Grand Lake Clarity Adaptive Management Annual Report

2021

Grand Lake Adaptive Management Committee

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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) 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 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."

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 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 (CBT) Project operational approaches to meet the Clarity Goals, and resultant effects on water quality and on 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 at the bottom and surface, and pH in Shadow Mountain Reservoir near the surface. Following implementation of the MOU, surface dissolved oxygen in Shadow Mountain Reservoir proved unhelpful as an indicator and was removed from the process.

This report meets the reporting requirements of the Clarity MOU and the Water Quality Control Commission.

2021 Adaptive Management Process

This section describes how the Adaptive Management process was carried out in 2021.

1. Adaptive Management Committee Representatives

The Adaptive Management Committee (AMC) comprises representatives of Reclamation, Northern Water, Grand County, NWCCOG, and the River District. A list of the representatives that attended the meetings in 2021 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 through September 11 period. This process is illustrated in **Figure 1**.

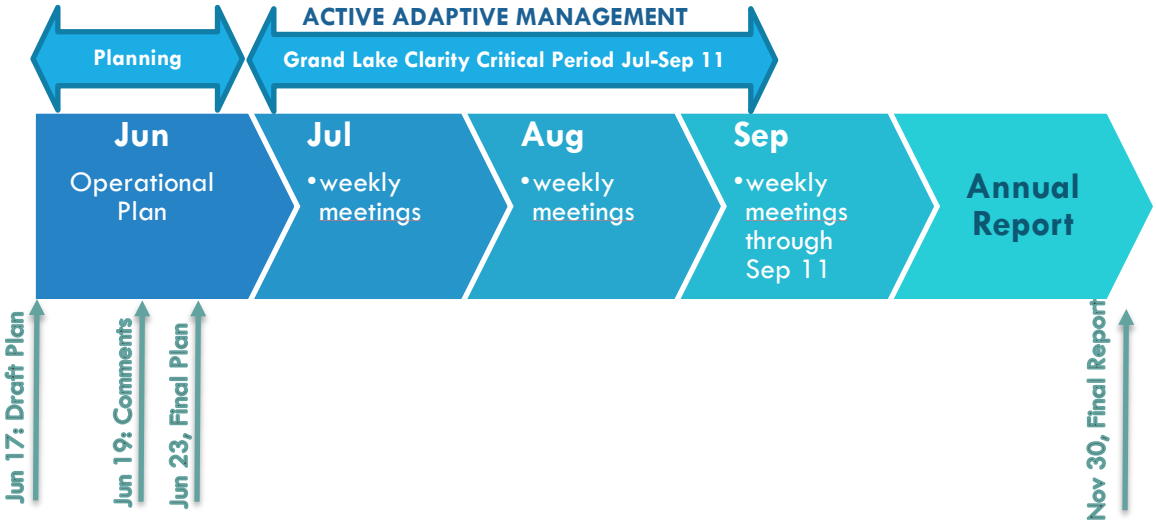

Figure 1: Adaptive Management Process

Section V.C. of the Clarity MOU specifies that operational scenarios along with corresponding water quality model runs shall be presented by Reclamation to the Adaptive Management Committee.

2. East Troublesome Fire and 2021 GLAM 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. Watersheds burned in the fire included Willow Creek, Stillwater, North Fork and North Inlet (89, 90, 29, and 42% burned, respectively), all of which flow into the Three Lakes System. The extent of impacts of the fire on water quality and the duration of those impacts are as yet unknown and difficult to forecast, however research from previous wildfires suggests that impacts will likely be severe and of long duration. In 2021, runoff from the fire area impacted

water quality in the Three Lakes and the Colorado-Big Thompson system, particularly in Willow Creek Reservoir. Sediment, debris, nutrients, and other parameters of concern (e.g., manganese) are expected to increase for many years to come. Subsequent ecosystem changes, such as increased algal and cyanobacteria growth, have already occurred.

Due to these anticipated effects from the ETF, the AMC met and agreed to an amended GLAM process in 2021 that consisted of the following changes:

- "Reclamation presented only one operational scenario for the year.
- Preseason modeling of the operational scenario to forecast water quality response was not conducted.
- Data collection and analysis continued per the annual monitoring plan, including additional wildfire related monitoring programs.
- The AMC met weekly from July 1 through September 11 to discuss the data and observations on clarity.
- If a specific objective was identified, and there were sufficient data to support an investigative effort, the AMC agreed to 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.
- A summary report of the GLAM season and process is being produced to document the 2021 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. "

All other conditions of the MOU have been retained and conducted as described in the MOU.

The letter memorializing the agreed to changes is included in Appendix D.

3. Planning Process

In accordance with the Modification of Grand Lake Clarity Stakeholders' Memorandum of Understanding, the AMC met virtually on June 16, 2021 to review the proposed operational scenario and discuss the anticipated approach to the 2021 season. Prior to this meeting, Reclamation developed an operational scenario using its Annual Operational Plan (AOP) model, and in accordance with the 2021 agreement, this plan was not run through the water quality model.
At the meeting on June 16, 2021, Reclamation presented their operational scenario. Members of the AMC discussed the plan. The Kickoff Meeting materials as well as the operational scenario are compiled in Appendix E.

The Adaptive Management Committee began weekly conference calls on July 1, 2021 and continued to meet weekly until September 9, 2021.

A schedule of all the meetings is included in Appendix F. Weekly meeting materials, notes and plans are compiled in Appendix G.

The Adaptive Management Committee held a debriefing meeting on September 30, 2021. This meeting focused on discussion of possible improvements to the process, lessons learned, and recommendations for following years. Debrief Meeting materials are located in Appendix H.

4. 2021 Operational Plan

Reclamation prepared an operational plan for presentation and discussion at the June 16, 2021 kickoff meeting. The scenario presented sought to comply with Senate Document 80 by operating in such a manner as to achieve the five primary purposes:

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, and
5) To maintain conditions of river flow for the benefit of domestic and sanitary uses of this water."

The Northern Water Board set a preliminary 50% quota on October 8, 2020 and later allocated an additional 20% on April 9, 2021 for a total quota of 70%. Despite an average amount of spring precipitation in Grand County, drought persisted into the clarity season and forecasted summer meteorology showed an increased chance of below average precipitation.

1. Plan selection

The Final Operational Plan, as presented by Reclamation during the Kickoff Meeting, is quoted below:

- "No active concerns about loss of water supply potential (i.e. no likelihood of Granby spill). Below-100% fill targets at Horsetooth have only limited impact on operations.
- No east slope priority water expected.
- Time Adams Tunnel diversions to avoid unnecessary conflict with east slope opportunities (e.g. skim) and keep flows above Mary's Power Plant generation minimum.
    - Maintain 11 days of 40 cfs minimum flow from Grand Lake into Shadow Mountain (June 30 – July 10).
- Maintain a significant flow through Shadow Mountain to cool reservoir waters, retarding algal growth rate.
- Minimize conveyance of project water around hydropower machinery (maximize east slope skim generation).
- Generate hydropower during high-value summer months.
- Distribute water diverted through Adams Tunnel to Carter Lake and Horsetooth Reservoir to favorably impact 2021 recreation and 2022 fill.

  Much of this is subject to uncertain, and potentially severe post-fire impacts. (These were not included in the scenario except a behind-the-scenes attempt to preserve flexibility to respond.)"

Grand Lake Clarity & Shadow Mountain Reservoir Water Quality

This section describes observed water quality in Shadow Mountain Reservoir and clarity in Grand Lake during the 2021 adaptive management season (Jul 1 - Sep 11). The monitoring sites are shown in Figure 2. Secchi measurements are recorded at all sites and two buoys equipped with real-time sensors collect data over a vertical profile every four hours at SM-MID and SM-DAM.

