# Evaluate effects of summer flow management on survival of age-0 Colorado pikeminnow in the middle Green River, Utah

by

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## Executive Summary

Colorado pikeminnow *Ptychocheilus lucius* abundance in the Green River Basin has declined rapidly from over 4,000 adults in 2000 to about 850 individuals by 2018. Survival of young fish to the adult life stage (e.g., recruitment) was low during that 2000-2018 interval, which resulted in insufficient numbers of young fish to replace adults as they died, and subsequent population decline. A number of causes have been implicated in the decline, including lack of appropriate habitat when young fish colonize nursery reaches in summer. Invasive predaceous fishes have also been identified as a factor that negatively affect survival of young Colorado pikeminnow. Based on analysis of extensive historical data, timing of onset of appropriate base flows released from Flaming Gorge (FG) Reservoir, as well as the magnitude of those base flows in summer, have been identified as a major contributors to survival of young pikeminnow. Because abundance of young fish drives adult population abundance 7-10 years later, management of base flows to achieve stronger year-classes of Colorado pikeminnow has been an emphasis of the Upper Colorado River Endangered Fish Recovery Program (Recovery Program). Requests by the Recovery Program for specific, experimental summer base flows (Bestgen and Hill 2016a) to increase survival of young pikeminnow require that a study plan be in place to evaluate effects of management. This study plan describes that evaluation process.

This study plan follows the basic framework described for other flow management activities in Reach 2 of the middle Green River, Utah (i.e., RK 555.1- 396.2, 158.9-km Green River reach between the Yampa River and White River confluences). Those include the larval trigger study plan (LTSP), which is designed to increase survival of early life stage razorback sucker *Xyrauchen texanus* in spring (LaGory et al. 2012), as well as a plan designed to evaluate effects of flow spikes in early summer to reduce abundance of invasive smallmouth bass *Micropterus dolomieu* in the Green River downstream of Flaming Gorge Dam (Bestgen and Hill 2016b; Bestgen 2018). The goal of this study plan is to describe a procedure to assess the effects of experimental base flows on young life stages of Colorado pikeminnow over time.

Experimental base flow targets vary from year to year based on projected and observed hydrologic conditions in the Green and Yampa rivers and are intended to be in place on or before first presence of pikeminnow larvae as they emerge from spawning areas in the tributary Yampa River and drift downstream into the Green River. Analysis of 41 years of data (1979-2019) showed that Flaming Gorge Dam releases (Greendale gage) that promote high survival of young Colorado pikeminnow are typically in the range of 25-65 $m^3$/sec (883-2,295 cfs) at first presence

of larvae. Downstream, flows at first presence of larvae in the middle Green River (Jensen gage) that promote highest survival were in the 50-150 $m^3$/sec range (1,766-5,297 cfs), when mean daily water temperatures were 19-23°C, with the higher flow magnitudes due, in part, to input of the tributary Yampa River. Higher or lower flows and colder water temperatures resulted in much lower survival. The mean daily flow levels for the period August-September that promoted highest survival of young Colorado pikeminnow ranged from 48.1-85 $m^3$/sec (1,700-3,000 cfs; Bestgen and Hill 2016a; LaGory et al. in review). Achieving those target flow and temperature levels in the Green River at Jensen may require rapid reductions of flows from FG dam to minimal levels after spring high flow releases or smallmouth bass flow spikes have ended because the unregulated Yampa River is typically high and still declining from snowmelt runoff levels in late spring and early summer.

Predictions of Colorado pikeminnow larvae first presence will be used to inform managers how and when to achieve the desired base flow condition in anticipation of the onset of larval drift. Predictions are based on past empirical information and modeling, and on sampling conducted in the lower Yampa River from 1990-2019 (except 1997, 29 years). The desired onset date is four days prior to the first predicted date of pikeminnow larvae first presence to make it more likely that conditions are met and to provide time for backwaters to be colonized with an invertebrate food base. Daily drift net sampling of Colorado pikeminnow larvae downstream of the Yampa River spawning area will provide real-time evaluation of the effectiveness of experimental base flows from a timing perspective, i.e. whether the desired base flow conditions were in place when larvae first entered the Green River. Another purpose of real-time monitoring is if larvae arrive prior to predictions, which will then indicate that base flow onset should be implemented as soon as possible. Information from real-time fish sampling will be supplemented with real-time flow and water temperature monitoring at the confluence of the Green and Yampa rivers to provide an evaluation of the physical conditions throughout the larval drift period. This is important because fragile early life stage Colorado pikeminnow may be susceptible to temperature shock, if they drift from a warm Yampa River into a cold Green River. The existing river stage monitoring conducted by the U. S. Geological Survey (USGS) at the Jensen, UT, gage will be used to evaluate backwater stability in the middle Green River through the nursery period (date of first presence to 30 September), which is another metric we will use to evaluate the overall effectiveness of an annual base flow experiment.

Subsequent sampling to estimate Colorado pikeminnow abundance and growth (length) in downstream, middle Green River nursery habitat, in summer and autumn will provide the annual measure of success of flow and water temperature conditions to promote survival and eventual recruitment. Autumn standardized backwater sampling will continue as it has since 1979. A summer sampling program will be added, which has proven effective in the past to measure mid-summer survival patterns of young Colorado pikeminnow (Bestgen et al. 2006a). That summer sampling will strengthen monitoring efforts that may otherwise miss effects of conditions that may alter survival of Colorado pikeminnow young in backwaters between mid-summer and autumn, including sediment deposition events. The ultimate measure of success of base flow management will be survival of young pikeminnow to the adult life stage in the Green River basin. To that end, a capture-tag-recapture sampling program to estimate adult and recruit abundance and vital rates is ongoing since 2000 (18-year period; Bestgen et al. 2010; Bestgen et al. 2018).

Thus, this study plan uses long-term sampling programs already in place to document effects of base flow management, and sampling has been demonstrated effective in measuring the needed population endpoints. Additional evaluations of efficacy of young-of-year (YOY) sampling in backwaters may be undertaken as needed to verify relationships with abundance. Management to reduce effects of nonnative fishes (Recovery Program projects 123a and 123b; https://coloradoriverrecovery.org/documents-publications/work-plan-documents/project-annual-reports.html), another factor that may affect young pikeminnow survival, is also ongoing in the Green River basin.

