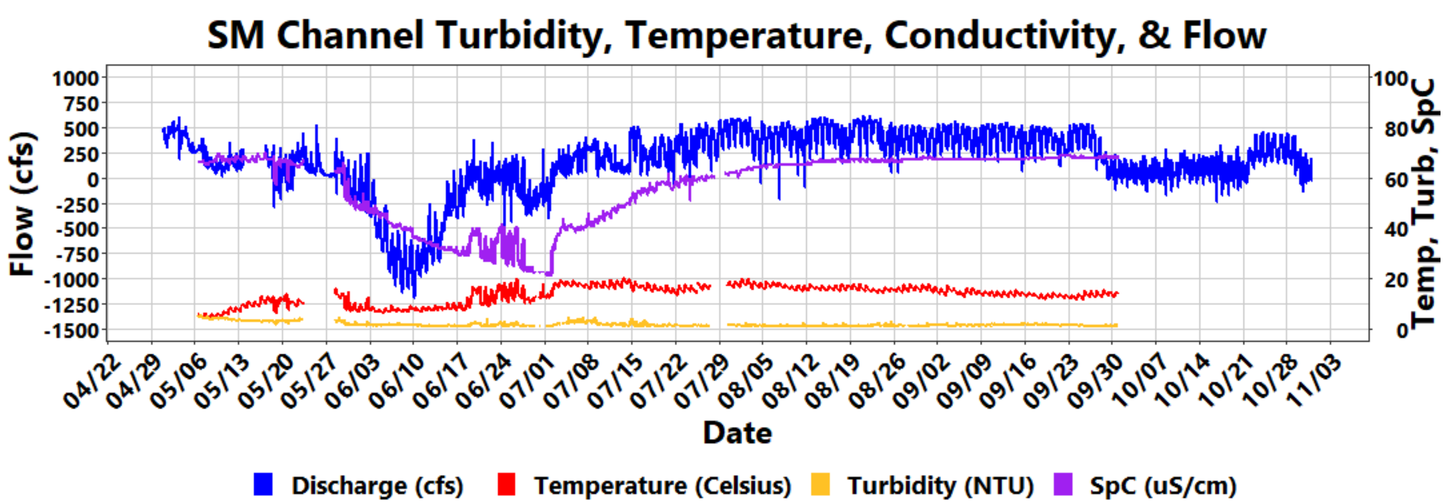

Figure 13. Water quality in the connecting channel between Grand Lake and Shadow Mountain Reservoir showing flow, temperature, turbidity and specific conductivity.

Water quality data collected in Grand Lake and Shadow Mountain Reservoir include physical profiles measuring temperature, DO, pH, chlorophyll-*a* RFU, phycocyanin RFU, turbidity and SpC. Discrete chlorophyll *a* and phytoplankton samples were taken weekly in Grand Lake and Shadow Mountain Reservoir and bi-weekly at SM-CMK by the USGS. A summary of these water quality conditions is listed below followed by the respective figures. (Figure 14 - Figure 37).

- Water quality profiles in Grand Lake indicate low chlorophyll *a* RFU and phycocyanin RFU, pH generally below 8 and low turbidity throughout the GLAM season. Temperatures in Grand Lake follow 2024 meteorological trends with the warmest surface temperatures during the first week of August followed by cooling into mid-September (Figure 5). Slight increases in phycocyanin RFU were observed in Grand Lake on July 3 following the onset of flow reversal. The increase was minimal and cannot be definitively attributed to pumping, however, the profile does indicate higher surface phycocyanin on July 3 than on any other measured date at GL-MID (Figure 14). Parameters related to algal growth, including chlorophyll *a*, DO, surface pH, phycocyanin and surface turbidity, show few other indications of significant algal growth in Grand Lake in 2024. (Figure 14)
- Temperatures at both SM-DAM and SM-MID showed the warmest period at the end of June and first few days of July just before Farr pumping began. Following the start of Farr pumping, both sites remained cooler for the remainder of the GLAM season. Based on target temperatures for limiting phytoplankton growth in Shadow Mountain Reservoir (Hydros 2022), daily average temperatures from 0-1 meter and 0-5 meters were evaluated in 2024. Temperatures were generally cooler than 14 degrees C for the 0–5-m interval and generally cooler than 16 degrees C for the 0-1 meters interval. Despite the cool temperatures, significant growth of Asterionella was not observed. (Figure 15, Figure 16, Figure 17, Figure 18, Figure 19, Figure 20)
- DO in Shadow Mountain Reservoir followed typical surface concentrations, and did not manifest the prolonged low concentrations at the bottom of the reservoir. DO concentrations triggered the indicator threshold of 3 mg/L with a minimum value of 2.9 mg/L lasting for less than a day. Once summer Farr pumping began, bottom DO concentrations increased above the 3 mg/L threshold and remained high as typical of years with high summer Farr pumping. (Figure 21, Figure 22, Figure 23, Figure 24)
- pH in Shadow Mountain Reservoir did not exhibit any notable conditions throughout the GLAM season, remaining between 7 and 8 for almost the entire period. The indicator threshold of 8 was triggered at SM-MID, however, the peak in pH at 8.1 lasted only a day before returning to a value less than 8 (Figure 25, Figure 26).
- Chlorophyll *a* RFU, chlorophyll *a* grab samples, and phycocyanin RFU remained low throughout the whole GLAM season with no significant peaks or indications of algal growth. (Figure 27, Figure 28, Figure 29, Figure 30, Figure 31, Figure 32)
- Turbidity in Shadow Mountain Reservoir remained low through the GLAM season and was not affected by some moderate precipitation and turbidity events in the inflows. Turbidity events in the North Fork and North Inlet followed precipitation and were generally short-lived, returning to typical concentrations within hours. (Figure 33, Figure 34, Figure 35, Figure 36)
- Specific conductivity in Shadow Mountain Reservoir followed typical trends in 2024, increasing throughout the GLAM season with the consistent inflow of water from Granby Reservoir. (Figure 37, Figure 38)

