

Grand Lake Clarity Adaptive Management 2023



Grand Lake Adaptive Management Committee

Grand Lake Clarity Adaptive Management 2023

Contents

Background & Purpose of the Report	1
2023 Adaptive Management Process	3
1. Adaptive Management Committee Representatives	3
2. East Troublesome Fire and 2023 GLAM Process Changes	4
3. Planning Process	6
4. 2023 Operational Plan	7
Grand Lake Clarity & Shadow Mountain Reservoir Water Quality	12
1. Operations and Water Quality Summary Results	13
2. Goal Qualifier Assessment and Water Quality Indicators	30
Lessons Learned & Recommendations	33
1. Changes Implemented during 2023 Season Weekly Report and Meeting	33
2. 2023 Important Observations	33
3. Recommendations	34
Appendices	35
References	36

Grand Lake Clarity Adaptive Management 2023

Figures

Figure 1: Adaptive Management Process.....	3
Figure 2. Map of Monitoring Locations used during the GLAM season.	12
Figure 3. Grand Lake and Shadow Mountain Reservoir Inflows.....	14
Figure 4. Percent of Normal Precipitation (5) 7/1/2023-9/30/2023 for Colorado.....	16
Figure 5. Departure from Normal Temperature (F) 7/1/2023-9/30/2023 for Colorado..	16
Figure 6. Shadow Mountain Reservoir Channel, North and East Inlet, Adams Tunnel flows and Farr pumping.....	17
Figure 7. Grand Lake Secchi with Farr Pumping and North & East Inlet inflows.	18
Figure 8. Shadow Mountain Reservoir Secchi with Farr Pumping and North Fork flows.	19
Figure 9. Shadow Mountain Reservoir and Grand Lake Daily Average Secchi with Farr Pumping and Inflows.	20
Figure 10. 2023 pH values (color) and daily Farr Pump flow (line) at SM-MID and SM- DAM.	21
Figure 11. Buoy temperature data in profile form at SM-MID in profile form at SM- DAM, in time series form at SM-MID and in time series form at SM-DAM.....	22
Figure 12. DO data in profile form at SM-MID, in profile form at SM-DAM, surface DO in time series form at SM-MID, surface DO in time series form at SM-DAM, bottom DO in time series form at SM-MID and bottom DO in time series form at SM-DAM.....	23
Figure 13. Chlorophyll a and phycocyanin data averaged between 0 and 2 m depths in time series form at SM-DAM and SM-MID. Chlorophyll data in profile form at SM-MID and SM-DAM. Phycocyanin data in profile form at SM-MID and SM-DAM.	24
Figure 14. Chlorophyll a in Shadow Mountain Reservoir and Grand Lake.....	25

Grand Lake Clarity Adaptive Management 2023

Figure 15. Turbidity profiles with Farr pumping rates at SM-MID and SM-DAM. Conductivity profiles with Farr pumping rates at SM-MID and SM-DAM.....	26
Figure 16. Provisional North Fork Turbidity time series.	27
Figure 17. Supply Creek as seen from Shadow Mountain Reservoir which experienced a washout in September of 2023.	29
Figure 18. Temperature, DO, and Turbidity at North Inlet at Summerland Park (USGS).	29
Figure 19. Discharge, temperature, pH, DO, and turbidity time series at GR-Pump.	30

Tables

Table 1: Clarity Goal Qualifiers and Water Quality Indicators Summary.....	31
Table 2. Summary of Grand Lake average Secchi depths since MOU implementation...	32
Table 3. Summary of Grand Lake minimum Secchi depths since MOU implementation.	32

Background & Purpose of the Report

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) formalized 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 Grand Lake Clarity narrative standard:

"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." (Grand Lake, Shadow Mountain Reservoir, and Granby Reservoir)

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 Water Quality Control Commission (WQCC) in April 2016 and the Clarity Goals were adopted as Goal Qualifiers. In the May 9, 2016 Statement of Basis and Purpose (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

Grand Lake Clarity Adaptive Management 2023

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 also requires 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 on clarity in Grand Lake. The Clarity MOU specifies consideration of three water quality indicator thresholds: Grand Lake Secchi depth at index sites, Shadow Mountain Reservoir dissolved oxygen at the bottom and surface, and pH in Shadow Mountain Reservoir near the surface.

This report meets the reporting requirements of the Clarity MOU and the WQCC.

2023 Adaptive Management Process

This section describes the 2023 Adaptive Management process.

1. Adaptive Management Committee Representatives

The Adaptive Management Committee (AMC) comprises representatives from the Clarity MOU partners including Reclamation, Northern Water, Grand County, NWCCOG, and the River District, as well as several parties that are not signatories to the MOU. A list of the representatives that attended the meetings in 2023 is included in Appendix C.

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

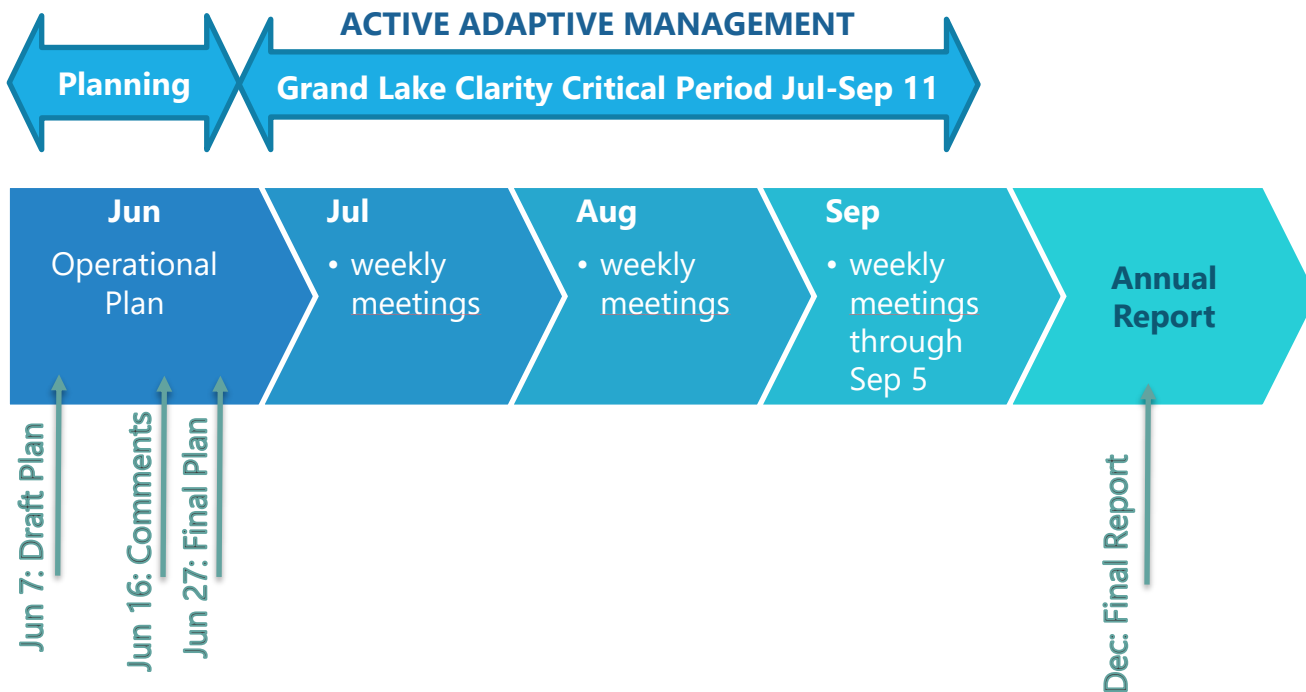


Figure 1: Adaptive Management Process.

Grand Lake Clarity Adaptive Management 2023

2. East Troublesome Fire and 2023 GLAM Process Changes

On October 14, 2020, the East Troublesome Fire (ETF) ignited 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, until 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 percent burned, respectively), all of which flow into the Three Lakes (Willow Creek is a pumped inflow). Since the ETF, the Three Lakes System has seen instances of higher nutrient concentrations, higher turbidity, higher total suspended solids, and at Willow Creek, the presence of late-season cyanobacteria blooms. In August 2021, there was a blackwater event in the North Inlet into Grand Lake that brought some of the highest concentrations on record for nutrients, total suspended solids, and many other constituents into the Three Lakes System. While events of this magnitude have not been witnessed in years since, there is still evidence of changes in water quality related to the ETF. Post-fire conditions are complex and there is a great amount of uncertainty on the what the duration and magnitude of long-term effects will be to Three Lakes System.

Due to the effects from the ETF, the AMC met and agreed to amend the GLAM process in 2021, 2022 and again in 2023. The amended process was documented modification letter, signed by the parties to the Clarity MOU. The letter 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 2023 operations.*
- Data collection and analysis will continue per the annual monitoring plan, including additional wildfire related monitoring programs.*

Grand Lake Clarity Adaptive Management 2023

- *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 2023 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.

Grand Lake Clarity Adaptive Management 2023

3. Planning Process

Date	Description
May 30, 2023	Kickoff Meeting The AMC reviewed Reclamation’s Draft operational plan. The plan is described in Section 4 below and the Kickoff Meeting materials are included in Appendix E. As described above Reclamation did not run the plan through the water quality model.
June 6, 2023 – June 27, 2023	Pre-Season Weekly Meetings In lieu of modeling and in accordance with the MOU modification for 2023 the AMC met weekly before the GLAM season to discuss current conditions.
July 6, 2023 – September 5, 2023	GLAM Season Weekly Meetings The AMC held weekly meetings to discuss water quality and operations to optimize clarity and gain insight about system dynamics. Meeting materials, notes and recordings are compiled in Appendix G.
October 19, 2023	Debrief Meeting The AMC held a debrief meeting to discuss possible improvements to the process, lessons learned and recommendations for future years. Meeting materials as in Appendix H.

A schedule of all meetings is included in Appendix F.

