LTEMP SEIS Cool Mix Flow Summary Report

U.S. Department of the Interior

July 2025

Mission Statements

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The mission of the Bureau of Reclamation is to manage, develop, and protect water and related resources in an environmentally and economically sound manner in the interest of the American public.

Cover Image – Photo by Bureau of Reclamation, Glen Canyon Dam overlooking the tailwaters and operations of the bypasses for the cool-mix experiment.

LTEMP SEIS Cool Mix Flow Summary Report

Prepared by:

Bureau of Reclamation
Technical Service Center
Denver, Colorado

U.S. Department of the Interior **July 2025**

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BRIAN HINES Digitally signed by BRIAN HINES
Date: 2025.08.13 09:55:19
-06'00'

Prepared by: Brian Hines, Bureau of Reclamation, Biologist

BRYCE MIHALEVICH Digitally signed by BRYCE MIHALEVICH
Date: 2025.08.13 10:01:10 -06'00'

Prepared by: Bryce Mihalevich, Bureau of Reclamation, Civil Engineer

WILLIAM STEWART Digitally signed by WILLIAM STEWART
Date: 2025.08.15 07:56:30 -07'00'

Checked by: Bill Stewart, Bureau of Reclamation, Program Manager

Peer Review Certification

This section has been reviewed and is believed to be in accordance with the service agreement and standards of the profession.

MATTHEW O'NEILL Digitally signed by MATTHEW O'NEILL
Date: 2025.08.14 16:04:16 -07'00'

Peer reviewed by: Matt O’Neill, Bureau of Reclamation, Biologist

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Acronyms and Abbreviations

1D	one-dimensional
approx.	approximately
ASB	artificial spawning bed
AZGFD	Arizona Game and Fish Department
DOI	U.S. Department of the Interior
ft	foot/feet
ft/s	feet per second
ft^3/s	cubic feet per second
GCD	Glen Canyon Dam
GCMRC	Grand Canyon Monitoring and Research Center
GFS	Global Forecast System
GIS	Geographic Information System
LTEMP	Long-Term Experimental and Management Plan
mm	millimeter(s)
mm/month	millimeters per month
m/s	meters per second
MST	mountain standard time
MWh	megawatt-hours
NPS	National Park Service
PI	Planning/Implementation
Reclamation	Bureau of Reclamation
RM	River Mile
ROD	record of decision
ROW	River Outlet Works
SEIS	Supplemental Environmental Impact Statement
SRP	soluble reactive phosphorus
SSS	side-scan sonar
TL	total length
USGS	U.S. Geological Survey

U.S.	United States
WAPA	Western Area Power Administration

Symbols

°C	degree Celsius
°F	degree Fahrenheit
$	dollar(s)
=	equal to
>	greater than
≥	greater than or equal to
<	less than
≤	less than or equal to
µg/L	micrograms per liter
%	percent
+/-	plus or minus

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Executive Summary

In 2024, the Bureau of Reclamation implemented the "Cool Mix" flow alternative as part of the Glen Canyon Dam Long-Term Experimental and Management Plan Supplemental Environmental Impact Statement to combat the reproduction of invasive smallmouth bass downstream from Glen Canyon Dam (GCD). The Cool Mix flow released cold water through bypass tubes (River Outlet Works, bypassing the dam generators) to mix with warmer penstock flows. These flows aimed to cool the river to 15.5 Celsius (°C), temperatures too cold for smallmouth bass spawning. Environmental conditions (daily average river temperatures exceeded 15.5 °C for three consecutive days) were triggered in early July, and Cool Mix flows continued through November 18. This experiment was conducted with coordination across federal and state agencies, including the U.S. Geological Survey, National Park Service, Arizona Game and Fish Department (AZGFD), and the Western Area Power Administration.

The Cool Mix flows effectively maintained temperatures below the critical spawning threshold for most of the implementation period, reducing thermal conditions suitable for smallmouth bass. Post-hoc modeling indicated the river would have exceeded 15.5 °C for roughly 135 days without intervention, compared to only 29 days with Cool Mix flows. Biological monitoring showed no evidence of smallmouth bass recruitment in 2024, with reduced growth rates and absence of young-of-year fish. Green sunfish also exhibited reduced recruitment and higher average sizes, suggesting minimal reproduction. Rainbow trout, a prized cold-water sportfish, demonstrated increased growth and improved condition during the experiment period. Humpback chub, a federally protected native species, experienced average growth compared to past years and maintained healthy condition during the experiment, indicating minimal adverse impacts.

Despite ecological success, the Cool Mix flow had substantial financial implications. Approximately 32.5 percent of river flows were bypassed, resulting in 372,341 megawatt hours of foregone hydropower generation and $18.97 million in replacement energy costs that were funded from the Basin Fund. This led to deferred capital infrastructure investments and increased financial strain on GCD's hydropower operations. However, coordinated scheduling allowed optimization of bypass flows during off-peak hours, partially mitigating financial impacts while ensuring ecological targets were met.

Overall, the 2024 Cool Mix flow experiment appeared to achieve its goal of impeding smallmouth bass reproduction and reducing invasive species proliferation below GCD without significantly harming native species. The experiment highlights the utility of adaptive flow management in ecological conservation, though its financial cost emphasizes the need for refined temperature modeling, cost-optimization strategies, and sustained multi-agency collaboration. Future strategies will need to address the continued presence of invasive cohorts spawned in prior years and maintain readiness to deploy similar interventions in a fiscally sustainable manner.

Introduction

Smallmouth bass (*Micropterus dolomieu*) were introduced to the upper Colorado River basin in the late 1960s. Since 2003, individual bass were periodically captured in Glen Canyon, immediately downstream from Glen Canyon Dam (GCD). These fish were assumed to have passed through GCD and any reproduction downstream from GCD was historically limited, presumably due to unfavorable cold-water conditions. In July 2022, a single juvenile smallmouth bass was captured in Glen Canyon at the 12-mile slough. Capture of this smallmouth bass, coupled with the recent establishment of green sunfish (*Lepomis cyanellus*), set off alarm bells for natural resource managers. These captures coincided with the warmest recorded GCD release temperatures to date (21 degrees Celsius [°C]), which represents a 6.5 °C increase from the maximum release temperatures averaged over the previous 10 years. Warmer temperatures driven by record low reservoir levels enabled successful reproduction of smallmouth bass downstream from GCD. Monitoring efforts in 2022 and 2023 found 362 individuals between GCD and Lees Ferry, and 1,113 individuals between GCD and River Mile (RM) 16. The highest densities of smallmouth bass were in the first 15 miles between GCD and Lees Ferry, which is known as the Lees Ferry reach (figure 1). This significant increase in smallmouth bass reproduction raised concerns about their potential impact on native fish populations, including the largest federally protected humpback chub population which resides downstream from Lees Ferry in Grand Canyon.

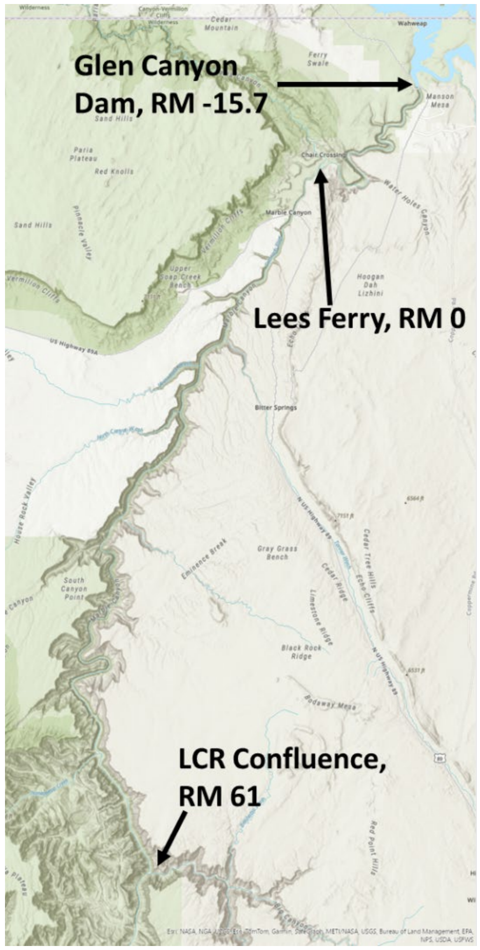

Figure 1.—The action area discussed here, showing key locations such as Glen Canyon Dam (River Mile 15.9), Lees Ferry (RM 0), and the Colorado River's confluence with the Little Colorado River (LCR; RM 61).

In response to these changing conditions, the Secretary of the Interior's acting designee (Acting Designee) for the Glen Canyon Dam Adaptive Management Work Group provided a directive to develop a strategic plan to prevent, detect, and respond to cool and warmwater invasive fish establishment below GCD (GCDAMP 2023). Additionally, the Acting Designee directed the Bureau of Reclamation (Reclamation) to identify and analyze operational alternatives at GCD to disrupt the spawning of smallmouth bass and other warmwater nonnative fish that pass through the dam (termed 'entrainment').

Reclamation published the Final Glen Canyon Dam Long-Term Experimental and Management Plan (LTEMP) Supplemental Environmental Impact Statement (SEIS) and Record of Decision (ROD) in July 2024 (Reclamation 2024). The LTEMP SEIS analyzed six alternatives, and the

"Cool Mix" flow (a method for releasing cold water through the dam from deep within the reservoir through the River Outlet Works (ROW), or bypass tubes, to cool river temperatures) was chosen for implementation in 2024. In 2024, the ROD provided guidance for Cool Mix flow operations, stating that a Cool Mix flow would be triggered when the average daily temperature at River Mile (RM) 61 exceeded 15.5 °C (60 degrees Fahrenheit [°F]) for three consecutive days (Reclamation 2024). River Mile 61 was chosen to ensure unfavorable conditions for smallmouth bass in the first 75 river miles below GCD which constitute critical habitat for humpback chub. The threshold temperature of 15.5 °C was chosen based on scientific literature that indicated smallmouth bass start to spawn after temperatures reach and maintain 16.0 °C for several days. A weekly adaptive decision-making process was used in coordination with Western Area Power Administration (WAPA) to most effectively balance hydropower production and bypass flow volumes to meet downstream temperature targets. Temperature data was expected to use real-time stream gage readings at the dam and Lees Ferry along with existing downstream models (e.g., Dibble et al. 2021 and Mihalevich et al. 2022). The Cool Mix flow was planned to remain in effect until the mean daily water temperature (without bypass) at RM 61 fell below 15.5 °C. The ROD also stated that the planning and implementation process described in LTEMP would be used to assess monitoring results, including effectiveness of experimental flows and potential off-ramps (see below).

A monitoring plan (LTEMP SEIS ROD attachment B) was developed by the U.S. Geological Survey's (USGS) Grand Canyon Monitoring and Research Center (GCMRC) to evaluate the effectiveness of the Cool Mix flow in 2024. The monitoring plan outlines a comprehensive approach to assess various smallmouth bass population metrics, including abundance and catch, distribution and dispersal patterns, growth, diet, and genetic kinship analysis to assess entrainment (figure 2).

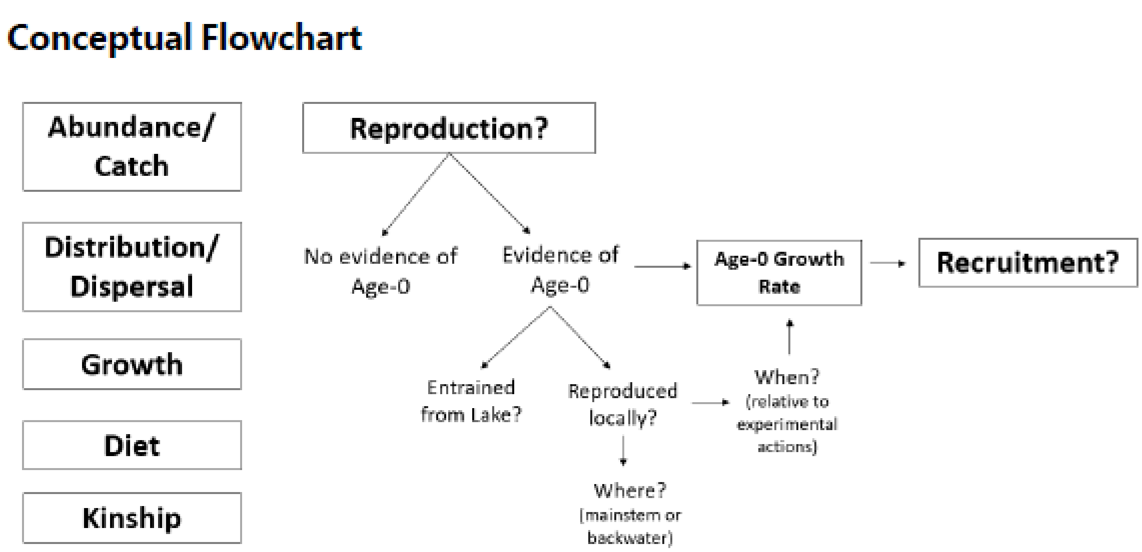

Figure 2.—Conceptual model of the monitoring approach taken to determine the effectiveness of Cool Mix flows in 2024 (LTEMP SEIS ROD attachment B).

This report summarizes the actions and outcomes of implementing the Cool Mix flow in 2024 including monitoring done by the National Park Service (NPS), the USGS Grand Canyon Monitoring and Research Center (GCMRC), the Arizona Game and Fish Department (AZGFD), and the Bureau of Reclamation. We thank each of these agencies and their staff for their efforts in this intense summer, and we particularly highlight the efforts of the Reclamation and WAPA staff who turned the Cool Mix flow from a paper exercise into reality.