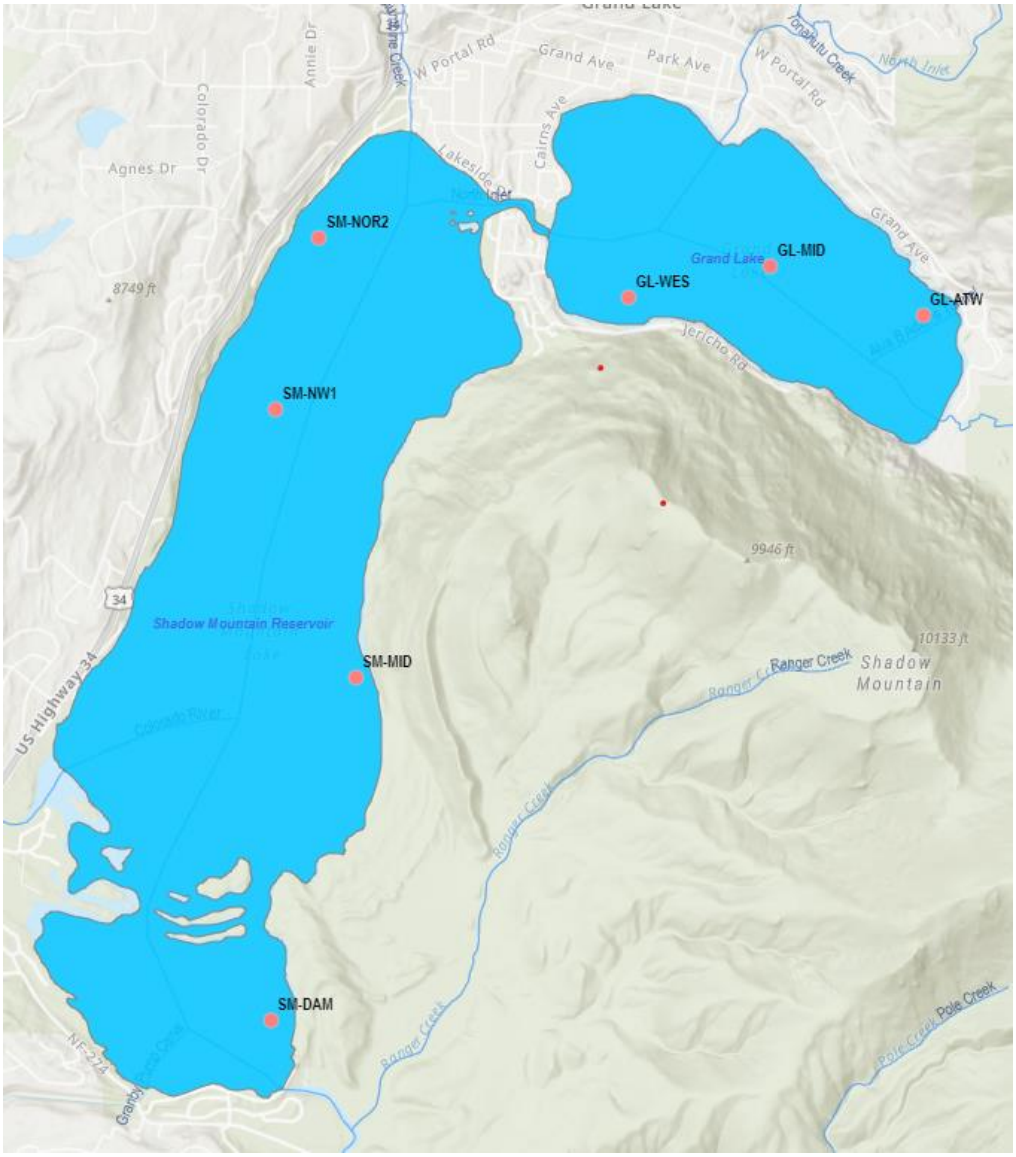

Figure 2: Monitoring locations in Grand Lake and Shadow Mountain Reservoir.