Grand Lake Clarity Adaptive Management 2023

4. 2023 Operational Plan

Reclamation prepared an operational plan during the spring and presented it to the AMC for discussion at the May 30, 2023, 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 Granby and Willow Creek reservoirs, facility outages and other operating constraints, operations that help to optimize Grand Lake clarity, considerations for power generation and East Slope water. The culmination of these concerns resulted in only one operational proposal with no other alternatives for consideration in the 2023 season.

The Northern Water Board of Directors sets a C-BT Project water delivery quota each year, which quantifies the amount of C-BT water the Board makes available to allottees each year within the Northern Water boundaries. Quotas are expressed as a percentage of 310,000 acre-feet (AF), the amount of water the C-BT project was designed to deliver each year, based on the need for supplemental water on the East Slope. The Northern Water Board set a preliminary 40% quota in November 2022 and allocated an additional 30% in April 2023 for a

Grand Lake Clarity Adaptive Management 2023

total quota of 70%. This quota is important for Grand Lake Adaptive Management because of its direct influence on operations and water moving throughout the system.

The constraints section from the 2023 Operational Plan, as outlined by Reclamation, is summarized below. This Operational Plan was a guiding document but was not prescriptive.

Operations were constrained by the following Operation and Maintenance (O&M) projects:

1. Chimney Hollow Wye with Carter Lake Conduit (9/11/23-12/11/23), prevented flow to Carter Lake
 - a. This outage was rescheduled from Spring 2023 to Fall 2023 because of concern surrounding significant, avoidable collection system spill because of the inability to move water to Carter Lake during the outage.
2. Mary's Lake Power Plant maintenance (10/3/2022-7/15/2023)
3. Pole Hill Power Plant damage limiting power operations to 24 MW (~ 425 cfs (cubic feet per second)) to full load while minimizing operations between speed no-load and 24 MW. This will cause Reclamation to bypass the power plant or maintain flows > 425 cfs. Bypassing results in lost power opportunity.
4. Power line work between Flatiron and Estes Park constrained peak generation (6/2/23-8/11/23)
5. Hansen Feeder Canal constrained to <475 cfs

Each of the above contributed to operational constraints, but even more than the O&M Projects, operations were constrained by East Slope hydrology in 2023. Colorado's Northern Front Range experienced one of the wettest April-July periods on record with some areas receiving more than fifteen inches of precipitation during those 4 months, more than the total annual average precipitation of those areas. Because of this, demand for C-BT water remained low through the Spring and early Summer, leaving Horsetooth Reservoir and Carter Lake near full. Meanwhile, the C-BT junior water right on the Big Thompson River, was in priority for

Grand Lake Clarity Adaptive Management 2023

much of the runoff season. Northern Water and Reclamation maximize this water right when it is available. Therefore, there was little space on the East Slope to put West Slope water during the Spring and early Summer of 2023.

The following is an excerpt from the Bureau of Reclamation's Operational Plan in May 2023 and constitutes a "best case scenario":

1. Carter Lake

- a. We try to keep Carter Lake as full as reasonable, to reduce the likelihood and magnitude of west slope spill. This requires movement of water through the Adams Tunnel.
- b. We approached near-fill at Carter once in 2023.
- c. Pumping to Carter Lake is underway in mid-May. We anticipate topping off its storage near the end of May.
- d. We restart the pump one more time around June 14 and then run it through September 7. 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. In reality, this operation will be very difficult to get just right due to demands varying daily outside of the modeled simulation.
- e. An outage for construction to connect Chimney Hollow facilities to the C-BT Carter Lake Interconnect runs from 9/11 to 12/11/2023. The proposed operations and this outage will not adversely affect Carter Lake conditions going into 2024.

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 runs 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 is occurring, diversion of this water at Dille Diversion site is prioritized to allow storage at Carter and Horsetooth 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 is not happening, this limitation results in some marginal opportunity for east slope

Grand Lake Clarity Adaptive Management 2023

skim operations through Olympus Tunnel, using its remaining capacity up to 550 cfs.

- d. Horsetooth fills to 5929.14 feet on July 6, within 0.4 feet of desired and within the reasonable accuracy of the model uncertainty.
- 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 early September, Adams Tunnel diversions are set to maintain 425 cfs at Pole Hill. 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 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. When east slope priority water exists at sufficiently high levels, it displaces the need for diversion while east slope conveyance capacities to fill Carter and Horsetooth 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 277 cfs early in June to 550 cfs for much of the period. Pumping at Farr Plant to support this begins July 7.
- c. Weekend reductions in diversion through Adams Tunnel commence 7/22, with reduced flows at 420 cfs. Weekday flows will work with east slope flows to take advantage of remaining skim opportunities while keeping the system running near capacity.
- d. On September 8, following shutdown of pumping to Carter, diversions remain near 425 until 9/30, reflecting minimum generation flows at Pole Hill.

4. Grand Lake / Shadow Mountain Reservoir Connecting Channel:

- a. Highly dependent on the shape of uncertain west slope hydrographs, flows remained from Grand Lake into Shadow Mountain Reservoir from mid-May through June 29, except for 4 discontinuous days in mid-June. Efforts to minimize west slope spill do not allow for the "settling period" in late-June and early-July.

Grand Lake Clarity Adaptive Management 2023

Even with reversal of flows from Shadow Mountain Reservoir into Grand Lake beginning on June 30, Granby experiences a minimal spill of 130 acre foot. By choosing not to pump into a Granby spill from June 19 through July 15, Willow Creek Reservoir experiences a 3,116 acre foot spill.

Grand Lake Clarity Adaptive Management 2023

Grand Lake Clarity & Shadow Mountain Reservoir Water Quality

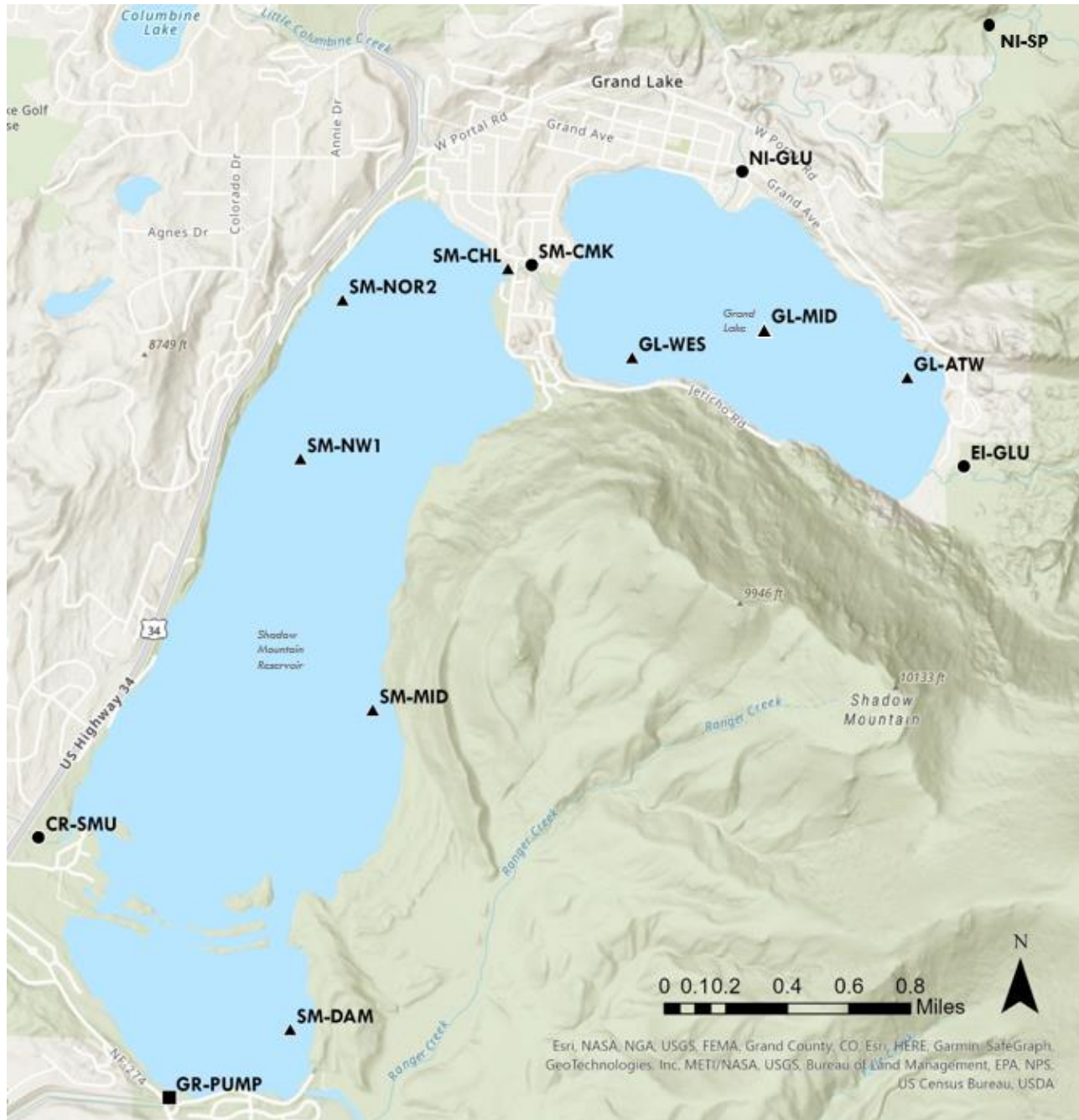


Figure 2. Map of Monitoring Locations used during the GLAM season.

Grand Lake Clarity Adaptive Management 2023

This section describes observed water quality and clarity in Shadow Mountain Reservoir and Grand Lake during the 2023 GLAM season (July 1 - September 11). Figure 2 shows the monitoring sites where data are 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 (Figure 2). Real-time data collection also occurred at GR-PUMP, CR-SMU, and NI-SP (USGS site). Farr Pump flows are measured at GR-PUMP.