Implementation

General Overview

During normal operations, GCD releases water through penstocks (water intakes) that direct water to the dam's generators that create power. Declining Lake Powell levels mean the penstocks draw from warm surface water, resulting in the river temperature warming and a higher likelihood of fish utilizing warm surface waters (e.g., smallmouth bass) being entrained through the penstocks of the dam and released into a warming river below GCD and smallmouth bass concerns. To cool the river water, Reclamation proposed alternative flows that release water through the ROW, which are four large tubes through the dam that are deeper in the water than the penstocks but do not power the generators. The water released through the ROW is known as bypass because it bypasses the generators and thus does not create power. To determine what the temperature of the river immediately below the dam will be when the ROW are operating, scientists need to know the volume of the penstock (warm) and ROW (cold) water releases and how those waters mix. Furthermore, the river will warm or cool as the water flows through the canyon downstream depending on the season. To calculate what the river's temperature will be at a given distance from the dam, scientists must determine the dam's release temperature (the mix of warm penstock and cold bypass water) and apply corrections to that based on how long the water is moving and how the predicted weather will change water temperature. Cooling the river may have ecological impacts that require monitoring, and bypassing the generators reduces power output and thus reduces revenue for WAPA.

Pre-implementation

In April 2024, in anticipation of a decision to run a smallmouth bass flow option, Reclamation focused on data availability and collection, as well as the specifications for bypass releases. Reclamation concluded that for the Cool Mix flow experiment, two of the four ROWs (specifically ROWs 3 and 4) would be sufficient, providing a combined release capacity of 7,500 cubic feet per second (ft^3/s). This arrangement enabled the concurrent relining project for ROWs 1 and 2. To streamline operations during the initial implementation phase, a limit of four changes per day to the bypass release volumes was established.

Water temperature data to be used for determining bypass volumes included monthly forebay profiles and GCMRC's continuous sensor located immediately downstream from the dam.

Further downstream, multiple water temperature sensors were available for monitoring the experiment. This included locations at Lees Ferry (RM 0), RM 30 and RM 61. For RM 30 and RM 61, GCMRC staff had to manually download this information. In late May, discussions between Reclamation and GCMRC resulted in an agreement for bi-monthly data updates at RM 61, which transitioned to weekly updates by late June. By the end of June, Reclamation acknowledged the need for real-time continuous data at RM 61 and initiated plans to upgrade the gage during a mid-August, river trip.

Reclamation used the process-based one-dimensional (1D) model described in Mihalevich et al. (2022) and the statistical model reported in Dibble et al. (2021) for predicting river temperatures. The first estimate of bypass water volumes needed for Cool Mix flows was conducted using the Colorado River Mid-term Modeling System April 24-month study hydrologic forecasts. The Dibble model was used to back-calculate optimal release water temperatures to meet the 15.5 °C target temperature at RM 61, while the selective withdrawal algorithm in the CE-QUAL-W2 model for Lake Powell estimated the necessary weekly bypass flow under the calculated release temperatures. In May, WAPA informed Reclamation of the development of an optimization tool in collaboration with Argonne National Lab, aimed at maximizing power purchase costs during Cool Mix flow implementation by optimizing penstock release hours. This prompted Reclamation to create a river temperature delta lookup table, generated by running the 1D model with observed inputs from 1990 to 2023, varying GCD release temperatures from 10 °C to 18 °C in 0.5 °C increments. This lookup table, compiled as an Excel workbook, included hourly temperature deltas for locations RM 0 (Lees Ferry), RM 15, RM 30, and RM 61 within the Grand Canyon, and was shared with WAPA.

On-Ramp

In June 2024, Reclamation initiated a series of internal weekly calls with Reclamation staff from the Adaptive Management Group, Water Quality and River Operations groups (Reclamation Group) and WAPA staff from the Scheduling, Environmental and Modeling groups (WAPA Group) to facilitate the implementation and coordination of smallmouth bass flow management. These calls focused on reviewing the latest data from RM 61, analyzing river temperature model forecasts, discussing the daily allowed changes to bypass flows, and addressing the maximum permissible temperature change per hour in the river. On June 28, data from RM 61 was available only up to June 18, as GCMRC staff were still manually downloading this information weekly. The 14-day model forecast at that time indicated a single-day exceedance of the temperature threshold of 15.5 °C on June 29 and a three-day exceedance beginning on July 6. Therefore, it was anticipated that RM 61 would exceed the 3-day average temperature limit within 1–2 weeks, however the ROD was still pending signature.

By the week of July 1, 2024, a subsequent data download from GCMRC revealed temperature exceedances at RM 61 had already occurred for three consecutive days. All river temperature models utilized—including the 1D model (Mihalevich et al. 2022), statistical model (Dibble et al. 2021), and lookup table model—forecasted continuous exceedances of the temperature threshold under current operations as analyzed by Reclamation Group. During this week, WAPA

Modeling provided Reclamation Water Quality with three hydrographs for testing that included weekly average bypass flows of 1,766 ft^3/s, 2,095 ft^3/s, and 3,280 ft^3/s, all with bypass durations of 16 hours from 10 p.m. to 2 p.m mountain standard time (MST). Analysis of the river temperature forecast models indicated that a weekly average bypass of 3,280 ft^3/s would be required to keep temperatures within acceptable limits. The ROD was signed on July 3rd, and the first Glen Canyon directive authorizing the release of Cool Mix flows was issued by the Reclamation River Operations shortly thereafter on July 5th. This directive specified the initiation of Cool Mix flows starting July 9 at midnight with a hydrograph featuring a 5,000 ft^3/s peak bypass flow for 16 hours (table 1).

Table 1.—Hourly GCD release schedule issued under the first directive of LTEMP SEIS Cool Mix flows

Hour System Time (MST)	Bypass Release (ft^3/s)	Penstock Release (ft^3/s)	Total Release (ft^3/s)
0:00	5,000	4,480	9,480
1:00	5,000	4,480	9,480
2:00	5,000	4,480	9,480
3:00	5,000	4,480	9,480
4:00	5,000	4,480	9,480
5:00	5,000	4,480	9,480
6:00	5,000	4,480	9,480
7:00	5,000	4,480	9,480
8:00	5,000	4,480	9,480
9:00	5,000	4,480	9,480
10:00	5,000	4,480	9,480
11:00	5,000	4,480	9,480
12:00	5,000	6,086	11,086
13:00	5,000	10,086	15,086
14:00	0	15,086	15,086
15:00	0	15,086	15,086
16:00	0	15,086	15,086
17:00	0	15,086	15,086
18:00	0	15,086	15,086
19:00	0	15,086	15,086
20:00	0	15,086	15,086
21:00	0	14,480	14,480
22:00	5,000	6,980	11,980
23:00	5,000	4,480	9,480

Implementation

The amount of bypass flow needed to cool the river down below 15.5 °C at RM 61 was determined through collaborative modeling efforts by Reclamation and WAPA. This process began with Reclamation Water Quality sending WAPA Modeling the latest estimates of penstock and bypass release temperatures. The WAPA Modeling group used a modeling tool developed by Argonne that incorporated the daily scheduled water release, discharge ramp rates, temperature deltas from the lookup table (described above), energy load pattern, and the purchase power price curves. WAPA Modeling created multiple hydrographs with varying amounts of bypass flow release patterns aimed at meeting the downstream temperature criteria. Reclamation Water Quality evaluated whether WAPA Modeling’s hydrograph(s) would maintain < 15.5 °C temperatures at RM 61 using the river temperature models discussed above (e.g., Mihalevich et al. 2022; Dibble et at. 2021, and the lookup table). River temperature model forecasts included 16-day weather forecasts from the Global Forecast System (GFS) model (NCEP 2015). Due to the uncertainty in meteorological forecasts used in the river temperature models, Reclamation Water Quality evaluated forecasted river temperatures on a 3-day rolling average. Depending on model results, the Reclamation Group would either accept one of the hydrographs or request a modified pattern from WAPA Modeling if none of the proposed patterns met downstream temperature criteria. Once a pattern met temperature threshold limits, a directive confirming the release pattern was issued by Reclamation River Operations. This weekly collaborative cycle was repeated throughout the implementation of Cool Mix flows (table 2).

Table 2.—Weekly process of implementation for the smallmouth bass flow experiment

Day of the Week	Activity
Monday	Reclamation Water Quality updated WAPA Modeling on current release penstock and bypass temperatures WAPA Modeling developed 2–4 weekly hydrographs using the river temperature lookup table and the penstock and bypass temps
Tuesday	WAPA hydrographs tested in river temp models by Reclamation Water Quality Reclamation Group meeting to discuss model outputs and determine hydrograph(s) that meet objectives for further discussions with WAPA Group
Wednesday	Coordination meeting between Reclamation Group and WAPA Group to discuss model outputs and hydrograph(s) for a final hourly release pattern determination
Thursday	Reclamation River Operations issued a directive confirming the release pattern

Day of the Week	Activity
Friday	LTEMP Planning and Implementation Technical Team meeting to discuss experiment updates (every other Friday)
Saturday	New hydrograph implemented by Reclamation and WAPA

Throughout the experiment, Planning/Implementation (PI) Leadership and Technical Teams, as defined in the LTEMP ROD, met to discuss status of the smallmouth bass flows with regards to smallmouth bass captures, instream temperatures, and other issues. These meetings occurred every other Friday during implementation.

Off-Ramp

The LTEMP SEIS and ROD stated that the PI process would be used to assess monitoring results, including effectiveness of experimental flows and potential off-ramps. Off ramp discussions began in late-October when modeling results forecasted river temperatures could fall below 15.5 °C at RM 61 without Cool Mix flows. However, releases from GCD penstocks were still warmer than 18 °C for most of October, which could have provided favorable spawning conditions for smallmouth bass in the Lee’s Ferry reach if the experiment were to conclude. On November 5, 2024, the PI Leadership and Technical teams discussed moving the targeted river mile for maintaining 15.5 °C temperatures from RM 61 to the releases out of GCD (RM 15.7). A five member panel of expert biologists from GCMRC, U.S. Fish and Wildlife Service, NPS, WAPA, and the Arizona Game and Fish Department assessed the risks of off ramping while release temperatures were above 15.5 °C. Experts from four out of the five agencies expressed concern regarding the potential for smallmouth bass to spawn and overwinter in the Lees Ferry reach and suggested maintaining Cool Mix flows until dam release temperatures were below 15.5 °C. In a memo issued by the Designee to the Adaptive Management Work Group on November 6, 2024, the target location for maintaining a 15.5 °C threshold was adjusted so cool water would be maintained from GCD to Lees Ferry. The experiment concluded on November 19, 2024, when penstock release temperatures from GCD fell below 15.5 °C.

Results

Hydrology

During the 133 days of Cool Mix flow releases, 893,919 acre-feet of water was bypassed, which consisted of 32.5 percent (%) of the total flow below GCD (table 3). Glen Canyon Dam releases during the Cool Mix flows maintained the monthly planned volume, and the volume necessary to meet the 2024 water year volume of 7.48 million acre-feet. To reduce experimental costs, Reclamation coordinated with WAPA to preserve on-peak hours for hydropower generation (typically 3 p.m. to 10 p.m.) and time Cool Mix flow releases during off-peak hours (figure 3). Release data from GCD between July and November 2024 is provided in appendix A.

Table 3.—Total and bypass release volumes and percentage of flow that was bypassed for months during Cool Mix flow implementation in 2024.

Dates	Total Release [kAF]	Bypass Release [kAF]	Volume Bypassed [%]
9–31, July	554,542	167,416	30%
1–31, August	759,780	257,447	34%
1–30, September	568,347	253,624	45%
1–31, October	482,582	168,301	35%
1–18, November	388,196	47,130	12%

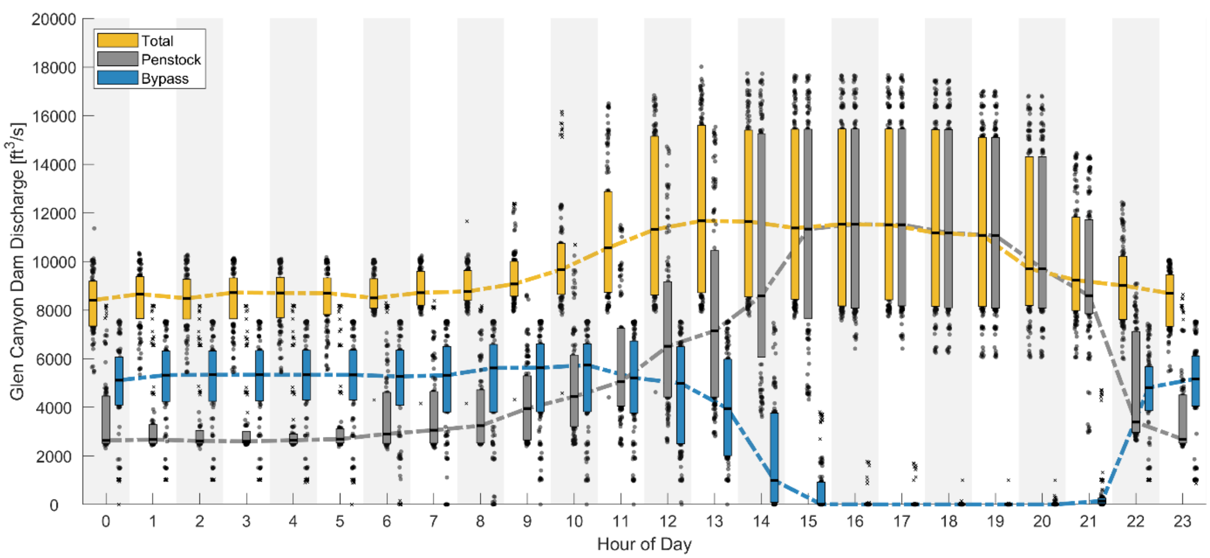

Figure 3.—Boxplots of total, penstock, and bypass release discharge from Glen Canyon Dam for each hour of the day between July 9, 2024, and November 18, 2024. Colored boxes represent the 25th and 75th inner quartile range with the black dash indicating the 50th quantile. All data points are marked by black dots. Outliers are marked by black stars. Dashed lines connect median values between each hour of the day.