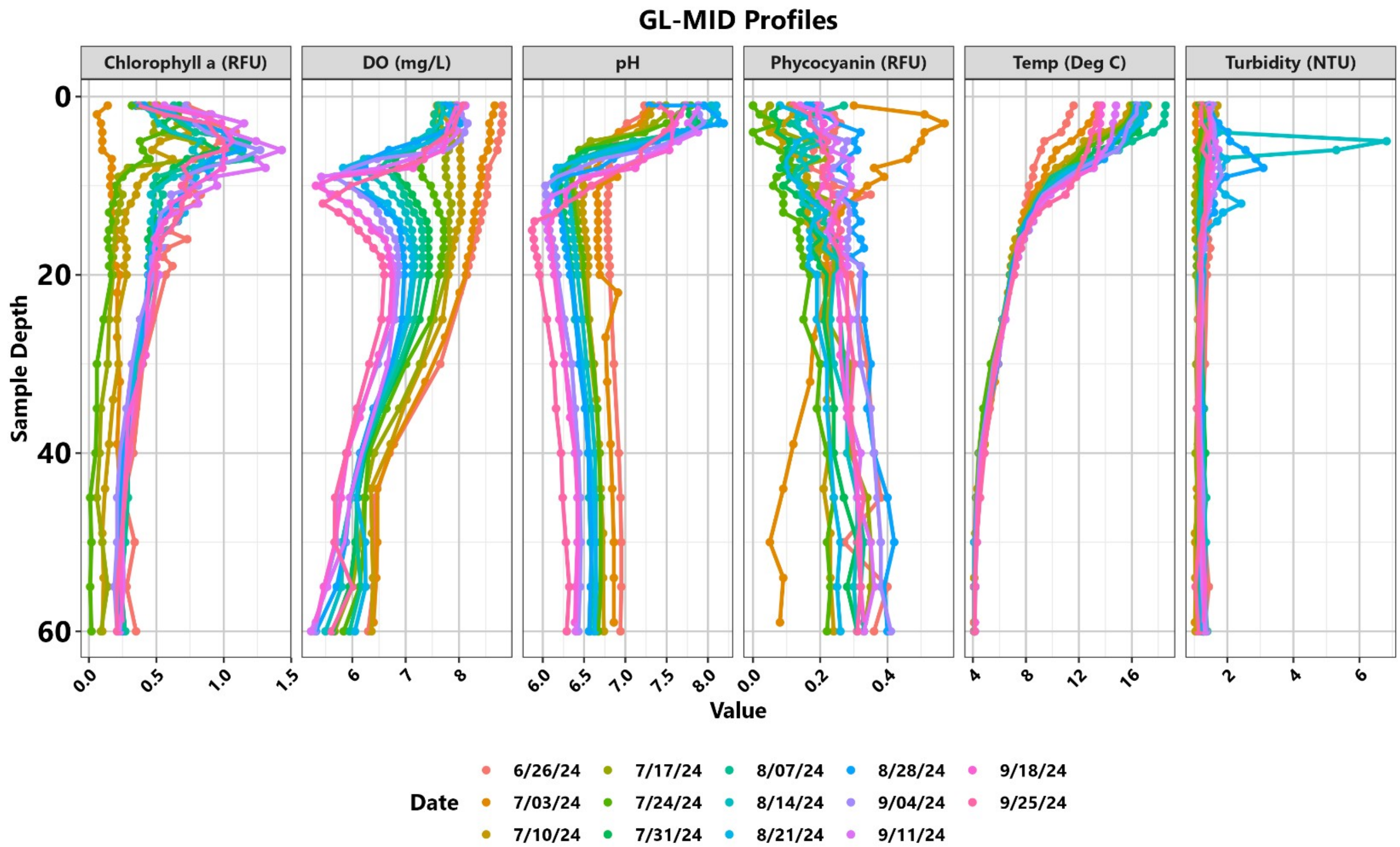

Figure 14. Discrete water quality profiles at GL-MID in 2024.

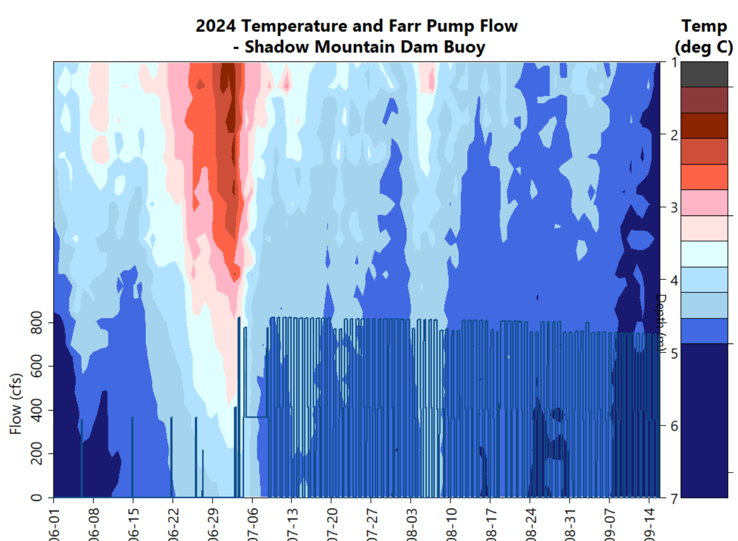

Figure 15. 2024 Temperature (color) and Farr Pump flow (line) at SM-DAM

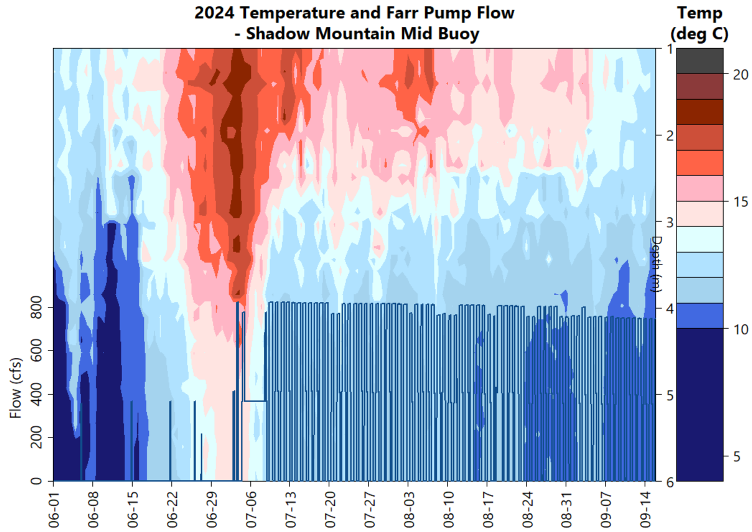

Figure 16. Temperature (Deg C) (color) and Farr pump flow (line) at SM-MID

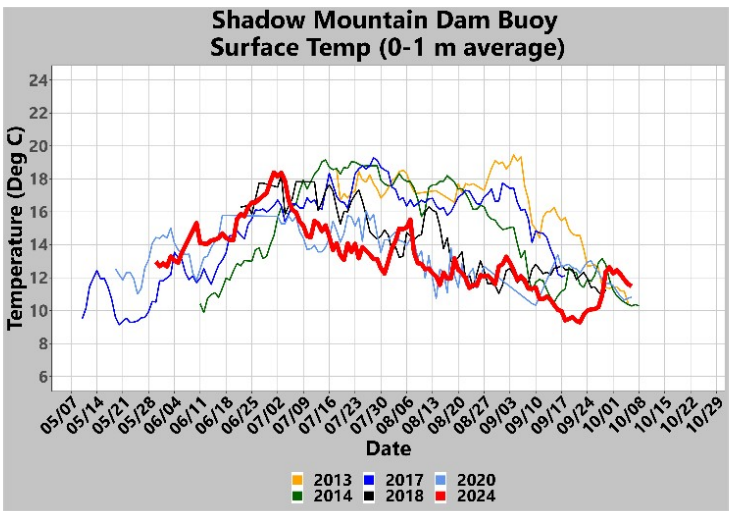

Figure 17. Average daily surface temperature from 0-1 meters in Shadow Mountain Reservoir at SM-DAM. 2024 data is shown in red with other colors showing reference years.

