Considerations for Implementation of a Trout Management Flow Experiment

Problem

The Glen Canyon Dam Adaptive Management Program (GCDAMP) is tasked with adaptively managing the Glen Canyon Dam to improve resources downstream. The 2016 Long-Term Experimental and Management Plan (LTEMP) Environmental Impact Statement (EIS) Record of Decision (ROD) and Biological Opinion (BO) are the guiding documents that provide a framework for managing those resources related to the operations of Glen Canyon Dam. Maintaining a rainbow trout sport fishery at Lees Ferry while preventing movement of this non-native species downriver where it may negatively affect humpback chub are two seemingly opposing objectives that present a challenge for managers and the GCDAMP. One of the experiments outlined in the ROD & BO referred to as a trout management flow (TMF) is one of the proposed tools designed to reduce the recruitment of rainbow trout and thus preserve that balance between maintaining the fishery and protecting humpback chub.

Purpose

The purpose of this report is to review the current state of science regarding the design, implementation, and effectiveness of implementing a TMF experiment as a tool for managing rainbow trout. It also includes additional factors that may affect the decision-making process. The report also evaluates the conditions under which a TMF experiment is most likely to meet intended rainbow trout management and learning objectives. Sources of uncertainty are categorized in the document based on the potential to address them through a small-scale field-based or laboratory study or through experimental implementation. A list of additional tools that has been considered for managing trout is also included (Tables 2, 6). Although recommendations for next steps are included, this report is not a decision document, but rather a resource to facilitate the process for determining when or if to implement a TMF. TMFs were originally designed to manage rainbow trout at Lees Ferry; however, due to the increasing population of brown trout at Lees Ferry and the threat they pose to humpback chub, potential adjustments needed to apply a TMF to brown trout are described in the Other Considerations section.

Background

Completion of Glen Canyon Dam in 1963 resulted in the delivery of water and hydroelectric power to millions of people across the western United States. However, it also altered water quality, temperature, nutrients, sediment load, and flow of the Colorado River downstream from the dam. Hydropower production from the dam results in releases of water volumes which vary daily in conjunction with the power needs of the recipients based on the time of day and year. These daily flow fluctuations affect the physical conditions of the river resulting in habitat modifications that impact early life stages of fish (Korman & Campana 2009). The fluctuations also cause a vertical and longitudinal shift in wetted nearshore habitat, which can push juvenile trout away from preferred habitat leading to slower growth and higher predation rates (Scruton et al. 2003).

Changes to the river from dam operations resulted in cooler summer and warmer winter water temperatures and reduced turbidity, which contributed to the population decline of native fishes. Introduction of non-native fish, along with habitat and water temperature alterations created by the dam, have reduced the growth rate and survival of humpback chub (Yackulic et al. 2014). Growth rates of humpback chub are slower in colder water making them vulnerable to predation for a longer period (Yackulic et al. 2014; Ward & Morton-Starner 2015; Yackulic et al. 2018). Juvenile humpback chub survival has the largest impact on population dynamics of the species, and survival rates are lower when rainbow trout abundance is higher and water temperature is lower (Yackulic et al. 2018). Interactions with non-native fish are another contributing factor in the decline of humpback chub (Yard et al. 2011).

The National Park Service (NPS) introduced brown trout into tributaries downstream from the dam in the late 1920s and early 1930s for recreational fishing but have recently increased in abundance upstream of Lees Ferry (Runge et al. 2018). Though brown trout are more piscivorous than rainbow trout, both species pose a threat to humpback chub, and based on stomach content analysis, both species seem to preferentially consume native versus non-native fish (Yard et al. 2011). From 2014-2016, brown trout populations began increasing in Lees Ferry and have continued to increase their population (Runge et al. 2018), reaching ~30% of the catch by 2021 (Yard & Dibble, unpublished data).

Due to the impacts these non-native salmonids may have on recovery of humpback chub, effective management tools are essential. Options with minimal impacts on other GCDAMP resources are limited. Timing and variation of flows can reduce the abundance of trout depending on how flows align with spawning, egg development, and fry emergence (Korman and Campana 2009, Korman et al. 2011b, Avery et al. 2015). Trout management flows (TMFs) builds on this concept of using flows from the dam to decrease recruitment of juvenile trout to the adult population. In addition to flow, prey availability, turbidity-driven feeding efficiency, and intraspecific competition are other drivers that can affect rainbow trout growth and abundance (Korman et al. 2021).

When the LTEMP BO and EIS were developed, rainbow trout were the non-native species of most immediate concern to humpback chub, and consequently the specific elements of the hydrograph for a TMF targeted rainbow trout. As such, this review focuses on rainbow trout, but includes how a TMF could be modified to target brown trout (see Summary and Considerations section).

Recreational Rainbow Trout Fishery

Trout thrive in the clear cold water found downstream from Glen Canyon Dam compared to the warm and turbid Colorado River that existed prior to its completion. The tailwater stretch of the river below the dam was stocked with rainbow trout a year after the dam was completed. Initially, releases from the dam fluctuated dramatically, which prevented successful reproduction and recruitment owing to daily changes in river stage of 10 feet that alternately dried and scoured trout egg nests (redds) and displaced sensitive fry. In the absence of natural spawning and recruitment, the rainbow trout population in Glen Canyon was only sustained by continued stocking. However, changes to dam management in 1991 reduced the daily fluctuations in stage to approximately 3 feet, which allowed natural reproduction and survival of rainbow trout fry to occur (McKinney et al. 2001). By 1992, monitoring indicated that natural reproduction was occurring, and regular stocking was discontinued after 1998 (Avery et al. 2015). The rainbow trout fishery was designated "blue-ribbon" status based on the larger-than-average fish that were caught during that time (Avery et al. 2015). The rainbow trout population has fluctuated since then, and while regular stocking was discontinued, Arizona Game and Fish Department (AGFD) still maintains use of stocking as a management tool when catch rates decline below fishery management goals stated in the NPS Comprehensive Fisheries Management Plan (CFMP) Environmental Assessment (NPS CFMP EA 2013). Stocking of triploid rainbow trout most recently occurred in November 2018 (526 rainbow trout) and May and June 2019 (5,956 rainbow trout). Catch rates, size, and condition are metrics used to measure the status of the tailwater fishery, and to determine whether stocking is necessary (NPS CFMP EA 2013, Rogers 2015).

Biology & ecology

Rainbow trout spawning occurs in Glen Canyon between February and April with emergence ensuing approximately two months after fertilization. Immediately after fry emerge from gravels rainbow trout are thought to be most vulnerable to flow variations (i.e., April- June; Korman et al. 2011b). Spawning is assumed to be limited in Marble Canyon due to sub-optimal habitat conditions (Korman et al. 2012).

Because trout visually detect prey, they become less effective predators as turbidity increases, except when prey are abundant (Barrett et al. 1992; Yard et al. 2011; Ward et al. 2016). Since turbidity and temperature increase downstream, trout dispersal downstream is limited except when abundance and competition are high (typically following large recruitment years), or fish condition is poor (Korman et al. 2016; Korman et al. 2021). Rainbow trout that move from Glen Canyon to Marble Canyon may be more likely to persist in Marble Canyon when turbidity levels are low due to low sediment inputs from the Paria River (Korman et al. 2016; Korman et al. 2021). Large recruitment events that have led to higher densities of rainbow trout in Glen Canyon (e.g., the equalization flow in 2011) have resulted in downstream emigration into Marble Canyon and near the confluence of the LCR (Korman et al. 2016).

Lab trials indicate that relatively small changes in turbidity (25 formazin nephlometric units) can significantly alter predation vulnerability of humpback chub from trout (Ward et al. 2016). Although primary and secondary production are highest in Glen Canyon compared to downriver, growth of rainbow trout is generally lower than downriver (Yard et al. 2016). Density, competition, prey size and availability, water temperature and velocity affect the maximum size of rainbow trout (Dodrill et al. 2015). Rainbow trout select prey based on width (Dodrill et al. 2021), and typically prey on midges (chironomid), black flies (simuliid), and *Gammarus lacustris* (amphipod) which are the most abundant prey in the river (Cross et al. 2011).

Fluctuations in flow affect trout density, recruitment, and the maximum length of adults. Based on an analysis of data across tailwaters of the western U.S., releases of high volumes of water during early life history stages can decrease rainbow trout recruitment (Dibble et al. 2015). This same analysis indicated that large daily variations in flow due to hydropower releases can moderately decrease adult rainbow trout size (Dibble et al. 2015). Research suggests that increased flow fluctuations during the rainbow trout spawning and incubation period are unlikely to be effective at regulating the population because age-0 trout exhibit compensatory survival (Korman et al. 2011b).