The number of years needed to evaluate managed summer base flow experiments is uncertain, but to have a reasonable chance of success for average or greater survival in about 50% of years, several conditions have to be met. These include (1) adequate production of Colorado pikeminnow larvae in summer, (2) suitable water temperatures at the confluence of the Green and Yampa rivers, (3) suitable timing of the onset of base flows, (4) suitable magnitude of base flow levels, and (5) flow stability in summer to achieve suitable backwater habitat. To determine if an individual year is considered a valid ‘experiment’, we developed a scoring system to evaluate conditions to achieve successful survival rates (incorporating the above five factors with a maximum possible score of 1 each). To meet those conditions, a total score of 4 or more out of 5 possible points must be achieved in that year. A score of 4 is the minimum deemed important to achieve average or greater year-class strength, whereas absence of several important conditions would likely produce a pikeminnow year-class that is less than average abundance. A score of less than 4 would disallow counting that year among those hypothesized to have minimally adequate conditions for high survival of Colorado pikeminnow young.

Information gathered in such years will not be discarded but rather, would be used to evaluate factors that affect Colorado pikeminnow survival during the base flow period and the importance of each of the proposed metrics described.

The relatively high minimum score of 4 recognizes that based on past research, each metric is thought important for survival, and absence of one or more conditions likely would result in year class failure or much reduced abundance. In other words, inclusion of such years would compromise the evaluation because some poor survival years are expected even if ideal conditions are met. Other conditions that will exclude a year as a qualifying experiment include absence of larvae production and a relatively rare event (only one known [2014] in the last 10 years), excessive silt deposition in backwaters due to storms. Because some of these factors are out of the control of operators of Flaming Gorge Dam, some allowance must be made for that in the evaluation and compliance process, and will affect the number of years over which the experiment takes place.

We preliminarily recommend that eight years of conditions that meet the minimum evaluation targets described above be observed before making final judgments on the efficacy of base flow management to increase survival of young Colorado pikeminnow. That many years is needed because, based on historical data, average or greater survival of Colorado pikeminnow was achieved only in about 50% of years when flow timing and magnitude targets were met. Eight years of target conditions would then translate into about 4 years of average or greater survival, if historical conditions and assumptions hold, and give managers reasonable confidence whether base flow management promotes higher survival of young pikeminnow. We recommend that years to include in the base flow experiments begin in 2020. Evaluating prior years can be an additional task of this project, but beginning now rather than back casting best reflects current conditions including present, reduced abundances of adult Colorado pikeminnow. Use of prior years is also confounded by dissimilar management of flow releases; for example, the base flow onset timing metric is now recommended as an explicit and well defined criterion whereas in the past, it was only loosely defined and a lesser consideration. Finally, because we also used data collected since 2012, the last year of data included in Bestgen and Hill (2016a) to derive evaluation metrics, a post-hoc analysis of those years would be circular and flawed.

Timing of targeted base flows to accommodate other annual fish flow management actions at Flaming Gorge Dam, including the Larval Trigger Study Plan (LTSP) and smallmouth bass flow spikes, was also considered. It was concluded that, in most years, base flow management for Colorado pikeminnow would fit well in the context of other annual operations including provision of high flows in spring for enhanced floodplain connectivity to promote survival of razorback sucker larvae (LTSP), and flow spikes to reduce reproductive success of smallmouth bass. Other monitoring (i.e., invasive woody plants) is also discussed and will be implemented in studies conducted by others. These managed flow releases and associated water temperatures are offered as a promising strategy to increase survival of native Colorado River basin fishes such as Colorado pikeminnow and could provide another tool for managers to improve their status..Results from summer base flow management studies will be reported annually under Recovery Program Project 22f, which will then be available for incorporation into the detailed Recovery Program annual flow request letter. A longer-term interim report where initial findings are evaluated will be prepared after four years of data are available (2020-2023), perhaps in 2024, if sample identification tasks are completed in a timely fashion. The report will be relatively brief but would include a general discussion of project progress as well as an evaluation of the metric scoring system (deviations to which would also be considered annually). That duration offers a reasonable likelihood that two or more years of conditions will occur that constitute adequate evaluation years; a shorter duration may not permit that. The interim report is not considered a decision-point for whether the study should continue, since approval of the study plan by the Biology Committee indicates a commitment to the longer study time horizon. A comprehensive final report will be prepared after the desired number of suitable evaluation years is achieved, which will guide future implementation of base flow management, including whether the study, and proposed experimental summer base flow management, should continue.

**Key words:** flow management, reproduction timing, Colorado pikeminnow, survival, invasive species, regulated flows, water temperatures, native and endangered fishes, upper Colorado River basin, Green River, Yampa River

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**Study justification and evaluation of Green River summer base flow management**

***Background and justification***.—Colorado pikeminnow *Ptychocheilus lucius* abundance in the Green River basin (Figure 1) has declined rapidly from over 4,000 adults in 2000 to about 850 individuals by 2018 (Figure 2). Survival of young fish to the adult life stage (e.g., recruitment) has been low during that interval, which resulted in insufficient numbers of young to replace adults as they died, and subsequent population decline. A number of causes have been implicated in the decline, including lack of appropriate habitat when young fish colonize nursery reaches in summer, and summer base flow levels that are sometimes not optimal for pikeminnow survival. Invasive fishes have also been implicated in the demise of native Colorado River basin fishes, including Colorado pikeminnow (Bestgen et al. 2006a). Understanding patterns of young pikeminnow survival was a research need highlighted in the Green River Study Plan (Green River Study Plan ad hoc Committee 2007), a document which identified uncertainties in flow and water temperature recommendations implemented for Flaming Gorge Dam operations. That need was also recommended and evaluated in the Green River Evaluation and Assessment Team (GREAT) report, which evaluates efficacy of Green River flow and water temperature patterns to benefit endangered fishes (LaGory et al. in review).

Detailed studies using two long-term datasets reported aspects of reproduction, survival, and status of early life stages of Colorado pikeminnow in the Green and Yampa rivers of the Green River subbasin, Utah and Colorado (Bestgen and Hill 2016a). They used daily drift net sampling of Colorado pikeminnow larvae in summer in the lower Yampa River from 1990-2019 (Bestgen and Hill reported on only 1990-2012 data, no sampling in 1997) to estimate timing of reproduction and a larvae transport abundance index, a flow-corrected metric of annual reproductive effort.