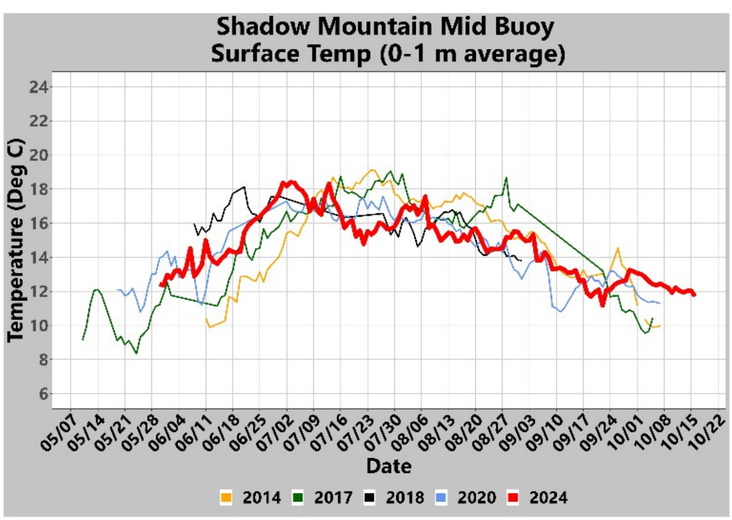

Figure 18. Average daily surface temperature from 0-1 meters in Shadow Mountain Reservoir at SM-MID. 2024 data is shown in red with other colors showing reference years.

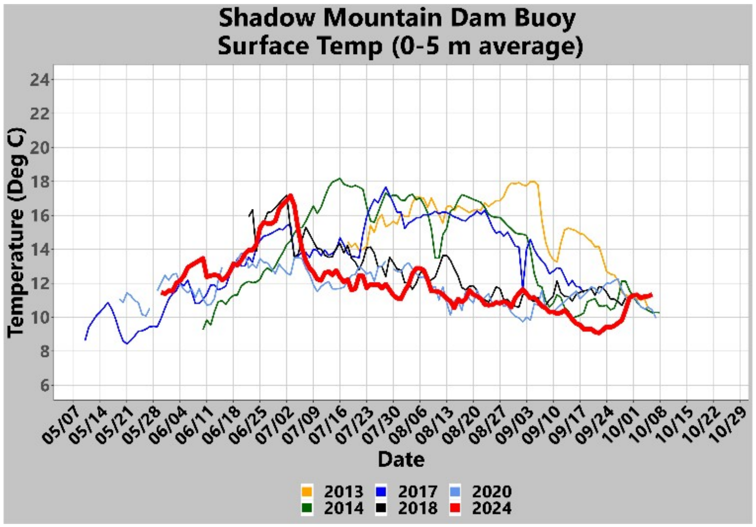

Figure 19. Average daily surface temperature from 0-5 meters in Shadow Mountain Reservoir at SM-DAM. 2024 data is shown in red with other colors showing reference years.

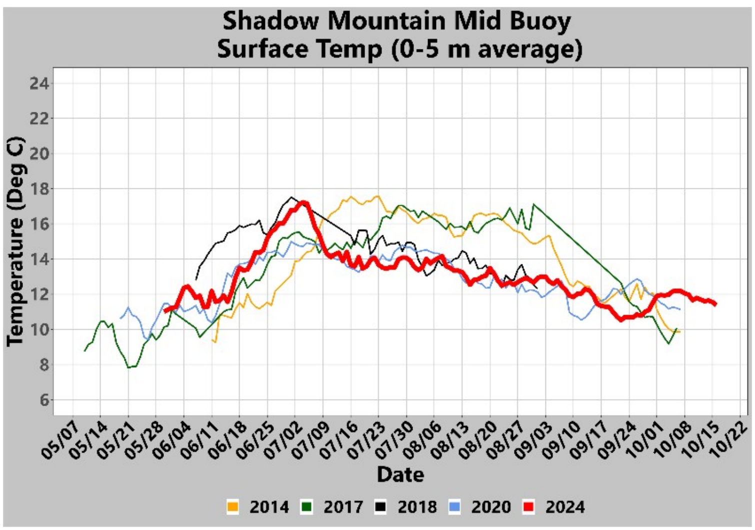

Figure 20. Average daily surface temperature from 0-5 meters in Shadow Mountain Reservoir at SM-MID. 2024 data is shown in red with other colors showing reference years.