Phosphorous concentrations in Glen Canyon are low which affects prey availability. Declines in prey availability due to the low phosphorous levels have resulted in poor growth and condition of rainbow trout (Korman et al. 2021). Fluctuations in rainbow trout abundance can be seen in Figure 1, which shows the population dynamics of this species in Lees Ferry since 2012 (Figure 1; Table 1). Based on mark-recapture data, rainbow trout dispersal downriver of Lees Ferry is low on a per capita basis but is most likely to occur when recruitment is high, or fish condition is poor (Korman et al. 2016). Maintaining low rates of dispersal downriver are the most feasible way of maintaining low densities near the Little Colorado River to minimize negative effects of competition and predation on humpback chub (Korman et al. 2021).

Potential Parasite & Pathogen Concerns

Because TMFs are a population-level management tool, transfer of parasites and pathogens to humpback chub is a potential concern. Introduction of pathogens and parasites through stocked fish is a concern especially with parasites such as Ich (*Ichthyophtirius multifiliis*) which have the potential to perpetuate throughout the Colorado River (Ward, unpublished data). Though salinity levels in the Little Colorado River provide anti-parasite protection to humpback chub, Ich could limit larval survival and recruitment of humpback chub in other tributaries (Ward 2012). The parasites and pathogens found in rainbow trout tend to be specific to trout or other cold-water species because the pathogens require a thermal optimum, meaning that there is not a concern for transmission to humpback chub due to the difference in thermal habitat preference of the fish. However, internal parasites such as Asian tapeworm could be transmitted from non-native warm water species such as carp to humpback chub (Ward 2007).

Figure 1. Abundance of rainbow trout by size class from 2012-2020

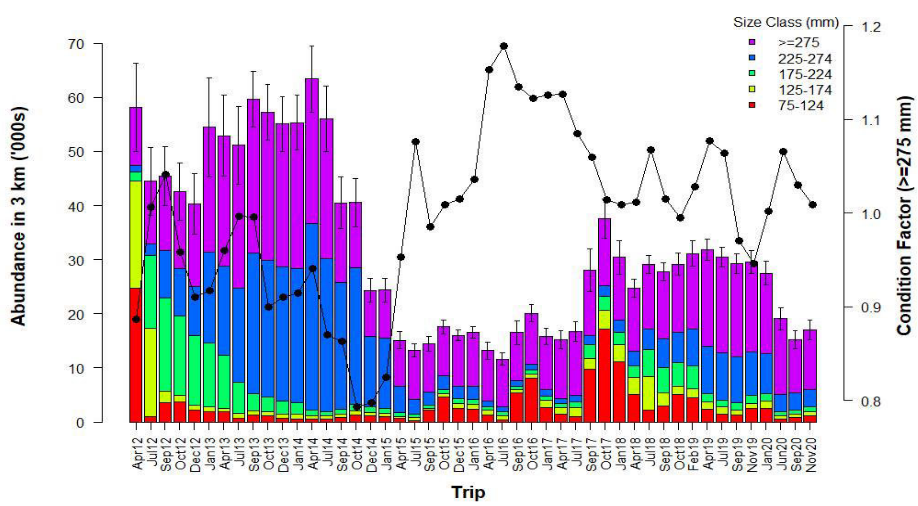


Table 1. The fall population estimate (n) of adult (>225mm) rainbow trout at Lees Ferry from 2015-2020 with 95% confidence intervals.

Year	225-274 mm n (95% CI)	>275 mm n (95% CI)
2015	19,700 (12,200-27,200)	131,200 (61,300-201,000)
2016	7,000 (3,200-10,800)	249,100 (185,100-313,100)
2017	16,100 (8,800-23,400)	106,600 (82,500-130,600)
2018	48,200 (35,900-60,500)	107,800 (88,300-127,300)
2019	64,500 (50,000-79,000)	138,100 (109,600-166,600)
2020	25,400 (14,800-36,000)	84,000 (59,100-108,900)

Trout Management Tools and Experimental Actions

Trout management flows (TMF) are one of the experiments identified in LTEMP as a potential tool for managing rainbow trout. The experiment was designed to reduce recruitment of young-of-the-year (YOY) rainbow trout to minimize migration downriver where they may negatively impact humpback chub. In the context of TMFs, it is important to note there are other potential tools available for managing trout (Table 2). Some of these have been utilized extensively while others have been suggested as potential options that would require further evaluation or compliance prior to implementation (LTEMP ROD 2016, NPS CFMP EA 2013, NPS NNAS EA 2018). Due to the unknown efficacy of a TMF, examination of alternate options may be warranted. Some of these tools have been evaluated previously while others would require careful evaluation prior to implementation. This table includes various options but does not imply that implementation would be possible.

Table 2. Potential or existing management tools and experimental actions for managing trout listed alphabetically and based on their impact to other resources (table created based on information from Bair et al. 2017 presentation on management options during Brown Trout Workshop 2017, NPS Non-Native Aquatic Species EA 2018 & subsequent ideas by stakeholders).

Trout Management Tool or Experimental Action	Advantages	Disadvantages
Angling regulations	▪ Unlikely to affect downstream resources ▪ May diminish tribal concerns since fish will likely be consumed ▪ Inexpensive	▪ May have a negative impact on the angling community ▪ Catch rates may not be sufficient to limit the population ▪ Populations can rebound quickly meaning ongoing efforts would be necessary
Chemical controls	▪ Effective at removing non-native fish ▪ Cost effective	▪ Could have negative impacts on non-target aquatic species in the immediate area ▪ May require additional compliance & permits ▪ Would only be effective in isolated areas such as tributaries or the slough ▪ Tribal concerns
Desiccation of redds	▪ Species specific ▪ May affect recruitment	▪ Tribal concerns ▪ Efficacy of managing trout is unknown

High flow experiments (fall)	▪ Depending on timing may increase the sand index ▪ Would improve beaches for recreational use ▪ Diminished tribal concerns	▪ May cue brown trout to migrate upstream to Glen Canyon which could increase the number of brown trout that spawn ▪ May improve brown trout egg survival & recruitment ▪ May negatively impact the aquatic food base depending on the timing ▪ Any adjustments to the timing prescribed in LTEMP would require environmental compliance and permits ▪ Efficacy of managing trout is uncertain ▪ May increase costs to generate electricity
High flow experiments (spring)	▪ May reduce brown trout recruitment depending on the timing ▪ May improve the condition of the rainbow trout fishery ▪ May improve the food base depending on the timing ▪ May increase turbidity to benefit native species ▪ Could improve aquatic habitat	▪ May negatively affect the food base depending on the timing ▪ Any adjustments to the timing prescribed in LTEMP would require environmental compliance and permits ▪ Efficacy of managing trout is uncertain ▪ Depending on timing may negatively impact the sand index ▪ May increase costs to generate electricity
Large-scale fishing with gill nets	▪ Cost effective ▪ Likely to have population level impacts on competition & density ▪ Diminished tribal concerns since fish would likely be consumed ▪ Could be accomplished quickly	▪ Would require additional compliance & permits ▪ May not be effective given flow & habitat conditions ▪ Efforts would need to be ongoing to account for how quickly rebounding trout populations ▪ May conflict with NPS regulations
Mechanical removal (electrofishing, various nets, etc)	▪ Less impacts to non-target species ▪ Limited impact to rainbow trout fishery	▪ Tribal concerns ▪ Populations can rebound very quickly meaning efforts would need to be ongoing ▪ Expensive and time & labor intensive ▪ Angler concerns with effect on fishery
Rainbow trout stocking	▪ Stocking with individuals that could outcompete brown trout or are less vulnerable to whirling disease could cause a decrease in brown trout populations	▪ Efficacy is highly uncertain. ▪ Rainbow trout may be more likely to move downstream under high densities and negatively impact humpback chub
Spawning site disruption	▪ Species-specific ▪ Reduced risk of trout moving downriver	▪ Efficacy of managing trout is unknown ▪ Conflicts with tribal concerns ▪ Labor and time intensive

Temperature control device	▪ Could change the temperature to affect the rainbow trout fishery, humpback chub and other native or nonnative species	▪ Efficacy is uncertain ▪ Would require appropriate environmental compliance and permitting ▪ The cost would be very high ($15-150 million) ▪ Depending on the temperature it may impact native species
Trout management flows	▪ May reduce the density of rainbow trout resulting in an increase in size (reduced competition) ▪ May positively impact humpback chub (reduced predation and competition) ▪ May positively affect the food base depending on timing	▪ May negatively impact the rainbow trout fishery ▪ May negatively impact sand resources ▪ May negatively affect food base depending on timing ▪ Tribal concerns ▪ The cost to generate electricity could be significant ▪ Efficacy is unknown
Turbidity enhancement	▪ May reduce trout predation on humpback chub ▪ Diminished tribal concerns	▪ May be expensive depending on mechanism to increase sediment ▪ May reduce gross primary productivity/food base