1. Operations and Water Quality Summary Results

Operations Summary

Peak runoff into the Three Lakes in 2023 was reached on June 8 at a daily average of 2,346 cfs (Figure 3). The total April through July runoff volume of 252 thousand acre-feet (KAF) was close to the May most probable forecast of 235 KAF and well within the bounds of the maximum forecast of 293 KAF. Much higher than anticipated precipitation on the East Slope reduced demand and moved the project into priority on the East Slope from mid-May through mid-July. A total of 25.2 KAF of East Slope priority water was collected and placed into storage in Carter Lake and Horsetooth Reservoir. The precipitation and available priority water prevented significant movement of water from the West Slope to the East Slope in the early summer leading to a significant spill of 48,005 acre-feet (AF) from Granby Reservoir from June 12 to July 17, with an additional 12,280 AF spilling from Willow Creek Reservoir for a total spill of 60,285 AF. Weather during the clarity season was warm with slightly above average precipitation following a cooler than average March through June (Figure 4).

Grand Lake Clarity Adaptive Management 2023

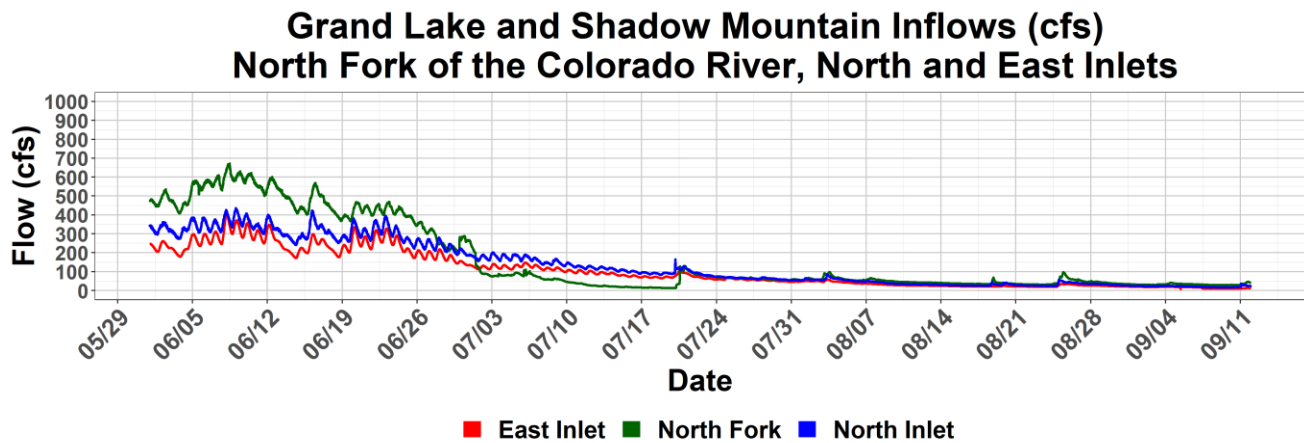


Figure 3. Grand Lake and Shadow Mountain Reservoir Inflows.

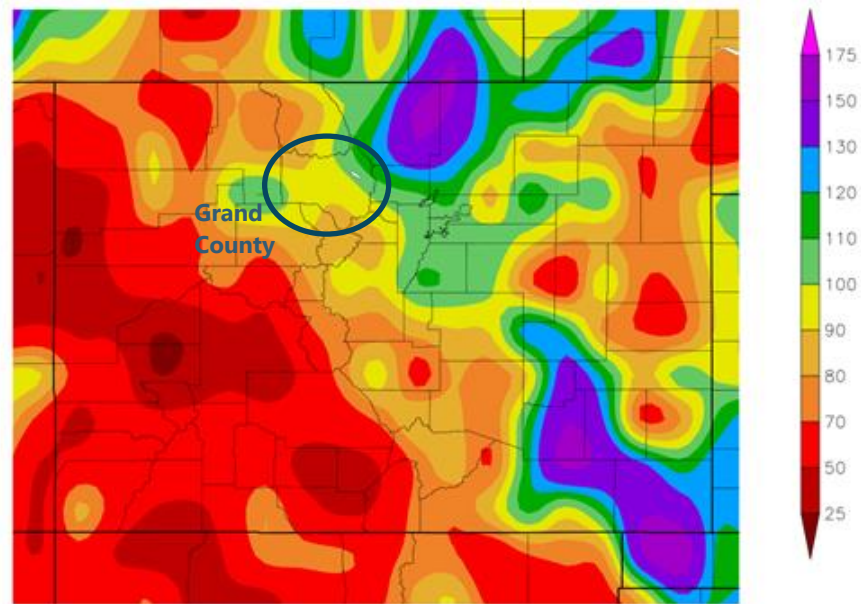
Flow direction in the connecting channel is important for understanding clarity responses to changing flows in both Grand Lake and Shadow Mountain Reservoir. During runoff, water flows from Grand Lake into Shadow Mountain Reservoir and is shown as negative flow in Figure 6. Once pumping begins, the flow reverses, moving water from Shadow Mountain Reservoir into Grand Lake, shown as positive flow in Figure 6. Beginning in the first few days of July, the flow gauge at Chipmunk Lane (in the channel connecting Grand Lake and Shadow Mountain Reservoir) indicated oscillating flow directions between Shadow Mountain Reservoir and Grand Lake. By mid-July, water was consistently flowing from Shadow Mountain Reservoir into Grand Lake. Due to surface winds and other confounding factors, there is considerable noise in the Chipmunk Lane flow data when there are large changes in Adams Tunnel flows or the flow in the channel is minimal in either direction, which makes it difficult to determine the direction of flow. In those situations, the AMC can use specific conductivity in the channel as a reliable indicator of flow direction in the channel.

Regular off-peak pumping operations began on July 17th, which is later than average and about ten days later than predicted by Reclamation's operational plan (Figure 6). The decision

Grand Lake Clarity Adaptive Management 2023

to start pumping was based on a number of factors including: space becoming available for water on the East Slope, minimizing spill out of Granby Reservoir, maximizing the length of the settling period in Grand Lake, and utilizing skim water for East Slope power generation. Water was pumped at Farr at an average daily rate of between 300 and 500 cfs, and when possible, during off-peak power cost hours.

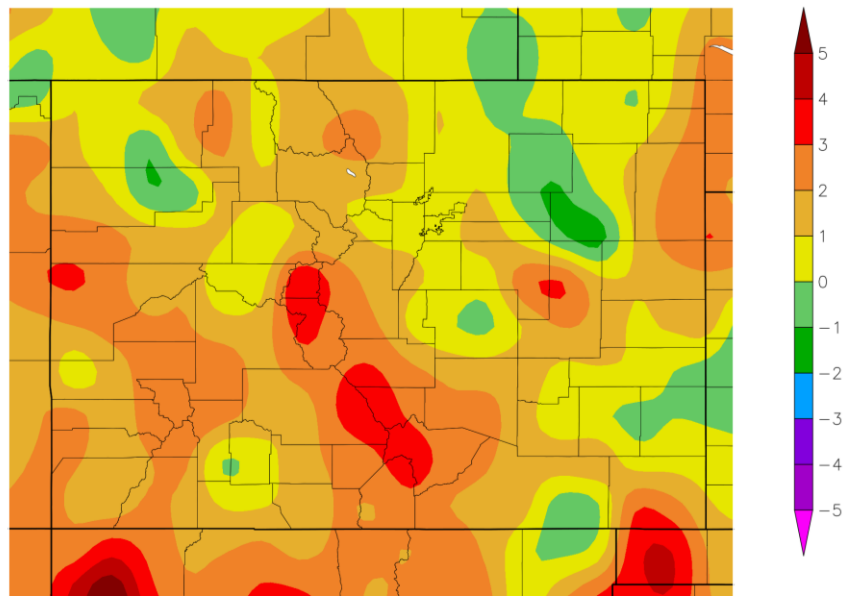
Grand Lake Clarity Adaptive Management 2023



Generated 10/4/2023 at HPRCC using provisional data.

NOAA Regional Climate Centers

Figure 4. Percent of Normal Precipitation (5) 7/1/2023-9/30/2023 for Colorado



Generated 10/4/2023 at HPRCC using provisional data.

NOAA Regional Climate Centers

Figure 5. Departure from Normal Temperature (F) 7/1/2023-9/30/2023 for Colorado

Grand Lake Clarity Adaptive Management 2023

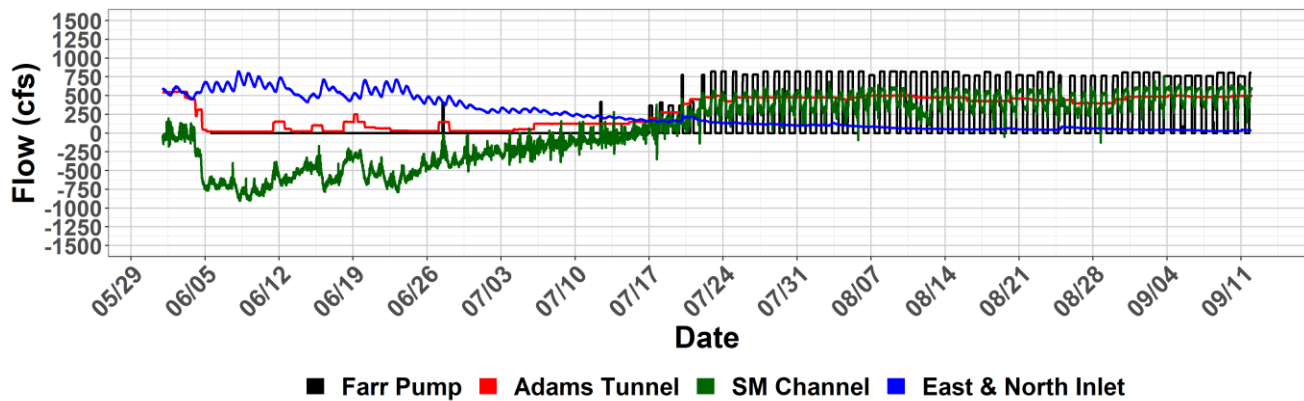


Figure 6. Shadow Mountain Reservoir Channel, North and East Inlet, Adams Tunnel flows and Farr pumping.