Water Quality

Temperature

River temperatures in the Lees Ferry reach and further downstream in Marble and Grand Canyon reaches are largely driven by release temperatures from GCD but are also influenced by additional factors such as local meteorology and seasonal canyon shading (Mihalevich et at. 2020). Release temperatures from GCD historically reach an annual maximum in October or November, depending on water storage conditions. Over the summer months (June through August) release temperatures are relatively cold with river temperatures warming as they move downstream. When GCD release temperatures peak in October or November, river temperatures are typically cooling as they flow downstream.

Water temperatures at the USGS Lees Ferry (RM 0) gage averaged 14.1 °C during Cool Mix flow implementation (figure 4). The warmest temperatures in Lees Ferry occurred in late October, with a maximum daily average of 16.22 °C. At that time, river temperatures were generally cooling as they moved downstream, so the 15.5 °C temperature target was still being met at RM 61.

Mean daily river temperatures at RM 61 hovered around 15.5 °C throughout implementation of the Cool Mix flow experiment (figure 5). Efforts to minimize bypass volumes combined with unexpected meteorological conditions resulted in temporary exceedances of 15.5 °C at RM 61 throughout the summer. Exceedances were often remedied by the following week's modeling and implementation strategy. Reclamation reserved the ability to issue within week changes to bypass volumes throughout the experiment. On September 27, 2024, in response to exceedances observed at RM 61, a within week directive was issued to increase planned weekly average bypass volumes from 3,283 ft^3/s to 3,889 ft^3/s. This directive came the day before an existing directive was to go into effect. Overall, river temperatures at RM 61 exceeded 15.5 °C for 29 days in 2024 (14 exceedance days occurred after Cool Mix flow implementation). In contrast, 2022 and 2023 had 156 and 152 days above 15.5 °C at RM 61, respectively.

A post-hoc modeling analyses conducted for this report using the Mihalevich et al. (2022) model with observed penstock release temperatures suggests that RM 61 would have experienced approximately (approx.) 135 (±5) days of temperatures over 15.5 °C in 2024 had Cool Mix flow not occurred (figure 5). River temperature predictions at RM 61 have a root mean squared error of 0.45 °C over the 2024 Cool Mix flow period.

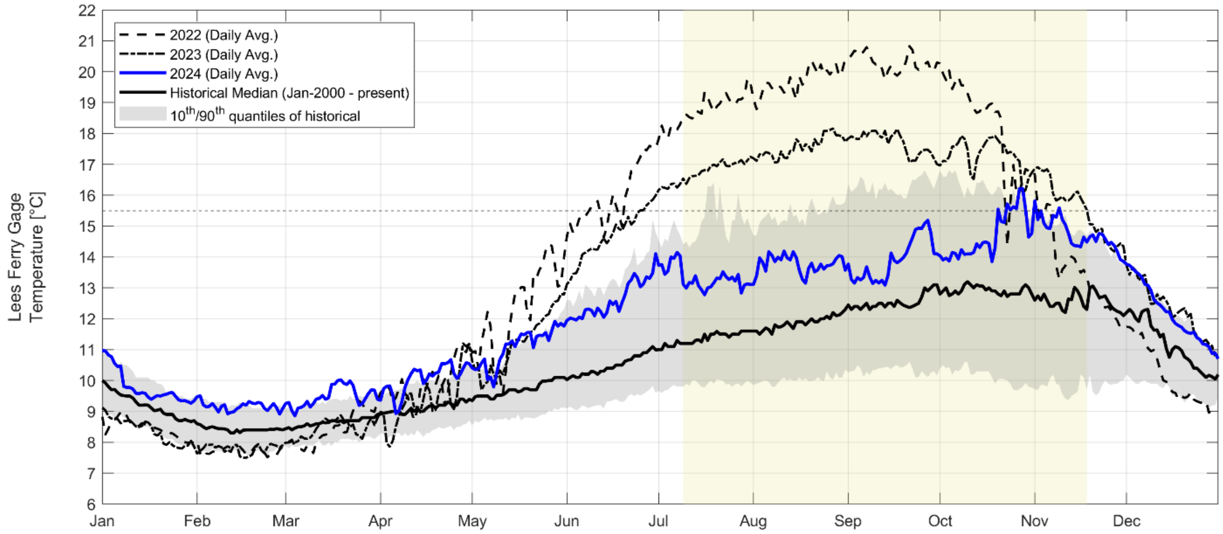

Figure 4.—Daily average river temperatures measured at Lees Ferry (NWIS: 09380000). Dotted horizontal line demarcates 15.5 °C. Shaded yellow band indicates the temporal duration of the Cool Mix flow experiment.

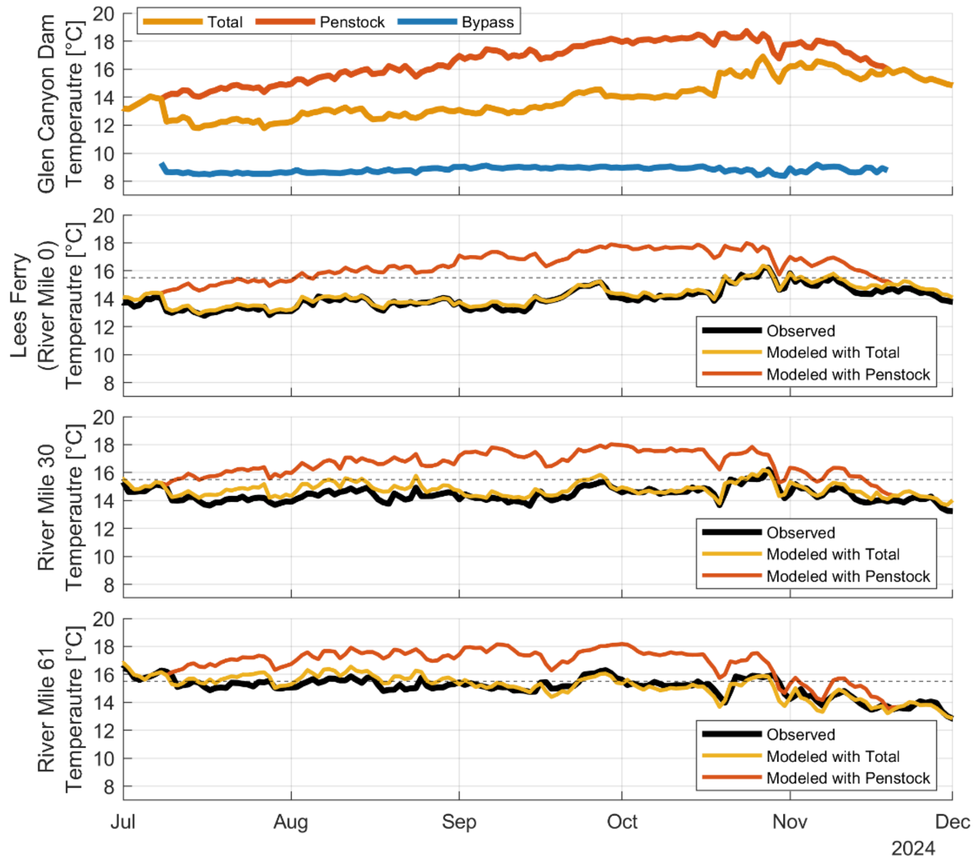

Figure 5.—Post-hoc modeling analysis showing observed temperatures from at GCD, RM 0, RM 30, and RM 61 and model predictions with (orange line) and without cool-mix (red line) at downstream river locations from July–December in 2024.

Specific Conductivity

Specific conductivity concentrations, a surrogate for total dissolved solids (TDS), below GCD increased during the cool-mix implementation due to bypass release, which drew from the deeper, more saline hypolimnion in Lake Powell (figure 6). There is no limit on TDS concentrations released from GCD, however higher exports of TDS from GCD are a concern to the Colorado River Basin Salinity Control Forum, as elevated levels could impact TDS concentrations in releases from downstream Hoover Dam, Parker Dam, and Imperial Dam.

Soluble Reactive Phosphorus

Soluble reactive phosphorus (SRP) is a form of phosphorus that is dissolved in the water and is immediately available for biological uptake. Typically, high levels of SRP can be harmful to aquatic environments causing degraded water quality and eutrophication (Wilhelm et al 2018), whereas very low SRP can limit food web production (Elser et al 2007). Worldwide, among unpolluted rivers, average SRP is approx. 10 micrograms per liter (µg/L) (Meybeck 1982, 1993). Over the past approx. 30 years, concentrations of SRP at Lees Ferry have averaged 4 µg/L (Andrews and Deemer 2024). During the 2024 Cool Mix flow experiment, SRP in the dam draft tubes was <1µg/L, but concentrations of SRP at the depth of the bypass intake were higher, resulting in tailwater SRP concentrations of about 3 µg/L (Bridget Deemer per comm). Although there was an increase in SRP during the Cool Mix flow experiment, the value (3 µg/L) is well below the average for unpolluted rivers (10 µg/L) and is still below the long-term average SRP for Lees Ferry (Andrews and Deemer 2024).

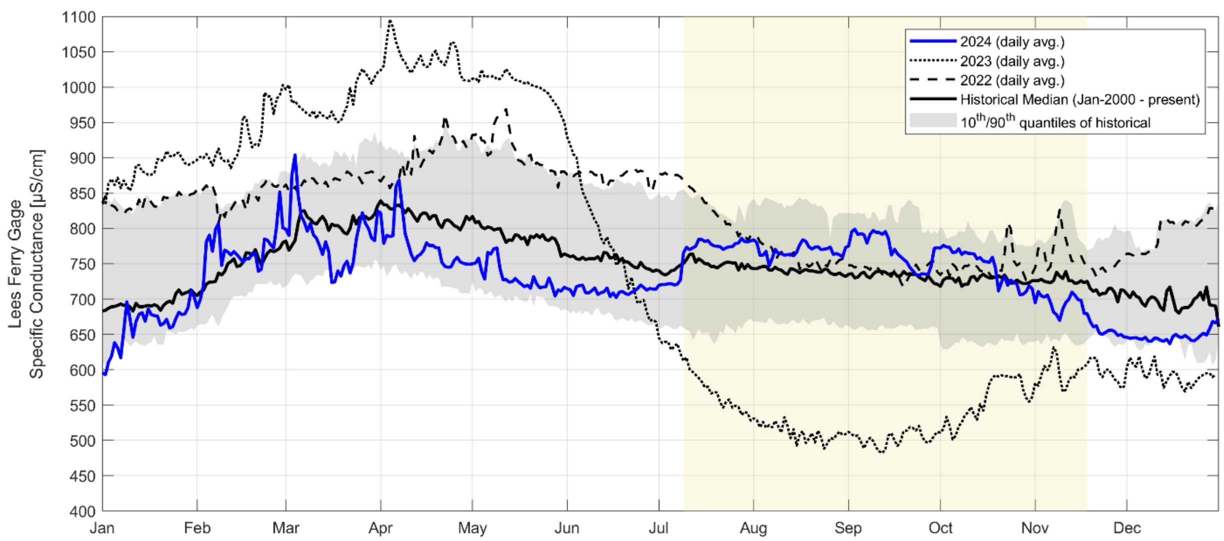

Figure 6.—Daily average specific conductance measured at Lees Ferry (NWIS: 09380000). Shaded yellow band indicates the temporal duration of the Cool Mix flow experiment.

Dissolved Oxygen

Dissolved oxygen concentrations in the river increased during Cool Mix flow implementation due to the aeration of bypass water as it is ejected from the hollow jet valves (figure 7). Measurements of dissolved oxygen approx. 1 kilometer below the dam indicated periods of 118% of saturation during bypass releases (Deemer per comm). This level of saturation is consistent with high dissolved oxygen concentrations measured below the dam during High Flow Experiments (Hueftle and Stevens 2001; Vernieu 2010).

High dissolved oxygen concentrations during Cool Mix flows raised concerns about gas bubble trauma in fish below the dam. Researchers from GCMRC collected water samples August 15–16, 2024, to characterize total dissolved gas pressure during Cool Mix flow implementation. Spot measurements of total dissolved gas recorded a maximum of 114% of saturation at RM -10.2 at 10:55 a.m. on August 16, 2024 (Bridget Deemer per comm). The Environmental Protection Agency limit on total dissolved gas is 110% for freshwater use. During fish passage spill operations for Endangered Species Act (ESA)-listed juvenile salmonids in the Columbia River Basin, the limit is 125% of total saturation (USACE 2025). Despite elevated levels of total dissolved gas pressure in the Lees Ferry reach during the Cool Mix flows, there were no confirmed cases of gas bubble trauma.

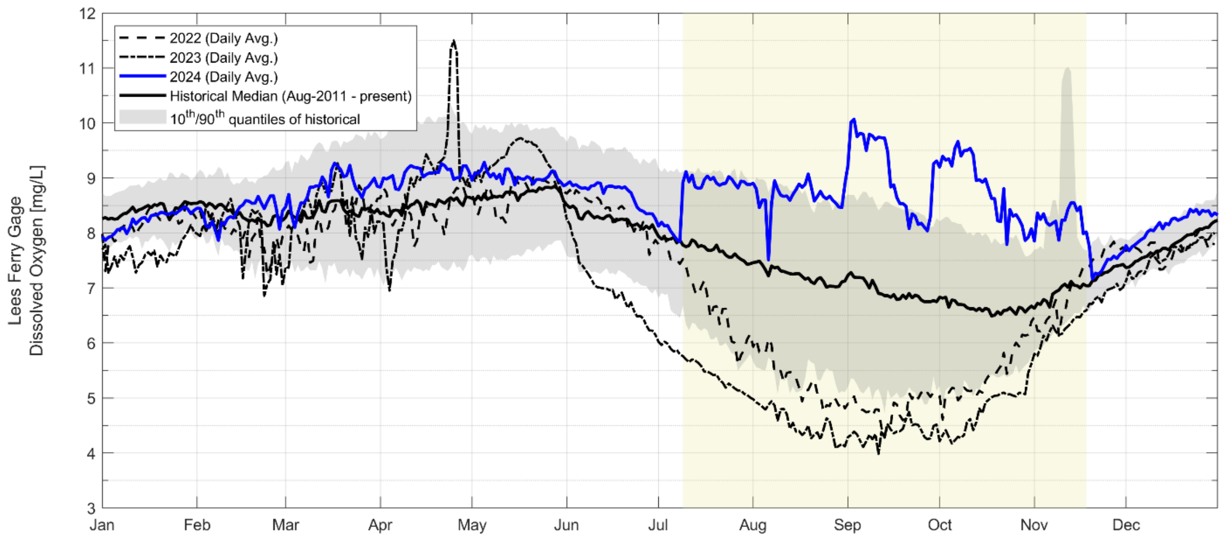

Figure 7.—Daily average dissolved oxygen measured at Lees Ferry (NWIS: 09380000). Shaded yellow band indicates the temporal duration of the Cool Mix flow experiment.