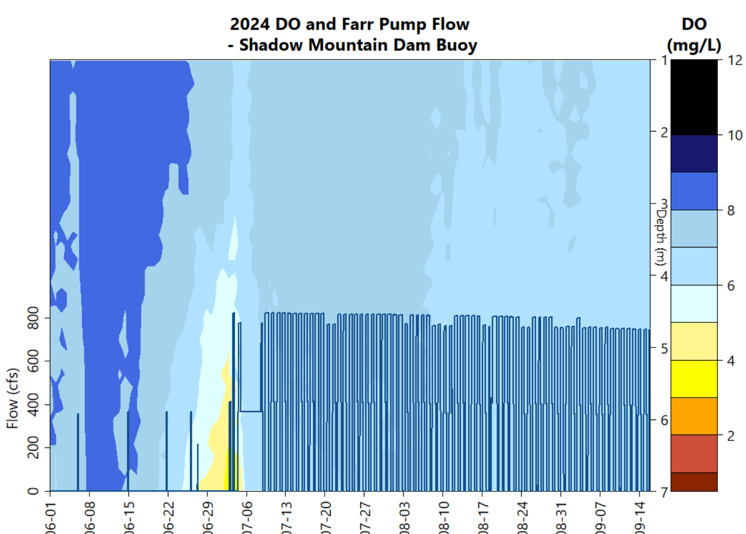

Figure 21. 2024 Dissolved Oxygen (color) and Farr pump flow (line) at SM-DAM

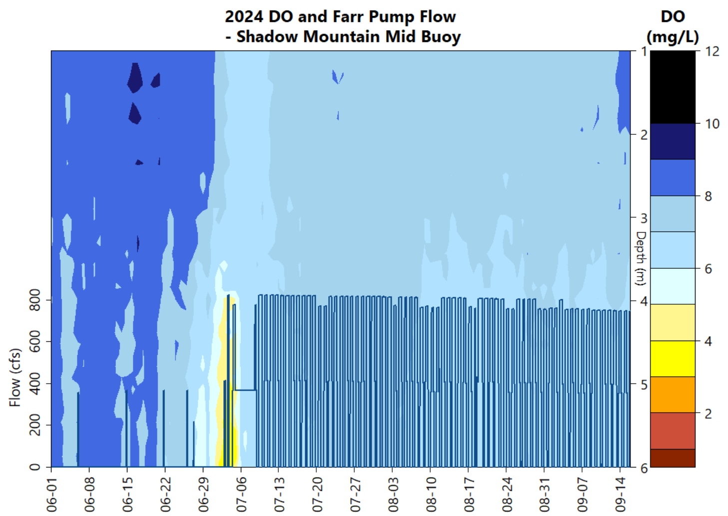

Figure 22. Dissolved Oxygen (mg/L) (color) and Farr pump flow (line) at SM-MID

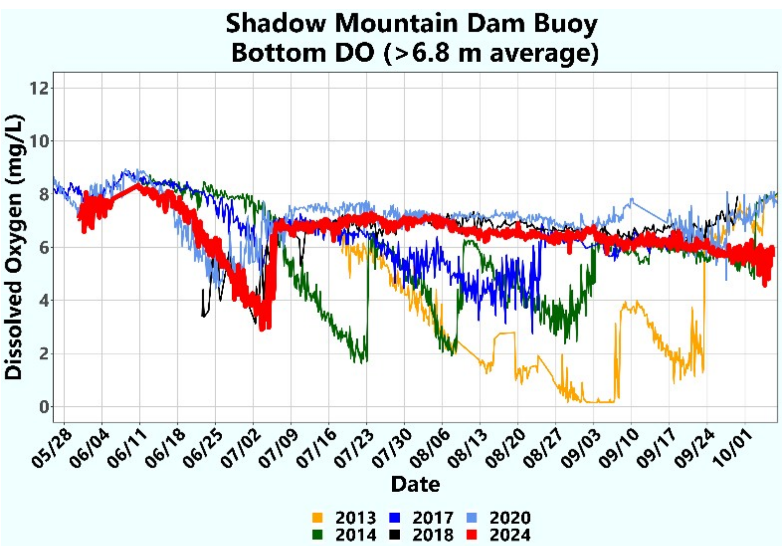

Figure 23. Dissolved Oxygen at the bottom of Shadow Mountain Reservoir (SM-DAM). 2024 data is shown in red with other colors showing reference years.

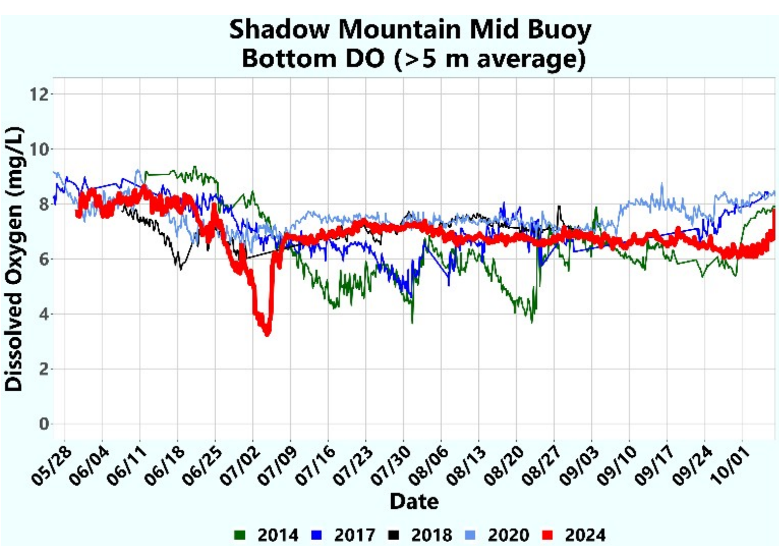

Figure 24. Dissolved Oxygen at the bottom of Shadow Mountain Reservoir (SM-MID). 2024 data is shown in red with other colors showing reference years.