A second main dataset used to understand reasons for low pikeminnow survival was annual (autumn) seine sampling to estimate density of age-0 Colorado pikeminnow in channel margin backwaters (Bestgen and Hill 2016a). This sampling program was from 1979-2019, data which was extended here from the 2012 end date in Bestgen and Hill (2016a). That sampling was conducted in middle (and lower) Green River nursery habitat reaches that were supplied with drifting larvae from upstream spawning areas. The middle Green River reach (Reach 2) extends from the confluence of the Green and Yampa rivers (RK 551.1) downstream to the White River (RK 396.2; 158.9-km reach; Muth et al. 2000). The lower Green River, Reach 3, is downstream of there to the confluence with the Colorado River (RK 396.2-0.0). Because production of age-0 pikeminnow is positively related to recruitment of adults several years later (adults take 7-10 years to mature; Figure 3), factors that drive abundance of young fish affects subsequent abundance of adults. The goal of Bestgen and Hill (2016a) was to examine relationships between peak and summer base flow and other environmental factors relative to 1) production of larvae from spawning areas, 2) production of age-0 pikeminnow in backwaters in summer, 3) abundance of larvae relative to age-0 Colorado pikeminnow, and 4) abundance of age-0 to age-1 pikeminnow the next year. They also examined abundance patterns of selected nonnative fishes, including red shiner *Cyprinella lutrensis*, a potential competitor with and predator on native fish larvae including Colorado pikeminnow, other nonnative minnows, and smallmouth bass *Micropterus dolomieu*, relative to the same flow and environmental parameters to better understand potential interactions. For this study plan, we will focus mainly on the spawning area in the lower Yampa River and the nursery habitat in the middle Green River, Utah (Reach 2), the reach that is influenced most heavily by Flaming Gorge Dam releases.

The aforementioned long-term studies documented Colorado pikeminnow reproduction each year that sampling occurred in the middle Green River. Timing of summer reproduction was positively related to peak spring runoff magnitude, as well as water temperature. Regression models described timing of reproduction (first reproduction subsequently converted to first presence) relatively well. Abundance of larvae produced from spawning areas was positively correlated with both spring peak and mean July-August flow in the downstream portions of the Yampa River. In low flow years in the lower Yampa and middle Green River sections, few larvae were produced from spawning areas and transported downstream to nursery habitat (e.g., 1994, 2002, 2007, 2012), so few age-0 pikeminnow were documented in middle Green River backwaters in autumn. In most other years in the middle Green River, production of larvae was likely sufficient to produce more age-0 fish, but other unknown factors limited their survival to autumn.

Historical data gathered since 1979 indicated that densities of age-0 Colorado pikeminnow captured in backwaters in autumn in the middle Green River has declined (Bestgen et al. 2018, unpublished data). Decline of young pikeminnow translated into decline of adults such that in 2000 over 4,000 adult fish inhabited the Green River basin, but by 2018, that number was only about 850 individuals (K. R. Bestgen, unpublished data). Exact mechanisms influencing survival and abundance of age-0 Colorado pikeminnow in middle Green River backwaters were not always evident, but moderate base flows when larvae were first present and for the remainder of the summer often coincided with higher abundance. In contrast, lower pikeminnow abundances were noted in years when flows were very low or high when larvae were first detected and when low and high base flows occurred in summer. For example, in the middle Green River, average or higher abundance of Colorado pikeminnow in autumn occurred when Flaming Gorge Dam flow releases were 25-65 $m^3$/sec (883-2,295 cfs) at first presence of larvae (Figure 4; Appendix I). Above average abundance of Colorado pikeminnow was also nearly exclusively associated with middle Green River flows (combination of Flaming Gorge flow releases and that of the unregulated Yampa River) of 50-150 $m^3$/sec (1,766-5,297 cfs) at first presence of larvae. In contrast, lower flows produced no average or higher abundance year classes and higher flows produced year classes with average or higher abundance in only 2 of 13 (15%) years. Above average abundance was also exclusively associated with water temperatures at first presence of 19-23°C in the middle Green River (Figure 4); below average abundances were realized in all three colder years. Methods for the first presence analyses described above are presented in Appendix I, because those were not presented in Bestgen and Hill (2016a).

In an analysis of effects of summer base flow magnitude, abundance of age-0 Colorado pikeminnow was average or higher in 50% of years (63% reported in Bestgen and Hill [2016a], with the difference due to more recent lower than average survival years which lowered the mean) when mean August-September base flow levels were 48-85 $m^3$/sec (1,700-3,000 $ft^3$/sec, Table 1). These flow values represent what managers should target per the first presence of larvae criterion described below and ideally should be achieved before first presence is predicted (after subtracting the 4-d long or longer buffer) or as soon as possible after that, recognizing that flows may sometimes be higher due to higher Yampa River flows. Flow values in Figure 4 for both Flaming Gorge flow releases and those at Jensen, Utah (Panels A and B, respectively) illustrate the range of flow variation at time of first larval appearance under which above average recruitment occurred and should not be confused with the actual objectives listed in Table 1. The difference between flow levels in Figure 4 (panel B) and those in Table 1 is usually a result of higher inflows of the unregulated Yampa River during late June or July in most years, which is also when most instances of larval emergence occur. The flow range portrayed in Figure 4 may be used to evaluate experiment success from one year to the next. For example, if onset flow target dates are not met but flows at first presence of larvae occurred in the range where average or greater recruitment was historically observed, that information will be useful to explain and understand recruitment patterns and adequacy of the metrics to determine a successful experiment. The range of flow values portrayed in Figure 4 could also be used as target guidelines if those in Table 1 cannot be met prior to first presence of Colorado pikeminnow larvae. Not meeting the recommended flow targets at first presence of larvae should not be a reason to cancel the experiment that year, because other factors yet to be measured would remain in play that would affect recruitment.

In only a single year in seven since 2012, the last year of data analyzed by Bestgen and Hill (2016a), was Colorado pikeminnow autumn abundance above average (2015). In three of those other years from 2013-2019 (2016, 2017, 2019) base flows were very high in early summer when pikeminnow larvae were first present, and in 2014, base flows were high and silt loads in backwaters in late summer and autumn were extreme, and may have had negative effects on YOY pikeminnow. Fewer adult pikeminnow that produce fewer offspring could also contribute to reduced YOY abundance. Over the longer time series, abundance was above average in only 15% of years with lower flows and was never above average in higher flow years; data for these relationships include that from Bestgen and Hill (2016a) plus years 2013-2019 (Figure 5). Because we also used data collected since 2012, the last year of data included in the Bestgen and Hill (2016a) report, to derive evaluation metrics, we felt a post-hoc analysis of those years would be circular and flawed. Moderate summer base flows also produced the largest year-classes of Colorado pikeminnow in the lower Green River (Bestgen and Hill 2016a). At moderate flow levels, backwater distribution, number, and area may be optimized thereby providing sufficient habitat to increase survival of early life stages of Colorado pikeminnow. In years with low base flows, the low abundance of age-0 Colorado pikeminnow might be due to sub-optimal habitat conditions, low food abundance, or lack of sufficient larvae transported to nursery areas to produce a strong year class. In years when base flows were higher than 85 $m^3$/sec (3,000 $ft^3$/sec, and usually > 2,500 $ft^3$/sec) in the middle Green River, abundance of age-0 Colorado pikeminnow in autumn was low, presumably because few low-velocity channel margin nursery habitats developed in such years when larvae were available or larvae never colonized those backwaters. Higher production from both the lower and the middle Green River nursery reaches is needed to produce sufficient numbers of age-0 Colorado pikeminnow to support substantial recruitment and higher abundance of adults in the system.