Turbidity

Turbidity, a relative measure of water clarity, in the Lees Ferry reach was unaffected by the Cool Mix flows (figure 8). Spikes in turbidity observed at Lees Ferry can be associated with turbid release from GCD following rainfall-runoff events, or from rainfall-runoff events in the Lees Ferry reach itself that result in suspended sediment entering the river. Research on the effects of water clarity on native Grand Canyon fishes suggests that relatively small increases in turbidity (as low as 25 Formazin Nephelometric Units [FNU]) in the Colorado River may be sufficient to increase survival of juvenile humpback chub by reducing predation mortality from rainbow and brown trout (Ward et al. 2016).

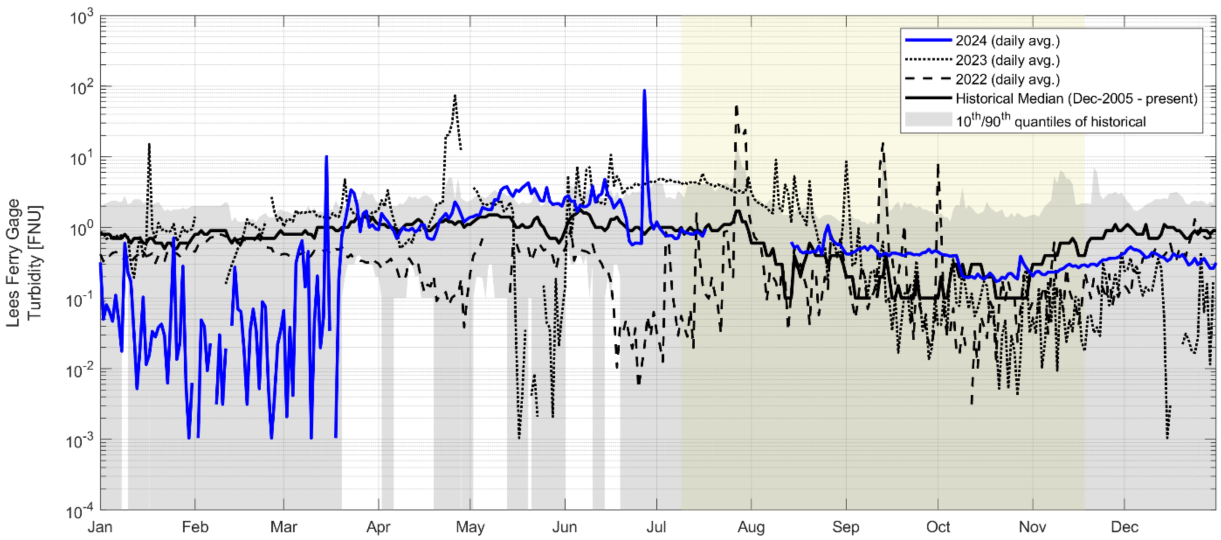

Figure 8.—Daily average turbidity measured at Lees Ferry (NWIS: 09380000). Shaded yellow band indicates the temporal duration of the Cool Mix flow experiment.

Biology

Monitoring Effort

The GCMRC developed a conceptual monitoring approach to guide efforts to evaluate the effectiveness of the Cool Mix flows on smallmouth bass reproduction and recruitment (figure 1). The conceptual approach addressed abundance/catch, distribution, growth, diet and genetic kinship (relatedness among individuals captured in Lake Powell and downstream from GCD). In 2024, significant resources were dedicated to monitoring the effects of water temperature on the smallmouth bass population while also addressing the need to remove smallmouth bass from the ecosystem as part of an ongoing rapid response effort. To achieve these dual objectives, GCMRC collaborated with the NPS and other organizations to establish methods for systematically analyzing presence-absence data, alongside capturing fish for removal through a well-structured experimental design.

A multi-agency effort employed a multitude of sampling techniques, including boat and backpack electrofishing, seine and hoop netting, environmental DNA surveys, sonar surveys, snorkel surveys, artificial bass nests, and visual scanning for nests.

Table 4.—Multi-agency sampling efforts in the Colorado River between Glen Canyon Dam and the Little Colorado River confluence in 2024. Reach acronyms are: Lees Ferry (LF), Paria River to Badger Creek (PBR), Lees Ferry to Little Colorado River confluence (LF to LCR) and the Little Colorado River (LCR).

			Reaches Surveyed:			
Event	**Agency**	**Date**	**LF**	**PBR**	**LF to LCR**	**LCR**
Lees Ferry electrofishing	GLCA	5-Mar	X			
Lees Ferry fish population monitoring	AGFD	11-Mar	X			
Lees Ferry electrofishing	GLCA	1-Apr	X			
Mainstem fish, monitoring	AGFD	3-Apr		X	X	
Lees Ferry trout population monitoring	AGFD	4-Apr	X			
Lees Ferry netting	GLCA	8-Apr	X			
Paria to Badger backwater sampling	GRCA	9-Apr		X		
Lees Ferry electrofishing	GLCA	15-Apr	X			
Little Colorado River chub monitoring	FWS/USGS	16-Apr				X
Lees Ferry netting	GLCA	22-Apr	X			
Juvenile HBC monitoring	USGS	23-Apr			X	
Lees Ferry electrofishing	GLCA	29-Apr	X			
Lees Ferry netting	GLCA	6-May	X			
Paria to Badger backwater sampling	GRCA	7-May		X		
Lees Ferry electrofishing	GLCA	13-May	X			
Mainstem fish, monitoring	AGFD	17-May		X	X	
Lees Ferry netting and slough block net Installation	GLCA	20-May	X			
Paria to Badger electrofishing	GRCA	20-May		X		
Little Colorado River chub monitoring	FWS/USGS	21-May				X
Lees Ferry electrofishing	GLCA	27-May	X			
Sonar Survey	Reclamation	28-May	X			
Lees Ferry electrofishing	GLCA	3-Jun	X			
Paria to Badger backwater sampling	GRCA	4-Jun		X		
Lees Ferry netting	GLCA	10-Jun	X			
Paria to Badger electrofishing	GRCA	10-Jun		X		
Trout recruitment, growth and population dynamics	USGS/AGFD	13-Jun	X			
Lees Ferry netting	GLCA	17-Jun	X			
HBC AGG/NN surveillance downstream	GRCA	19-Jun		X	X	
Lees Ferry electrofishing/maybe only one boat	GLCA	24-Jun	X			
LCR Juvenile HBC monitoring (3 camps)	FWS/USGS	27-Jun				X
Lees Ferry electrofishing	GLCA	1-Jul	X			
Juvenile HBC monitoring	USGS	5-Jul			X	
Lees Ferry netting	GLCA	8-Jul	X			
Lees Ferry trout population monitoring	AGFD	8-Jul	X			

			Reaches Surveyed:			
Event	Agency	Date	LF	PBR	LF to LCR	LCR
Paria to Badger electrofishing	GRCA	8-Jul		X		
Lees Ferry electrofishing	GLCA	15-Jul	X			
Mainstem fish survey, HBC-Seining	USGS	18-Jul		X	X	
Lees Ferry electrofishing/Maybe only one boat	GLCA	22-Jul	X			
Paria to Badger backwater sampling	GRCA	23-Jul		X		
Lees Ferry netting	GLCA	29-Jul	X			
Paria to Badger electrofishing	GRCA	29-Jul		X		
Lees Ferry electrofishing	GLCA	5-Aug	X			
Reclamation sonar/snorkel/seining survey	Reclamation	6-Aug	X			
Lees Ferry Electrofishing/maybe only one boat	GLCA	12-Aug	X			
Paria to Badger backwater sampling	GRCA	13-Aug		X		
Lees Ferry netting	GLCA	19-Aug	X			
Paria to Badger electrofishing	GRCA	19-Aug		X		
Lees Ferry netting	GLCA	26-Aug	X			
Non-native fish surveillance	Biowest	27-Aug		X	X	
Mainstem fish, HBC-aggregations (netting)	FWS	28-Aug		X	X	
Lees Ferry electrofishing	GLCA	3-Sep	X			
Lees Ferry netting	GLCA	9-Sep	X			
Paria to Badger electrofishing	GRCA	9-Sep		X		
Lees Ferry electrofishing	GLCA	16-Sep	X			
Lees Ferry netting	GLCA	23-Sep	X			
Non-native fish surveillance/eDNA survey	GRCA	23-Sep		X	X	
Lees Ferry electrofishing	GLCA	30-Sep	X			
Paria to Badger electrofishing	GRCA	7-Oct		X		
Mainstem fish monitoring	AGFD	9-Oct			X	
Lees Ferry electrofishing	GLCA	15-Oct	X			
Non-native fish surveillance downstream electrofishing	GRCA	21-Oct		X	X	
Lees Ferry electrofishing	GLCA	28-Oct	X			
Trout recruitment, growth and population dynamics	USGS/AGFD		X			
Paria to Badger electrofishing	GRCA	11-Nov		X		
Lees Ferry electrofishing	GLCA	18-Nov	X			

In total, 38 surveys were conducted in the Lees Ferry reach of Glen Canyon National Recreation Area (NRA), 21 surveys in the section from the Paria River confluence to Badger Rapids in Grand Canyon National Park (NP), 11 trips covering the area from Lees Ferry to the confluence with the Little Colorado River, and 3 trips into the Little Colorado River itself.

Smallmouth Bass

As anticipated, the Cool Mix flows negatively impacted smallmouth bass in Glen Canyon and Grand Canyon, leading to reduced growth (as inferred from modal progression: Charles Yackulic, pers comm), a decline in relative abundance, and no confirmed recruitment or spawning observed (Shollenberger et al. 2025; Yackulic 2025).

Abundance/Catch

In 2023, the mean daily catch per unit effort (CPUE) of smallmouth bass between GCD and Lees Ferry increased from May to July. The highest CPUE in 2023 occurred in October when young of the year smallmouth bass grew to catchable sizes (figure 9). In 2024, SMB relative abundance remained stable throughout the year, indicating that no new fish were growing to catchable size and suggesting that no reproduction occurred. Both juvenile and large adults (i.e., >200 millimeter [mm]), were more abundant in 2023 compared to 2024 (Shollenberger et al 2025). Due to low capture rates in 2023–2024, relative abundance estimates for smallmouth bass below Lees Ferry were not calculated (Shollenberger et al. 2025).

Length-frequency data (figure 10) revealed the presence of a new year class of smallmouth bass in 2023, shown by the larger proportion and abundance of juvenile smallmouth bass (20–30 mm) in June–August (figure 10b) and growing larger into the fall (figure 10c). In 2024, we did not see fish within this size class (20–30 mm) supporting a lack of bass reproduction below the dam in 2024.

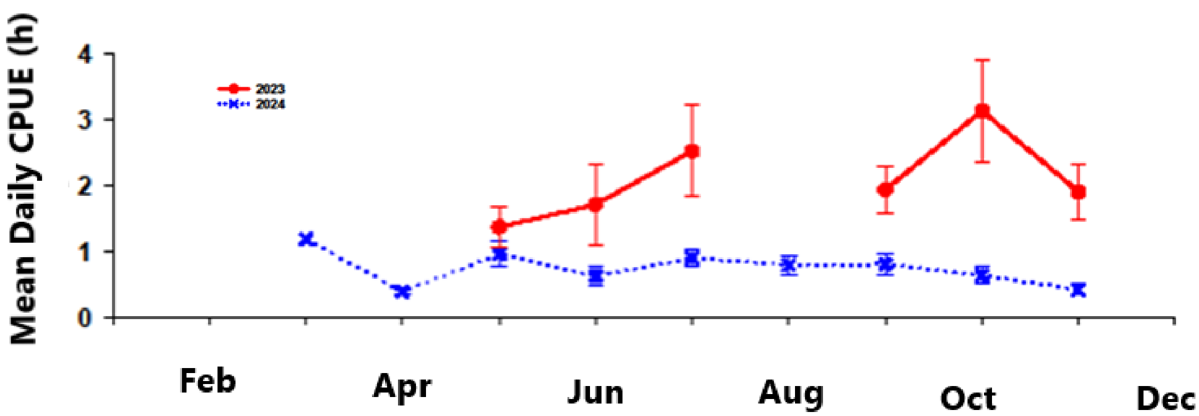

Figure 9.—Mean daily catch per unit effort (CPUE) of smallmouth bass residing in the Colorado River between GCD and Lees Ferry from March through November 2024. Error bars represent standard error (SE).