1. Summary of Grand Lake clarity, operations, and inlet hydrology

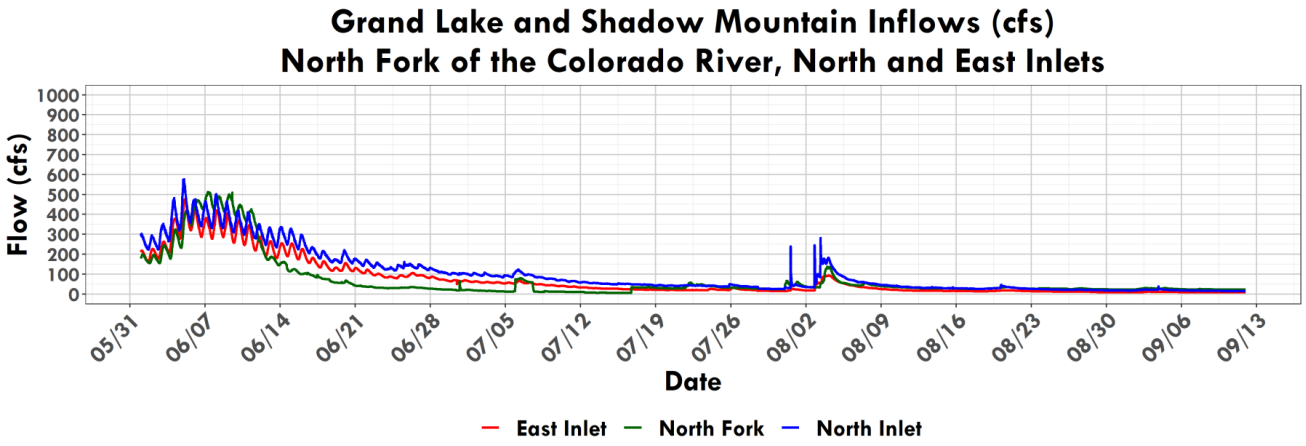

Figure 3: Grand Lake and Shadow Mountain Reservoir inflows

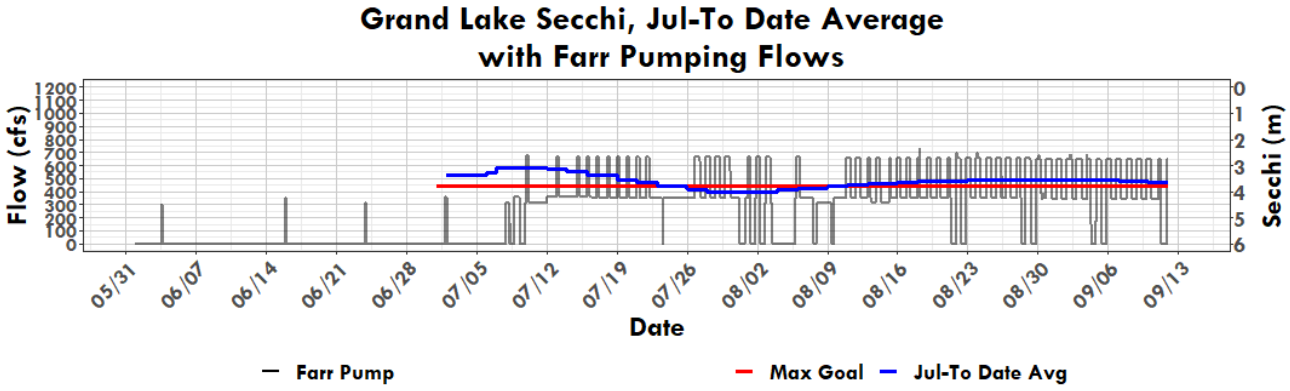

Figure 4 - Grand Lake Clarity Season Average Secchi and Farr Pump Flows

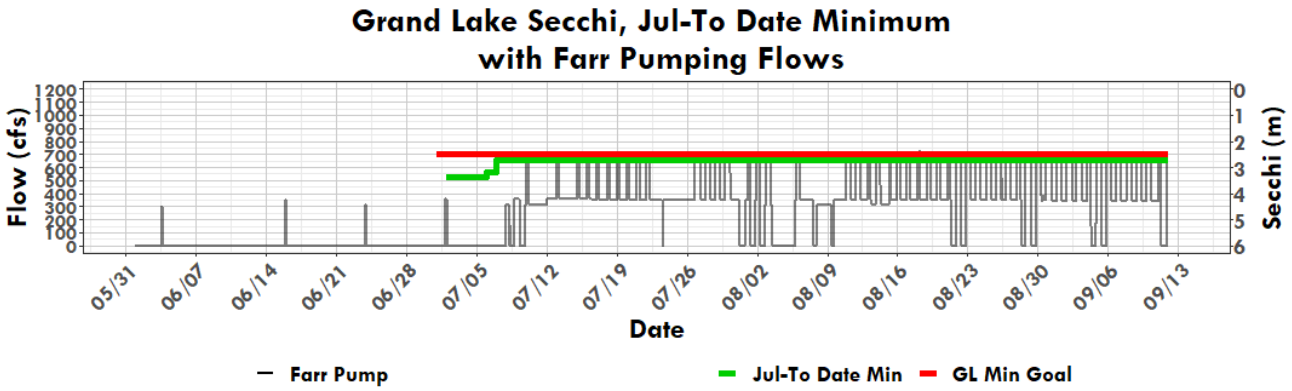

Figure 5 - Grand Lake Clarity Season Minimum Secchi and Farr Pump Flows

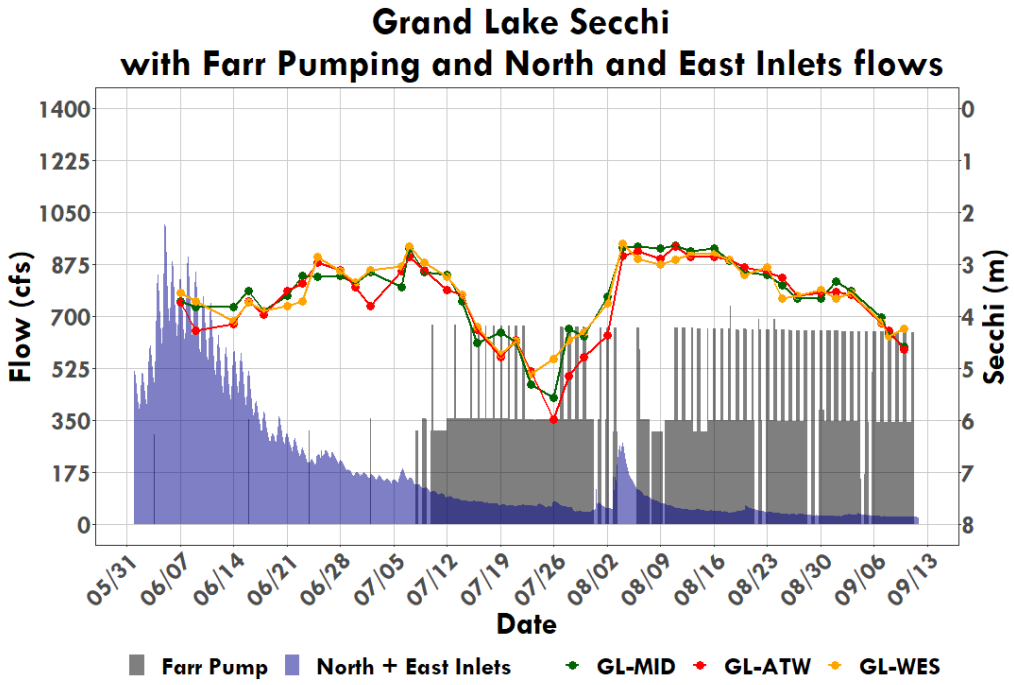

Figure 6 - Grand Lake Secchi, Farr Pump Flows and Inflows

2. Shadow Mountain Reservoir Water Quality Summary

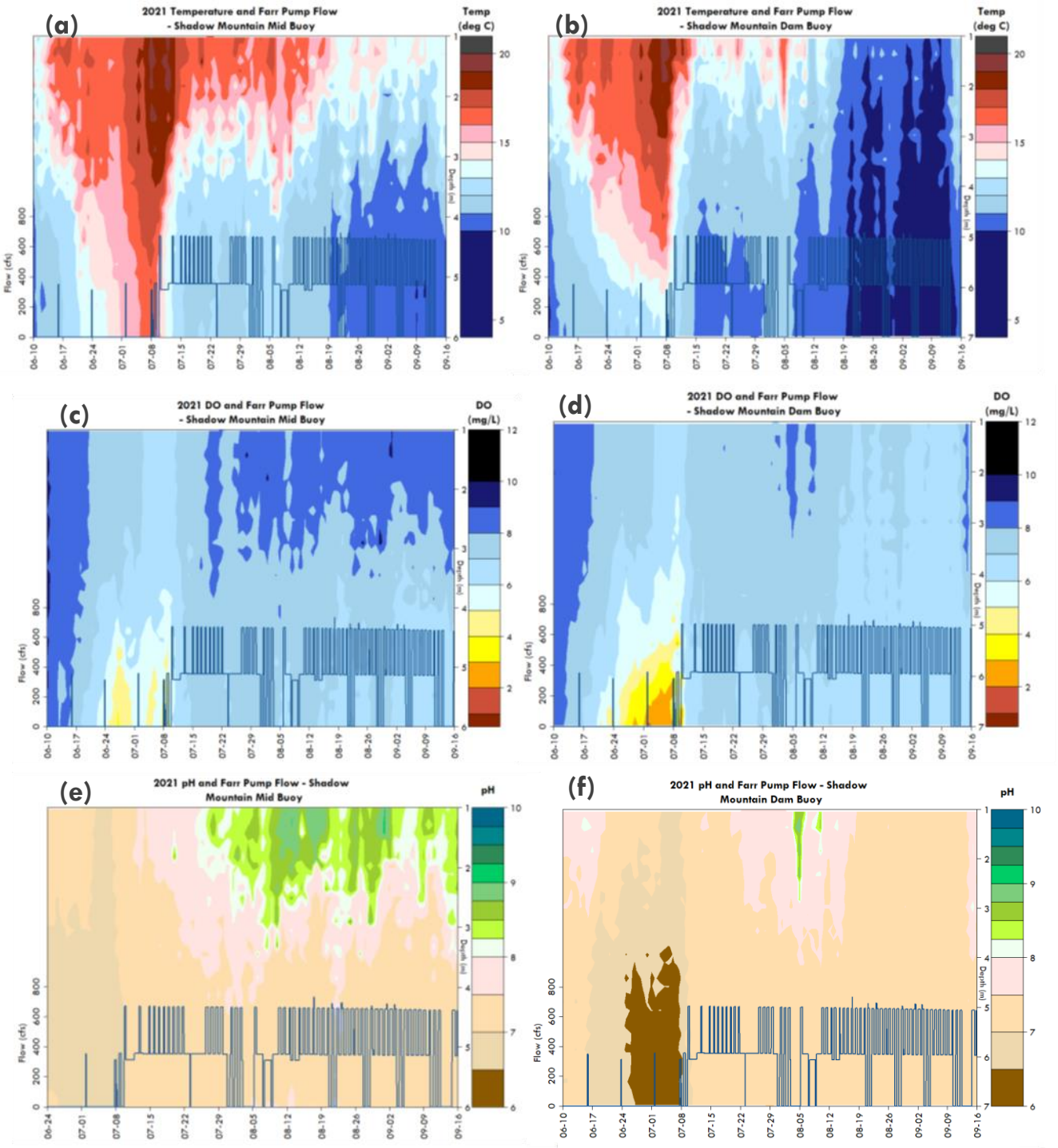

Figure 7: Shadow Mountain Buoy water quality depth profiles (a) SM-MID Temperature, (b) SM-DAM Temperature, (c) SM-MID DO, (d) SM-DAM DO, (e) SM-MID pH, and (f) SM-DAM pH