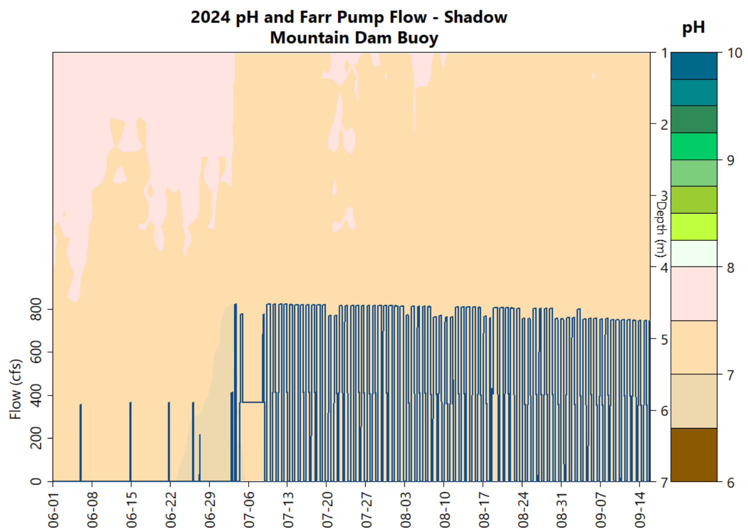

Figure 25. 2024 pH (color) and Farr pump flow (line) at SM-DAM

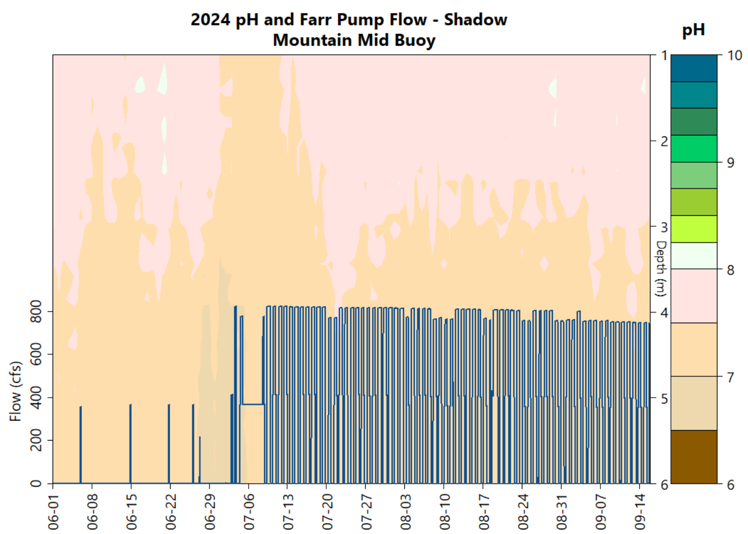

Figure 26. pH (color) and Farr pump flow (line) at SM-MID

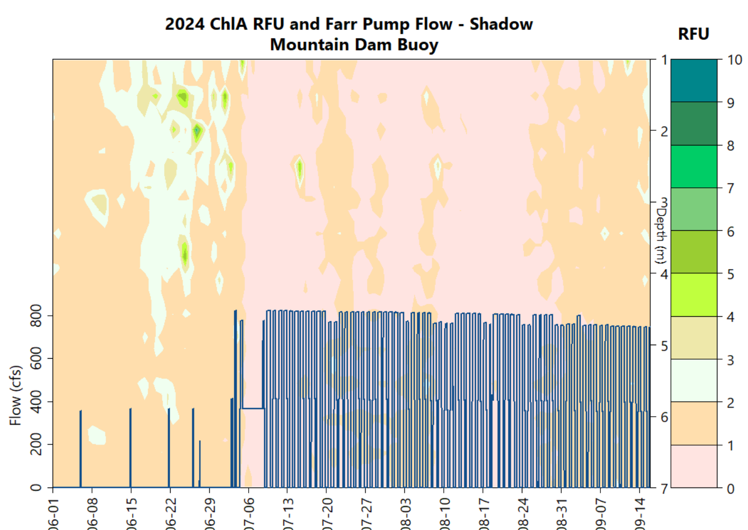

Figure 27. 2024 Chlorophyll a RFU (color) and Farr pump flow (line) at SM-DAM

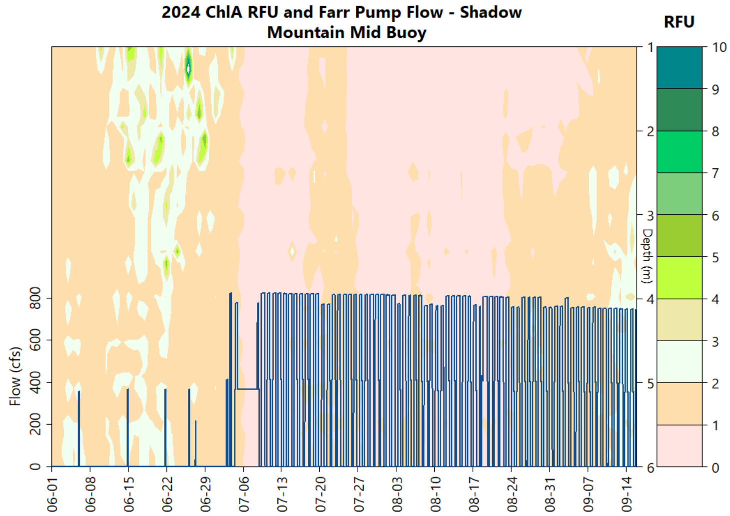

Figure 28. Chlorophyll a RFU (color) and Farr pump flow (line) at SM-MID

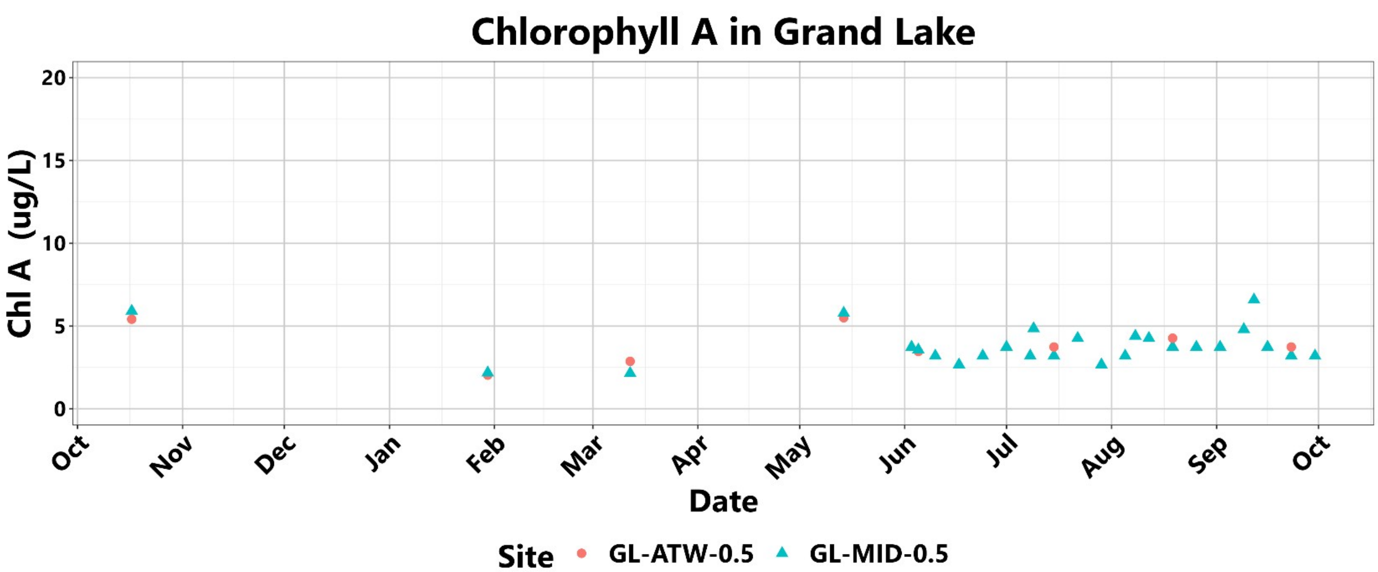

Figure 29. Discrete Chlorophyll a concentration in Grand Lake.

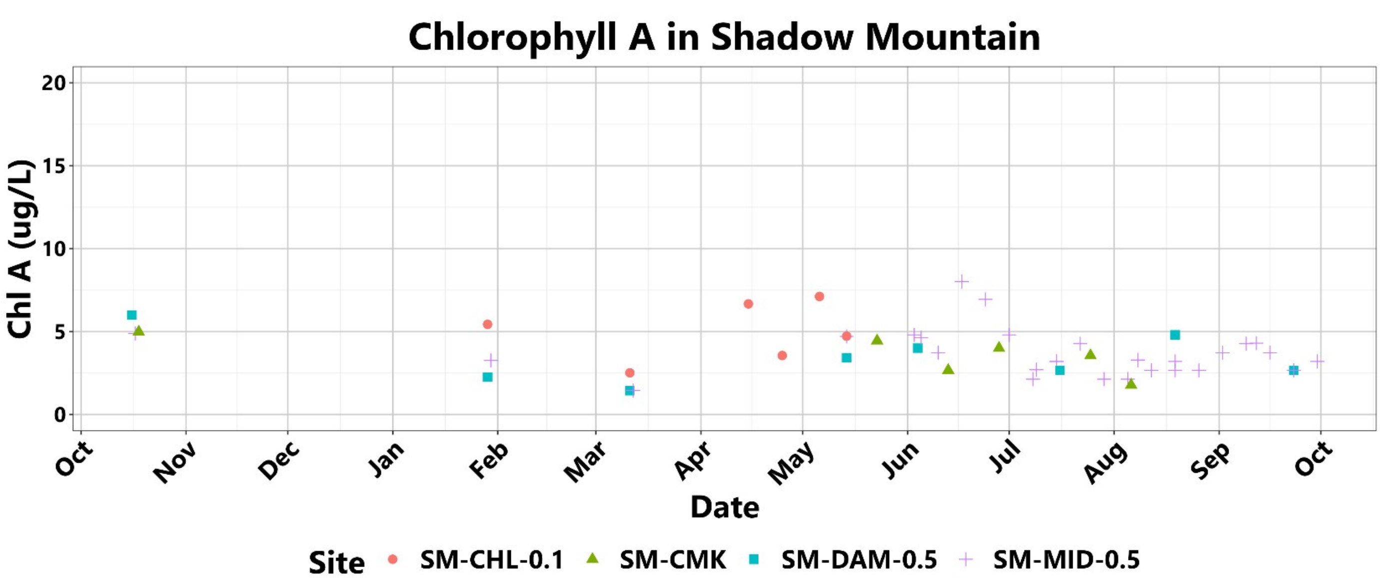

Figure 30. Discrete chlorophyll a concentration in Shadow Mountain Reservoir.