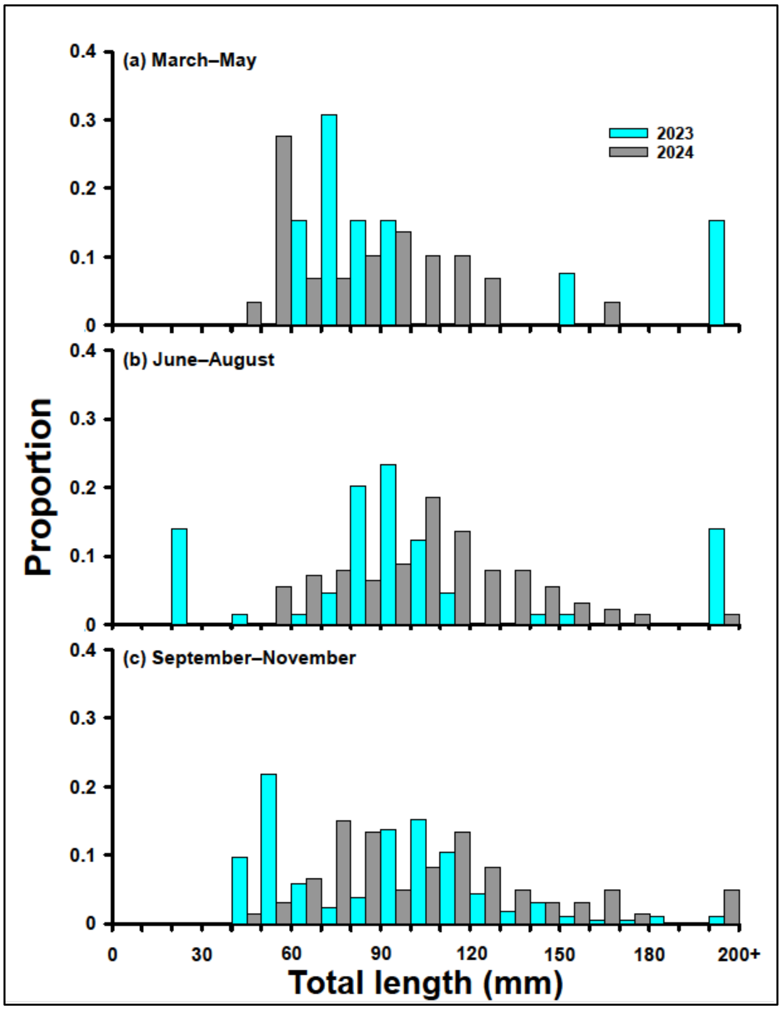

Figure 10.—Total length (TL) frequency histograms for smallmouth bass during (a) March–May, (b) June–August, and (c) September–November between GCD and Lees Ferry in 2023 and 2024.

Distribution

From 2022–2024, the furthest downstream smallmouth bass were captured was at RM 16.38R in November 2023. The furthest downstream adult smallmouth bass (>200 mm) was captured within the slough at RM 12.19L in July 2023. Distribution of smallmouth bass in 2024 was similar to that observed in 2023 with the exception that bass were largely absent from the 12-mile slough (figure 11; Shollenberger et al 2025). A total of 252 smallmouth bass were captured across all projects (Drew Eppehimer per comm), with 191 of those fish captured in the Glen Canyon reach (RM –15.71 to RM 0). Bass captures in the PBR reach (RM 0 to RM 8) increased slightly in 2024 (13 individuals captured vs 8 in 2023), suggesting that large-scale migration downstream is not yet occurring.

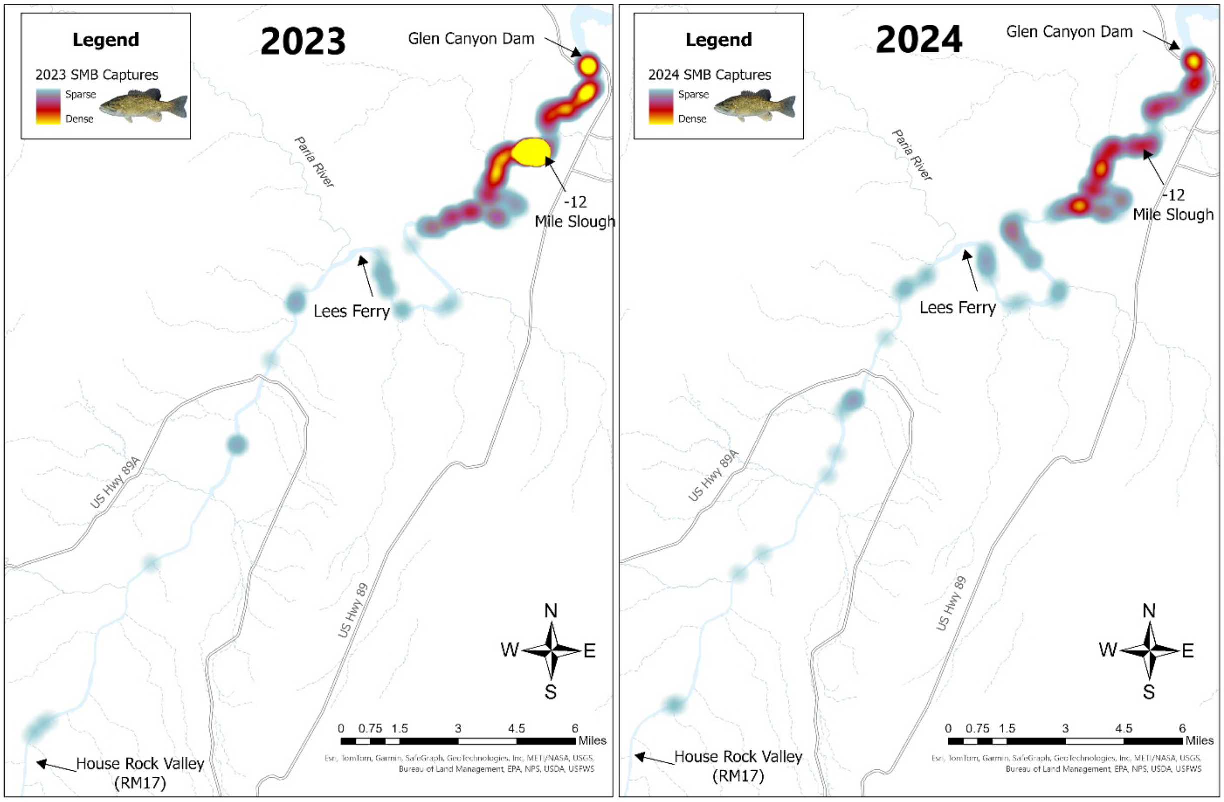

Figure 11.—Relative density heat map for smallmouth bass captures in Grand Canyon National Park (GRCA) and Glen Canyon National Recreation Area (GLCA) between GCD and Badger Rapid in 2023 (left) and 2024 (right).

Growth

Length frequency histograms for smallmouth bass between GCD and Lees Ferry in 2023 and 2024 (September–December) suggest two cohorts in each year (figure 10). The average total length of these cohorts can be compared between years to estimate average growth. The 2023 length frequency histogram has a younger cohort with a mean length of approx. 54 mm (fish likely born in 2023) and another with a mean length of approx. 109 mm (fish likely born in 2022, Charles Yackulic per comm). The 2024 length frequency histogram has one cohort with a mean length of 63 mm, fish likely born in 2023, and another with a mean length of 117 mm, fish likely born in 2022 (Charles Yackulic per comm). The difference between these average lengths suggests that the 2022-year class grew an estimated average of 8 mm and 2023 year class grew 9 mm between Fall of 2023 and 2024. In the previous year, smallmouth bass grew an estimated average of 25 mm from Fall 2022 to Fall 2023 (Charles Yackulic per comm). Assuming the birth year of fish were categorized accurately, these data indicate that the bass growth rate was about 1/3 in the Cool Mix flow temperatures of 2024 compared with warmer dam releases in 2023. Otoliths from smallmouth bass were collected in 2024 to confirm cohort assignments, but these data are not yet available.

Diet

The GCMRC is currently analyzing the stomach contents of the smallmouth bass collected in Colorado River in 2024. Sixty smallmouth bass stomachs have been processed (Drew Eppehimer per comm).

Kinship

A kinship genetic analysis project is currently underway at GCMRC, in collaboration with outside partners. This work will identify genetic relationships among smallmouth bass captured in Lake Powell and downstream from GCD to evaluate the relatedness of smallmouth bass in different cohorts and from different capture locations. With sufficient sampling in both Lake Powell and downstream from GCD, this information can be used to make inferences on whether individual smallmouth bass were spawned locally or if they originated from Lake Powell. Other objectives of this work are to estimate the number of adult breeders (Nb) over a single reproductive year, any changes to effective population/breeding size (Ne) over time and identify geographic areas of reproductive hotspots.

Preliminary, unpublished results using microsatellite data from juvenile smallmouth bass captured in Lees Ferry in 2022 and a few samples from Lake Powell indicate the number of breeding adults during the initial phase of this invasion was large, with at least 94 parental pairs contributing to the juveniles collected in the initial year of sampling and an effective population size (Ne) of 214 (95% CI: 171–267; assuming monogamous mating). The juvenile progeny collected were dispersed widely throughout Glen Canyon (Osborne et al. 2024). The small sample size from Lake Powell precluded a definitive assessment of spawning origin (i.e., local reproduction in Lees Ferry or entrainment of juveniles from Lake Powell) for individuals collected in 2022 at the start of the invasion. Understanding this nuance may alter management strategies to reduce the likelihood of successful recruitment. Additional tissue samples collected from 2023-2024, along with 2022 samples, will be sent to a different laboratory to complete the work associated with this project.

Other Observations

In addition to traditional sampling, several new or non-traditional methods were implemented to help determine whether smallmouth bass were spawning. This work includes artificial spawning beds (NPS), side scan sonar identification of bass nests (USGS/Reclamation/NPS), environmental DNA (eDNA) sampling, and snorkel surveys (NPS/USGS/Reclamation).

Beginning in early June 2024, Glen Canyon NRA personnel deployed artificial spawning beds (ASBs) in pairs (one commercially made and one self-fabricated, figure 12) at four locations along the river at depths of approximately 1–2 meters. These beds provide optimal spawning substrate and overhead cover and aim to lure bass to spawn there rather than in harder to access, less visible sites. The HOBO temperature loggers were installed alongside these beds to monitor water temperature conditions. These nests were visually monitored weekly and snorkel surveys were conducted in August in the lower 12 Mile Slough as well as in the 11.82R and 11.55R backwaters in the vicinity of the ASBs. These surveys employed a double-pass method to assess the presence and abundance of target species and to evaluate the efficacy of snorkel survey techniques in the Glen Canyon section of the Colorado River. No bass were detected using the ASBs.

Figure 12.—Fabricated (left) and commercial (center) artificial spawning beds. Right image shows a fabricated bed deployed.

Side-scan sonar (SSS) has been used in other systems to identify smallmouth bass spawning beds. This technique was used in conjunction with USGS flow modeling (Wright et al. 2024) to identify sites in the Glen Canyon reach with optimal bass spawning habitat requirements (never dries out, is <0.1 meters per second (m/s) for at least some portion of the day, water velocity never > 0.3 m/s during typical GCD releases, course substrate, reasonably flat terrain, depth around 1 to 1.5m; Reclamation 2024). In May, Cameron Bodine (with Northern Arizona University at the time) with NPS and Reclamation assistance used SSS to map substrate types in the Lees Ferry reach and identified two sites (figure 13) as optimal for bass nest detection. The USGS and Reclamation biologists conducted a second survey scanning for nests in August (figure 13). Snorkel surveys were also conducted during this trip in backwaters and shallow areas. No bass or nests were detected by either method, but SSS techniques are ready for use in 2025.

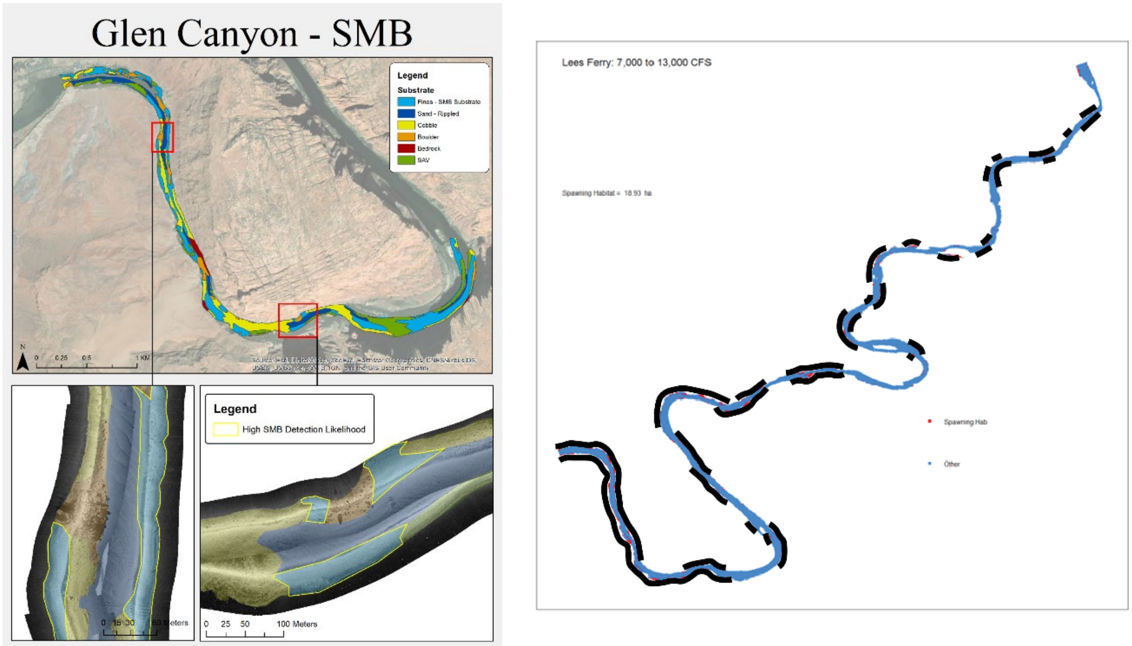

Figure 13.—Substrate identification and two optimal bass nest survey sites (left) identified near Lees Ferry using side-scan sonar. Sonar was again used in August (right panel) to search for bass nests (black segments represent scanned area).