TMF Experimental Design

Experimental Theory

The experimental theory behind a TMF is that peak discharge of water from the dam is used to push YOY trout into higher elevation near-shore shallow water environments, and then the water level is dropped rapidly with the objective of stranding fry and fingerling-sized trout (<6 months old) in the shallows. Ideally, the reduction in recruitment would lead to lowered densities of trout and may result in an increase in the growth rate and size of adult rainbow trout which is more desirable to anglers. Presumably the reduction in density of rainbow trout in Glen Canyon would lead to decreased competition, and thus less movement downriver into Marble Canyon or the confluence of the Little Colorado River where they may negatively impact humpback chub. During this TMF, as described in the LTEMP ROD, flows are raised above normal operating levels for a prolonged period, and then dropped rapidly to a lower level. Although the TMF was designed to be implemented during periods of high rainbow trout recruitment, it could also be implemented to determine its efficacy as a tool for managing trout and evaluating the impact on humpback chub survival. The TMF would likely need to be implemented multiple times to be most effective, and there is flexibility to implement it up to 3 cycles per month from May through August.

LTEMP identifies specific options for dam operations (including hourly, daily, and monthly release volumes) including experiments that could be implemented to improve conditions and minimize adverse impacts to resources downriver. Release volumes fluctuate based on hydroelectric power demand, but the limits for the elements of base operations (minimum and maximum flows, daily range, ramp rates, etc.) are specified (LTEMP ROD page 30; B-3).

Prior to 1991, large hourly variations in flow caused by power loads were normal; during this time, the rainbow trout population was only maintained by stocking. Recruitment success appeared to increase when flows were controlled and steady (Korman et al. 2012). Fluctuations in flow may limit survival rates of juvenile rainbow trout by displacing them from preferred habitats, depleting food, and causing an increase in stress, energetic costs, and predation (Korman & Campana 2009). Floods or high flow releases from the dam are known to affect the survival rates of incubating life stages and juvenile rainbow trout (Korman et al. 2011a). Once more stable flows were incorporated into dam management in 1991, the rainbow trout population became self-sustaining (Avery et al. 2015).

Juvenile trout tend to utilize low angle shoreline for rearing likely due to lower depth and water velocity compared to high angle shorelines (Korman et al. 2011b). Rainbow trout growth is affected by high fluctuating flows because there is an energetic cost associated with young trout maintaining position in fluctuating environments (Korman and Campana 2009). Fluctuations in flow, even for a short period, can result in dewatering of spawning habitat, which can cause increased mortality of eggs. Fluctuations can also cause displacement of juvenile fish from shallow low-velocity habitats along the shoreline that are most conducive to efficient foraging (Korman et al. 2011b). Survival of trout in response to a fluctuating flow may depend on the timing of changes in flow variability relative to early life stage shifts in use of low (cobble bars) and high angle (talus slopes) shorelines (Korman et al. 2011b). Habitat use of early life stages of trout also varies by season meaning that the timing of flow fluctuations can impact survival (Yard et al. 2016).

Recruitment could be limited by increasing flow variation in late spring or summer when age-0 trout utilize near-shore shallow-water environments (Korman et al. 2011b). Adults tend to shift towards deeper water during increases in discharge (Pert and Erman 1994), meaning they are less susceptible to stranding and are less likely to be directly affected by TMFs.

Triggering Mechanism
TMFs are an experimental management tool designed to control production of trout at the recreational trout fishery in Glen Canyon and limit emigration downriver where they may negatively impact humpback chub. The LTEMP BO specifies that TMFs may be implemented when observed or predicted rainbow trout recruitment levels are high (Table 3). Rainbow trout recruitment is the metric for determining when a TMF should be implemented because downriver dispersal of trout is most likely to occur when recruitment is high. Rainbow trout are most likely to be vulnerable to TMFs from May through July, but recruitment cannot be forecast from field data reliably until July. By July, only 50% of rainbow trout age-0 remain in low-angle habitat, where they may be more vulnerable to stranding during a TMF (Yard & Korman, ARM 2020). In other words, the timeframe when recruitment forecasting can most reliably be determined occurs in the middle of the window when TMFs can be implemented, thus affecting our ability to effectively utilize field data to forecast recruitment. However, a model has been developed which utilizes soluble reactive phosphorous and spawner abundance to predict rainbow trout recruitment (Yackulic, unpublished data). Although model inputs can always be improved and may need to be adjusted to account for the effect of increasing numbers of brown trout on rainbow trout recruitment, the existing model provides a basis for predicting recruitment.

As specified in the LTEMP ROD, TMFs could also be implemented early in the LTEMP period to learn more about the effectiveness of the flow as a management tool. Other flows listed in the

LTEMP EIS that may influence the decision to implement a TMF include equalization flows and high flow experiments (HFE). Equalization flows are thought to cause a subsequent increase in rainbow trout (Avery et al. 2015) which might also impact the decision to implement a TMF. Implementation may also follow a spring HFE which is expected to increase rainbow trout recruitment by stimulating the food base and thus trout production (LTEMP ROD page 53). Regardless, potential short-term unacceptable impacts to other resources would need to be considered annually in the decision to implement a TMF (LTEMP ROD page 39).

Subsequent TMFs would only be implemented if the initial TMF proved to be successful in reducing trout recruitment in Glen Canyon and there were not long-term unacceptable impacts to other resources such as increased costs or population level effects to species of concern or population level increases in non-native fish. Ideally, if a TMF was successful, it would reduce the number of times mechanical removal would be needed.

Table 3. LTEMP considerations for implementing a TMF (from LTEMP ROD page 39, B-12)

Experimental Treatment	Trigger & Primary Objective	Replicates	Duration	Annual Implementation Considerations	Long-term Off-ramp Conditions	Action if Successful
Trout management flows	Trigger: Predicted high trout recruitment in the Glen Canyon reach Objective: Test efficacy of flow regime and survival of humpback chub	Implement as needed when triggered after consultation with tribes; test may be conducted early in the 20-year period even if not triggered by high trout recruitment	Implemented up to 3 cycles per month, in as many as 4 months (May-August)	Potential short-term unacceptable impacts on resources listed in Section 1.3	TMFs have little or no effect on trout recruitment after at least three tests; or long-term unacceptable adverse impacts on the resources listed in Section 1.3 are observed	Implement as adaptive treatment triggered by predicted high trout recruitment in Glen Canyon, taking into consideration Tribal concerns

Hydrograph Elements for TMF implementation

The 2016 LTEMP ROD includes normal operating restrictions for operation of the dam (Table 4). There are also certain guidelines for implementing a TMF described in the ROD. A TMF may be implemented up to three periods per month from May through August and feature repeated fluctuation cycles that consist of relatively high flows (e.g., 20,000 cubic feet per second [cfs]) sustained for a period of time (potentially ranging from 2 days to 1 week) that would inundate low-angle nearshore habitat and prompt young fish (specifically rainbow trout) to move into the shallows along the channel margins (Table 4). The high flows would be followed by a rapid drop to a very low flow (e.g., 5,000 cfs to 8,000 cfs) within normal operations (Table 4) which would potentially strand YOY trout, and depending on the time of year, possibly expose eggs, and prevent them from hatching. The low flow would be maintained for a period of less than a day (e.g., 12 hr) to limit adverse effects to the food base (Table 4). A low flow during the day is expected to have the best chance of exposing stranded fish to direct sunlight and heat, thereby increasing mortality. If the low flow was timed during the day, operating restrictions specify that flows must be ≥ 8,000 cfs from 7 am – 7 pm. Up-ramp rates for the TMF would be the same as the limit for this alternative overall (i.e., 4,000 cfs/hr). The down-ramp from peak to base would be over a single hour (e.g., 15,000 cfs/hr for a drop from 20,000 cfs to 5,000 cfs).

Table 4. LTEMP requirements for normal operations (LTEMP ROD page 30; B-3)

Implementation timeframe	# of cycles per month	Peak magnitude	Minimum flow	Ascending ramp rates	Descending ramp rates	Maximum daily flow range*
May to August	≤3	≤ 25,000 for normal operations for 2 days to 1 week	5,000-8,000 cfs for < 1 day (e.g. 12 hr) (5,000 from 7 pm-7am and 8,000 from 7 am-7pm)	≤4,000 cfs	≤ 2,500 cfs (can exceed this for a TMF)	10 x monthly volume (in kaf) June to Aug., and 9 x monthly volume in other months not to exceed 8,000 cfs

*The maximum daily flow range is based on the monthly release volumes which vary depending on the flow parameters determined during the August 24-month study for the next water year.