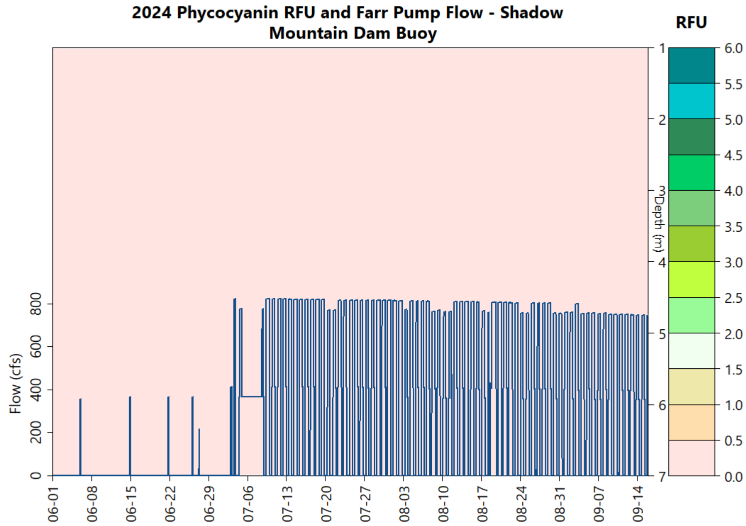

Figure 31. 2024 Phycocyanin RFU (color) and Farr pump flow (line) at SM-DAM

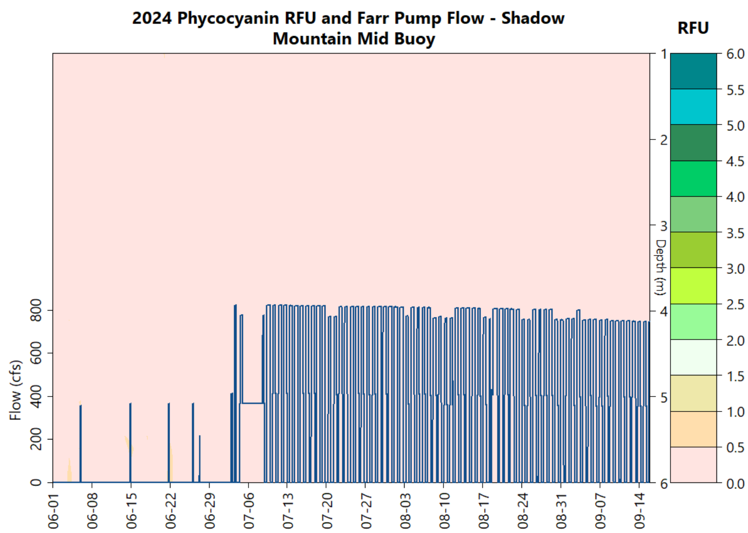

Figure 32. Phycocyanin (RFU) (color_ and Farr pump flow line at SM-MID

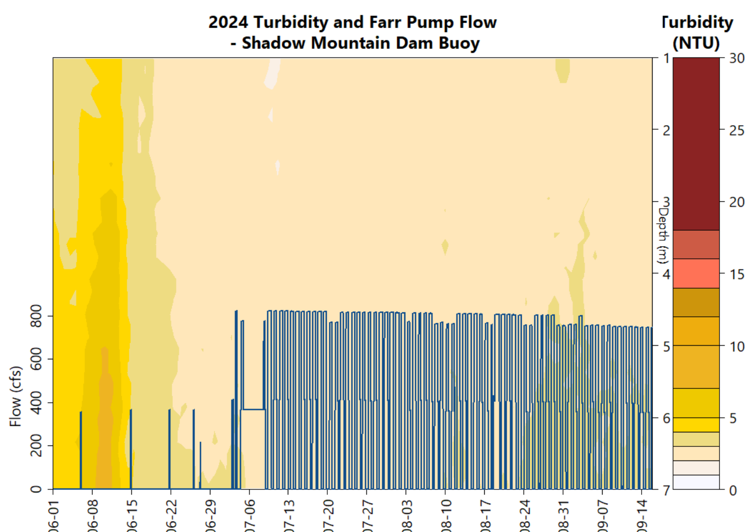

Figure 33. 2024 Turbidity (color) and Farr pump flow (line) at SM-DAM

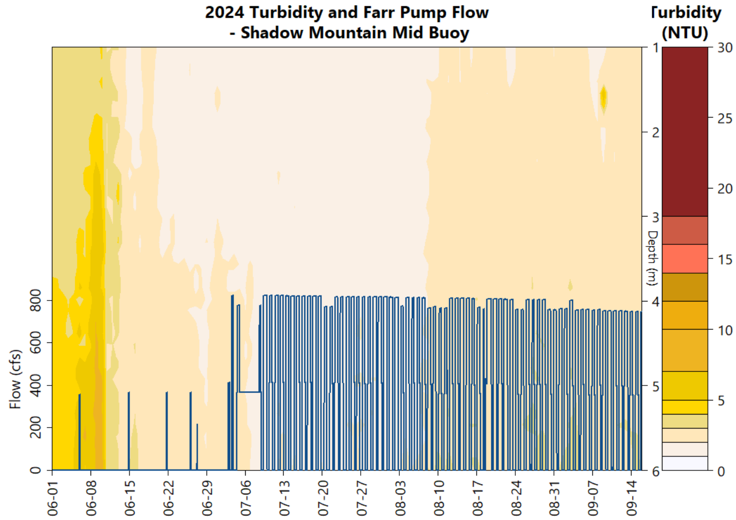

Figure 34. 2024 Turbidity (NTU) (color) and Farr pump flow (line) at SM-MID

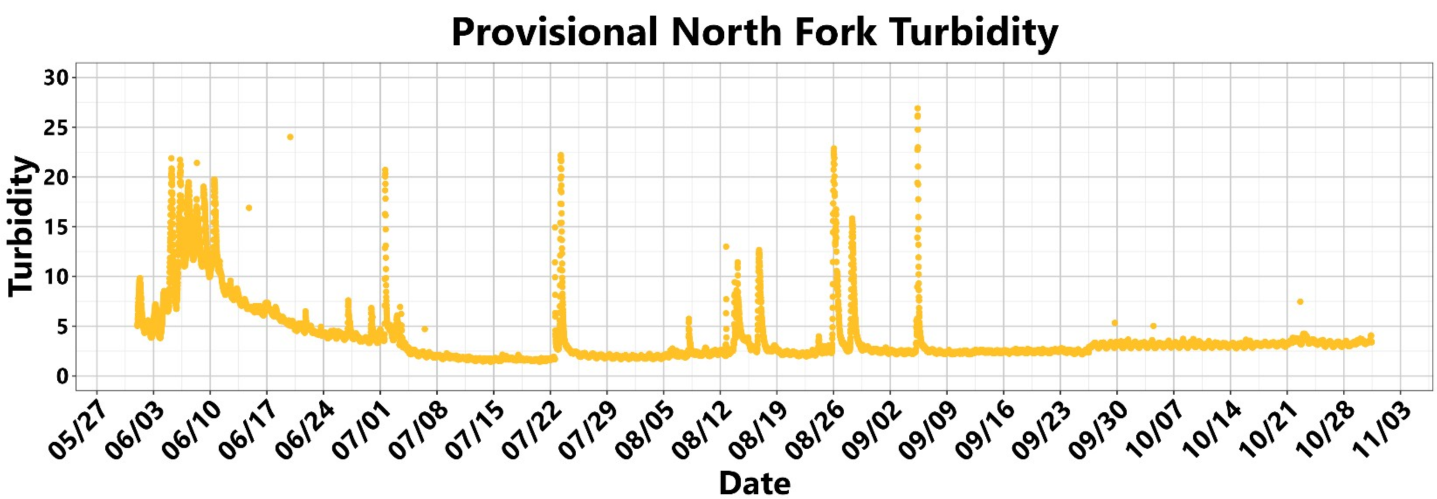