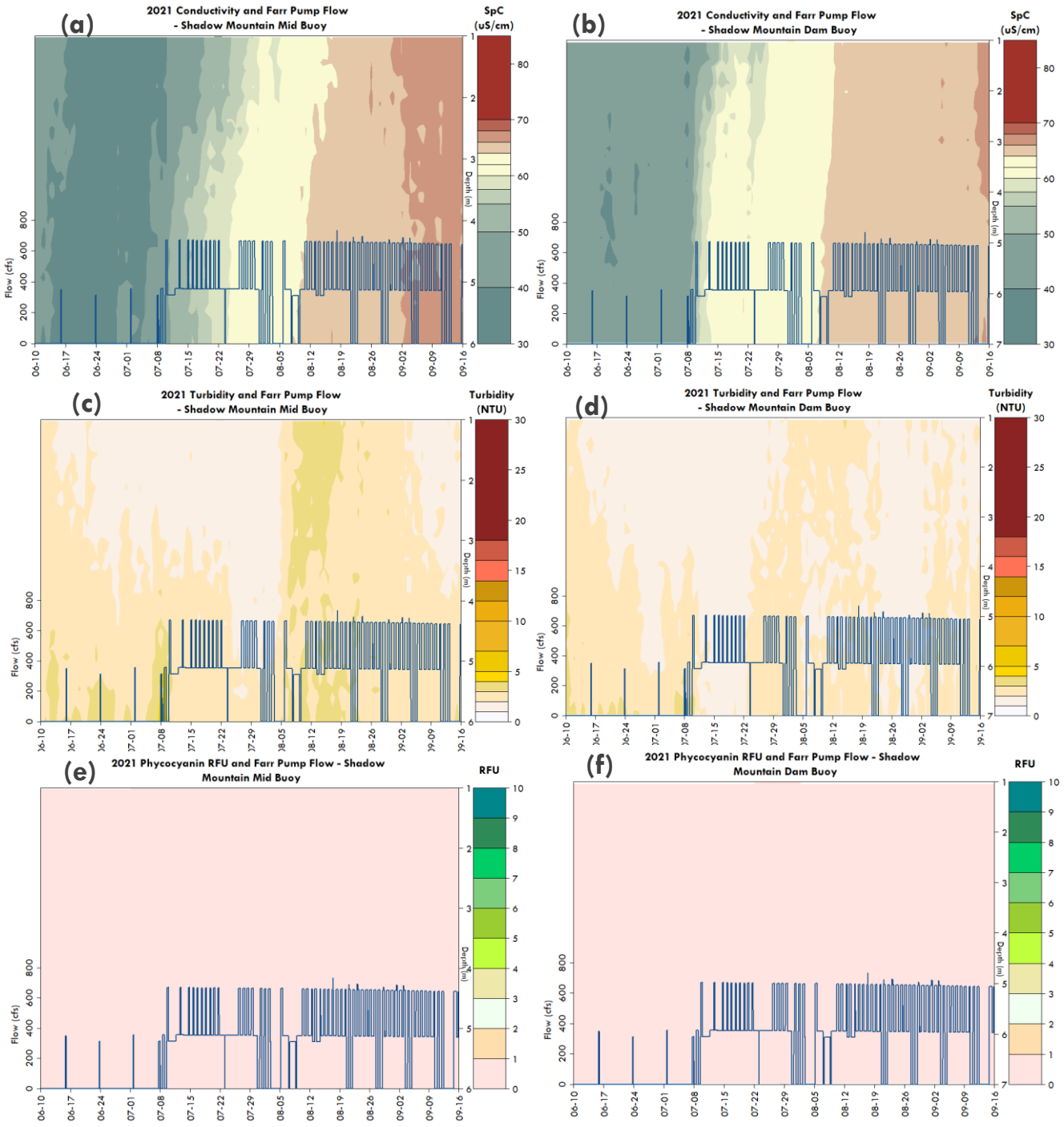

Figure 8: Shadow Mountain Buoy water quality depth profiles (a) SM-MID Specific Conductivity, (b) SM-DAM Specific Conductivity, (c) SM-MID Turbidity, (d) SM-DAM Turbidity, (e) SM-MID Blue Green Algae (RFU), and (f) SM-DAM Blue Green Algae (RFU)

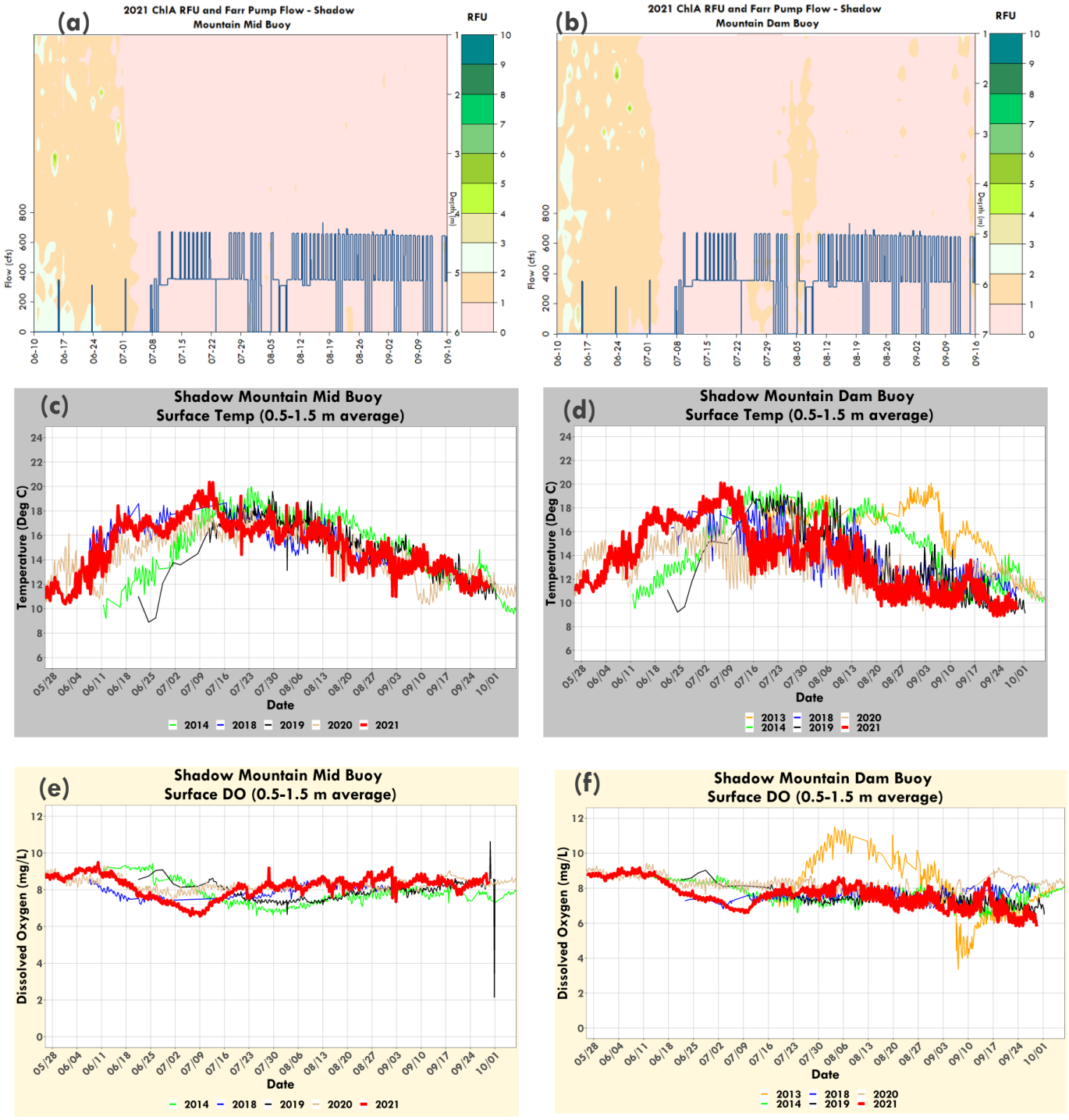

Figure 9: Shadow Mountain Buoy water quality depth profiles (a) SM-MID Chlorophyll a, (b) SM-DAM Chlorophyll a, (c) SM-MID Surface Temperature, (d) SM-DAM Surface Temperature, (e) SM-MID Surface DO, and (f) SM-DAM Surface DO