Clarity and Water Quality Summary

Clarity in Grand Lake was high at the start of the clarity season in early July and remained high following runoff with Secchi depth averaging more than 5 meters until pumping began on July 17th. The GCWIN Field Staff noted a few days during the pre-pumping period where lower clarity was observed that correlated with high winds, which may have led to mixing, surface water debris and surface roughness. As mentioned in the operations section, the daily average Farr pumping rate following the July 17th pump start through the end of the GLAM season was generally between 300 and 500 cfs. Clarity at each of the three index sites (GL-MID, GL-ATW and GL-WES) in Grand Lake was generally very similar to one another (Figure 7). One notable exception to this pattern, however, was on July 21st, just a few days after Farr pumping had begun. Clarity was 3.02 meters at the GL-WES site, 4.02 meters at GL-MID, and 5.21 meters at GL-ATW reporting more than a one-meter difference between each site moving from west to east across the lake. This pattern clearly demonstrates changes in water clarity as correlated with the start of Farr pumping and movement of water from Shadow Mountain Reservoir into Grand Lake. This observation indicates how lower clarity water from Shadow Mountain

Grand Lake Clarity Adaptive Management 2023

Reservoir reached the GL-WES site first and had begun to reach the GL-MID site but had not yet impacted clarity at the GL-ATW site. By July 24th, when the next clarity measurements were taken, the three sites reported clarity within 0.15 meters of one another with an average of 3.92 meters. The maximum clarity in Grand Lake during the 2023 GLAM season was at the GL-ATW site on July 13th with a Secchi depth of 5.75 meters.

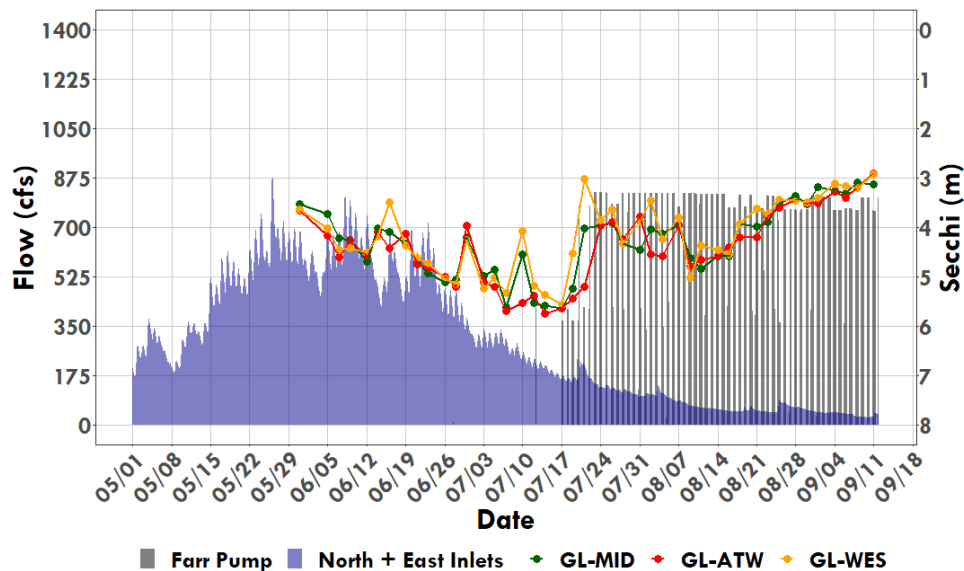


Figure 7. Grand Lake Secchi with Farr Pumping and North & East Inlet inflows.

Average daily Secchi depth in Shadow Mountain Reservoir remained between 1.5 and 4.3 meters during the clarity season (Figure 8). There was a significant increase in clarity in Shadow Mountain Reservoir between the first week of July and when the pumps turned on July 17th. Typically, Secchi depth was highest at SM-MID and lowest at SM-NOR2. At all but one of the observations between July 31st and August 21st, SM-DAM had the lowest Secchi depth in Shadow Mountain Reservoir. The pH water quality indicator of 8.0 S.U. in Shadow Mountain Reservoir was crossed on July 1st at SM-MID and exceeded 8.0 on 17 of the days during the

Grand Lake Clarity Adaptive Management 2023

clarity season. The pH at SM-MID reached a maximum value of 8.36 on July 12th. The pH at SM-DAM also exceeded the 8.0 threshold but was almost always lower than pH at SM-MID (Figure 10). Dissolved Oxygen in Shadow Mountain Reservoir fell below the water quality indicator of 3 mg/L on July 17th-19th but returned to concentrations above the threshold on the 20th after several days of consistent Farr Pumping and movement of water through the reservoir.

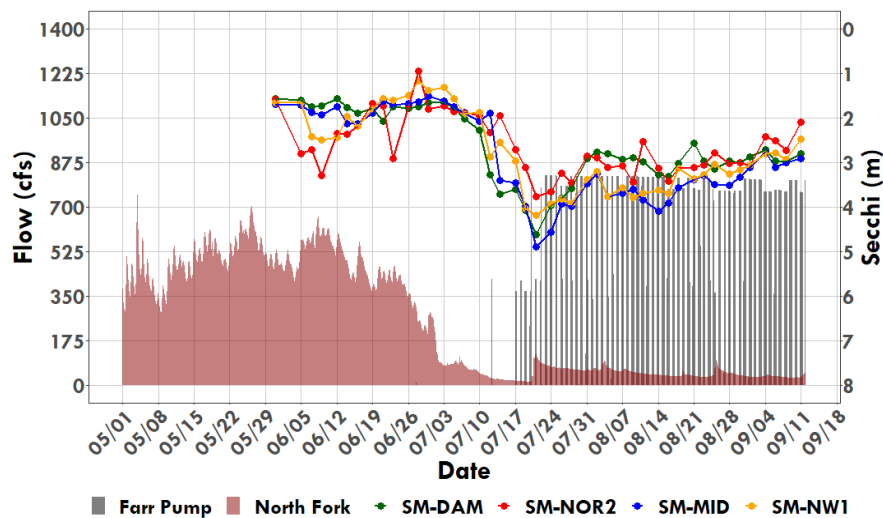


Figure 8. Shadow Mountain Reservoir Secchi with Farr Pumping and North Fork flows.

Prior to the beginning of Farr pumping, Grand Lake clarity averaged 2.78 meters greater than clarity in Shadow Mountain Reservoir with a maximum difference of 3.61 meters greater on July 7th. Once Farr Pump turned on, clarity in Shadow Mountain Reservoir was slightly greater than Grand Lake for two consecutive observations which was followed by a slight improvement in Grand Lake clarity. Throughout the GLAM season, Grand Lake had a Secchi depth on average 1.16 meters greater than the Secchi depth in Shadow Mountain Reservoir. Both water bodies saw steady and similar decline in clarity beginning in mid-August and continuing through the remainder of the clarity season (Figure 9).

Grand Lake Clarity Adaptive Management 2023

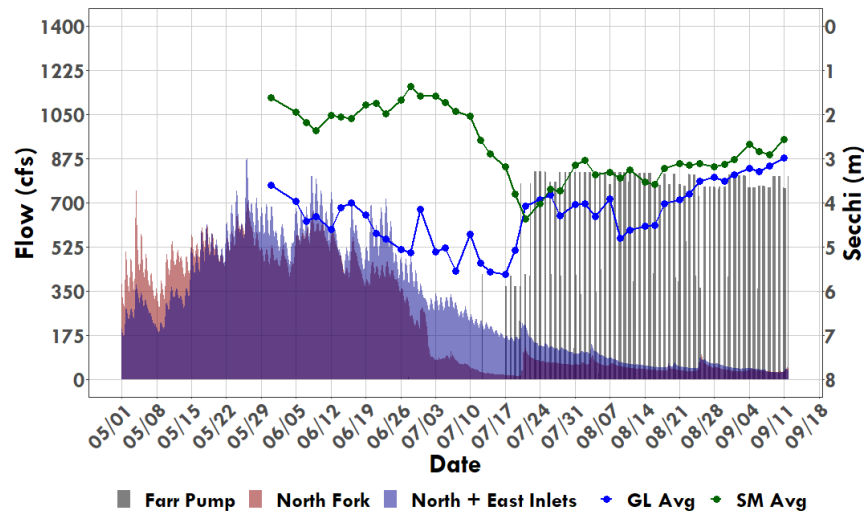


Figure 9. Shadow Mountain Reservoir and Grand Lake Daily Average Secchi with Farr Pumping and Inflows.

Other water quality data collected from Shadow Mountain Reservoir included water temperature, surface dissolved oxygen, chlorophyll-a relative fluorescence, phycocyanin relative fluorescence, turbidity, and specific conductivity.

- pH at both SM-MID and SM-DAM remained relatively consistent throughout the GLAM season with some instances of pH above 8 SU at both sites (Figure 10)
- Temperatures at both SM-MID and SM-DAM were high in the early GLAM season but cooled significantly with the start of Farr Pumping in the third week of July. (Figure 11).
- Surface dissolved oxygen was similar to past years, dropping slightly during the middle of July (Figure 12). Bottom dissolved oxygen was very low at both SM-DAM and SM-MID which both dropped below 3 mg/L, SM-DAM reaching a minimum of 1.88 mg/L just before pumping operations began. After pumping began, bottom dissolved oxygen increased to levels between 5 and 8 mg/L and remained there through the rest of the GLAM season (Figure 12).