Figure 35. Turbidity (NTU) in the North Fork of the Colorado River just upstream of Shadow Mountain Reservoir

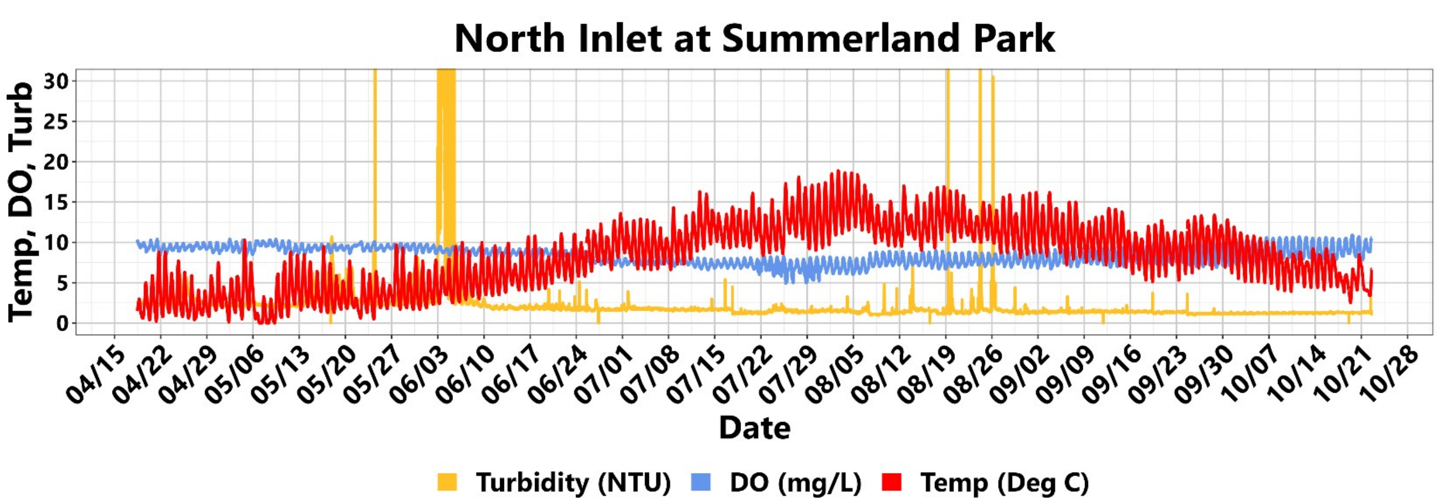

Figure 36. Turbidity, dissolved oxygen and temperature in the North Inlet at Summerland Park.

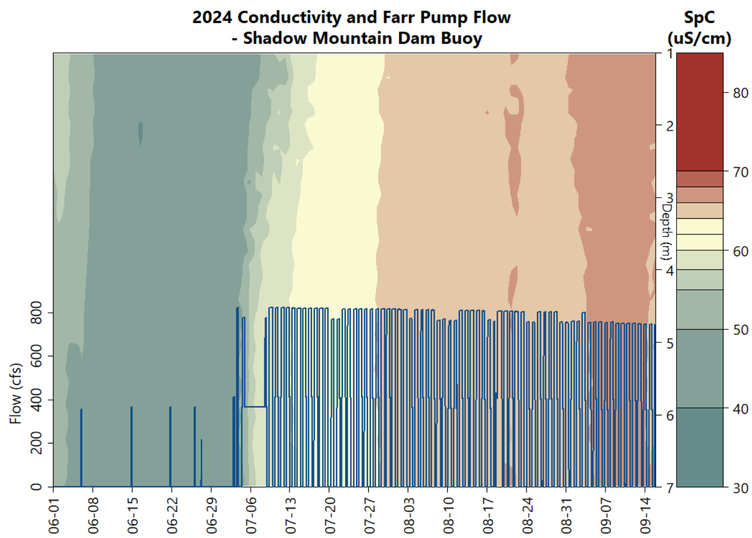

Figure 37. 2024 Specific Conductivity (uS/cm) (color) and Farr pump flow (line) at SM-DAM

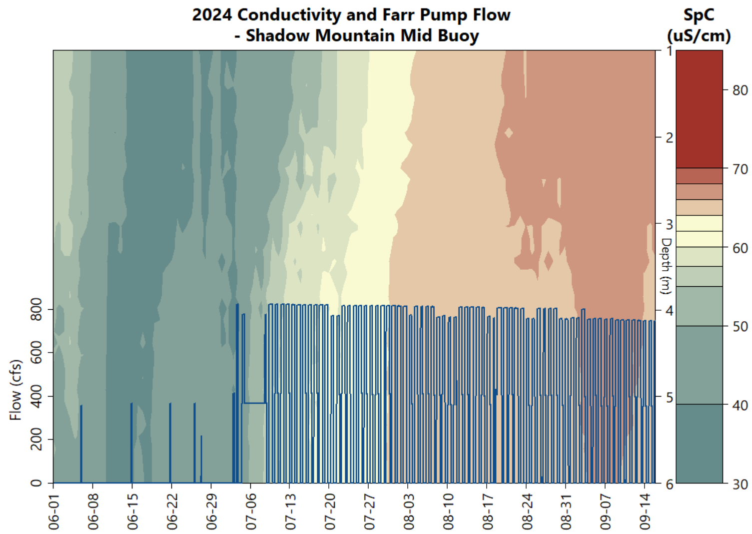

Figure 38. 2024 Specific Conductivity (uS/cm) (color) and Farr pump flow (line) at SM-MID.