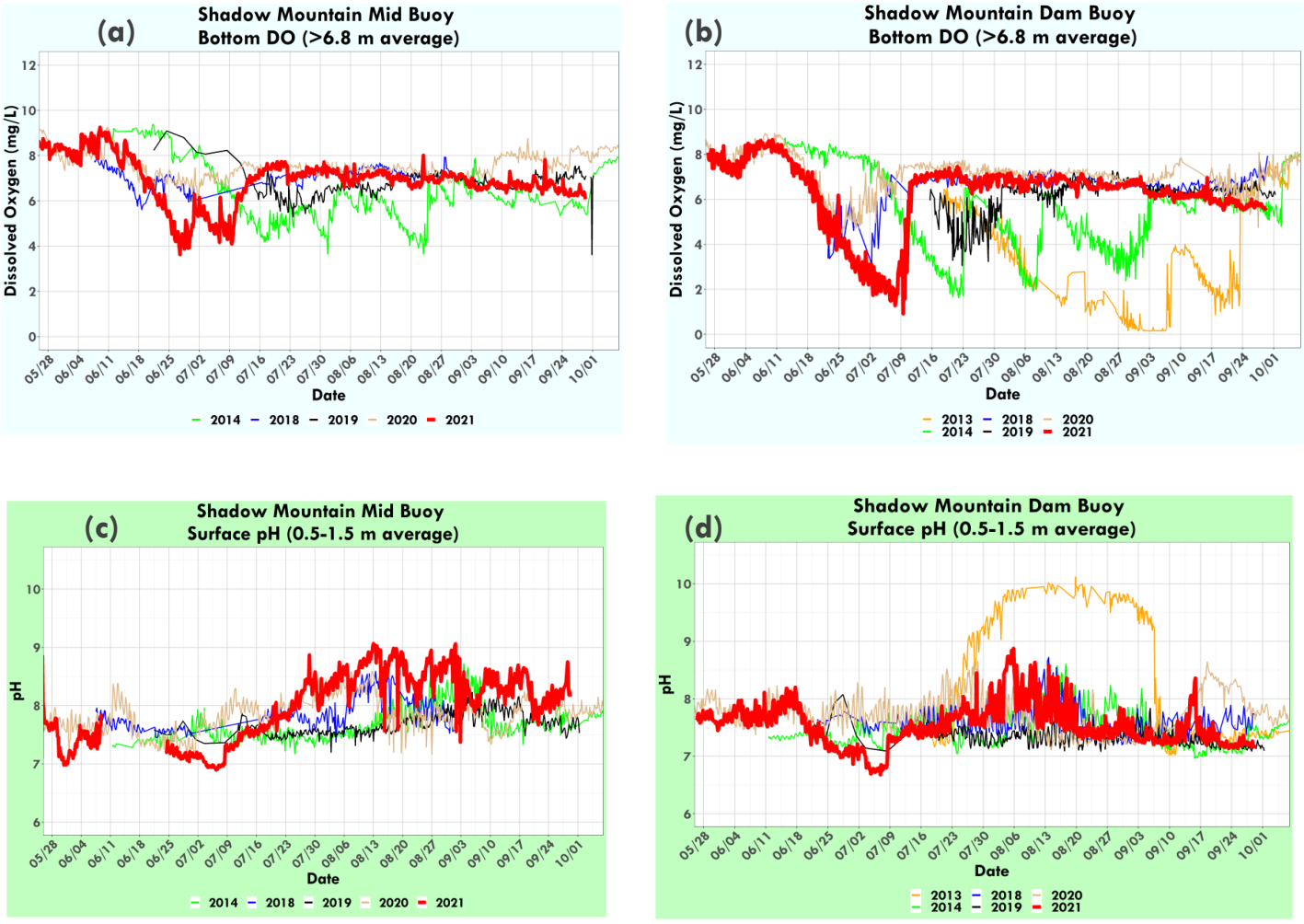

Figure 10: Shadow Mountain Buoy water quality depth profiles (a) SM-MID Bottom DO, (b) SM-DAM Bottom DO, (c) SM-MID surface pH, and (d) SM-DAM surface pH.

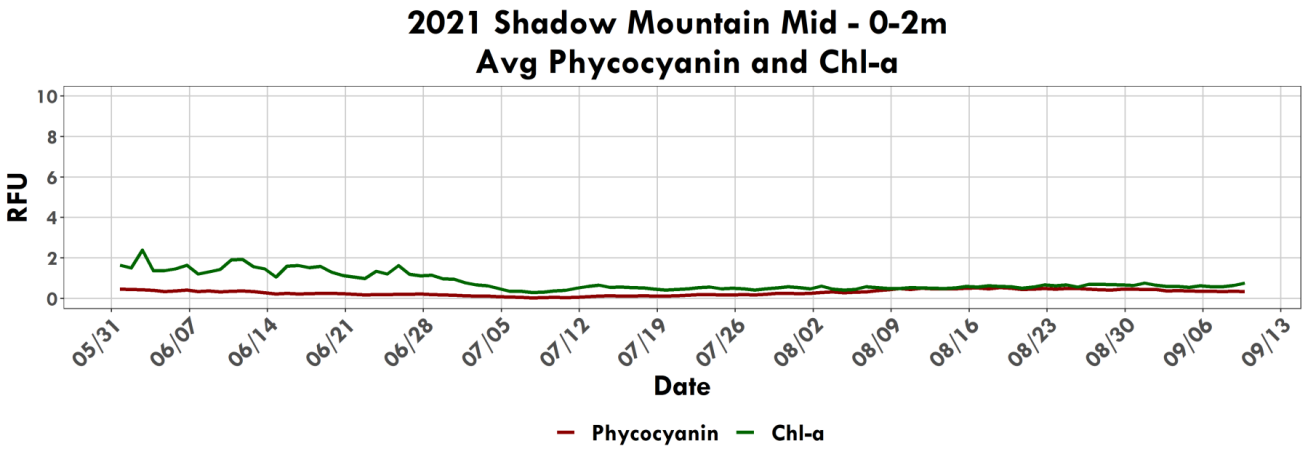

Figure 11: Shadow Mountain Dam buoy measurements of Phycocyanin and Chlorophyll-a RFUs.

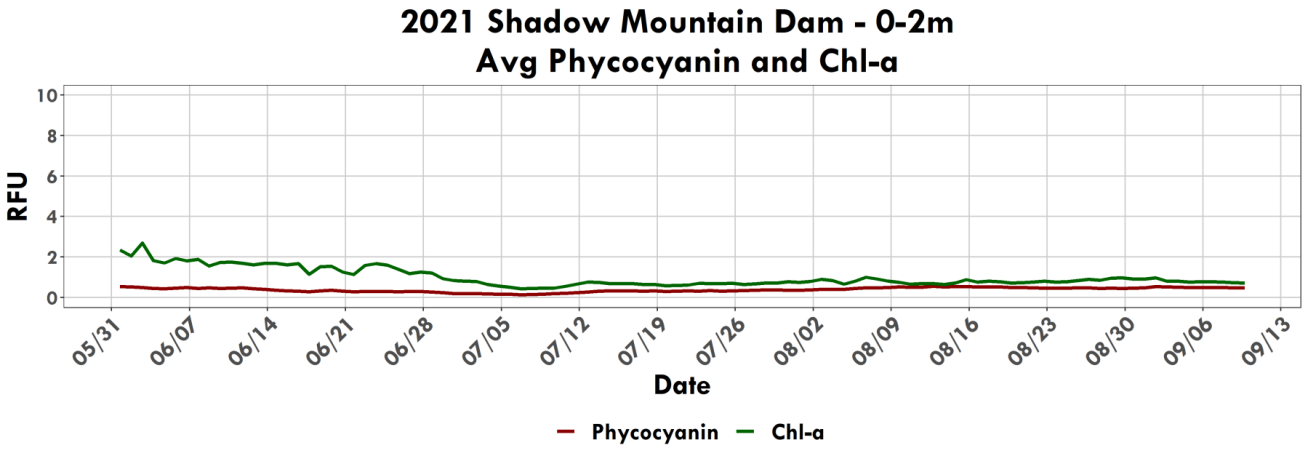

Figure 12: Shadow Mountain Mid buoy measurements of daily average Phycocyanin and Chlorophyll-a RFUs.