Growth (mm total length) of age-0 Colorado pikeminnow was also positively related to length of the summer growing season and summer water temperature. Growth of age-0 Colorado pikeminnow was positively related to water temperature in July-August (the warmest months of the year) and negatively related to August-September base flow levels. In contrast, age-0 Colorado pikeminnow were shorter in higher flow years. Fast summer growth of age-0 Colorado pikeminnow is important because their early life survival is size-dependent, with larger and faster growing fish surviving at higher levels in summer while smaller (shorter) fish had reduced survival overwinter (Haines et al. 1998; Bestgen et al. 2006a)

Although relationships between individual environmental variables and Colorado pikeminnow abundance were sometimes inconsistent, a clear signal was that timing of base flow onset (a variable not analyzed in Bestgen and Hill, 2016a) and certain flow magnitudes favored survival of larger numbers of age-0 Colorado pikeminnow. This was also true in the lower Green River, where age-0 Colorado pikeminnow densities were historically higher and more age-1 to age-5 juveniles were produced. This was also true in the middle Green River, where age-0 densities have been relatively low in most years since in 1994. Proper timing, magnitude, and temperature of water releases from Flaming Gorge Reservoir may be useful to improve survival of young Colorado pikeminnow in the Green River. This plan describes how to assess effects of changes in Green River flow timing and magnitude to benefit Colorado pikeminnow.

***Other experimental flow releases for endangered fish management, Green River***.— We include here a brief discussion of other flow management actions, whether implemented or proposed, to add a temporal perspective to the summer base flow plan; those details are also in LaGory et al. in review), the Green River Evaluation and Assessment Team report. Requests for adjustments in flow releases from Flaming Gorge Dam for various purposes, including creating beneficial conditions for Colorado pikeminnow, razorback sucker, and other species, creates a need to consider the temporal schedule of these flow experiments to ensure that detrimental overlap of desired flows does not occur. Elevated flow releases already occur in spring of most years during the peak or just post-peak of Yampa River snowmelt flows (Figure 6). This program, the Larval Trigger Study Plan (LTSP, LaGory et al. 2012), uses releases of water in spring to connect floodplain wetlands with the Green River at a time when razorback sucker larvae are present, and allows early life stages to rear in relatively warm and food-rich environments. Fast growth of larvae in summer increases the likelihood that young razorback suckers will survive and perhaps recruit to the adult life stage, a rare event in the wild (Bestgen et al. 2011; Webber et al. 2013; LaGory et al. in review; Recovery Program technical and annual reports, https://coloradoriverrecovery.org/documents-publications/documents-publications.html e.g., annual report for Project FR-165). The flows implemented under the LTSP have been successful in entraining larvae into floodplain wetlands each year from 2012-2019, and from 2013-2019 nearly 5,000 wild juveniles were produced from only a single wetland, Stewart Lake. Several wetlands entrained larvae in 2019, and Stewart Lake alone produced several hundred juveniles (Partlow et al. 2019 annual Recovery Program report;

https://coloradoriverrecovery.org/documents-publications/work-plan-documents/arpts/2019/hab/FR-165_FY19AR-Final.pdf ). The number of juveniles produced in Stewart Lake alone far exceeds the number known from all previous upper Colorado River basin studies ever, beginning in the early 1960's, and thus, the floodplain wetland program is considered a provisional success, pending recruitment of juveniles to the adult life stage.

Another proposed but not implemented flow release experiment is a summer flow spike from Flaming Gorge Dam coincident with smallmouth bass reproduction. The goal of such a release would be displacement of eggs and larvae of smallmouth bass from spawning nests, which if successfully implemented over several years, would reduce their abundance and negative effects on native fishes (Bestgen 2018). Because summer base flow management will occur mainly after LTSP and smallmouth bass flow spikes, few biological overlaps in timing or competing interests are anticipated. The aforementioned GREAT report discusses implementation of all these flow management actions (LaGory et al. in review).

**Summer base flow management and evaluation**

The intent of this plan is not to be overly prescriptive, but rather to project clarity for recommendations to increase the chance that a maximum score for each of the metrics is achieved, which increases the likelihood that a successful annual experiment is achieved. To assist the reader with understanding the scheduling and considerations of how to conduct and evaluate summer base flow management in the Green River downstream from Flaming Gorge Reservoir, we offer an overview and flow chart of actions (Tables 2-3; Figure 7) and a description of steps to consider as guidelines so operations may be as successful as possible. We follow with more in-depth considerations and justifications for each step in the process. We also suggest LaGory et al. (in review) as a resource that contains additional details and justification regarding Green River base flow management. Finally, we discuss potential modifications to the plan based on observations from studies as they proceed and an evaluation matrix. Text boxes alert the reader to the major components of the study design. We note that with the exception of summer ISMP-type (Interagency Standardized Monitoring Program; McAda et al. [1994]) sampling, we will draw on continued, long-term existing monitoring programs to inform evaluation of these experiments.

Each spring the Flaming Gorge Technical Work Group (FGTWG, official agencies represented include U.S. Fish and Wildlife Service, U.S. Bureau of Reclamation, Western Area Power Association, plus other invited technical experts) will discuss implementation of managed summer base flows, an action that should be attempted every year and under all hydrologic conditions. Other stakeholder issues are also considered at this time, in conjunction with development of spring and summer operations plans, which are developed by the Bureau of Reclamation. A main information need is determining the type of hydrologic condition present (or predicted) in the upper Green River basin, which, because the condition is based on April-through-July runoff in both the Green and Yampa rivers, will not necessarily be known until spring runoff is underway or nearly over. Understanding the type of flow year in both the Green River and the Yampa River is important because differences in relative river volume contributions and their timing may be key considerations in management and operation of Flaming Gorge Dam. For example, a high snowpack year in the Green River basin may require dam safety flow releases to begin early (e.g., spring 2017) so that base flow timing requirements can be met. Alternatively, a high Yampa River flow condition may require dropping flow releases from Flaming Gorge Dam to meet the requirements for timing and magnitude of base flows in the Green River at Jensen, Utah. Because water temperatures and flows in the Yampa River are the main drivers of Colorado pikeminnow spawning and first presence of larvae, understanding and anticipating those conditions is particularly important.