Grand Lake Clarity Adaptive Management 2023

- Chlorophyll *a* fluorescence at the surface of SM-DAM and SM-MID remained below 7 RFU throughout the GLAM season (Figure 13), with grab sample concentrations peaking around 15 ug/L in Shadow Mountain Reservoir in the first week of July and remaining between 0 and 7.5 ug/L in Grand Lake during the GLAM season (Figure 14).
- Phycocyanin fluorescence remained very low (<1 RFU) in both water bodies throughout the entirety of the GLAM season (Figure 13).
- Turbidity at both SM-MID and SM-DAM remained below 5 NTU during the GLAM season (Figure 15).
- Specific Conductivity increased throughout the clarity season at both SM-MID and SM-DAM as more water from Granby Reservoir moved through the system following typical annual patterns (Figure 15).

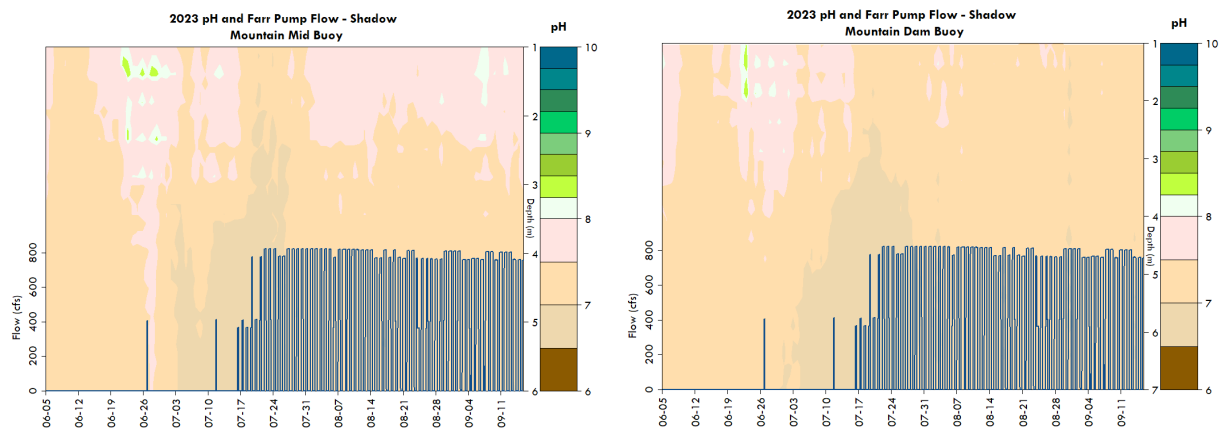


Figure 10. 2023 pH values (color) and daily Farr Pump flow (line) at SM-MID and SM-DAM.

Grand Lake Clarity Adaptive Management 2023

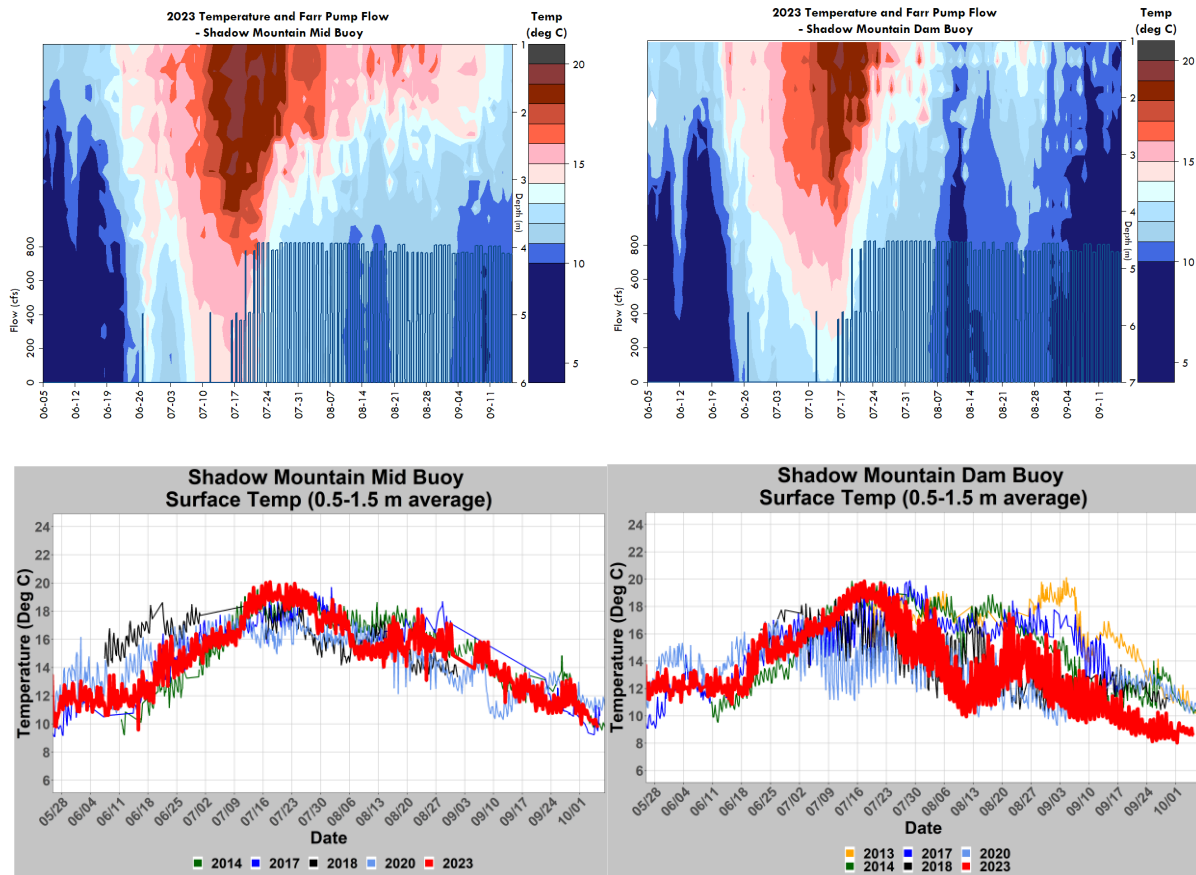


Figure 11. Buoy temperature data in profile form at SM-MID in profile form at SM-DAM, in time series form at SM-MID and in time series form at SM-DAM.

Grand Lake Clarity Adaptive Management 2023

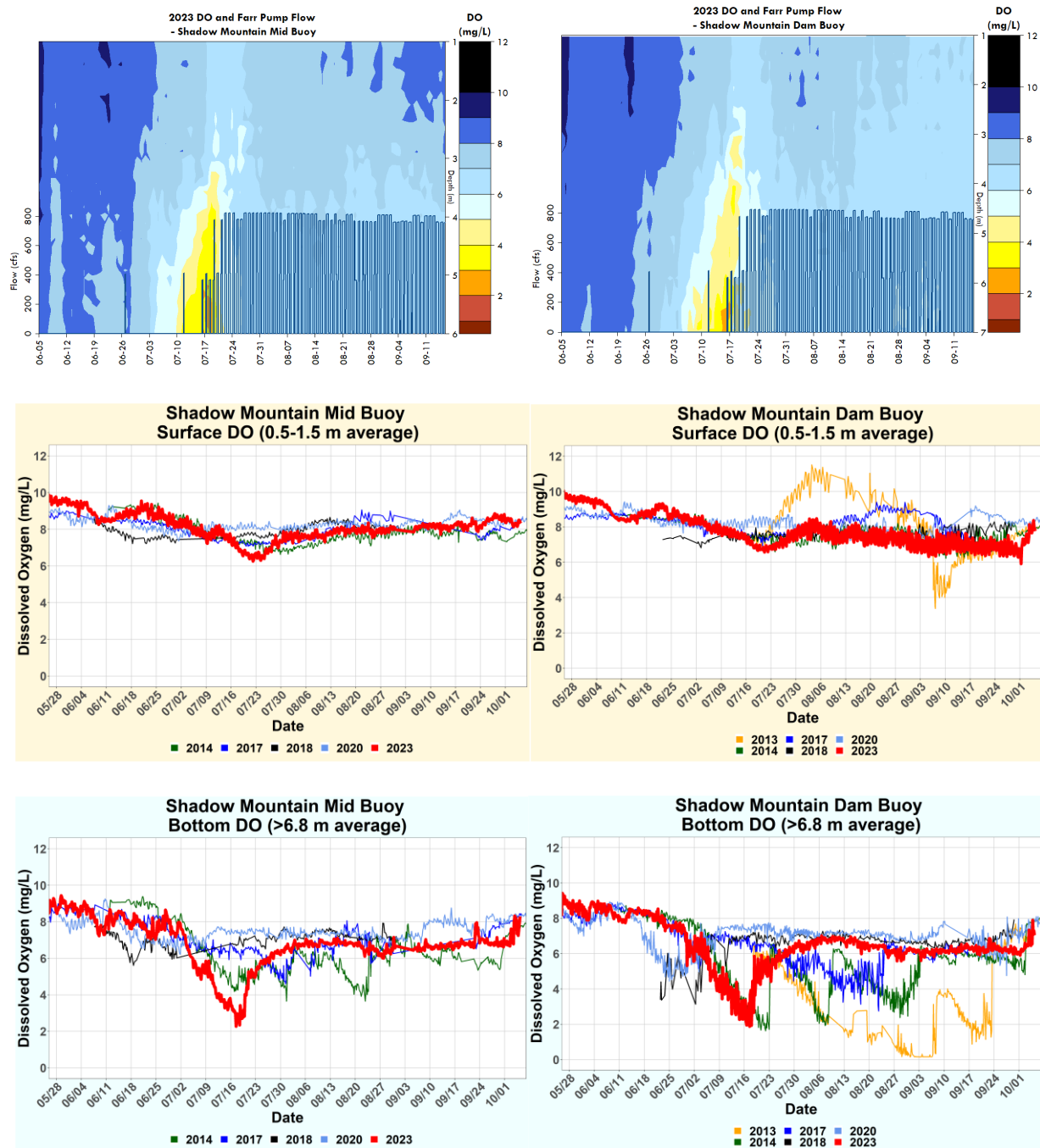


Figure 12. DO data in profile form at SM-MID, in profile form at SM-DAM, surface DO in time series form at SM-MID, surface DO in time series form at SM-DAM, bottom DO in time series form at SM-MID and bottom DO in time series form at SM-DAM