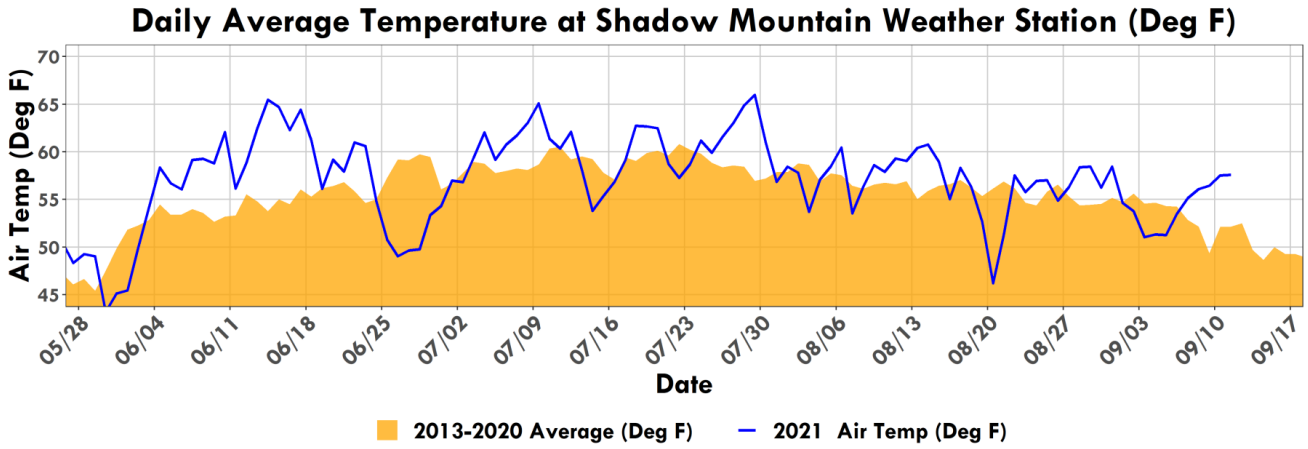

Figure 13: 2021 air temperature compared to the average of past years (2013-2020)

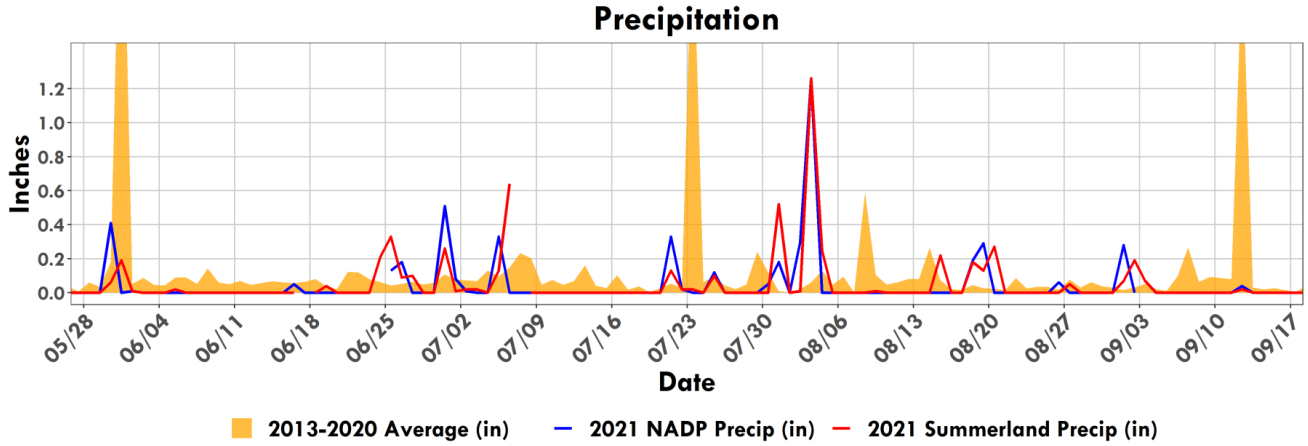

Figure 14: 2021 precipitation compared to the average of past years (2013-2020)

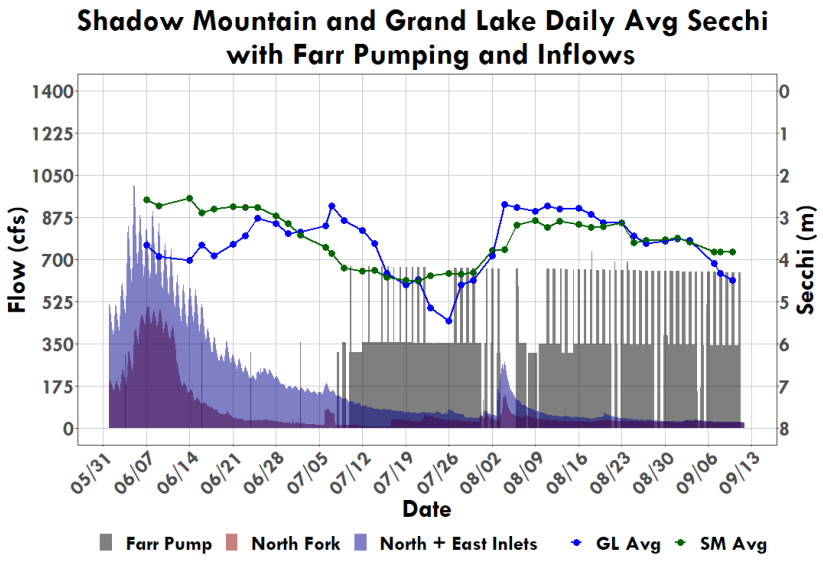

Figure 15: Shadow Mountain Reservoir and Grand Lake Average Secchi, Farr Pump Flows and Inflow