Grand Canyon National Park personnel collected environmental DNA samples in September 2024 to identify the distribution of smallmouth bass below Lees Ferry. This technique attempts to find and amplify smallmouth bass DNA present in 5L water samples and is typically effective at determining the presence/absence of rare species in aquatic systems (Carim et al. 2016). Standard curves can be used to determine the relative concentration of DNA in the water column by providing an estimate of the number of copies/L. Water filtration associated with eDNA sampling can be difficult in the Colorado River, below the Paria River, due to high turbidity loads, which clogs filters and reduces the amount of water that can be used per sample to detect the DNA of target species. Samples were collected from both sides of the river every mile from RM 0.0 to RM 30.0 and then were collected every 2.5 miles until RM 65.0, resulting in 273 samples collected from 91 sites. Grand Canyon's sampling detected smallmouth bass DNA in four samples with the furthest downstream positive sample at RM 37.5 (figure 14). Samples with positive detections were re-analyzed in the lab to confirm initial results. While DNA degrades over time due to solar radiation, high temperatures, and biological activity, it is currently unknown the rate at which DNA degrades and disperses in the Colorado River for rare species. Studies from other systems indicate DNA can travel hundreds of meters or more from the source location.

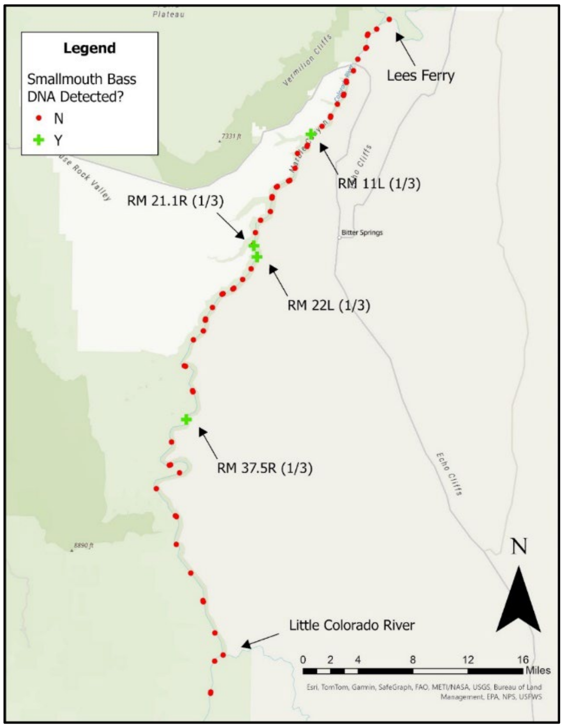

Figure 14.—Map of positive and negative eDNA sampling sites within GRCA from September 2024. Numbers in parentheses denote number of replicates at each respective site that were positive for smallmouth bass DNA.

Green Sunfish

The 2024 Cool Mix flows appeared to have had a negative effect on green sunfish in Glen and Grand Canyons with reduced growth, recruitment, and relative abundance (Shollenberger et al 2025). The highest concentrations of green sunfish occurred just below GCD and at the -12 Mile Slough (figure 15). Although green sunfish was the most abundant nonnative fish present above Lees Ferry in 2024, with a total of 11,740 captured, NPS' electrofishing catch per unit effort remained stable (March through November) through Glen Canyon compared to 2023, which suggests limited reproduction occurred in 2024 (figures 16 and 17; Shollenberger et al 2025). Reproduction of green sunfish occurred in 2023 and the increase in relative abundance during the fall can in part be attributed to YOY fish growing into a catchable size; this was not observed in 2024 (figures 16 and 17). In both Lees Ferry and the PBR reach catch rates increased in the fall in 2023 indicating reproduction and successful recruitment; this increase was not observed in 2024 indicating limited reproduction. One caveat to this is the AZGFD's standardized monitoring data. Their data has shown an increasing number of green sunfish, with CPUE of green sunfish increasing at a rapid rate since 2022 (D. Rowgowski per comm).

Sizes of green sunfish in 2024 were larger than in 2023 (figures 18 and 19, Shollenberger et al 2025). Recruitment of green sunfish appeared to be limited above RM 61 compared to 2023 with the captures of young of the year green sunfish only being observed in a few locations (RM 209, Shollenberger et al 2025; -12 Mile Upper Slough, Shollenberger et al 2025; 15.19 Dam Slough Clancy per comm, and Hidden Slough, Hines per comm). When the average size is on the smaller side (i.e., 40–80 mm) the population is likely dominated by small young of year fish. Likewise, if the average size is greater the following year (i.e., 2023 compared to 2024) then that would suggest a reduction of young of the year fish and the population is dominated by 1–2 year old fish.

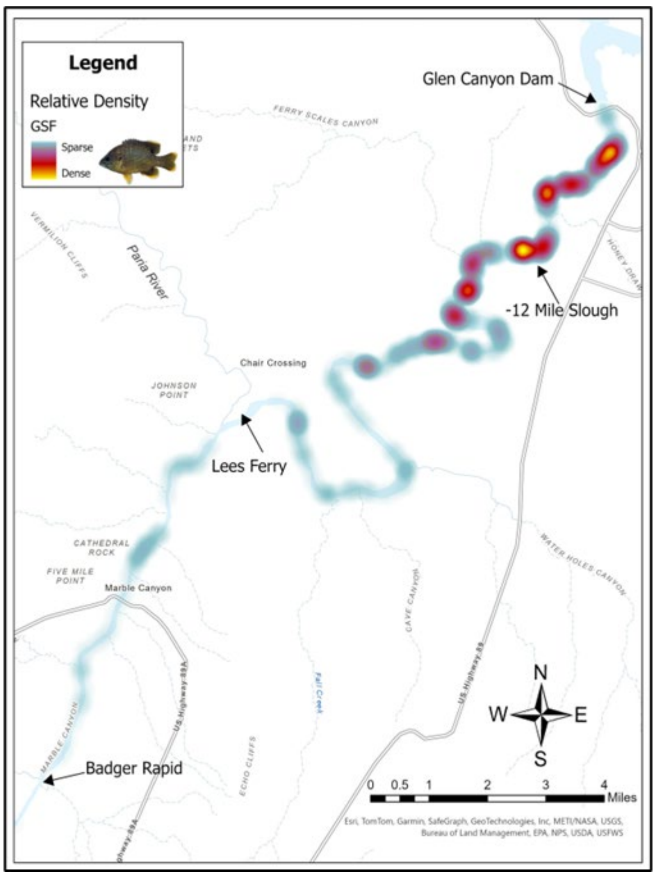

Figure 15.—Relative density heat map for green sunfish captures in GRCA and GLCA between GCD and Badger Rapid in 2024.

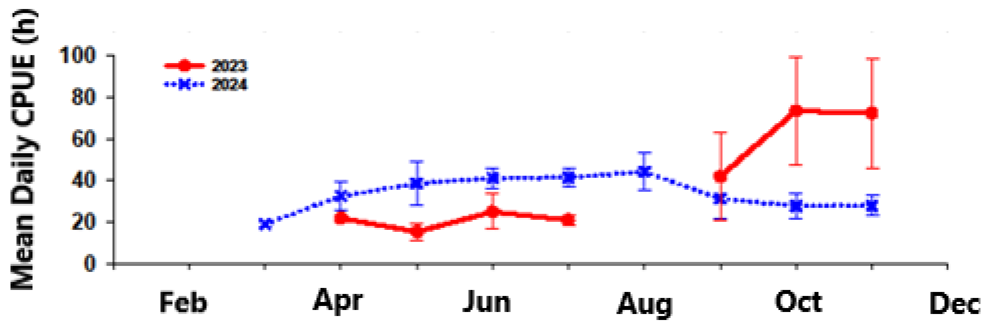

Figure 16.—Mean daily catch per unit effort (CPUE) of green sunfish residing in the Colorado River between GCD and Lees Ferry from March through November 2024. Error bars represent standard error (SE).

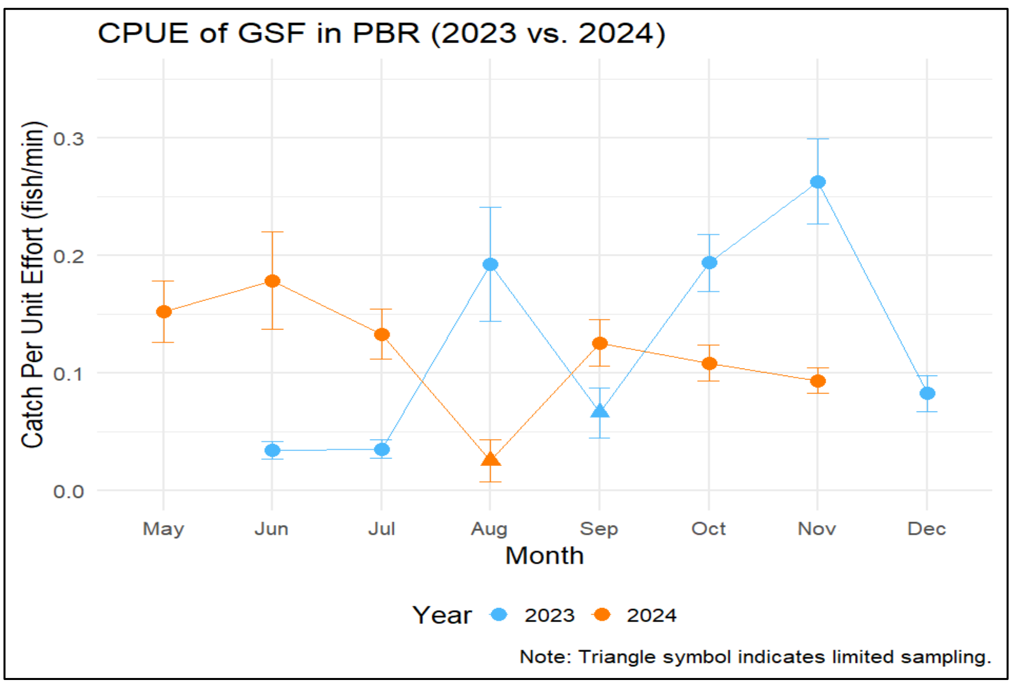

Figure 17.—CPUE for green sunfish from electrofishing efforts in the Paria to Badger reach in Grand Canyon in 2024 vs. 2023.

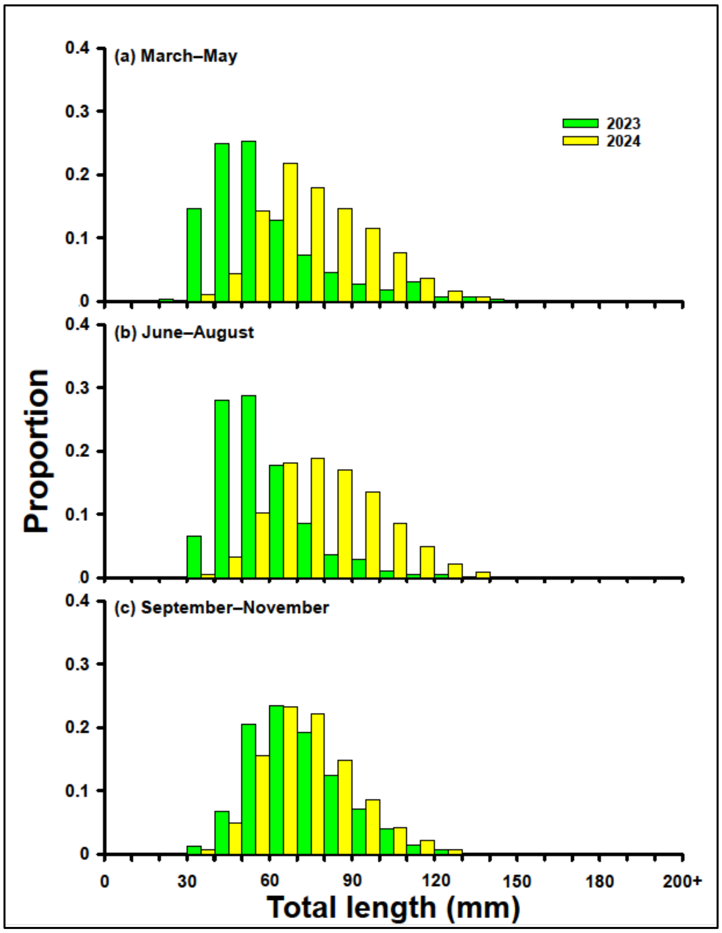

Figure 18.—Total length (TL) frequency histograms for green sunfish during (a) March–May, (b) June–August, and (c) September–November between GCD and Lees Ferry in 2023 and 2024.

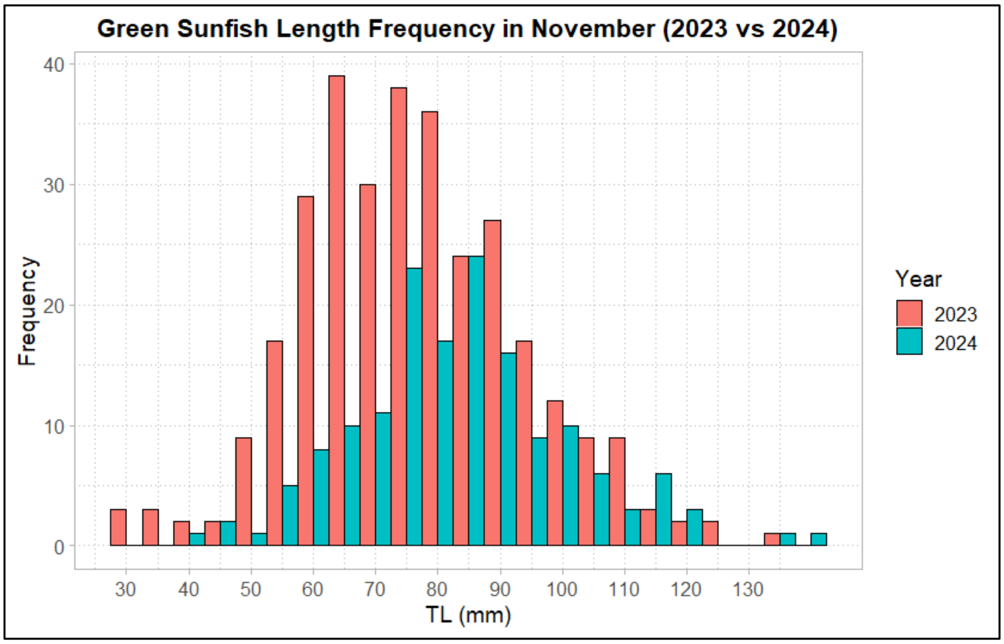

Figure 19.—Length Frequency of green sunfish captured in the Paria to Badger reach in November 2023 compared to November 2024.