> **Experimental base flow management study component**:
>
> Convene FGTWG in spring to discuss base flow

Once hydrologic conditions are established, a decision is made whether the summer base flow experiment can proceed. This decision, made mainly by the U. S. Bureau of Reclamation in coordination with the FGTWG, should be based on information including existing water levels in Flaming Gorge Reservoir, and the type of hydrologic condition present. Evaluation of those factors is needed because in lower flow conditions in the Yampa River, higher dam releases are needed to meet recommended base flow magnitudes, which may reduce Flaming Gorge Reservoir elevations (LaGory et al. review draft). In the case where extreme low reservoir levels from extended drought are combined with anticipated low reservoir inflows, managers may choose to implement only a partial experiment (e.g., part of summer), or to not implement the summer base flow experiment at all; this is anticipated to be a rare condition

> **Experimental base flow management study component**:
>
> Assess summer base flow feasibility

based on past history. If base flow experiments were deemed too detrimental to reservoir storage levels, management would use the recommendations in Muth et al. (2000) as further defined in the 2006 Record of Decision. Otherwise, if adequate water supplies were available, hydrologic conditions were suitable, and nonnative vegetation encroachment concerns and other pertinent issues were adequately addressed, the full experiment should be implemented.

> **Experimental base flow management study component**:
>
> Predict/measure time of first pikeminnow presence

Perhaps the most critical piece of information needed for summer base flow management is the appropriate timing of onset of the targeted Green River base flow conditions. This is important because adequate flow levels are needed for backwater formation and for invertebrate communities to develop before or by the time Colorado pikeminnow larvae are drifting downstream from spawning areas. In drier hydrologic conditions, flow magnitudes will likely be relatively low and suitable for backwater formation before pikeminnow hatching and drift begins. In other conditions, such as in average or higher flow years, or when Green River flows are especially high, at least two methods are available to assist in creating and evaluating a successful base flow experiment.

The first and primary method to estimate base flow onset involves estimating first spawning, drift, and first presence of pikeminnow larvae via a predictive equation (Bestgen and Hill 2016a; Appendix I). This equation will be updated prior to summer 2021 with information gathered since 2012 (Bestgen and Hill 2016a), and uses anticipated peak flow levels and degree-day accumulation to predict first spawning timing, which can be adjusted to date of first larvae presence by adding 12 days (incubation and drift time) to the estimate. Predictions of first presence vary by several days around a mean condition with variation due to complex environmental conditions and fish behavior and physiology. Therefore, we will subtract 4 days from the estimated first presence date to make it more likely that the Green River will be at desired base flow conditions prior to first presence of pikeminnow larvae. This will also provide time for backwater habitats to be colonized with an invertebrate food base; four days (mean of 3.5 d, rounded to four) is the time to median hatch of several chironomids from different families (Jackson and Sweeney 1995), a food type important to young fishes in backwaters including Colorado pikeminnow (Muth and Snyder 1995). Along with past empirical observations and environmental data, that prediction will give managers a preliminary estimate of desired timing for planning to ensure that spring peak flows, or smallmouth bass flow spikes, are sufficiently reduced in anticipation of beginning the base flow period. Mean date of first pikeminnow larvae presence, based on observations in drift net samples collected since 1990, is 4 July.

A second and mostly confirmatory method involves capture of larvae in drift nets downstream of the Yampa River spawning bar. If larvae are captured prior to the predicted date of first presence (offset four days earlier), their presence will then signal recommended onset of base flow conditions. Primary uses of the sampling data are to measure year class strength of larvae, duration of larval drift, and overall, the effectiveness of the experiment that year. This real-time sampling tool is similar to use of first presence of razorback sucker larvae in the LTSP.

Estimating timing of first presence of Colorado pikeminnow larvae will occur regardless if experimental base flows or those in Muth et al. (2000) are implemented, because this is critical information for each of the summer flow management protocols. First presence of pikeminnow larvae was identified in Muth et al. (2000, Table 5.3) as information that should be considered to determine onset of base flow conditions in the Green River.

**Experimental base flow management study component**:

Implement timing and magnitude of summer base flows

Predictions of first presence of Colorado pikeminnow larvae should be used to guide the rate and timing of down-ramping Flaming Gorge releases to achieve desired base flows. Higher Flaming Gorge release levels may result from spring peak releases to inundate floodplain wetlands (LTSP; LaGory et al. 2012), or flow spikes to reduce smallmouth bass reproductive success (Bestgen 2018). Given the importance of base flow onset timing to young Colorado pikeminnow survival, every attempt should be made to achieve this metric in all flow conditions. In relatively low flow years, base flows may already be at target levels by the time Colorado pikeminnow larvae are present (e.g., summer 2020), which contrasts with higher flow years when pikeminnow presence may be later and during higher flows. Flows from Flaming Gorge Dam ideally should be adjusted as fast as necessary (up to 2,000 cfs per day) to meet the needed flow conditions in the middle Green River (LaGory et al. in review).

**Experimental base flow management study component**:

Down ramp Flaming Gorge flow releases to meet base flow targets

Down ramp rates should follow those described in LaGory et al. (in review), which are up to 56.6 $m^3/d$ (2,000 cfs/day) under experimental conditions. Achieving correct down ramp timing and onset of base flows is critical to providing suitable backwater habitat and water temperature conditions in the middle Green River that should promote higher survival of pikeminnow larvae. There is no specific evaluation component for this action, but will rather depend on whether base flows are achieved at the recommended time and abundance of pikeminnow in summer and autumn sampling to determine effects. Sampling under Recovery Program Project FR-115 (Bestgen and Crist 2000; Bestgen et al. 2006b; Bestgen et al. 2007) should detect adverse nonnative fish effects as well as effects on native fishes from this action, particularly in Reach 1.

> **Experimental base flow management study component**:
>
> Adjust flow and water temperature to meet targets

To achieve recommended base flow timing and level, high, unregulated Yampa River flows should be offset by reduced releases from Flaming Gorge Reservoir, perhaps to minimum levels, so necessary flow target levels are achieved when first presence of pikeminnow larvae is predicted or observed. This was the protocol followed in the 1990's (Muth et al. 2000), whereby releases were typically reduced to 800 cfs (22.7 $m^3$/sec) after spring peak flow operations to reduce flow levels in the middle Green River, and increased later to meet targets as needed after that (Figure 4.4 in Muth et al. 2000).