Grand Lake Clarity Adaptive Management 2023

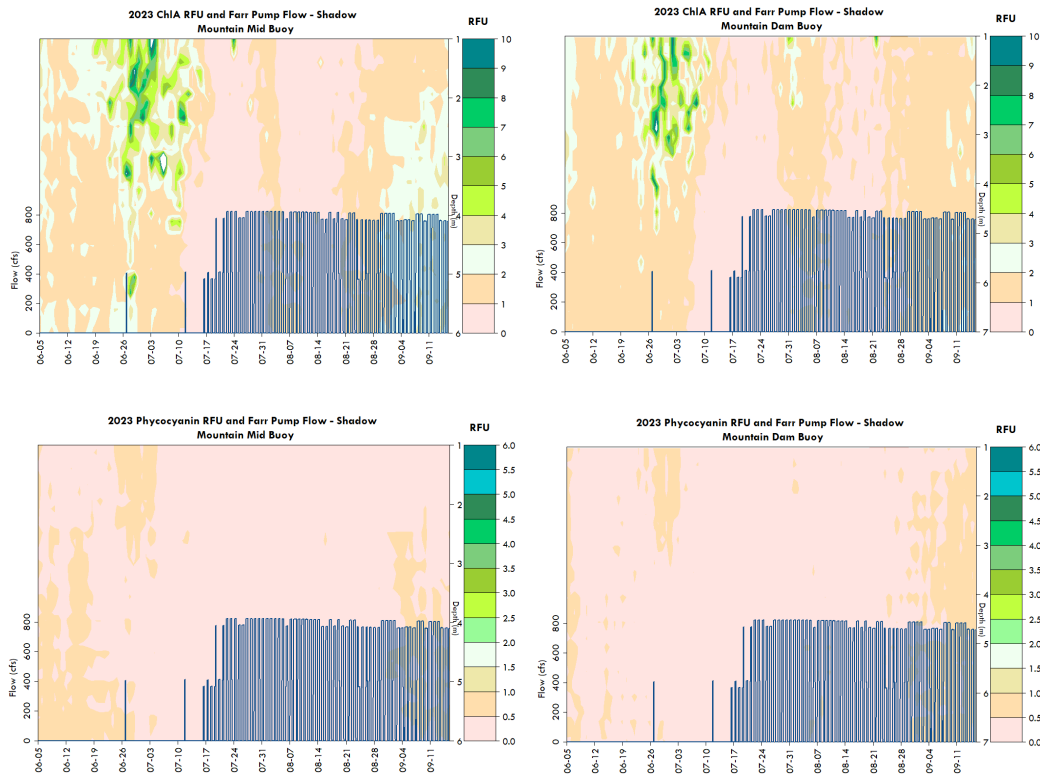
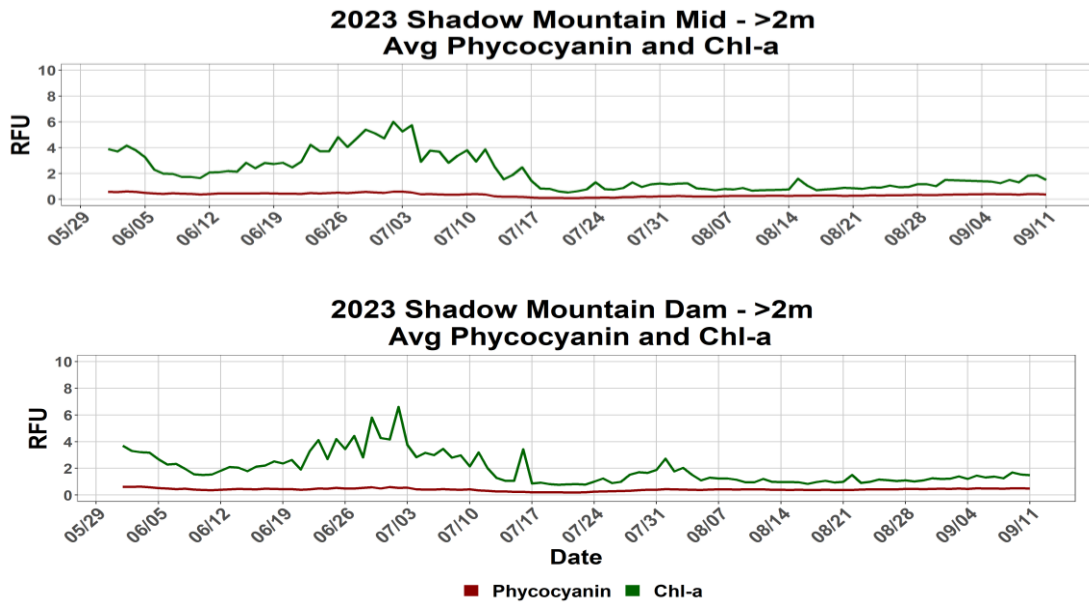


Figure 13. Chlorophyll a and phycocyanin data averaged between 0 and 2 m depths in time series form at SM-DAM and SM-MID. Chlorophyll data in profile form at SM-MID and SM-DAM. Phycocyanin data in profile form at SM-MID and SM-DAM.

Grand Lake Clarity Adaptive Management 2023

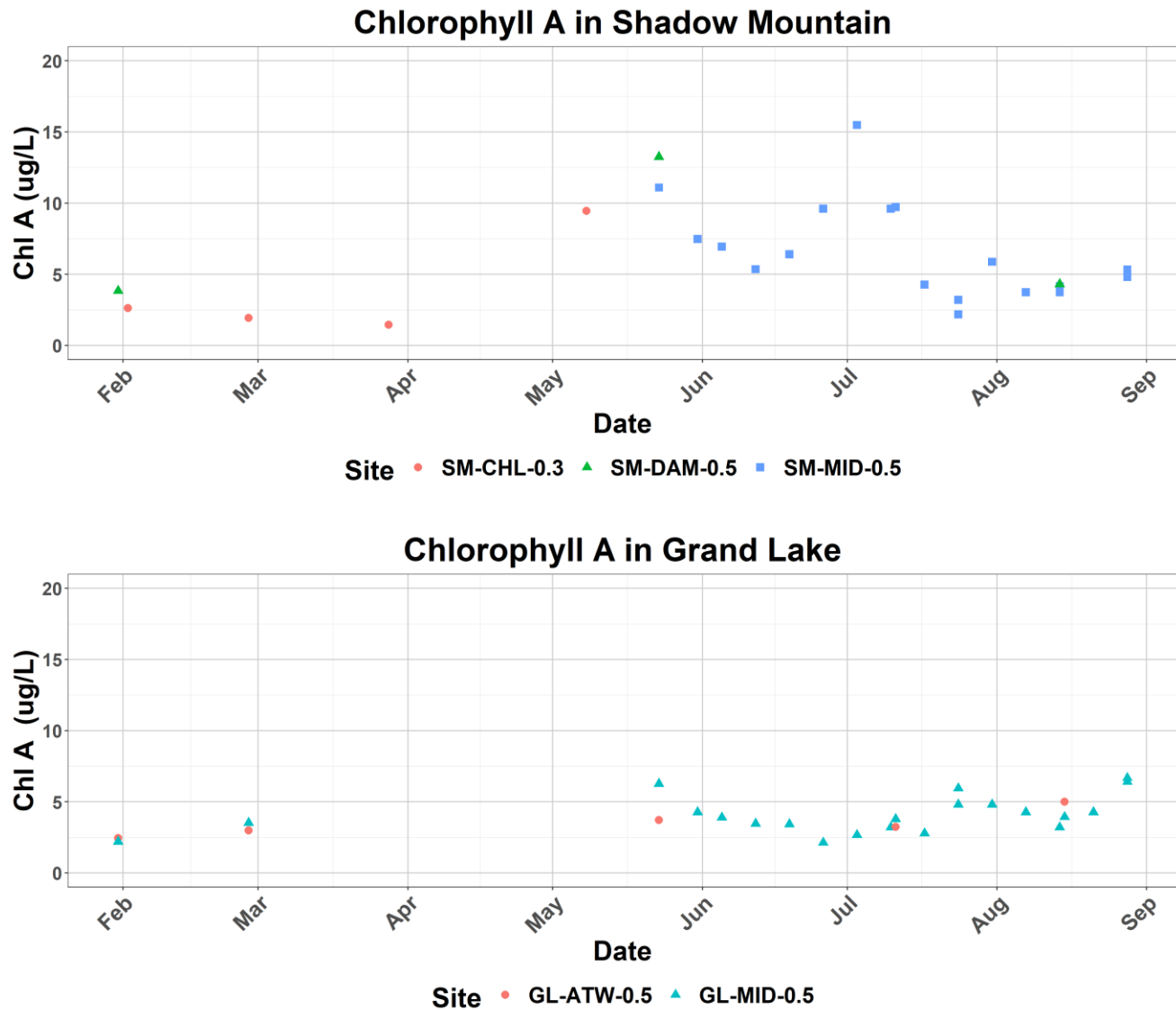


Figure 14. Chlorophyll a in Shadow Mountain Reservoir and Grand Lake.