Humpback Chub

Growth and condition are the two available parameters to best assess the effects of Cool Mix flows on humpback chub in the Grand Canyon. Observed growth for humpback chub from Juvenile Chub Monitoring (JCM) east (100–150 mm) in 2024 from July to October was 7.6 (standard error of +/- 0.5) mm/month, matching the predicted growth of 8 mm/month (figure 20, Charles Yackulic per comm). If the Cool Mix flow experiment had not occurred in 2024, predicted average river temperature would have been approx. 17.2 °C (Charles Yackulic per comm). Comparing the predicted river temperature from Charles Yackulic's modeling with figure 20, humpback growth would have approx. 4 millimeter per month (mm/month) more without the Cool Mix flow releases.

Condition is another parameter available to assess the effect of Cool Mix flows on humpback chub. Relative condition of humpback chub from JCM data in 2024 is very similar to (≥ 1) previous years for juvenile and adult humpback chub around RM 61 (Ben Miller per comm). One exception was condition for adult humpback chub around RM 61 during the summer season, which fell below 1(1 is the value of an expected weight for a fish given its length (Maria Dzul per comm).

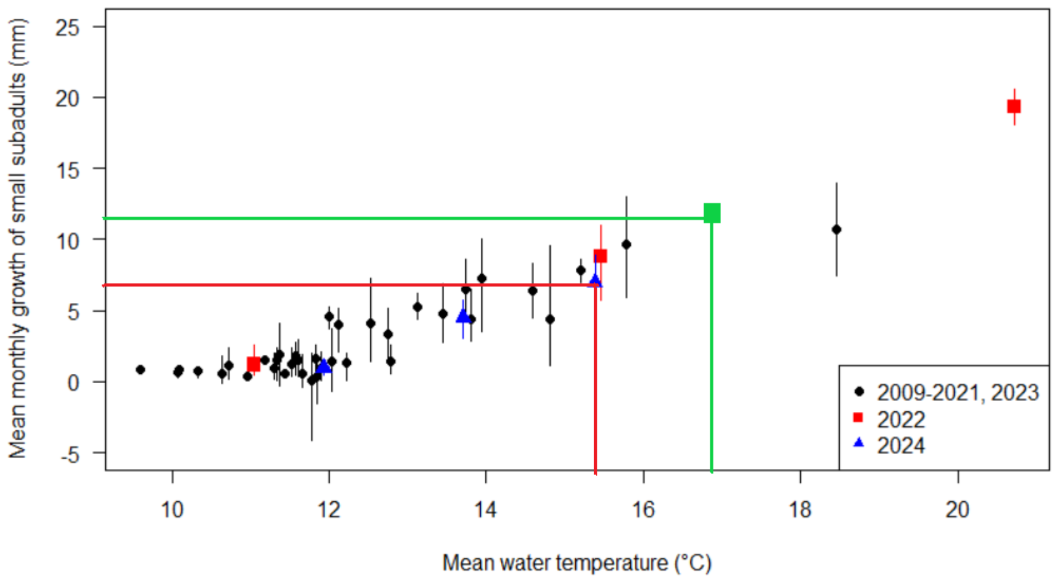

Figure 20.—This figure from Maria Dzul's presentation on humpback chub monitoring from the Annual Reporting meeting in April 2025. Mean monthly growth of subadult (100–149 mm) humpback in JCM east in relation to mean river temperature during 2024. Red line shows 2024 growth at 15.5 °C (during Cool Mix flow) and the green line shows predicted growth at approx. 17 °C (predicted river temperature in 2024 without Cool Mix flows).

Rainbow Trout

In 2024, Cool Mix flows appeared to positively influence rainbow trout, with summer-fall growth reaching the second highest levels recorded from 2013 to 2024, comparable to 2016 (Josh Korman, personal communication). The findings suggest a difference of approximately 6 grams each month in growth for a 300 g rainbow trout between conditions with and without Cool Mix flow (Josh Korman, personal communication). Over the four-month period of Cool Mix flows, this difference would result in a total difference of 24 g (Josh Korman, pers comm). Without Cool Mix flow, a 300 g trout would have lost about 6% of its body weight, whereas it experienced a gain of around 1% with Cool Mix flows (Josh Korman, personal communication).

It's also important to consider the context of summer-fall growth rates, which can vary significantly across seasons and years. Key factors affecting the condition factor over the 13-year period include very low growth during several summer-fall periods (2013–2014, 2019, 2023) and strong growth during most winters and some springs, particularly starting in 2016 (Josh Korman, personal communication). With positive growth rates in 2024, the condition factor approached the highest levels recorded for summer and fall during the 13-year span (Josh Korman, personal communication). However, poor survival of fry after reproduction (e.g., due to brown trout) could be the limiting factor at this point (Josh Korman, personal communication). Another caveat to consider is abundance has a large negative effect on condition (Dave Rogowski per comm). The fewer fish that are present in the system, the higher the condition for those few fish (i.e., more resources available means more growth and better condition).

Other Fish Species

The effects of Cool Mix flow releases on other native species (i.e., flannelmouth and bluehead suckers and speckled dace) were not assessed in 2024.

Another species to note is Walleye. Captures of walleye have been gradually increasing since 2021 (9 in 2021, 15 in 2022, 60 in 2023, and 58 in 2024; Shollenberger and Arnold per comm). In 2024, a majority of the walleye captures (39) occurred in the Lees Ferry 5 miles or less downstream from GCD (Shollenberger and Arnold per comm). All but one of the walleye captured in 2024 were adults. This increase in walleye catch could be the product of increased sampling in the Lees Ferry reach with the rapid response work. The AZGFD standardized monitoring has not seen an increase in walleye captures (Dave Rogowski per comm). Walleye are considered cool water species and spawning typically ranges from 8–10ºC in the southern portions of their range (Bozek 2011). Optimal growth for year-1 walleye is around 22ºC (Koenst and Smith 1976) and for juvenile species it ranges from 20–24ºC. (Coutant 1977; Wismer and Christie 1987). Cooler waters produced by cool mix flows has the risk of producing temperatures near ranges to initiate a Walleye spawn. This risk is likely low since 2024 cool mix flows remained above optimal spawning temperatures and below optimal growing ranges for both Age-1 and juvenile walleye.

-12 Mile Slough

Work in the -12 Mile Slough during 2024 included a block net (to prevent fish from entering the lower slough), fyke netting, artificial spawning beds, temperature monitoring, and fish salvage (only in upper slough; Shollenberger et al 2025). The block net effectively prevented most fish from entering the lower slough; coupling the block net with electrofishing and fyke nets, all fish were removed from the area (Shollenberger et al 2025). No smallmouth bass spawning activity was observed in the slough or on the artificial spawning beds (Shollenberger et al 2025). Cool Mix flows also effectively reduced the water temperature in the lower slough to below suboptimal spawning temperatures for smallmouth bass (Shollenberger et al 2025). A fish salvage occurred in the upper -12 Mile Slough on October 30, 2025. Two juvenile carp (78 and 138 mm) and 25,161 green sunfish (11 > 100mm) were captured and removed (Shollenberger et al 2025). All fish were retained for beneficial use (Shollenberger et al 2025).

Hydropower

Generation and Cost

During cool mix flows, Reclamation generated 727,023 megawatt-hours (MWh) of energy from GCD. Over this period, WAPA estimates that the amount of water bypassed, which accounts for 32.5% of the total release during the experiment, could have generated an additional 372,341 MWh, or a 51% increase in generation (table 5).

Table 5.—Hydropower impacts due to the 2024 SEIS release

Week Number	Dates	Power Purchased (MWh)	Cost of Replacement Power
1	Jul 9–Jul 13	13,701	$794,926
2	Jul 14–Jul 19	18,855	$912,171
3	Jul 20–Jul 26	20,698	$1,029,830
4	Jul 27–Aug 2	24,171	$1,285,250
5	Aug 3–Aug 9	21,038	$1,097,984
6	Aug 10–Aug 14	15,300	$765,375
7	Aug 15–Aug 23	35,329	$1,647,206
8	Aug 24–Aug 30	24,315	$1,159,515
9	Aug 31–Sep 6	28,707	$1,520,643
10	Sep 7–Sep 13	28,723	$1,533,172
11	Sep 14–Sep 20	22,788	$1,219,986
12	Sep 21–Sep 27	19,106	$1,038,945
13	Sep 28–Oct 4	22,616	$1,204,973
14	Oct 5–Oct 11	20,404	$1,132,923
15	Oct 12–Oct 18	18,298	$974,870
16	Oct 19–Oct 25	12,435	$666,398
17	Oct 26–Nov 1	7,557	$382,120
18	Nov 2–Nov 8	8,154	$297,029
19	Nov 9–Nov 15	8,465	$263,080
20	Nov 16–Nov 18	1,682	$44,020
Total		**372,341**	**$18,970,416**

Basin Fund

Cost estimates of the cool mix experiment are preliminary, and work is being conducted by Argonne National Laboratory to complete a formal analysis before the end of FY25. The preliminary cost estimate of replacement energy acquired during this experiment is approximately $18.97M (table 5). Revenues from the Basin Fund were used to purchase this replacement energy. Since 2019, basin fund balance has ranged from $79M to $203M as reported at the April 2025 GCDAMP annual reporting meeting. This includes an addition of

$85M in Infrastructure Investment and Job Act funds in 2022/2023. The Basin Fund began FY24 with a balance of $203M and ended FY24 with a balance of $184M. WAPA calculates the end of FY25 Basin Fund Reserve target balance to be $279M. The Basin Fund Reserve target is the projected cost of WAPA and Reclamation capital replacement and replacement power purchase for the next three years and the cost of operations and maintenance for the next three months. The Basin Fund was operated within an acceptable level of risk to WAPA in FY24, but the 2024 cool mix experiment created a funding shortfall for the capital replacements program for the CRSP system. This prompted WAPA to make a $6.8M (approx. 30%) cut to its capital program and Reclamation used $36M in carryover and other miscellaneous revenues of offset reductions in its capital program to keep the Basin Fund operating at an acceptable level of risk. These cuts resulted in many capital replacement projects being deferred to FY26. The only work WAPA is approved for in FY25 is for critical transmission and communication equipment replacements.

Power Reliability

The cool mix flows did not have a direct effect on the reliability of power to customers. There were no Energy Emergency Alerts 3 (EEA3) or California Independent Operator (CAISO) emergencies in 2024 that required a response from GCD.

As described in the LTEMP SEIS, WAPA and Salt River Project exchanges hydropower generated at GCD for coal-generated thermal power generated at Craig, Hayden, and Four Corners. The 2024 SEIS release did not allow for enough generation at GCD for the exchange at all times and initially caused some transmission congestion. The WAPA was able to move some delivery locations to resolve the congestion. The WAPA also applied additional purchases at Four Corners to keep the exchange whole. Argonne National Laboratory's report on the impacts of these cool mix flows will contain more detail on this exchange.

Additionally, WAPA did not specify or require a certain generation type for the replacement power. The 2024 LTEMP SEIS assumed replacement power to offset the impacts of this experiment would be generated primarily from existing thermal powerplants on the WECC regional grid (see Section 3.9 Air Quality, pages 3-227 to 3-230). Argonne National Laboratory's report on the impacts of these Cool Mix flows will contain more detail on replacement energy source type and emissions.

Capacity

Reclamation expended considerable effort to develop an optimization strategy with WAPA to maximize bypass during off-peak hours (at night and at mid-day) and maximizing power generation during on-peak hours (afternoon and evening) while still meeting downstream daily average temperature targets (figure 1). This helped reduce the experiment's impact on marketable capacity by providing as much generation as possible during hours of peak power demand, especially during the evening hours when the economic value of capacity was greatest. How much this effort offset replacement power costs will be included in Argonne National

Laboratory's report on the impacts of these cool mix flows. The WAPA indicated that the cost savings was likely to be worth the effort and could not identify any needs for improvement with this optimization strategy over what was done in 2024.

Sediment

The Cool Mix flow experiment was conducted by substituting discharge through the power units with an equal discharge of water through the river outlet works. Therefore, the experiment did not result in a change in the total release of water through the dam. Because sediment transport is controlled by discharge and only very weakly affected by water temperature, the experiment had a negligible effect on sediment transport in 2024 (Paul Grams per comm). There was a minor localized effect on a sand bar immediately downstream from GCD, because the river outlet works create a different velocity pattern at the base of the dam (Paul Grams per comm).

Discussion/Conclusions

The core focus of the 2024 LTEMP SEIS flow experiment was to evaluate sub-annual flow options designed to disrupt the establishment of smallmouth bass and other warmwater nonnative invasive fish below GCD (Reclamation 2024). These flows would limit additional recruitment, which could threaten populations of humpback chub.

The Cool Mix flow implemented in 2024 was effective in cooling the river below 15.5 °C to RM61 from July 8 to November 18. A total of 14 days exceeding that temperature after implementation began, compared to a modeled 135 (±5) days of temperatures over 15.5 °C had flows not been implemented. Temperatures at the Lees Ferry gage, immediately downstream from where most bass have been detected, averaged 14.1 °C for the duration of the experiment. Impacts to water quality, including dissolved oxygen, specific conductivity, and soluble reactive phosphorus, were largely negligible during the Cool Mix flows. Dissolved oxygen concentrations did increase during the Cool Mix flow releases to near the EPA limit, but no gas bubble disease was detected during any of the sampling trips. Despite various challenges in on-ramping, maintaining temperatures, accommodating power production needs, and off-ramping, the experiment met its primary goal of keeping the river below predicted bass to spawning temperatures.