Targeted flow magnitudes for Reach 2 of the Green River (which also will benefit Colorado pikeminnow in Reach 3) should be set based on hydrologic conditions established early in this process. Because flows from the unregulated Yampa River typically continue to decline through summer, flows from Flaming Gorge Reservoir may be adjusted upward to compensate (the 2006 ROD allows flows to be adjusted +/- 40% of the average recommended values to meet objectives within a given year). This will ensure base flows remain in the window relevant for the hydrologic condition for that year for the remainder of the summer (through September 30). This process of active management of flow releases from Flaming Gorge Dam should occur regardless of whether experimental base flows are implemented, or if flow releases are per recommendations in Muth et al. (2000). Under each management scenario, flows after September will revert back to the Muth et al. (2000) recommendations.

Attention should also be paid to water temperature differences of the Green and Yampa rivers at their confluence in Echo Park, Dinosaur National Monument. Recommendations for temperature differences under experimental base flows and those in Muth et al. (2000; Table 5.5) are identical and state that the Green River should be no more than 5°C cooler than the Yampa River during the summer base flow period. Those conditions can usually be attained using the warmest releases possible from Flaming Gorge Dam (15-16°C) such that water temperatures in upper Lodore Canyon are 18°C or greater for 3-5 weeks beginning at the start of the base flow period (Table 5.4, Muth et al. 2000). Water temperature differences between the Green and

Yampa rivers at the confluence will likely be minimized when this experiment is implemented. This is because reduced releases from Flaming Gorge Dam early in the year to offset the typically higher Yampa River flows, coupled with highest possible release temperatures, should allow water to warm more quickly as it moves more slowly downstream (Bestgen and Crist 2000). The Program Director's office will investigate potential use of a telemetered temperature device to allow for real-time measurements and reporting at the Green and Yampa River confluence.

> **Experimental base flow management study component**:
>
> Assess flow and temperature management effects, summer and autumn

Base flow monitoring studies described herein would be ongoing throughout the summer (Table 3). For example, annual drift net sampling will occur daily to document the onset, duration, and intensity of Colorado pikeminnow reproduction throughout the summer. Those data will be used to estimate the *larval transport abundance index*, a measure of reproductive output that corrects for differences in river flow across years. That index will be used in the evaluation process to determine relative success of experimental base flow management and is important because if few larvae reach nursery habitat reaches, it is unlikely that a strong year class would be produced in the middle Green River even if flow and water temperature conditions were suitable. This measure may be increasingly important in light of recent declines in adult pikeminnow abundance (Bestgen et al. 2018).

The new mid-summer and the regular autumn backwater sampling (ISMP) will document survival, abundance, and size (length) of early life stages of Colorado pikeminnow; mid-summer sampling is the only new monitoring needed to implement this program and will be conducted as a replacement task for Project 158. The ISMP is a standardized sampling program (Project 138), which has been used in autumn since 1979 to assess age-0 pikeminnow stock characteristics in the middle and lower Green River. A similar program will be implemented in mid-summer in the middle Green River that essentially mirrors the design of autumn sampling, and will occur about 6 weeks following documentation of first presence of Colorado pikeminnow; a follow-up sampling pass several weeks later is also planned. Using a standardized interval like 6 weeks after first presence rather than a set date, will allow for a consistent growth and survival period for pikeminnow to occur so that data may be equitably compared over different types of hydrologic years and conditions. Summer and autumn sampling will allow a more robust understanding of factors affecting year class survival, and because it is staggered through time, will allow investigators to determine if a year class was negatively affected by a mid-summer or later environmental event such as flood-caused sediment deposition. This staggered approach will be more effective than a single monitoring event in autumn, to detect effects on year classes that may be independent of flow and water temperature conditions when Colorado pikeminnow larvae were colonizing backwaters in late spring and early summer. The ISMP approach will be revisited prior to 2021 sampling to ensure that it is giving managers the necessary information and that exact protocols regarding timing, methods, and flexibility in conducting that work are in place, with a goal of obtaining the most accurate information possible.

Green River flow and water temperature monitoring will be ongoing, using USGS flow gages and real-time (but not uplinked) continuous temperature recorders, including those at the Green-Yampa River confluence, which is important for daily monitoring and documentation of temperature differences between the typically warmer Yampa River and the cooler Green River. In lieu of telemetered data, it may be possible to model water temperatures at the confluence to estimate differences between the two systems. Data from USGS flow monitoring gages will also ensure that flow magnitude at the onset of pikeminnow drift, and through the summer, are consistent with recommended levels. Flow fluctuations due to storm events are not considered in this evaluation, nor are releases from Flaming Gorge Reservoir expected to be adjusted in response to these fluctuations. Observations from the Jensen stage recorder at the gage site will be used to monitor that daily backwater stability recommendations (no more than 0.1 m stage fluctuation in a 24-hr period) are met. Gages and observations will also be used to determine frequency and magnitude of flow and sediment pulses from upstream rainstorms, events which may affect survival of Colorado pikeminnow larvae.

Ultimately, providing flow and water temperature conditions consistent with higher survival of young Colorado pikeminnow in the basin is hypothesized to increase abundance of larger life stages including juveniles, recruits, and adults (Bestgen et al. 2018). Since 2000, there has been an ongoing program to estimate abundance and vital rates of those large life stages of Colorado pikeminnow, and to determine population trends over time, the ultimate measure of management actions. Other studies will monitor effects of summer base flow management, as well as other flow management activities, on nonnative shrub proliferation and channel narrowing (Trammell et al. 2020).

Base flow management should be attempted each year, pending discussions of water availability, priorities for other flow management actions, and other pertinent issues including nonnative vegetation encroachment. This frequency is attainable because the range of variation in flows and water temperatures has been accounted for in flow recommendations (Muth et al.

2000) as implemented in the Record of Decision. In other words, recommended summer flow and water temperature patterns should be attainable because higher flows are recommended in wetter hydrologic conditions, and lower flows in drier conditions.

The relative success of summer base flow management on age-0 Colorado pikeminnow survival will be evaluated each year based on how well driving variables met conditions conducive to producing an average or greater abundance year class of Colorado pikeminnow. The endpoint biological metrics are mainly ISMP-estimated abundance of age-0 pikeminnow in summer and autumn. Because survival and abundance of young Colorado pikeminnow are affected by numerous factors, ISMP abundance data will be evaluated in the context of how well biological and environmental conditions thought to drive young pikeminnow survival and abundance were met that year.