Goal Qualifier Assessment and Water Quality Indicators

In 2024, both the 3.8 meter GLAM season average Secchi depth goal qualifier and the 2.5 meter minimum Secchi depth goal qualifier were met as shown in Table 1. The GLAM season average Secchi depth in Grand Lake was 4.5 meters and the minimum Secchi depth in Grand Lake was 3.7 meters. Between 2016 and 2024 the average and minimum goal qualifiers have been met 55% and 77% of the years, respectively. As outlined by the Clarity MOU, the AMC also tracks DO and pH as water quality indicators in the system throughout the GLAM season. DO at the bottom of Shadow Mountain Reservoir dipped just below the 3 mg/L water quality indicator at the SM-DAM site and did not cross the threshold at the SM-MID site. The minimum DO value in Shadow Mountain Reservoir was 2.9 mg/L which occurred on July 3 and 4 just as Farr pumping began moving water through Shadow Mountain Reservoir, increasing the DO concentrations in the water body. Surface pH in Shadow Mountain Reservoir also just crossed the pH indicator threshold of 8 at the SM-MID site, with values at or just above 8 on August 29 and 30, reaching a maximum value of 8.1 on the evening of August 30. The pH threshold was not triggered at the SM-DAM site. Both the DO and pH values showed only small exceedances of the thresholds, aligning with the other water quality parameters described above that indicate conditions for good clarity in Shadow Mountain Reservoir in 2024. In 2016, the AMC noted that percent saturation of DO greater than 100% was not a helpful indicator and has not been used in a significant way since.

Table 1. Clarity Goal Qualifiers Summary

	Goal Qualifier	Qualifier Met?	Final Exceedance Value	Qualifier Exceedance Date
Grand Lake Clarity Running Average Jul-To Date (m)	3.8 m	**Yes**	NA	NA
Grand Lake Clarity Running Minimum Jul-To Date (m)	2.5 m	**Yes**	NA	NA

Table 2. Summary of Water Quality Indicators

	Indicator Threshold	Threshold Exceeded?	Final Exceedance Value	Date Indicator Threshold Exceeded (2024)
Shadow Mountain Reservoir Surface pH	8	**Yes**	8.1	8/30/24
Shadow Mountain Reservoir Bottom DO (mg/L)	3 mg/L	**Yes**	2.9 mg/L	7/3/24-7/4/24

Table 3. Summary of Grand Lake average daily Secchi depths since MOU implementation in 2016.

Year	Jul-Sep 11 Annual Average Secchi (viewscope) (m)	Clarity Goal (m)	Actual minus Goal (m)	Goal Met?
2016	3.3	3.8	-0.5	N
2017	3.9	3.8	0.1	Y
2018	4.6	3.8	0.8	Y
2019	4.8	3.8	1.0	Y
2020	3.0	3.8	-0.8	N
2021	3.6	3.8	-0.2	N
2022	3.2	3.8	-0.6	N
2023	4.2	3.8	0.4	Y
2024	4.5	3.8	0.7	Y

# Years Goal Met	5
Total # of Years	9
% of Years Goal Met	55%

Table 4. Summary of Grand Lake minimum daily Secchi depths since MOU implementation in 2016.

Year	Jul-Sep 11 Annual Minimum Secchi (viewscope) (m)	Clarity Goal (m)	Actual minus Goal (m)	Goal Met?
2016	2.4	2.5	-0.1	N
2017	2.7	2.5	0.2	Y
2018	3.9	2.5	1.4	Y
2019	4.0	2.5	1.5	Y
2020	2.4	2.5	-0.1	N
2021	2.7	2.5	0.2	Y
2022	2.6	2.5	0.1	Y
2023	3.0	2.5	0.5	Y
2024	3.7	2.5	1.2	Y
			# Years Goal Met	7
			Total # of Years	9
			% of Years Goal Met	77%

LESSONS LEARNED & RECOMMENDATIONS

Changes Implemented During 2024 GLAM Season

1. Incorporation of water quality profiles at GL-MID from GCWIN's new sonde into the weekly reports.
2. Average daily temperature in Shadow Mountain Reservoir for 0-1 meters and 0-5 meters intervals were included in the weekly report to provide context about temperature conditions for algal growth.
3. Phytoplankton biovolume data was looked at on a few occasions throughout the GLAM season to better understand the impact of operations on algal dynamics and Secchi depth.
4. Live data feeds were posted on the Three Lakes SharePoint site, representing near-real-time results for flow, water quality, and precipitation.
5. Colorado River flow at the Y-Gage on the mainstem of the Colorado River below Granby Dam (COLNGBCO) was added to the first page of the weekly report to note potential differences in flow between Granby Reservoir's dam releases and flow at the Y-Gage.

2024 Important Observations

1. Discussions with WAPA indicated power production is more valuable on weekdays than it is on the weekends. This observation aligns with Reclamation's historical practice pumping less on weekends for Grand Lake clarity.
2. Operational constraints due to hydrology, weather conditions, maintenance, water deliveries and power generation can limit the ability to make adaptive management decisions. In 2024, available storage on the east slope coupled with the spill on the west slope constrained early season operations.
3. Water temperatures in Shadow Mountain Reservoir did not contribute to significant algal growth despite the cooler temperatures sometimes favoring growth of diatoms (specifically Asterionella).
4. Algal growth in Grand Lake and Shadow Mountain Reservoir was minimal compared to most years. All typical algal groups were observed in both water bodies with diatoms dominating biovolumes in August and September. Asterionella and Dolichospermum biovolumes remained relatively low during the GLAM season. The continued weekly phytoplankton sampling and quick turnaround time allowed for more informed adaptive management discussions.
5. In the winter preceding the 2024 GLAM season, an unexpected, sustained outage on part of the East Slope C-BT infrastructure significantly decreased Adams Tunnel diversions between December and March. This meant high Farr pumping and significant flow through the Adams Tunnel was required in the late spring prior to runoff and throughout the GLAM season to ensure water supply to water users on the East Slope. Farr pumping began on July 3 and continued consistently throughout the GLAM season. Little to no settling period occurred in 2024. This prevented high temperatures and low DO in Shadow Mountain Reservoir. Other potential impacts on water quality from these operations are yet to be determined, however, many unique conditions were observed in 2024, and further exploration will be valuable.

Recommendations

1. Explore more regular use of phytoplankton data with the availability of weekly data, weekly processing time and new data viewing tools. This data could help inform adaptive management and improve understanding of phytoplankton dynamics within the water bodies.
2. Continue exploring a shorter version of the weekly GLAM meetings if clarity is good and there are no pressing discussions on the agenda.
3. Provide comparisons between GL-MID and SM-MID conditions using physical profiles for future weekly GLAM reports.
4. Incorporate the updated Three Lakes Water Quality Model into the GLAM Planning Process in 2025.

APPENDICES

REFERENCES

Hydros Consulting Inc. 2023. 2022 Operational and Water-Quality Summary Report for the Three Lakes. Prepared for Grand County, Northern Water, and the US Bureau of Reclamation.