In addition to the TMF described in the LTEMP ROD, a more recent hypsometric analysis conducted by GCMRC includes two additional alternatives for the hydrograph (Giardina et al. 2022). The first is to implement a TMF during years when equalization between Lake Powell and Lake Mead is required such as last occurred in 2011. Rainbow trout recruitment would be expected to be higher during equalization years (Avery et al. 2015). During equalization years, flows are higher and steadier than normal operations through spring and summer which provides sufficient time for age-0 trout to colonize the newly wetted habitat before the flows are dropped back to normal operational levels. The second alternative is referred to as "go low, not high." In this alternative, flows are rapidly decreased from the normal peak flow to lower than the normal minimum flow with the flow dropping to as low as ≈ 5,000 cfs which results in stranding in algae and submerged vegetation (Giardina et al. 2022). Downstream effects are minimized by using a short-duration low flow period followed by a rapid increase to a higher flow (Giardina et al. 2022). Wave attenuation dynamics predict that the rapid increase to a higher-level flow would move downriver so quickly that it would catch up with the lower flow released earlier in the day (Giardina et al. 2022). The potential impact to other resources such as downstream habitats utilized by humpback chub or recreation could be minimized with this strategy (Giardina et al. 2022).

Monitoring & Effectiveness

If TMFs are determined to be effective for controlling trout numbers while minimizing impacts to other resources, they may be deployed as an adaptive experimental treatment triggered by estimated trout recruitment. The efficacy would be measured by a reduction in trout numbers after accounting for compensatory survival[1] of remaining fish, an increase in the size and body condition of the rainbow trout at Lees Ferry, and either increased or stable humpback chub survival. Ongoing long-term research and monitoring programs that collect trout and humpback chub data (Trout Recruitment and Growth Dynamics (TRGD) project, Juvenile Chub Monitoring (JCM)-east, JCM-west and LCR sampling) would help inform these metrics. It is unknown if the flow modifications would result in stranding and mortality of juvenile humpback chub and depending on the timing it may overlap with periods when larval humpback chub are found in nearshore habitats.

[1] The natural mortality rate decreases when the population falls below a certain level to account for the lower population size.

Near the LCR confluence, under current temperature releases, negative impacts to YOY humpback chub would likely be minimal because spawning occurs in the LCR, fish that leave the LCR at smaller sizes are already expected to have extremely low survival, and most YOY leave in July or later when they are relatively large and capable of moving to avoid stranding (Yackulic et al. 2014). Warming mainstem conditions near the LCR could lead to increased survival of smaller fish that leave the LCR earlier in the season or potentially lead to mainstem spawning. Either of these conditions would increase the potential for stranding effects. In addition, mainstem spawning most likely occurs in the western Grand Canyon (Van Haverbeke et al. 2017), so early life stages of humpback chub may already be vulnerable to stranding though changes in flow decrease with increasing distance from the dam. On the other hand, a TMF is expected to benefit humpback chub by reducing rainbow trout and possibly other non-native predators, while not affecting existing habitat used by humpback chub. Either way, the impact of the TMFs on humpback chub and trout would be evaluated.

If TMFs prove to be effective in controlling trout production and emigration, regular implementation of TMFs may need to include variable timing to prevent adaptation of the population to specific timing (e.g., increase in recruitment by fall-spawning rainbow trout) (LTEMP ROD page 52, B-25) or to account for compensatory survival.

Summary

TMFs are intended to reduce the recruitment of rainbow trout within Glen Canyon. Higher recruitment leads to increased competition and lower condition of rainbow trout in the Lees Ferry recreational fishery which increases the likelihood of downriver dispersal and competition with and predation on humpback chub. Although implementation of a TMF may reduce recruitment of trout, it may negatively impact other resources by increasing energy generation costs, increasing beach erosion, conflicting with tribal concerns with the taking of life, and potentially stranding native fish species. There are also various design aspects that need to be determined prior to implementation. In addition, rainbow trout populations have remained low, and brown trout populations have increased drastically in Glen Canyon since 2016. Brown trout predation on humpback chub is now of more concern than rainbow trout, and because brown trout can outcompete and prey on rainbow trout, they are a threat to maintaining a viable recreational fishery in Glen Canyon. However, TMFs were not originally designed to target brown trout.

Other Considerations

Brown trout

Background

Brown trout were originally introduced into several of the Colorado River tributaries in the 1920s and 1930s. Since 2010, annual control efforts have been conducted in the Bright Angel Creek tributary to reduce the number of brown trout to reduce the risk of predation to humpback chub (Healy et al. 2020). The LCR is the most important tributary for humpback chub spawning and growth, and annual monitoring is conducted to ensure that recovery efforts are effective. Brown trout numbers have been increasing in Glen Canyon over the last several years (Table 5), which is due to successful reproduction and recruitment of locally hatched fish into the spawning class in combination with immigration from downstream reaches (Runge et al. 2018). This increase in brown trout population has likely led to increased competition with rainbow trout.

Brown trout spawn from October to December with emergence occurring approximately two months later; young fry are most vulnerable to fluctuations in flow following emergence (Runge et al. 2018). Based on a synthesis of data across tailwaters in the western U.S., high flow velocity during winter months when fry are growing and rearing can decrease brown trout recruitment (Dibble et al. 2015), possibly due to displacement or high energetic costs that decrease survival. Even though adult brown trout may not be directly affected by high flow volume, ultimately, flow can affect recruitment thereby altering fish density, which plays a role in determining adult size (Dibble et al. 2015).

Although diets of brown trout within their native range are dominated by aquatic invertebrates, in areas outside their native range such as the Colorado River, their diet switches to include fish which also allows them to grow larger in size (Budy et al. 2013). Their feeding strategy is flexible and allows them to feed on large numbers of small prey or small numbers of large prey (Sanchez-Hernandez and Cobo 2015). This is concerning not only due to the negative impact on native fish such as humpback chub, but it also means that they pose a threat to rainbow trout in Lees Ferry. Brown trout condition is higher than rainbow trout in Lees Ferry, which is likely due to their piscivorous diet as well as differences in their morphology (Yard & Korman, 2020 ARM).

In 2020, the number of small adult brown trout (200-349 mm) in Glen Canyon was estimated to be 7,000 and the number of large adults (>350 mm) was estimated as 4,300 (Table 5; Yackulic unpublished data). The population has been steadily increasing since 2015 (Table 5). Though most salmonids are not effective predators until they are > 300 mm, brown trout are piscivorous at smaller sizes and are tolerant of warmer water temperatures, making them more of a threat to humpback chub and other native fish (Ward and Morton-Starner 2015). However, brown trout are less effective predators of humpback chub as turbidity increases (Ward et al. 2016).

Table 5. The fall population estimate (n) of adult (>200 mm) brown trout at Lees Ferry with 95% confidence intervals from 2015-2020.

Year	>200-349 mm n (95% CI)	>350mm n (95% CI)
2015	1,400 (900-2,100)	1,400 (900-2,000)
2016	2,000 (1,500-2,600	1,300 (900-1,800)
2017	3,300 (2,500-4,400)	1,600 (1,100-2,100)
2018	4,200 (2,200-6,500)	3,400 (1,400-5,600)
2019	6,100 (4,900-7,300)	4,200 (3,200-5,200)
2020	7,000 (5,800-8,400)	4,300 (3,300-5,400)

Tools for managing brown trout

Many of the potential tools available for managing brown trout are the same as the ones for rainbow trout (Table 2). There are a few additional tools that might be applied specifically for brown trout (Table 6). For example, the National Park Service is currently evaluating an incentivized harvest program that rewards anglers for catching and retaining brown trout at Lees Ferry with the objective of reducing the population to an acceptable level. However, preliminary results from the program suggest an insignificant effect on overall population abundance due to low harvest rates (https://www.nps.gov/glca/planyourvisit/brown-trout-harvest.htm).

Table 6. Tools and experimental actions that may be used to manage brown trout populations (table created based on information from Bair et al. 2017 presentation on management options during Brown Trout Workshop 2017, NPS Non-Native Aquatic Species EA 2018 & subsequent ideas by stakeholders).