We postulate, based on the literature and experience, that at least five factors may affect pikeminnow survival and abundance in any given year (Table 4). These include: production level of larvae that summer, temperature differences of the Green and Yampa rivers at their confluence, timing and magnitude of base flows in nursery habitat reaches (includes ramp rate criteria), and flow stability in summer to maintain suitable backwater habitat. Below we justify the importance of these factors and describe a scoring system, recognizing that information to inform levels of support vary among each factor.

**Production of Larvae**. Adequate levels of larvae production are needed to produce a year-class of age-0 pikeminnow because mortality levels for larvae are high. We also recognize that different levels of larvae production may produce an adequate year class of age-0 Colorado pikeminnow because survival rates or habitat conditions may vary across years. Thus, a score of 1 is assigned when larvae production is ≥ 100% of average historical levels. A score of 0.5 is assigned when larvae production is 25-99% of the long-term average. A score of 0 is assigned when larvae production is < 25% of historical levels. A score of 0 may functionally negate the experiment for that year because without adequate larvae production, few or no age-0 fish are possible even with otherwise ideal conditions. In the unexpected circumstance that a reasonable year-class of pikeminnow is produced with low numbers of larvae (high survival of the few larvae produced), or if continued reductions in adult abundance affect larvae production, that restriction and scoring can be revisited. Even if few larvae are produced from the Yampa River in a given year, continuing the annual flow experiment through the summer remains a benefit because of the positive effects on young Colorado pikeminnow in downstream Reach 3 below the White River confluence (Bestgen and Hill 2016a, LaGory et al. in review). There is currently no monitoring of larval production in Reach 3, so reproductive success can only be measured during autumn seining for YOY fish.

**Green and Yampa River Water Temperatures.** Water temperature differences at the confluence of the Green and Yampa rivers are important because cold shock may impart direct or indirect mortality on fragile early life stage pikeminnow larvae as they drift from the warmer Yampa River into the cooler Green River (Berry 1988; Muth et al. 2000). A score of 1 is assigned when target water temperatures are reached by the time larvae begin to drift and when 0 days occur where water temperature differences are no more than 5°C for the entire period of larval drift. A score of 0.5 is assigned when water temperature differences ≥ 5°C occur for up to 5 days or 25% of the period of larval drift (whichever is shorter), as long as differences do not occur during the period(s) of peak production. A 0 score is assigned when temperature targets deviate from recommendations for a longer duration or when differences are > 5°C occur during the peak of larvae drift. Note that the period of larval drift is well defined by existing sampling, and this period is shorter than the base flow period, often ending by early to mid-August.

**Timing and Magnitude of Base Flows**. Base flow timing onset, which is influenced by spring down ramp rates (up to 2,000 ft $^{3}$/sec /day) needed to achieve recommended timing of base flow onset, and base flow magnitudes in summer, exert strong effects on Colorado pikeminnow survival (this document, Bestgen and Hill 2016a). First presence timing relative to habitat availability is important because backwaters must be available for occupancy by larvae, and are assumed to improve when they are adequately colonized by an invertebrate food base several days or more prior to arrival of larvae. Thus, when base flow target level is achieved four days or more before first presence of larvae is noted, a score of 1 is assigned. A score of 0.5 is assigned when base flow targets and water temperatures occur within 3 days before first presence or 7 days after, as long as the peak of larvae drift does not occur in the first week. A score of 0 is assigned if base flow onset occurs more than 7 days after first presence or if the peak of drift for that year occurs when flows are higher during that first 7-day period.

Maintaining target base flow levels through the nursery period (date of first presence to 30 September) is also important to provide adequate backwater habitat. Thus, a score of 1 is assigned when 90% or more of mean daily flow days falls in the range for the chosen hydrologic category for that year, beginning when base flow onset is achieved until 30 September. If mean daily flows remain in recommended ranges < 90% of days, a score of 0 is assigned.

**Summer Flow Stability**. Flow stability is thought important for backwaters to support an adequate invertebrate food base, reach adequate depths, and provide a relatively permanent feature of the streamscape (Muth et al. 2000). Thus, if flow stages deviate from the 0.1 m/d maximum change guideline (see LaGory et al. in review) for < 5% of days in the period from base flow onset until 30 September at the Jensen, Utah, gage a score of 1 is assigned. A score of 0 is assigned if stage recommendations are not met in ≥ 5% of days in the same base flow period described above. Meeting the metric score is based solely on stability of Flaming Gorge flow releases measured at the Jensen, Utah, gage, not stochastic events such as rainstorms that cause flow magnitude fluctuations.

**Backwater Habitat Condition.** We formerly included backwater habitat condition as one of six evaluation criteria but removed it, in part, because these processes were not necessarily a function of dam operations and because it was difficult to score using a well-defined threshold. It remains though that backwater condition during the summer importantly affects the likelihood of young pikeminnow survival. In some years when thunderstorms produce high sediment loads and extreme turbidity conditions in backwaters or river reaches, lower pikeminnow survival, or lower catchability, is the result (Bestgen et al. 2006a; e.g., low 2014 ISMP abundances of pikeminnow following high deposition of sediment). Thus, if condition of backwater habitat is good (i.e., backwaters not substantially filled with sediment from summer spates), as noted by ISMP sampling personnel in summer and autumn, we will consider the year a useful and valid experiment and it can count in the total evaluation years. If summer spates cause high fine sediment deposition and presumably poor invertebrate and fish survival conditions, then the validity of using that annual data point is questionable. This is because the fish response in such years is likely confounded by the unusually poor backwater conditions, regardless of the suitability of other conditions. This is similar to the pikeminnow larvae production criterion as explained above, where if no larvae are produced, it is not possible to have an experiment that year. Having the intermediate summer sampling will allow for an intermediate evaluation point and a possible exception to not using the year as a valid data point. For example, if conditions are adequate up until midsummer, and fish response is strong as demonstrated by sampling, but then conditions turn poor because of sediment deposition after that time, the year may still be judged a success and a valid experiment. The ISMP sampling crews will be primarily responsible for evaluating this criterion, in both summer and autumn, although other information such as sediment levels measured at USGS gages can also be examined. Those data will be useful to document sediment deposition events when researchers are not on the river to observe them.

We also recognize that this experiment is a discovery process, and that new information or changes in ecosystem dynamics may affect how the experiment is conducted or evaluated. For example, negative effects of nonnative fishes on native kinds are well known and predator loads in backwaters may be an additional confounding factor to consider when determining adequacy of years to meet evaluation criteria (e.g., Table 4). In theory, predator effects could be directly assessed using abundance measurements, or indirectly inferred from antecedent flow conditions that affect nonnative fish abundance. For example, abundance of nonnative fishes may be negatively affected by flows in the year prior that reduce reproductive success and thus improve survival of native fishes the following year.