Reproduction, growth, relative abundance, and recruitment of nonnative invasive fish were reduced because of the lower river temperatures produced below GCD. A multi-agency, multi-method sampling effort detected no evidence of smallmouth bass reproduction below GCD. No young of the year were captured, length frequency histograms show no small smallmouth bass were captured. Monitoring revealed the presence of two cohorts that were likely spawned in 2022 and 2023 when river temperatures were much higher. The smallmouth bass growth rate was reduced by more than 60% in 2024, which likely prevented many of these fish from reaching spawning size (estimated 200 mm TL) for 2025. The total number of smallmouth bass collected was also greatly reduced from the two previous years, though this may be due in part to reduce catchability in low temperatures (Drew Eppehimer per comm). There was also no change in distribution of smallmouth bass in the river below the dam.

Green sunfish also had a reduction in demographic parameters because of Cool Mix flows. The average size of green sunfish in 2024 was higher than in 2023, which might suggest changes in recruitment success and lower survival rates under the cooler water conditions. The highest concentrations of green sunfish captured in 2024 resided around the -12 Mile Slough. To alleviate the ongoing issues with invasive nonnative fishes around the upper and lower sloughs at RM -12, GLCA and Reclamation began a project in March 2025 to channelized both. This work will remove the two backwater areas by allowing the river to flow them, thereby eliminating the ability of warmwater nonnative fish to spawn and rear in these areas.

Humpback chub did not appear to experience any negative impacts from the Cool Mix flows, as water temperature was greater than the approx. 12C growth threshold. Growth was estimated to be reduced by 4 mm during Cool Mix flow compared to growth without Cool Mix flow, but the observed growth (8 mm/month) during Cool Mix flow was an average growth rate for humpback chub in the Grand Canyon (Maria Dzul per comm) because these fish regularly experience temperatures produced by the Cool Mix flows. The relative condition of humpback chub during the Cool Mix flow experiment did not deviate from the average relative condition (1) of humpback chub in the mainstem Colorado River from previous years.

Although Cool Mix flows appear to have positive effect on rainbow trout, their abundance is currently tied with lowest level measured over the 13-year period. Growth was likely better under Cool Mix flows than without and may lead to an increase in recruitment via better reproductive success. Poor survival of fry after reproduction (e.g., due to brown trout) could be the limiting factor at this point. The Cool Mix flows in 2024 may have a short-term benefit to rainbow trout, but bass flows are not likely to reverse the poor state of the fishery.

The Cool Mix flow came with a financial cost to hydropower as WAPA spent $18,970,416 to replace the power not generated due to bypass flows. Power purchases were funded through the Basin Fund, which is used for maintenance and upkeep of GCD and transmission lines that deliver the power. Due to this unplanned decrease in the basin fund, WAPA chose to defer $6.8M in capital project spending (30%) to FY26. Capital project deferment risks equipment failure as infrastructure ages.

Future Considerations

The Planning and Implementation team may choose to consider future changes to flows to reduce or halt the establishment and reproduction of cold and warmwater fish and improve the effectiveness and efficiency of experimental flows while helping to offset the financial cost to hydropower. The WAPA’s estimated costs using alternative river mile targets and off-ramp strategies provides a path forward for finding less financially impactful flow strategies. Improvements to temperature modeling are already underway, and additional methods for offsetting hydropower daily costs may be found. Strategies and funding to support future sampling, entrainment, and kinship studies can help understand the near-term threat smallmouth bass pose. Understanding the impact of this flow experiment on other resources and the big-picture ecology of the Grand Canyon will be valuable.

The Cool Mix flow experiment was successful at preventing smallmouth bass from reproducing below Glen Canyon Dam through the Grand Canyon segment of the Colorado River in 2024. The experiment reduced the growth rate and probably halted the reproduction of smallmouth bass in the Lees Ferry reach of the Colorado River, but the threat of establishment persists. The next several years are critical as smallmouth bass spawned in 2022 and 2023 will likely grow and become adults in 2025 and 2026 and be capable of spawning. The ability to use flow experiments to combat the establishment of smallmouth bass has been an excellent tool as part of a long-term plan to keep the threat of invasive nonnative fish low. Using the expertise of the smallmouth bass expert panels and the Planning and Implementation team, it is hopeful that solutions will be implemented to prevent smallmouth bass establishment in the Colorado River below GCD.

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Appendix A

Release data from GCD between July 2024 and November 2024

Table A-1.—Release data from GCD between July 2024 and November 2024

Datetime	Total Release (acre-feet)	Bypass Release (acre-feet)	Penstock Release (acre-feet)
7/1/2024	22586.274	0	22586.274
7/2/2024	23208.996	0	23208.996
7/3/2024	23366.596	0	23366.596
7/4/2024	22222.977	0	22222.977
7/5/2024	23625.31	0	23625.31
7/6/2024	21873.289	0	21873.289
7/7/2024	22061.404	0	22061.404
7/8/2024	23362.526	35.61983	23326.907
7/9/2024	23612.439	6642.8926	16969.546
7/10/2024	23486.952	6648.6777	16838.274
7/11/2024	23563.323	6732.8099	16830.513
7/12/2024	23502.439	6713.0579	16789.381
7/13/2024	23457.97	6627.7686	16830.202
7/14/2024	22974.046	7410.0826	15563.964
7/15/2024	22961.683	7383.8017	15577.881
7/16/2024	22932.296	7330.2479	15602.048
7/17/2024	23029.466	7390.1653	15639.301
7/18/2024	23026.788	7307.9339	15718.855
7/19/2024	23097.878	7377.686	15720.192
7/20/2024	22076.959	6765.3719	15311.587
7/21/2024	21791.016	6723.3884	15067.627
7/22/2024	23510.637	7197.2727	16313.364
7/23/2024	23512.202	7250.7438	16261.458
7/24/2024	23570.085	7256.1157	16313.969
7/25/2024	23320.321	7192.7273	16127.593
7/26/2024	23408.65	7233.3058	16175.344
7/27/2024	21829.726	7784.7107	14045.016
7/28/2024	21830.674	7710.7438	14119.931
7/29/2024	23602.524	8261.2397	15341.284
7/30/2024	23472.54	8185.2893	15287.25
7/31/2024	23608.631	8254.7934	15353.837
8/1/2024	25312.674	8827.6033	16485.07
8/2/2024	25313.508	8880.2479	16433.26
8/3/2024	23825.85	6753.4711	17072.379

Datetime	Total Release (acre-feet)	Bypass Release (acre-feet)	Penstock Release (acre-feet)
8/4/2024	23410.87	6618.0165	16792.854
8/5/2024	25297.042	7385.9504	17911.092
8/6/2024	25218.191	7431.157	17787.034
8/7/2024	25330.293	7412.8926	17917.401
8/8/2024	25270.933	7407.7686	17863.164
8/9/2024	25258.252	7405.0413	17853.211
8/10/2024	24033.932	7162.0661	16871.866
8/11/2024	23445.54	7021.7355	16423.804
8/12/2024	25230.736	7481.8182	17748.917
8/13/2024	25208.675	7492.2314	17716.444
8/14/2024	25169.685	7497.1074	17672.578
8/15/2024	24761.634	9390.0826	15371.551
8/16/2024	24817.081	9395.8678	15421.213
8/17/2024	23580.076	9344.7107	14235.365
8/18/2024	22691.73	9316.9422	13374.788
8/19/2024	24788.55	9450.4959	15338.055
8/20/2024	24932.169	9438.5124	15493.657
8/21/2024	24980.708	9453.0579	15527.65
8/22/2024	24826.987	9360	15466.987
8/23/2024	24650.171	9369.2562	15280.915
8/24/2024	23396.185	8226.7769	15169.408
8/25/2024	22703.202	8081.4876	14621.715
8/26/2024	24687.364	8306.4463	16380.917
8/27/2024	24967.788	8442.8926	16524.896
8/28/2024	24853.902	8366.5289	16487.373
8/29/2024	24653.907	8245.5372	16408.37
8/30/2024	24616.393	8323.4711	16292.922
8/31/2024	22545.854	10157.851	12388.002
9/1/2024	18133.937	9445.124	8688.8132
9/2/2024	18183.085	9485.9504	8697.1347
9/3/2024	19290.202	9846.7769	9443.4248
9/4/2024	19496.234	9917.1074	9579.1265
9/5/2024	19569.704	9982.3141	9587.3901
9/6/2024	19475.924	9868.595	9607.3289

Datetime	Total Release (acre-feet)	Bypass Release (acre-feet)	Penstock Release (acre-feet)
9/6/2024	19475.924	9868.595	9607.3289
9/7/2024	18587.269	9679.1736	8908.095
9/8/2024	18201.459	9411.7355	8789.7231
9/9/2024	19501.726	10024.463	9477.2628
9/10/2024	19496.269	10033.058	9463.2107
9/11/2024	19475.125	10068.678	9406.4471
9/12/2024	19459.699	10054.793	9404.9058
9/13/2024	19389.973	10050.992	9338.981
9/14/2024	18574.315	8243.5537	10330.761
9/15/2024	18177.386	7992.3967	10184.989
9/16/2024	19380.574	7780	11600.574
9/17/2024	19329.01	7737.7686	11591.241
9/18/2024	19275.531	7708.4298	11567.101
9/19/2024	19327.594	7755.7025	11571.892
9/20/2024	19294.753	7725.4546	11569.298
9/21/2024	18479.56	6708.9256	11770.635
9/22/2024	18152.389	6574.6281	11577.761
9/23/2024	19418.952	6531.4876	12887.464
9/24/2024	19481.6	6627.5207	12854.079
9/25/2024	19488.494	6610.0826	12878.412
9/26/2024	19636.622	6621.157	13015.465
9/27/2024	19526.019	6597.3554	12928.664
9/28/2024	17281.966	8101.7355	9180.2306
9/29/2024	16968.877	7873.3058	9095.5711
9/30/2024	18293.136	8565.7851	9727.3512
10/1/2024	16007.449	7388.3471	8619.1017
10/2/2024	16057.831	7419.0909	8638.7397
10/3/2024	15907.415	7345.8678	8561.5471
10/4/2024	15897.234	7391.3223	8505.9116
10/5/2024	15191.36	6785.124	8406.2364
10/6/2024	14903.658	6687.1901	8216.4678
10/7/2024	15920.029	7189.1736	8730.8554
10/8/2024	15938.632	7163.3058	8775.3265
10/9/2024	15914.323	7137.6033	8776.7198

Datetime	Total Release (acre-feet)	Bypass Release (acre-feet)	Penstock Release (acre-feet)
10/12/2024	15114.993	6111.157	9003.8364
10/13/2024	14881.592	6038.0165	8843.5752
10/14/2024	15704.732	6423.719	9281.0132
10/15/2024	15730.974	6450.5785	9280.395
10/16/2024	15807.332	6430.7438	9376.5884
10/17/2024	15828.301	6369.2562	9459.0446
10/18/2024	15785.65	6362.0661	9423.5843
10/19/2024	14932.46	4136.6116	10795.848
10/20/2024	14780.817	4050.8265	10729.99
10/21/2024	14111.862	4204.9587	9906.9033
10/22/2024	16033.076	4427.0248	11606.051
10/23/2024	15851.519	4477.438	11374.081
10/24/2024	15745.792	4317.6033	11428.188
10/25/2024	15785.852	4346.3636	11439.488
10/26/2024	14983.431	2290.3306	12693.101
10/27/2024	14772.045	2258.3471	12513.698
10/28/2024	15747.238	2711.9835	13035.255
10/29/2024	15756.87	2653.719	13103.151
10/30/2024	15869.77	2666.8595	13202.911
10/31/2024	15830.807	2701.3223	13129.484
11/1/2024	16986.85	2917.5207	14069.329
11/2/2024	16852.878	2840.0826	14012.795
11/3/2024	16722.954	2831.2397	13891.714
11/4/2024	16880.723	2820.3306	14060.393
11/5/2024	16717.274	2784.2149	13933.06
11/6/2024	16796.583	2822.8926	13973.691
11/7/2024	16846.443	2800.4132	14046.03
11/8/2024	16795.136	2820	13975.136
11/9/2024	16839.274	2917.438	13921.836
11/10/2024	16748.279	2918.0992	13830.18
11/11/2024	16898.324	2887.5207	14010.803
11/12/2024	16950.946	2925.2893	14025.657
11/13/2024	17046.585	2944.5455	14102.04
11/14/2024	16973.218	2932.562	14040.656

Datetime	Total Release (acre-feet)	Bypass Release (acre-feet)	Penstock Release (acre-feet)
11/13/2024	17046.585	2944.5455	14102.04
11/14/2024	16973.218	2932.562	14040.656
11/15/2024	16977.093	2943.8017	14033.291
11/16/2024	16948.838	1323.0579	15625.78
11/17/2024	16846.099	1362.0661	15484.033
11/18/2024	16964.259	1333.8843	15630.374
11/19/2024	16978.13	0.66116	16977.469
11/20/2024	16821.268	1.40496	16819.863
11/21/2024	16873.241	0.49587	16872.745
11/22/2024	16871.817	1.98347	16869.833
11/23/2024	16859.547	0.99174	16858.555
11/24/2024	16317.19	0	16317.19
11/25/2024	16579.56	0	16579.56
11/26/2024	16587.096	0	16587.096
11/27/2024	16608.389	0	16608.389
11/28/2024	16360.055	0	16360.055
11/29/2024	16629.689	0	16629.689
11/30/2024	16518.455	0	16518.455

Data can be accessed at the following URL:
https://www.usbr.gov/lc/region/g4000/riverops/_HdbDataViewer.html?query=svr=uchdb2&sdi=1920%2C4168%2C2216&tstp=DY&t1=2024-07-01T00:00&t2=2024-11-30T00:00&table=R&mrid=0&format=json