Trout Management Tool or Experimental Action	Advantages	Disadvantages
Brown trout stocking (Trojan Y chromosome)	▪ Stocking with YY female brown trout would result in all XY male offspring (prevent reproduction)	▪ Efficacy is highly uncertain ▪ May still have negative effects on rainbow trout & humpback chub ▪ Temporary increase in adult brown trout due to stocking ▪ Increased abundance may cause outmigration of brown trout into Marble Canyon
Incentivized harvest	▪ Species-specific ▪ May result in an increase in size of rainbow trout ▪ May alleviate tribal concerns assuming fish are consumed	▪ May be difficult to convince anglers to retain brown trout ▪ May not be effective at reducing the population
Vegetation (aquatic) removal	▪ Removing habitat assumed to be used by larval brown trout may result in decreased recruitment ▪ Limited impacts to other resources	▪ Efficacy is highly uncertain ▪ May require additional compliance ▪ May be expensive ▪ May push other non-native fishes downstream

Considerations for adapting hydrograph

The current design of the TMF experiment is unlikely to be effective for reducing recruitment of brown trout because the timeframe the experiment can be implemented (May through August) is after the two-month window when early life stages of brown trout are most vulnerable to flow (February through April). However, recent research suggests that larval brown trout may not utilize nearshore habitats but instead retreat to vegetation in deeper waters (Dibble, unpublished data). Because ambient temperatures are also typically lower February through April, survival rates of brown trout fry that have been stranded in shallow pools by low flows may be sufficiently high to prevent a population level effect on adult abundance. If this occurs, additional cycles/replicates of the TMF may be necessary to account for potentially higher survival rates due to lower temperatures. Although air and water temperatures are warmer by May when TMFs can currently be implemented (meaning mortality rates of stranded fish might be higher than February through April), YOY brown trout are sufficiently large and capable swimmers by May making them much less vulnerable to stranding during low flows. Thus, implementation of TMFs to limit brown trout recruitment would likely be most effective if implemented from February through April to coincide with emergence (Giardina et al. 2022), yet current compliance only allows for implementation from May through August. Additional environmental compliance would be needed to allow for TMF implementation in February, March or April when it is likely to be most effective at reducing brown trout.

Research Updates

Recruitment forecasting & modeling

Recent research suggests that condition of rainbow trout in the fall is a good predictor of sexual maturation rates for the following winter and spring (Korman et al. 2021). When factors support increased growth rates (i.e., prey availability, water temperature, etc.), fish condition is high (≥ 1: mass of an individual relative to the average mass of others of the same length), and the likelihood that the trout will reach sexual maturity and spawning activity increases. Understanding how condition affects sexual maturation and recruitment may help develop a more reliable method for forecasting recruitment which is the metric for determining when to implement a TMF. Recruitment forecasting can most reliably be determined using field data in July which is in the middle of the window when TMFs can be implemented.

The current nutrient model is perhaps a better method of predicting rainbow trout recruitment and it uses soluble reactive phosphorous in Lees Ferry as a predictor. Predictions of rainbow trout recruitment could potentially be improved by examining the amount of soluble reactive phosphorous during the previous year and the in-flows into Lake Powell in the current year. Recruitment estimates for rainbow trout are calculated based on the soluble reactive phosphorous inputs into Lake Powell from the current year and the number of rainbow trout >150 mm based on catch per unit effort data from the previous year (Yackulic, unpublished data). The model estimates could provide enough accuracy to aid with management decisions. However, the rainbow trout recruitment estimates may be below the model predictions if brown trout populations continue to increase and suppress rainbow trout.

Literature review & hypsometric analysis
GCMRC recently completed a literature review that examines the key factors affecting fish stranding and includes recommendations to guide the timing and flow rate for designing a TMF, based on existing literature (Giardina et al. 2022). The report also includes a hypsometric analysis to predict stranding risk for age-0 trout in Glen Canyon under a range of TMFs, using existing bathymetric data, flow, and habitat suitability models. The study examines stage-discharge relationships and hydraulic model predictions of depth and velocity.

Although the literature review and hypsometric analysis focused on rainbow trout, the key findings below may apply to rainbow trout and brown trout (Giardina et al. 2022):

- The greater the difference between the high and low flow elements of a TMF cycle, the greater the stranding risk.
- A steady flow of 16,000 cfs followed by a rapid drop to a low flow of 3,000 cfs would also be effective at stranding trout and may have less impacts to generation of electricity and sediment than a high flow of 25,000.
- Stranding risk is predicted to increase with decreases in the low flow element of the TMF.
- Compensatory survival can occur after a TMF meaning that repeated cycles are needed to be effective.
- Repeated cycles may also be necessary to account for the difference in size of susceptible trout due to the prolonged emergence period.
- If a TMF hydrograph design utilizes an increase from normal operations to a high flow prior to dropping to a low flow, the duration of time that the flow needs to remain high for fish to colonize the newly wetted habitat is unknown; the best available evidence indicates this process of colonizing newly wetted shorelines may take several weeks.

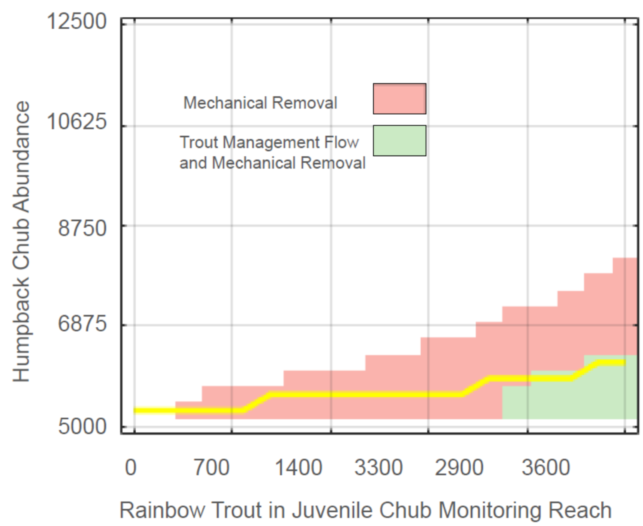
Brown Trout Early Life History
A project to examine the early life history of brown trout similar to one that was conducted for rainbow trout was included in the FY21-23 Triennial Budget and Work Plan. The data obtained from this project will increase understanding of early life stage vital rates for brown trout, assess hatch and swim-up dates to identify when brown trout emerge from gravel redds, and identify habitat use in low vs. high-angle shoreline habitat to understand stranding vulnerability to experimental flows, including TMFs. Initial results from this project suggest that there is uncertainty whether larval brown trout are utilizing nearshore habitats during their early life history meaning they may not be susceptible to nearshore stranding resulting from a TMF. During the spring disturbance flow in March 2021, flows were dropped to 4,000 cfs followed by a high flow of approximately 20,000 cfs. Since the low flow coincided with peak brown trout emergence it provided a unique opportunity to collect additional data on age-0 brown trout susceptibility to flows. However, since 2021 was the first year of the brown trout early life stage study (BTELSS), baseline data for comparison to a year that lacked a spring disturbance flow cannot be collected until FY22. Thus, it may be a few years before the effectiveness of the spring disturbance flow at reducing brown trout survival can truly be evaluated.

Trout Recruitment, Growth & Population Dynamics
The trout recruitment, growth and population dynamics (TRGD) project is ongoing and provides a long-term dataset and information on rainbow and brown trout populations in Lees Ferry. TRGD project data is used to determine the effects of experimental flows on trout recruitment, growth rates of juvenile and adult trout, and dispersal of age-0 trout from Glen Canyon to Marble Canyon. In addition, the TRGD project aims to understand other key factors (besides flow manipulation) that control the abundance and growth of trout populations, including fish density, prey availability, and nutrient concentrations from Lake Powell. An improved understanding of other ecosystem drivers that benefit the rainbow trout fishery could lead to the identification of non-flow policies that may limit downstream dispersal of rainbow trout and potentially control brown trout populations.

Bioeconomic model
A bioeconomic model to assess the impact of removing rainbow trout under different scenarios on adult humpback chub abundance has been developed to assist with management decisions (Bair et al. 2018, Donovan et al. 2019). The model is based on general assumptions in the LTEMP EIS and suggests that to cost-effectively meet humpback chub abundance goals, TMFs should be considered when rainbow trout recruitment is high (>1,000,000), rainbow trout populations in Marble Canyon and the JCM-east Reach (RM 63.45-65.2) are high (>290,000 and >2,000), and the humpback chub population is low (<7,000) (Donovan et al. 2019, Bair, unpublished data). Even when humpback chub populations are low, it is more cost effective to conduct mechanical removals than implement a TMF unless rainbow trout recruitment and populations in Marble Canyon and the JCM-east reach are high (Figure 2). One year of mechanical removals of rainbow trout at the LCR is estimated to cost $450,000 based on $75,000 for every month of removal (personnel, removal equipment, logistics, etc.) and 6 months of trips (Bair et al. 2018). The cost of implementing a single TMF is estimated as $450,000 (EIS Appendix K page K-114).