Grand Lake Clarity Adaptive Management 2023

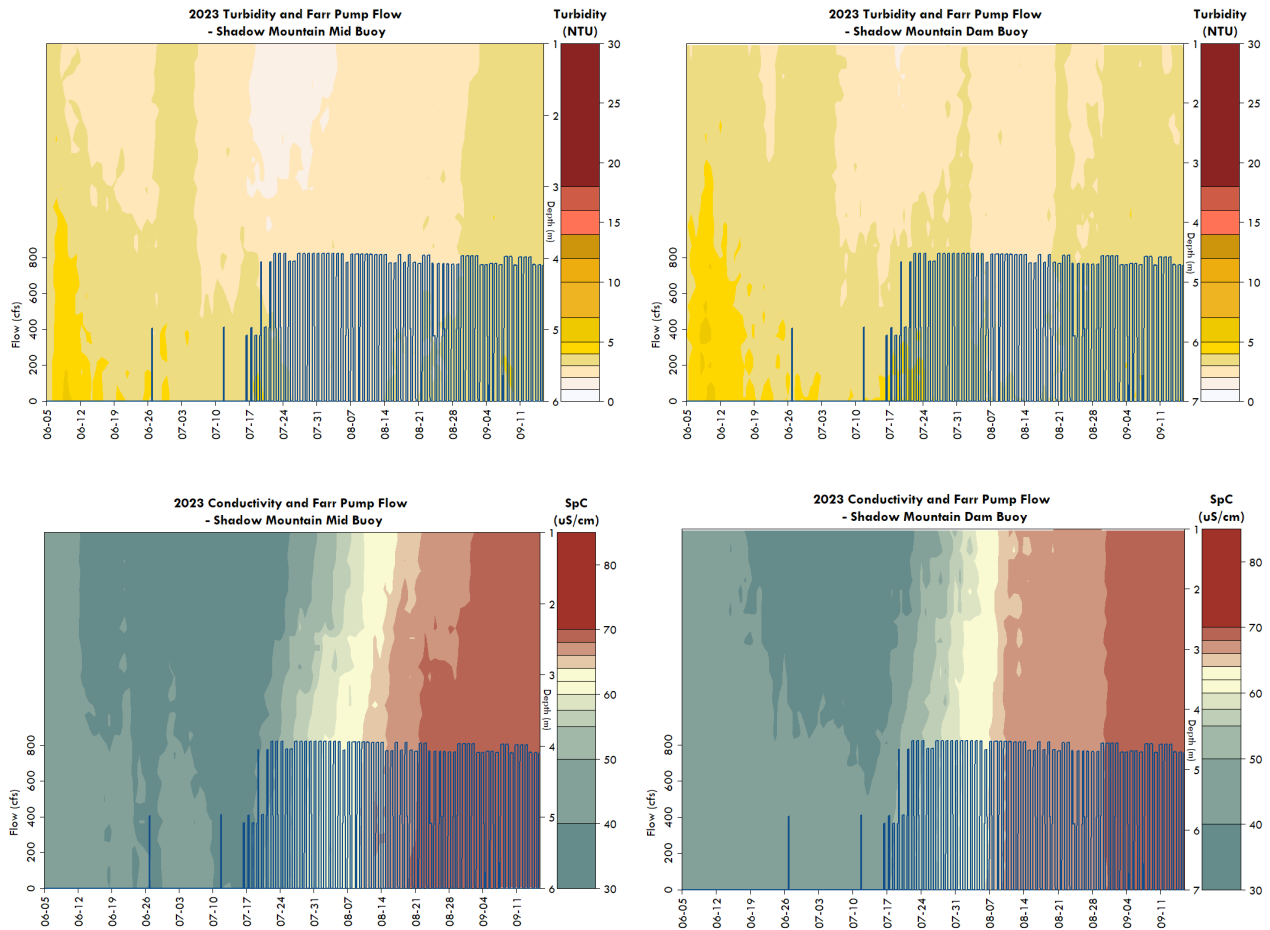


Figure 15. Turbidity profiles with Farr pumping rates at SM-MID and SM-DAM. Conductivity profiles with Farr pumping rates at SM-MID and SM-DAM.

Grand Lake Clarity Adaptive Management 2023

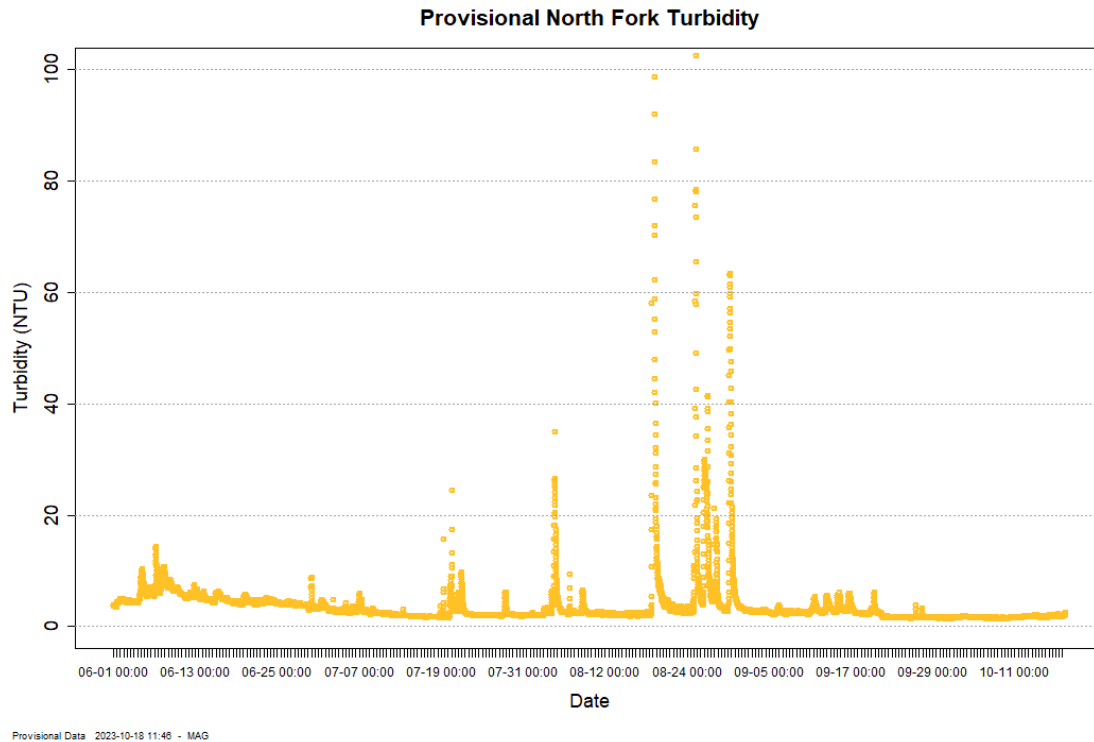


Figure 16. Provisional North Fork Turbidity time series.

The significance of the operational constraints due to high East Slope precipitation, O&M projects, and aging infrastructure limited the flexibility to adjust operations for GLAM in 2023. Because of the limited operational flexibility, the majority of the conversations during the weekly GLAM meetings focused on the current state of the system and expected conditions relating to both water quality and operations. The AMC did, however, discuss temperature in Shadow Mountain Reservoir, the presence of aquatic weeds, turbidity in the inflows into the Three Lakes System, and more during weekly meetings.

Shadow Mountain Reservoir water temperature continues to be a parameter of focus since Hydros Consulting presented an analysis of recent data showing that during July and August, warmer temperatures promote cyanobacteria dominance (specifically *Dolichospermum*) and

Grand Lake Clarity Adaptive Management 2023

colder temperatures promote diatom dominance (specifically *Asterionella*) (Hydros 2022). Both have the potential to reduce clarity. Hydros hypothesized that there may be an optimal intermediate temperature range that minimizes the growth of both types of phytoplankton. In mid-July, shortly after Farr Pump began moving water through Shadow Mountain Reservoir, a decrease in water temperature at the SM-DAM site was noticeable. The SM-MID site showed less of a change in water temperature as a result of pumping. This led the AMC to discuss increasing pumping operations in an attempt to cool temperatures further at the SM-MID site and curb potential algal growth. The AMC decided against additional pumping because of pumping costs and the potential for the excess water pumped to spill out of Shadow Mountain Dam before cooling more northern parts of the reservoir including the SM-MID site and beyond. Because of the required 1-ft cap on Grand Lake surface elevation fluctuation, plus operational constraints, there were very few other conversations about pumping as a control on temperature in Shadow Mountain Reservoir during the 2023 season.

Both Grand Lake and Shadow Mountain Reservoir appeared to experience a settling period after runoff but before Farr pumping began in 2023. Clarity measurements in Shadow Mountain Reservoir increased from its measured minimum, about 1.5 meters in mid-June, to more than 3 meters before Farr pumping began. Grand Lake also experienced some settling with clarity increasing from about 4 meters in mid-June to over 5.5 meters just before the beginning of pumping operations. A settling period in Grand Lake is typical but was longer than normal in 2023 due to a later pumping start date. In contrast to 2022, the only high turbidity events noted in 2023 occurred in the North Fork at the end of August when there was a washout in Supply Creek (Figure 17), and high turbidity levels were recorded both by the public and the CR-SMU gauge in the North Fork.

Grand Lake Clarity Adaptive Management 2023



Figure 17. Supply Creek as seen from Shadow Mountain Reservoir which experienced a washout in September of 2023.