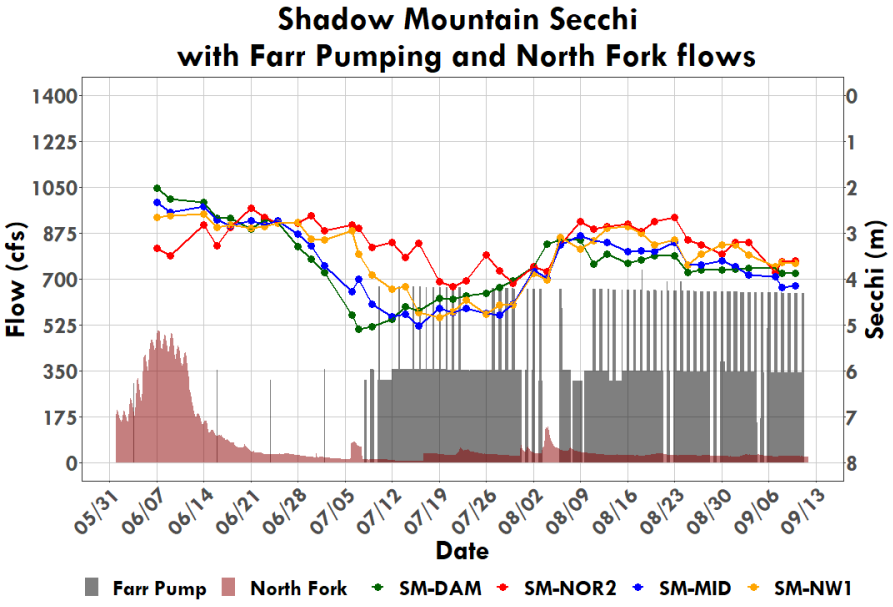

Figure 16: Shadow Mountain Secchi, Farr Pump Flows and Inflows

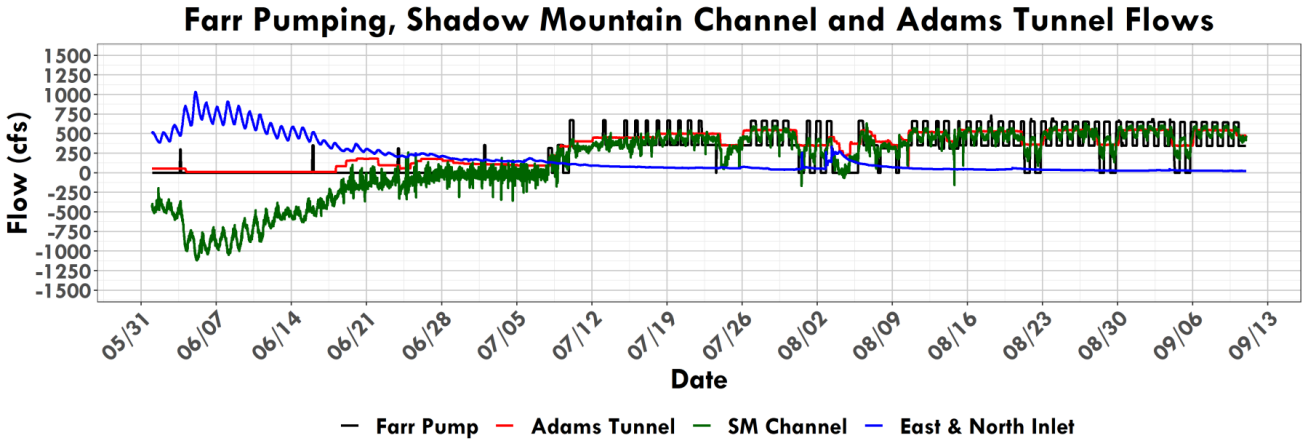

Figure 17: Farr Pumping, Shadow Mountain Channel, and Adams Tunnel Flows

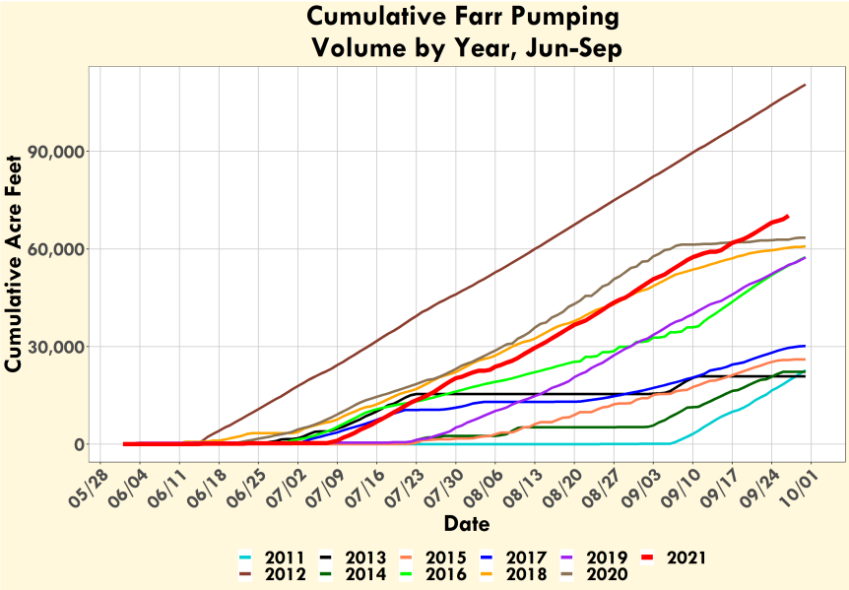

Figure 18: Cross year comparison of cumulative Adams Tunnel diversions between June and September.

3. Water Quality and Operations Summary Results

Peak flow into the Three Lakes system occurred on June 5, 2021 at a daily average of 2,302 cfs (Figure 3). From April to July, runoff totaled 164 KAF and was very similar to the BOR's May 2021 total projected runoff of 162 KAF. There was no Granby Reservoir spill. Weather during the clarity period was hotter than average with below average precipitation (Figures 13 and 14). Regular off-peak pumping operations, which generally ranged from 257 to 584 cfs on weekdays and 187 to 481 cfs on weekends, began shortly after the beginning of the clarity season on July 8; multiple short pulses, of approximately 300 cfs, occurred before the clarity season started (Figure 17). Water began flowing from Shadow

Mountain to Grand Lake on July 8 and continued flowing towards Grand Lake, which is up-gradient as a result of CBT operations, for the remainder of the GLAM season, with a few short exceptions.

Pumping rates on July 8 began at approximately 800 cfs, with occasional reductions to 400 cfs (Figure 17)., generally occurring on the weekends. The objective in the variations in pumping was to disrupt any unfavorable water quality conditions that could lead to reduced water clarity within the system. During the August 19 meeting, the group discussed changing the day of the weekly meetings from Thursdays to Wednesdays to allow Western Area Power Administration (WAPA) to consider proposed weekend changes prior to finalization of the week's trading schedule.

Grand Lake Secchi depth began the season below the 3.8 m average goal qualifier at 3.4 m (Figure 15). Secchi depths in Grand Lake increased between July 6 and July 26 and declined from 5.5 m to 2.6m between July 26 and August 3. Clarity then improved slowly until the end of the season with the last Secchi measurement at 4.4 m. Secchi depth in Shadow Mountain Reservoir stayed between 2.5 and 4.0 m during the clarity season (Figure 15), and both the surface pH and bottom DO water quality indicators exceeded their thresholds during the clarity season. The water quality indicator of 8.0 pH was exceeded on July 24 and cycled above and below 8.0 for 49 days, or 68% of the clarity season. The pH reached a maximum value of 9.1 on August 13. Bottom dissolved oxygen decreased below the water quality indicator of 3 mg/L between July 1 and 10 and reached a minimum value of 0.9 mg/L on July 9, just one day after pumping began. Bottom dissolved oxygen subsequently increased and stayed above 3 mg/L for the remainder of the season.

Other water quality data collected from Shadow Mountain Reservoir included water temperature, surface dissolved oxygen, chlorophyll-a, phycocyanin fluorescence, turbidity, and conductivity. Water temperatures at both SM-Dam and Mid were high at the beginning of the season and decreased following the start of pumping operations in July (Figures 7a, 7b, 9c, and 9d). Surface dissolved oxygen was higher than usual throughout the season (Figures 7c, 7d, 9e, and 9f). Bottom dissolved oxygen was low at both SM-Dam (minimum=0.9 mg/L) and SM-Mid (minimum=3.63 mg/L) before pumping operations began, but it increased to levels between 6 and 8 mg/L at the start of pumping operations (Figures 10a and 10b). Chlorophyll *a* at the dam and mid sites was low (0-1 RFU) for the entire season (Figures 9a, 9b, 11, and 12) despite high pH observed at the mid site, and public observations of collections of algae and aquatic plants in shallow areas. Surface pH at SM-MID was elevated from mid-July to the beginning of September (Figures 7e and 10c), while surface pH at SM-DAM was elevated at the beginning of August (Figures 7f and 10d). Phycocyanin (Figures 8e and 8f), turbidity (Figures 8c and 8d), and conductivity (Figures 8a and 8b) at both sites were low and did not display trends that were out of the ordinary.