Although the model was developed and applies specifically to rainbow trout it could be updated to incorporate brown trout. Brown trout parameters would have to be incorporated into the existing model, and the margin of error may be much greater than that for rainbow trout since there are many unknowns, but it would provide an idea of the targets for and the feasibility of removing brown trout.

Figure 2. The conditions under which mechanical removal and a combination of trout management flows and mechanical removal are cost-effective actions to meet humpback chub abundance goals. At a humpback chub population of approximately 8,000 it is most cost-effective to conduct mechanical removal (when other conditions warrant action). It does not become cost-effective to implement trout management flows until the humpback chub population falls below 6,500, the rainbow trout population in the juvenile monitoring reach is greater than 2,800, and the number of rainbow trout in Marble Canyon exceeds 300,000 adults and 1,000,000 recruits (Bair unpublished data).



Model to examine turbidity

Development of a model to examine how dam operations could be adjusted to increase turbidity may be helpful in determining whether it could be used to improve conditions for humpback chub and decrease efficiency of sight-feeding predators such as rainbow trout in Marble Canyon and near the LCR. As turbidity increases, reactive distance (feeding efficiency) decreases. Since higher reactive distance (i.e., lower turbidity) is positively related to rainbow trout growth, survival, and reproduction (Korman et al. 2021), and more rainbow trout are associated with lower juvenile humpback chub survival (Yackulic et al. 2018), an increase in turbidity could reduce predation. As such, a turbidity model could evaluate different scenarios and provide inputs for the bioeconomic model to aid decision making on dam operations.

Sources of Uncertainty

Though research over the last few years has helped provide clarity regarding some of the key questions (Table 7), there are still many elements for which answers might not be obtained until full implementation of a TMF.

Flow design

Although the LTEMP ROD provides parameters for base operations, it does not specify the exact design for the TMF but rather provides limits within which the TMF must be conducted. The design for implementing a successful TMF is unknown other than it must fall within the following limits:

- The maximum peak discharge of the TMF cycle must be below 25,000 cfs, but the threshold and duration that would be most effective at luring trout into the shallow water habitats is unknown.
- The time interval between reaching the maximum flow and initiating the flow recession is also a key uncertainty.
- The downward ramp rate can exceed the operational limitation of 2,500 cfs/hr, and while the hypsometric analysis suggests that faster rates optimize stranding, the specific down ramp rate needed is uncertain (Giardina et al. 2022).
- The minimum flow must be between 5,000-8,000 cfs depending on the time of day, but the minimum discharge at the peak of the TMF cycle is also unknown. The hypsometric analysis predicts that a low flow of 3,000 cfs would be most effective at stranding.
- The duration of the flow regardless of whether the flow starts out high or low is unspecified.
- Although there can be up to 3 cycles per month from May through August, the number of TMF cycles and the timing during that period (only in May and June, May, June & July, etc.) that are needed to account for compensatory survival and the extended emergence to have the desired affect are unknown.
- High recruitment is the trigger for a TMF, but it cannot be estimated using field data until the timeframe when the TMF is meant to be implemented. The current recruitment model uses the amount of soluble reactive phosphorous in the spring to estimate recruitment. The model could be modified to predict soluble reactive phosphorous in the spring by using the observed amount of soluble reactive phosphorous from the prior winter or fall. This would allow trout recruitment to be forecasted prior to the window when a TMF would need to be implemented.
- It is unknown exactly when the TMF cycle should be implemented but it is assumed to be most effective in May and June when peak rainbow trout emergence occurs and young trout are most vulnerable to flow changes (Yard & Korman, ARM 2020). If targeting brown trout it would likely need to occur between February and April.
- Based on the hypsometric analysis, the TMF could be designed with a “go high, then low” flow (as specified in the LTEMP ROD), an equalization flow, or a “go low, not high” approach (Giardina et al. 2022). Predicted stranding risk would vary depending on the approach selected and may have different impacts on other resources depending on the strategy (Giardina et al. 2022).

Key elements

There are several key elements that are uncertain; some of these can be resolved with study while others may not be known until a TMF is implemented (Table 7).

Table 7. Key Uncertainties and Possibility for Resolving Uncertainties with Experimentation (Adapted from discussions that occurred by a stakeholder group during a series of meetings in 2019).

Key Elements	**Questions**
Elements that can be resolved with study (lab-based, models, or by examining historical data)	▪ Are YOY brown trout susceptible to flow manipulations? ▪ Are YOY brown trout utilizing near-shore habitat where they would be susceptible to flow variations? ▪ What is the shortest duration of the low flow to be effective? ▪ What time of day is most effective?
Elements that can be resolved with small scale field testing	▪ What is the effectiveness of a TMF on different size classes?
Elements that can be resolved with full implementation	▪ Once the flow has dropped, what proportion of the population is removed? ▪ What flow recession rates are effective at stranding? ▪ What is the duration of the high flow that needs to be maintained for fish to colonize? ▪ How many cycles are needed to account for compensatory survival or extended emergence? ▪ What is the accuracy of recruitment forecasting?
Elements included in FY21-23 triennial budget & work plan (from Project H; TWP 2021-2023) that will help inform TMFs	▪ Understand the early life history stages of YOY brown trout in Glen Canyon ▪ Determine hatch and swim-up dates to identify when brown trout are likely to be emerging from gravel redds ▪ Identify habitat preferences for low angle and high angle nearshore habitat to understand whether brown trout are susceptible to flow manipulation. ▪ Determine the effects of flows on recruitment of YOY rainbow and brown trout in Glen Canyon, growth rate of juveniles & adults, and dispersal of YOY trout from Glen Canyon ▪ Understand the key elements of flow in the design of a TMF ▪ Is it necessary to implement a high flow followed by a drop or would a rapid drop from normal flow be sufficient to reduce YOY numbers? ▪ Understanding how trout condition affects sexual maturation and recruitment, which may help develop a more reliable method for forecasting recruitment

Impacts to other resources

TMFs were designed specifically to reduce recruitment of rainbow trout in the Glen Canyon reach to reduce the likelihood that they will move downstream and negatively impact humpback chub. However, the impacts of the flow on humpback chub are uncertain and the most effective flow components for designing the hydrograph are unknown. It is possible that social, recreational, environmental, and electricity generation costs may outweigh the uncertain benefits of TMFs. The effectiveness of implementing a TMF relies on the assumption that rainbow trout are the primary factor limiting humpback chub recruitment and adult abundance, and that implementation will impact rainbow trout population dynamics. However, other factors such as water temperature and food availability may be just as or more important in influencing humpback chub growth and survival rates (Yackulic et al. 2018).

The extent to which brown trout utilize nearshore habitat was originally thought to be minimal during the timeframe when they would most likely be susceptible to stranding (Yard & Korman, Annual Reporting Meeting 2020). However, brown trout numbers in Glen Canyon have been increasing and a project in the FY21-23 Triennial Work Plan includes a project to examine this more closely. Larval fish collected from shoreline habitats in 2021 and during the first four trips in 2022 were all identified as rainbow trout, suggesting that brown trout may not be utilizing shoreline habitats in early life stages in the same way as rainbow trout fry (Dibble, unpublished data). This means that a steady flow designed to lure fry into the nearshore environment to strand fish upon flow reduction may not work for this species since they are utilizing alternate, and perhaps offshore habitats.

Both rainbow and brown trout preferentially prey on native fishes including humpback chub compared to non-native fishes (Yard et al. 2011). However, rainbow trout are a desired species in the Glen Canyon reach due to the GCDAMP resource goal of a recreational sport fishery. Rainbow trout are also more susceptible to trout management flows during the timeframe that is specified in LTEMP and the habitats that early life stages occupy. Brown trout are perceived as a bigger threat when abundance is high because they are more piscivorous than rainbow trout.

Tribal Perspectives

The tribes that are part of the GCDAMP shared the following perspectives related to TMFs. This section is not a substitute for formal consultation but is meant to provide a deeper understanding of the tribal perspective and relationship to life and the Grand Canyon. Tribal concerns are an important component of a decision to implement a TMF.

Hopi (submitted by Jakob Maase)

Although the Hopi support removal of non-natives to protect native species, they do not support the taking of life for no purpose. Consumption of the removed fish by humans or eagles or another bird or animal would be consistent with Hopi values. Hopi are stewards of the land and recognize the interconnectedness of the ecosystem and are sensitive to the effects of each resource on the other. A TMF would be inconsistent with Hopi values because the larval fish that would be removed during the flow would not be used for another purpose.