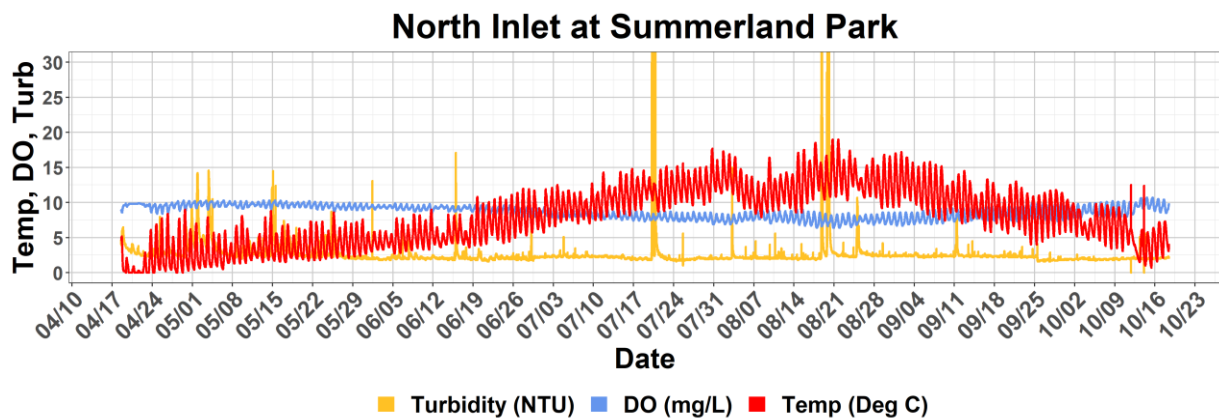


Figure 18. Temperature, DO, and Turbidity at North Inlet at Summerland Park (USGS).

Grand Lake Clarity Adaptive Management 2023

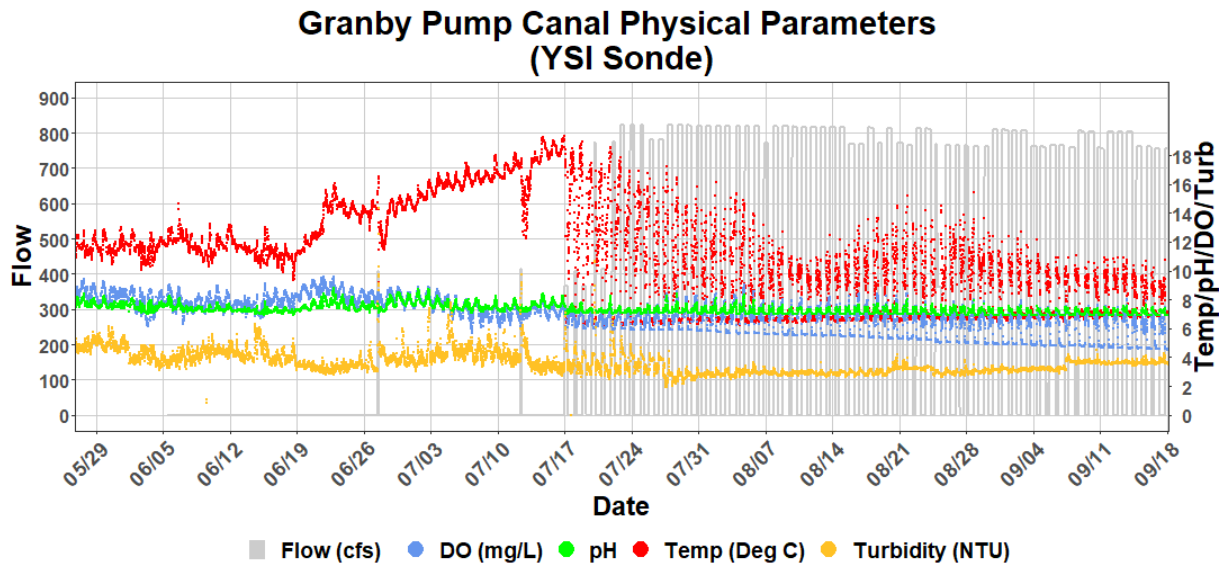


Figure 19. Discharge, temperature, pH, DO, and turbidity time series at GR-Pump.

2. Goal Qualifier Assessment and Water Quality Indicators

In 2023, both the 3.8 meter seasonal average Secchi depth goal qualifier and the 2.5 meter minimum Secchi depth goal qualifier were met as shown in Table 1. The July 1 – September 11 average Secchi Depth was 4.23 meters and the minimum Secchi Depth in Grand Lake was 2.99 meters. Between 2016 and 2023 the average and minimum goal qualifiers have been met 50 and 75% of the years, respectively (Table 2 and 3). As outlined by the Clarity MOU, the AMC also tracks Dissolved Oxygen and pH as water quality indicators in the system throughout the GLAM season. Dissolved Oxygen at the bottom of Shadow Mountain Reservoir dipped below the 3 mg/L water quality indicator at both the SM-MID and SM-DAM sites, reaching its minimum value of 1.88 mg/L on July 17th, just as Farr Pump begins to move water through Shadow Mountain Reservoir, but before flushing of water at SM-MID had occurred. The surface pH water quality indicator in Shadow Mountain Reservoir was also triggered with pH values over 8 SU on more than a dozen days during the GLAM season, reaching a maximum value of

Grand Lake Clarity Adaptive Management 2023

8.36 on July 12th. In 2016 the AMC noted that percent saturation of Dissolved Oxygen greater than 100% was not a helpful indicator of water quality issues and has not been used in a significant way since.

Table 1: Clarity Goal Qualifiers and Water Quality Indicators Summary.

	Indicator Threshold	Threshold Exceeded?	Final Exceedance Value	Date Indicator Threshold Exceeded
Grand Lake Clarity Season Average Jul-Sep11 (m)	3.8 m	No	NA	NA
Grand Lake Clarity Running Minimum Jul-Sep 11 (m)	2.5 m	No	NA	NA
Shadow Mountain Reservoir Surface pH	8	Yes	8.36	7/1-7/13, 8/22, 8/30-9/11
Shadow Mountain Reservoir Bottom DO (mg/L)	3 mg/L	Yes	1.88 mg/L	7/12-7/18

Grand Lake Clarity Adaptive Management 2023

Table 2. Summary of Grand Lake average Secchi depths since MOU implementation.

Year	Jul-Sep 11 Annual Average Secchi (viewscope)	Clarity Goal	Actual minus Goal	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

# Years Goal Met	4
Total # of Years	8
% of Years Goal Met	50%

Table 3. Summary of Grand Lake minimum Secchi depths since MOU implementation.

Year	Jul-Sep 11 Annual Minimum Secchi (viewscope)	Clarity Goal	Actual minus Goal	Goal Met?
2016	2.4	2.5	-0.08	N
2017	2.7	2.5	0.22	Y
2018	3.9	2.5	1.43	Y
2019	4.0	2.5	1.50	Y
2020	2.4	2.5	-0.09	N
2021	2.7	2.5	0.20	Y
2022	2.6	2.5	0.12	Y
2023	3.0	2.5	0.5	Y
# Years Goal Met				6
Total # of Years				8
% of Years Goal Met				75%

Lessons Learned & Recommendations

1. Changes Implemented during 2023 Season Weekly Report and Meeting

1. 15-minute Farr pumping data became available again after equipment upgrades and was added back into the report.
2. Changes to aesthetics throughout the report were made to increase readability of the report.
3. Number of years displayed on the buoy plots was refined to represent a few key years and compare trends to Secchi averages.
4. Running Secchi averages in Grand Lake for past years were added above the buoy plots to provide context for years that the goal qualifiers were/were not met.
5. Surface elevation of Granby Reservoir was added to the first page of the report.

2. 2023 Important Observations

1. Operational constraints due to hydrology, weather conditions, maintenance, water deliveries and power generation limit the ability to make adaptive management decisions. 2023 saw high East Slope precipitation during the spring and ongoing maintenance in the system which limited operational flexibility.
2. Measurements of specific conductivity in the connecting channel between Grand Lake and Shadow Mountain Reservoir continued to provide verification for the direction of flow at the Chipmunk Lane gauge, especially at lower flow rates and when the Adams Tunnel diversion is changing rapidly. This was a continued discussion in 2023 for the purposes of monitoring flow direction for clarity optimization. Based on some preliminary analysis done by Northern Water, specific conductivity may be a better indicator of flow direction than the Chipmunk Lane flow gauge in the connecting channel when flows are very low, there are high winds, or the Adams Tunnel is significantly varying its diversion rate. The flow gauge in the connecting channel may not have the sensitivity or resolution to reliably

Grand Lake Clarity Adaptive Management 2023

detect changes in flow direction at low flows where the sensor may be subject to currents or small changes. If specific conductivity is decreasing the flow is likely moving from Grand Lake into Shadow Mountain Reservoir and if the specific conductivity is increasing, then flow is likely moving from Shadow Mountain Reservoir into Grand Lake.

3. While aquatic weeds were present in Shadow Mountain Reservoir and were also observed in Grand Lake, Northern Water O&M Staff found significantly less accumulation on the screens at the West Portal than in past years. Staff did not have to clean the screens at all in 2023, versus some years when near-daily cleaning was required to maintain flows through the Adams Tunnel. This could be due to lower flows moving through the Adams Tunnel during the GLAM season and therefore lower velocities moving weeds towards the West Portal.
4. There was significant improvement in clarity in Shadow Mountain Reservoir prior to the start of Farr pumping. This could be due to a settling period of particles post-runoff, a decrease in algal growth as shown by lab and buoy data and/or cooler than average temperatures but warrants further investigation.

3. Recommendations

1. Explore making both past and real time data more available to the AMC either in the GLAM Reports or through some type of interactive dashboard similar to the Power BI tool shown at the Debrief Meeting.
2. Add past chlorophyll *a* data to the reports to provide context and comparison. This could be more useful than pH data.
3. Explore a shorter version of the weekly meetings during times when clarity is good. This may hinge on short updates provided by different groups: e.g. Northern Water providing weekly report, BOR providing a short operational summary etc.
4. Explore removal of detached weeds and weed mats that make their way into Grand Lake.

Appendices

- A. Clarity MOU
- B. Statement of Basis and Purpose
- C. Adaptive Management Committee Representatives
- D. 2023 GLAM Season Letter of Agreement
- E. Kickoff Meeting and Operation Plan Discussion
- F. 2023 Meeting Schedule
- G. Compilation of weekly meeting reports and notes
- H. Debrief Meeting
- I. Secchi Monitoring Program Summary

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.