Shadow Mountain Reservoir water temperature played a large role in operations discussions this season. During the first weekly meeting, Jean Marie Boyer with Hydros Consulting, presented their analysis using data over the past 14 years, and proposed a hypothesis regarding temperature, clarity, and phytoplankton growth. The hypothesis is that allowing water temperature in Shadow Mountain Reservoir to stay for too long under warm conditions (roughly, around or above 18°C) creates favorable conditions for cyanobacterial growth and allowing temperatures to stay too long under cool conditions (roughly, around or below 15°C) promotes *Asterionella* (a diatom) growth, both of which can impair clarity. Hydros suggested that there may be an intermediate water temperature range in Shadow Mountain Reservoir that results in minimizing the growth of both cyanobacteria and *Asterionella*. These conditions occurred in 2018 and 2019 – years where

average summer clarity in Shadow Mountain Reservoir was the highest over the 14-year period and there were no blooms of cyanobacteria or *Asterionella*. It was noted that water temperature is not the only important factor affecting algal growth and resultant clarity, but it appears to be important in Shadow Mountain Reservoir during the clarity season.

Since Farr pumping (which brings in cooler water from Granby Reservoir) directly affects temperature conditions in Shadow Mountain Reservoir, there is an opportunity to help optimize conditions for clarity using operational decisions. More work needs to be conducted to better determine appropriate temperature objectives (target locations, specific temperature ranges, duration, etc.). In addition, further analyses are needed to better understand how Farr pumping can be used to meet specific temperature objectives in Shadow Mountain Reservoir, considering several factors including Farr pumping rates, patterns, total pumping, and conditions in Granby Reservoir.

Effects from the ETF were observed in July and August following precipitation events. Notably, a larger precipitation event on August 3, with 1.24 inches of rainfall, resulted in highly turbid water in the North Inlet and a large sediment influx into Grand Lake. Prior to the precipitation event, the Grand Lake Secchi depth was 3.9m, following the precipitation event, the Secchi depth declined to 2.7 m. During this precipitation event, which occurred on both the East and West Slopes, Reclamation cut Adams Tunnel Diversions to the East Slope because sufficient water was in the system for power generation, and Lake Estes was reaching its maximum elevation. This event triggered the first field observations of "black, mulchy debris" in Grand Lake (Figure 19). Following this storm, flows from the Colorado River into Shadow Mountain Reservoir were also turbid.

Figure 19: Black, mulchy debris on Grand Lake Beach following August 3 precipitation event.

4. Goal Qualifier Assessment and Water Quality Indicators

In 2021, the 3.8 m running average Secchi depth goal qualifier was not met, but the 2.5 m minimum Secchi depth goal qualifier was met, as shown in Table 1. The average clarity was 3.6 m, and the minimum clarity was 2.7 m. Surface pH exceeded the water quality maximum trigger of 8 beginning July 24, and oscillated above and below 8 until September 11, exceeding the threshold for 68% of the season. The pH reached a maximum value of 9.1 on August 13 at SM-Mid. Bottom DO at SM-Dam exceeded the Bottom DO trigger at the beginning of the season prior to pumping and reached a minimum value of 0.9 mg/L on July 9. Once pumping operations started on July 8, Bottom DO began to increase above the threshold and remained above threshold for the remainder of the season.

Table 1: Clarity Goal Qualifiers and Water Quality Indicators Summary for 2021 Clarity Season

	Indicator Threshold	Threshold Exceeded?	Final Indicator Value	Date Indicator Threshold Exceeded (2021)
Grand Lake Clarity Running Average	3.8 m	Yes	3.6 m	07/01-07/26 08/11-9/11
Grand Lake Clarity Running Minimum	2.5 m	No	2.7 m	NA
Shadow Mountain Reservoir Surface pH	>8	Yes	9.1	7/24-09/11
Shadow Mountain Reservoir Bottom DO (mg/L)	<3 mg/L	Yes	0.9 mg/L	07/01-07/10

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

Year	Jul-Sep 11 Annual Average Secchi (viewscope)	Clarity Goal	Actual minus Goal	Goal Met?
2016	3.3	3.8	-0.53	N
2017	3.9	3.8	0.09	Y
2018	4.6	3.8	0.79	Y
2019	4.8	3.8	0.98	Y
2020	2.9	3.8	-0.85	N
2021	3.6	3.8	-0.20	N
			# Years Met	3
			Total # of Years	6

Table 3: Summary of 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

# Years Goal Met	4
Total # of Years	6

5. Water Quality and Operations Summary Discussion

Clarity in 2021 followed a similar trend as in previous years, showing that water quality in Shadow Mountain Reservoir impacts Grand Lake clarity as water moves through the connecting channel into Grand Lake during pumping operations. This year, better clarity in Shadow Mountain Reservoir improved Grand Lake clarity when pumping began on July 8. This improvement decreased as the season continued and clarity in Shadow Mountain Reservoir began to decline. Grand Lake clarity trends followed Shadow Mountain Reservoir clarity trends and the two began to synchronize around August 3, showing the connection between Shadow Mountain Reservoir and Grand Lake clarity.

Although impacts from the ETF were visible following precipitation events, the magnitude of effects that were expected failed to materialize, particularly in Shadow Mountain Reservoir. Conductivity, dissolved oxygen, and turbidity trends in Shadow Mountain Reservoir did not greatly differ from past years. Specifically, levels of chlorophyll and cyanobacteria remained low at the Shadow Mountain Reservoir mid and dam buoys, and in the connecting channel between Shadow Mountain Reservoir and Grand Lake throughout the clarity season. Future analyses may yield insight into whether attempts to optimize clarity by aiming for water temperatures in Shadow Mountain Reservoir near 15°-18°C helped to suppress algal growth.

Lessons Learned & Recommendations

1. Changes Implemented during the 2021 Season

Weekly Report and Meeting

1. One new precipitation station, Summerland Park, in the North Inlet basin was added to the precipitation plot to give a broader view of precipitation trends around Grand Lake.
2. During the 2021 GLAM season, the weekly meeting date and time was changed from Thursday at 2:30 PM to Wednesday at 10:30 AM to allow WAPA the opportunity to consider recommended changes for the weekend immediately following the meetings in their trading schedule. This time change was helpful for incorporating recommended changes into weekend operations. During the debrief, AMC members agreed on a meeting time of Tuesday afternoons for future GLAM seasons.

2. 2021 Important Observations

1. The committee did not observe the expected magnitude of post-fire impacts in the available data for the 2021 GLAM season. Many water quality variables in Shadow Mountain Reservoir were similar to past years, and while localized areas of cyanobacterial growth were observed, overall, chlorophyll and phycocyanin concentrations remained low. Although debris that affected clarity was observed in Grand Lake, it was minimal compared to expectations.
2. Higher clarity in Shadow Mountain Reservoir prior to the onset of pumping improved clarity in Grand Lake for a time after pumping commenced. As clarity in Shadow Mountain Reservoir decreased, clarity in Grand Lake also declined, and clarity trends in both water bodies followed similar patterns in the second half of the season.

3. Recommendations

1. The following changes are recommended for the weekly report:
    - Add pH, conductivity, and other parameters to the SM-CHL figure.
    - Change the axes for Grand Lake and Shadow Mountain Reservoir inflows to a log scale.
    - Change the layout of time series buoy data to match mid/dam layout for the profile graphs
    - Change “Max Goal” and “GL Min Goal” in figures on page 4 of report to “Average Goal Qualifier” and “Minimum Goal Qualifier”.
    - Modify the scale for chlorophyll a and phycocyanin to match Hydros, and to be able to see smaller changes.
    - Report minimum clarity not as a line, but as point measurements.

2. Resume consideration of special studies and analyses within the Three Lakes Technical Committee to understand factors affecting clarity in the system. This list includes:
    - Managing for temperature in Shadow Mountain Reservoir to minimize both cyanobacteria and diatom growth in order to optimize clarity.
    - Effects of Mysis shrimp on clarity in Grand Lake.

- Effects of white suckers on clarity in Shadow Mountain Reservoir.
- Effects of boat activity on Shadow Mountain Reservoir clarity and resulting effects in Grand Lake.

Appendices

A. Clarity MOU
B. Statement of Basis and Purpose
C. Adaptive Management Committee Representatives
D. GLAM 2021 Letter
E. Kickoff Meeting
F. 2021 Meeting Schedule
G. Weekly Meeting Reports and Notes
H. Debrief Meeting