Southern Paiute Consortium (submitted by Daniel Bulletts)

The Southern Paiutes have a deep spiritual, physical, and emotional connection to the Grand Canyon and the Colorado River. To place something there that is foreign to the ecosystem is not only wrong but will have some long-lasting negative affect over time and affect all that live and thrive in the Grand Canyon. Trout management flows conflict with our cultural connection to the Grand Canyon and Colorado River.

The Southern Paiute Consortium perspective related to trout management flows is simple. The more you try to manage and control the worse things will get. If the trout was meant to be in the Colorado River system Mother Nature will help that along but if they are not, then they will leave. Southern Paiutes believe that all life is special and has its place in the world and Mother Nature takes care of all life in her own special ways.

Pueblo of Zuni (adapted from Runge et al. 2015)

The Grand Canyon is the place of Zuni emergence into this current world at a place called *Chimik'yana'kya dey'a*, also known as Ribbon Falls in Bright Angel Canyon. The natural environment that Zuni people saw at Emergence became central to traditional Zuni culture. In fact, all of the plants that grow along the stream from Ribbon Falls to the Colorado River, and all the birds and other animals, springs, minerals and natural resources located in the Grand Canyon and its tributaries, have a central place in Zuni traditional cultural practices and ceremonial activities. The confluence of the Little Colorado and Colorado Rivers is understood to be a spiritual umbilical connection between the Pueblo of Zuni and the Grand Canyon that is facilitated through the union of the Zuni River with the Little Colorado and the Colorado Rivers. The confluence is also held by the Zuni people to be an extremely important and sacred place because of its abundance of aquatic and terrestrial life that simultaneously expresses and represents the fertility of nature.

The Colorado River is a particularly important place to the Zuni people because it was the location of an important historical event. This historical event was conveyed to Frank Hamilton Cushing, an American Anthropologist, by the Zuni in the late nineteenth century and is summarized below to convey the deep, intense, and remarkable significance that the Colorado River and the aquatic life within it indelibly hold for the Zuni people.

"Shortly after Emergence, men of the Bear, Crane, and Seed clans strode into the red waters of the Colorado River and waded across. The men of the clans all crossed successfully. The women travelling with them carried their children on their backs and they waded into the water. Their children, who were unfinished and immature (because this occurred shortly after Emergence), changed in their terror. Their skins turned cold and scaly and they grew tails. Their hands and feet became webbed and clawed for swimming. The children fell into the swift, red waters. Some of the children became lizards, others turned into frogs, turtles, newts, and fish. "The children of these clans were lost to the waters. The mothers were able to make it to the other side of the river, where they wailed and cried for their children. The Twins heard them, returned, and advised all the mothers to cherish their children through all dangers. After listening to the Twins, those people who had yet to pass through the river took heart and clutched their children to them and safely proceeded to the opposite shore. "The people who successfully made it out of the river rested, calmed the remaining children, and then arose and continued their journey to the plane east of the two mountains with the great water between." (Cushing, 1896, 1920, 1988; as summarized in Dongoske and Hays-Gilpin, 2016).

As a consequence of this historical event, all aquatic life is recognized by present day Zunis to be descendants of those Zuni children who were lost to the waters, thus creating a strong and lasting familial bond to all aquatic life and a fundamentally important stewardship responsibility. The animals, including all aquatic life, birds, plants, rocks, sand, minerals, and water in the Grand Canyon convey special meaning and have significant material and spiritual relationships to the Zuni people. To needlessly take life causes an imbalance in the natural world, and also disturbs the harmony and health of the spiritual realm and the Zuni peoples. As such, the Zuni people believe that actions that occur in the Colorado River in Grand Canyon directly affect the

Zuni people; for example, they believe that removing non-native fish may result in the demise of Zuni youth and pregnant women.

Navajo Nation (submitted by Erik Stanfield)
The overall ethic of Navajo Nation in relation to resource management is to find balance and beauty with the natural environment by avoiding invasive management practices that conflict with the paramount tribal value of maintaining natural and self-sustaining processes. This ethic also includes the avoidance of introducing and/or maintaining non-native populations of any species. TMFs conflict with tribal values in their support and maintenance of non-native species since these flows are not intended to mimic natural flows/processes but are to limit the spread of rainbow trout below Lees Ferry, and not an attempt to reduce or eliminate them. This activity does not support a natural process, highlights a conflict in balanced environmental management by actively supporting the existence/management of non-natives, and promotes an incoherent management strategy in the Colorado River.

Generally, TMFs are not in line with Navajo Nation values or with the natural process (and other compatible) LTEMP goals because of the narrow focus of the activity. It is, however, recognized TMFs may be important in providing some short-term protection for native species and in observing their efficacy as a management technique for potential use with other non-natives in the future.

Hualapai (submitted by Carrie Cannon)
Hayiŧađa, the Hualapai name for the Colorado River, is a descriptive terminology that refers to the water as the backbone or spine. Hualapai ancestral land base encompasses 7 million acres of northwestern Arizona bound by the Colorado River to the north and west, the Little Colorado River to the east, and the Bill Williams and Santa Maria Rivers to the south. Although the Hualapai ancestral land base once included a far greater region, our present-day Reservation encompasses 1 million acres which includes the mid-point of the Colorado River from river mile 165 to river mile 273 as the northern boundary. The Hualapai have had extensive relationships with tribal neighbors such as the Southern Paiute to the north, the Hopi to the east, and many other tribes in the region which also call the Grand Canyon home.

Hualapai look at the entire ecosystem in its totality, including the rock elements, the plants, the birds, insects, fish, mammals, the river itself, and their role among them as caretakers of this land that they call home. The TMF is an effort to restore an aspect of this ecosystem back to its former realm by working to find ways to promote the native fish that once abounded. Hualapai support decisions that attempt to restore balance and health to how the ecological system once functioned pre-dam. We are presented with many challenges in our modern era, including how the dam has dramatically changed the original landscape. Although Hualapai are working within a different set of circumstances than their ancestors encountered, they believe in adapting to seek the highest good for the land and its many inhabitants.

Recommendations/Next Steps

There are many unknowns related to whether implementation of a TMF experiment would be successful or not. The hydrograph that would be most effective needs to be determined. The first step would be to re-examine the existing management and experimental actions available for managing trout (Tables 2, 6), and to determine whether there are any that could be explored that would have fewer negative effects on other resources. Since the focus of this evaluation was on TMFs, these tools were not thoroughly evaluated in this report. It would also be valuable to determine if there are additional tools that could be evaluated or implemented.

It is unclear whether the costs to other resources of implementing a TMF outweigh the benefits. Implementation of a TMF conflicts with tribal concerns with taking of life (Appendix A) and anglers' concerns about the impact on the recreational rainbow trout fishery. However, if the recruitment model predicts that rainbow trout recruitment will be very high or the TMF is expected to positively impact humpback chub, implementation might be considered. Regardless, if a TMF is to be further considered as an option, there are several questions that could be addressed by designing a study to make a more informed decision related to implementation (Table 7).

If a TMF is determined to be a viable option or there is a desire to implement it as an experimental action, the bioeconomic model could be used to identify the conditions under which it should be implemented, similar to the sediment conditions required for implementing a high flow experiment. A multi-agency group of experts could then be assembled to evaluate the conditions and determine whether implementation of a TMF was warranted. As with the implementation of any experiment, the current conditions should be considered and a TMF should only be implemented if it is determined that no unacceptable adverse impacts are likely to occur. Per the LTEMP ROD, an unacceptable adverse impact will include significant negative impacts on resources as a result of experimental treatments that were not analyzed for Alternative D in the LTEMP EIS.

Literature Cited

Avery LA, Korman J, Persons WR. 2015. Effects of Increased Discharge on Spawning and Age-0 Recruitment of Rainbow Trout in the Colorado River at Lees Ferry, Arizona, North *American Journal of Fisheries Management* 35:671-680.

Bair LS, Yackulic CB, Springborn MR, Reimer MN, Bond CA, Coggins LG. 2018. Identifying cost-effective invasive species control to enhance endangered species populations in the Grand Canyon, USA. *Biological Conservation* 220:12-20.

Barrett, JC, Grossman GD, Rosenfeld J. 1992. Turbidity induced changes in reactive distance of rainbow trout. *Transactions of the American Fisheries Society* 121:437–443.

Budy P, Thiede GP, Lobon-Cervia J, Fernandez GG, McHugh, P, McIntosh A, Vollestad LA, Becares E, Jellyman P. 2013. Limitation and facilitation of one of the world's most invasive fish: an intercontinental comparison. *Ecology* 94: 366-367.

Cross WF, Baxter CV, Donner KC, Rosi-Marshall EJ, Kennedy TA, Hall Jr. RO, Wellard Kelly HA, Rogers RS. 2011. Ecosystem ecology meets adaptive management: food web response to a controlled flood on the Colorado River, Glen Canyon. *Ecological Applications* 21:2016-2033.

Dibble KL, Yackulic CB, Kennedy TA, Budy P. 2015. Flow management and fish density regulate salmonid recruitment and adult size in tailwaters across western North America. *Ecological Applications* 25:2168-2179.

Dodrill MJ, Yackulic CB, Kennedy TA, Hayes JW. 2016. Prey size and availability limits maximum size of rainbow trout in a large tailwater: insights from a drift-foraging bioenergetics model. *Canadian Journal of Fisheries and Aquatic Sciences* 73:759-772.

Dodrill MJ, Yackulic CB, Kennedy TA, Yard MD, Korman J. 2021. As the prey thickens: rainbow trout select prey based on width not length. Canadian Journal of Fisheries and Aquatic Science 78:809-819.

Donovan P, Bair LS, Yackulic CB, Springborn MR. 2019. Safety in numbers: Cost-effective endangered species management for viable populations. *Land Economics* 95:435-453.

Giardina M, Korman J, Yard MD, Wright S, Kaplinski M, Bennett G. 2022. A literature review and hypsometric analysis to support decisions on trout management flows on the Colorado River downstream from Glen Canyon Dam. USGS, Flagstaff, AZ. 126 pp.

Healy BD, Schelly RS, Yackulic CB, Omana Smith EC, Budy P. 2020. Remarkable response of native fishes to invasive trout suppression varies with trout density, temperature, and annual hydrology. *Canadian Journal of Fisheries and Aquatic Sciences* 77:1446-1462.
Hoffnagle, TL, Choudhury A, Cole RA. 2006. Parasitism and body condition in humpback chub from the Colorado and Little Colorado Rivers, Grand Canyon, Arizona. *Journal of Aquatic Animal Health* 18:184-193.

Korman J, Kaplinski M, Hazel III JE, Melis T, Sneep J, Magirl C. 2004. Effects of fluctuating flows from Glen Canyon Dam on the early life history stages of rainbow trout in the Lee's Ferry Reach of the Colorado River. FY2003 Draft Report, 124 pp.

Korman J, Campana SE. 2009. Effects of Hydropeaking on Nearshore Habitat Use and Growth of Age-0 Rainbow Trout in a Large Regulated River. *Transactions of the American Fisheries Society* 138: 76-87.

Korman, J, Kaplinski M, Melis TS. 2011a. Effects of fluctuating flows and a controlled flood on incubation success and early survival rates and growth of age-0 rainbow trout in a large regulated river. *Transactions of the American Fisheries Society* 140:487-505.

Korman J, Walters C, Martell SJD, Pine III WE, Dutterer A. 2011b. Effects of flow fluctuations on habitat use and survival of age-0 rainbow trout (*Oncorhynchus mykiss*) in a large regulated river. *Canadian Journal of Fisheries and Aquatic Sciences* 68:1097-1109.

Korman J, Martell SJD, Walters CJ, Makinster AS, Coggins LG, Yard MD, Persons WR. 2012. Estimating recruitment dynamics and movement of rainbow trout (*Oncorhynchos mykiss*) in the Colorado River in Grand Canyon using an integrated assessment model. *Canadian Journal of Fisheries and Aquatic Sciences* 69:1827-1849.

Korman J, Yard MD, Yackulic CB. 2016. Factors controlling the abundance of rainbow trout in the Colorado River in Grand Canyon in a reach utilized by endangered humpback chub. *Canadian Journal of Fisheries and Aquatic Science* 73:105-124.

Korman J, Yard MD, Kennedy TA. 2017. Trends in rainbow trout recruitment, abundance, survival and growth during a boom-and-bust cycle in a tailwater fishery. *Transactions of the American Fisheries Society* 146:1043-1057.

Korman J, Yard MD, Dzul MC, Yackulic CB, Dodrill MJ, Deemer BR, Deemer BR, Kennedy TA. 2021. Changes in prey, turbidity, and competition reduce somatic growth and cause the collapse of a fish population. *Ecological Monographs* 91: e01427.

Linder CM, Cole RA, Hoffnagle TL, Persons B, Choudhury A, Haro R, Sterner M. 2012. Parasites of fishes in the Colorado River and selected tributaries in Grand Canyon, Arizona. *Journal of Parasitology* 98: 117-127.

McKinney T, Speas DW, Rogers RS, Persons WR. 2001. Rainbow trout in a regulated river below Glen Canyon Dam, Arizona, following increased minimum flows and reduced discharge variability. *North American Journal of Fisheries Management* 21:216–222.

National Park Service Non-Native Aquatic Species Environmental Assessment [NPS NNAS EA] 2018. Expanded non-native aquatic species management plan in Glen Canyon National Recreation Area and Grand Canyon National Park below Glen Canyon Dam. 164 pp.

National Park Service Comprehensive Fisheries Management Plan Environmental Assessment [NPS CFMP EA] 2013. Grand Canyon National Park, Glen Canyon National Recreation Area Coconino County, Arizona. 160 pp.

Pert EJ, Erman DC. 1994. Habitat use by adult rainbow trout under moderate artificial fluctuations in flow. *Transactions of the American Fisheries Society* 123:913-923.

Runge MC, Yackulic CB, Bair LS, Kennedy TA, Valdez RA, Ellsworth C, Kershner JL, Rogers RS, Trammel MA, Young KL. 2018. Brown trout in the Lees Ferry Reach of the Colorado River—Evaluation of causal hypotheses and potential interventions. USGS Report 2018-1069., Reston, Virginia.

Rogers S. 2015. Arizona Game & Fish Fisheries Management Plan Colorado River – Lees Ferry 2015-2025.

Sanchez-Hernandez J, Cobo F. 2015. Adaptive flexibility in the feeding behaviour of brown trout: optimal prey size. *Zoological Studies* 54:26.

Sauterleute JF, Hedger RD, Hauer C, Pulg U, Skoglund H, Sundt-Hansen LE, Bakken TH, Ugedal O. 2016. Modelling the effects of stranding on the Atlantic salmon population in the Dale River, Norway. *Ecohydrology* 573:574-584.

Scruton DA, Ollerhead LMN, Clarke KD, Pennell C, Alfredsen K, Harby A, Kelley D. 2003. The behavioural response of juvenile Atlantic salmon (*Salmo salar*) and brook trout (*Salvelinus fontinalis*) to experimental hydropeaking on a Newfoundland (Canada) river. *River Research and Applications*19:577-587.

Van Haverbeke DR, Stone DM, Dodrill MJ, Young KL, Pillow MJ. 2017. Population expansion of humpback chub in Western Grand Canyon and hypothesized mechanisms. *The Southwestern Naturalist* 62:285-292.

Ward DL. 2007. Removal and quantification of Asian tapeworm from bonytail chub using praziquantel. *North American Journal of Aquaculture* 69: 207-210.
Ward DL. 2012. Salinity of the Little Colorado River in Grand Canyon confers anti-parasitic properties on a native fish. *Western North American Naturalist* 72:334-338.

Ward DL, Morton-Starner R. 2015. Effects of water temperature and fish size on predation vulnerability of juvenile humpback chub to rainbow trout and brown trout. *Transactions of the American Fisheries Society* 144:1184-1191.

Ward DL, Morton-Starner R, Vaage B. 2016. Effects of turbidity on predation vulnerability of juvenile humpback chub to rainbow and brown trout. *Journal of Fish & Wildlife Management* 7:1-8.

Yackulic CB, Yard MD, Korman J, Van Haverbeke DR. 2014. A quantitative life history of endangered humpback chub that spawn in the Little Colorado River: variation in movement, growth, and survival. *Ecology and Evolution* 4:1006-1018.

Yackulic CB, Korman J, Yard MD, Dzul M. 2018. Inferring species interactions through joint mark-recapture analysis. *Ecology* 99:812-821.

Yard MD, Coggins Jr LG, Baxter CV, Bennett GE, Korman J. 2011. Trout piscivory in the Colorado River, Grand Canyon: Effects of turbidity, temperature, and fish prey availability. *Transactions of the American Fisheries Society* 140:471-486.

Yard MD, Korman J, Walters CJ, Kennedy TA. 2016. Seasonal and spatial patterns of growth of rainbow trout in the Colorado River in Grand Canyon, Arizona. *Canadian Journal of Fisheries & Aquatic Sciences* 73: 125-139.

Yard MD, and Korman J. 2020. TRGD—Trout recruitment, growth and population dynamics—presentation to the Glen Canyon Dam Adaptive Management Program, Annual Reporting Meeting, January 14, 2020: Phoenix, Ariz., U.S. Geological Survey, Grand Canyon Monitoring and Research Center.