However, as a factor for evaluating experimental success in any given year, we specifically chose not to include a nonnative fish metric in the annual evaluation for several reasons. First, early life stages of smallmouth bass, a known and effective piscivore, are rare in ISMP autumn backwater samples in most years and would not be a good metric to assess. For example, since smallmouth bass established in the area in the early 1990's, autumn Green River ISMP backwater sampling detected the species in only 7 of 18 years (1994-2012 [Bestgen and Hill 2016a]), and only 17 individuals were captured; more recent sampling in Project 138 (https://coloradoriverrecovery.org/documents-publications/work-plan-documents/arpts/2019/rsch/138_FY19AR%20Final.pdf ) showed similar results. Nonnative cyprinid abundance is another possible metric to evaluate because red shiner and fathead minnow are known predators on early life stages of native fish (Ruppert et al. 1993; Bestgen et al. 2006a; Markle and Dunsmoor 2007) and are abundant in the Green River. However, assessing what constitutes an abundance level that may have a negative effect on young pikeminnow is uncertain, which creates problems for developing a scoring metric that is meaningful. Finally, because summer base flow levels are inversely associated with red shiner abundance (Bestgen and Hill 2016a), summer base flow magnitude is a surrogate measure of nonnative fish density that is already built in to the evaluation. We may also use information from ISMP samples to examine composition of the backwater fish communities as the experiment progresses, and scoring criteria can be altered using that data if it is merited, in the future.

All years going forward after approval of this plan, and including 2020, will be considered in interim and final evaluations of data collected to evaluate effects of Green River base flow management on survival of young Colorado pikeminnow. For an experimental year to be included among those that meet minimally adequate conditions for survival (not necessarily consecutive years), certain criteria must be met (Table 4). To meet those conditions, a total score of 4 or more out of 5 possible points must be achieved in that year. A score of 4 is the minimum deemed important to achieve average or greater year-class strength, whereas absence of several important conditions would likely produce a pikeminnow year-class that is less than average abundance. A score of less than 4 would disallow counting that year among those hypothesized to have minimally adequate conditions for high survival of Colorado pikeminnow young. Information gathered in such years would not be discarded but rather, would be used to evaluate factors that affect Colorado pikeminnow survival during the base flow period and the importance of each of the proposed metrics described in Table 4.

Study duration should be for a minimum of 8 years, with the condition that evaluation criteria and conditions were deemed minimally sufficient (see scoring criteria above) for survival of Colorado pikeminnow in all years. This duration is based on the idea that even under ideal conditions of onset timing, flow magnitude (Figures 4 and 5), and other conditions as well, above average year classes of pikeminnow are produced only in about 50% of years. Thus, even if conditions are adequate in all 8 years, only about half of those would be expected to produce an above average year class of pikeminnow. We will not back cast and include prior year observations in the evaluation period. This is because conditions were not managed for similarly in the past, especially for timing of onset of base flow conditions.

**End Products / Reporting**. Results from summer base flow management studies will be reported on annually under Recovery Program Project 22f, recognizing there may be a year offset for reporting some data because sample identification may require longer time frames. Project 22f is a logical place for the data because that is where drift netting results from the lower Yampa River are placed. Data reported will then be available for incorporation into the detailed annual flow request letter to the U. S. Bureau of Reclamation. A longer-term interim report where initial findings are evaluated will include a general discussion of project progress, an evaluation of the metric scoring system (deviations to which would also be considered annually), / and may propose study modifications if warranted. The interim report is not considered a decision-point for whether the study should continue; the Biology Committee recognized the importance of a longer study time horizon when they approved this study plan. The interim report will be prepared after four years of data are available (2020-2023), perhaps in 2024, if sample identification tasks are completed in a timely fashion. That duration offers a reasonable likelihood that two or more years of conditions will occur that constitute adequate evaluation years; a shorter duration may not permit that. A comprehensive report will be prepared after the desired number of suitable evaluation years is achieved, which will guide future implementation of base flow management, including whether the study, and the proposed experimental summer base flow management, should continue.

**Other Implementation Considerations.** The proposed summer base flow management is temporally positioned after other fish management flow release actions at Flaming Gorge Dam, including early spring flows to provide floodplain wetland habitat for young razorback suckers and flow spikes to disadvantage smallmouth bass reproduction. Thus, summer base flow management normally should not overlap with other flow management efforts, even if all were implemented in a single year, for the reasons described below. However, vagaries in flow and water temperature regimes, which may alter timing of Colorado pikeminnow reproduction in the Yampa River, need to be factored into a decision to implement a flow spike for smallmouth bass suppression in the adjacent Green River, and could result in an overlap.

In years when the hydrology of the Yampa and Green rivers is similar, overlap of spawning seasons for Colorado pikeminnow and smallmouth bass are not anticipated. This is because mean first presence date for Colorado pikeminnow larvae in the Yampa River is about 4 July, or 8-10 d after mean first smallmouth bass hatching (Bestgen 2018). However, because few pikeminnow typically occur in the early portion of the spawning season, overlap should be minimal for 10-14 d after smallmouth bass first hatch. This is important because high flows during a flow spike may negatively affect survival of Colorado pikeminnow larvae as they are transported downstream from the Yampa River into the Green River.

The potential for an overlap period merits careful attention, however, particularly if climatic and flow conditions differ greatly between the Yampa River and upper Green River basins. For example, if flows in the Yampa River are especially low and warm compared to higher releases from Flaming Gorge Dam, earlier pikeminnow spawning and greater overlap with the Green River smallmouth bass spawning season will be expected, and the potential for negative flow effects on pikeminnow larvae may be an issue. This will merit further discussion by the FGTWG members at the time such circumstances develop. Alternatively, if flows were lower and relatively warm in the Green River, and were higher and cooler in the Yampa River, less overlap will be expected because bass will spawn earlier and pikeminnow later. The largest peak of the Colorado pikeminnow drift period is typically 2-3 weeks after larvae first appear, and in a typical year usually in the third week of July. Thus, the end of the smallmouth bass hatching period typically barely overlaps with that of the first larger pulse of Colorado pikeminnow larvae of the year, so earlier flow spikes should not affect pikeminnow drift patterns.

**Other flow management considerations.** Reducing Green River releases from Flaming Gorge Dam after spring peak flows to minimal levels may have consequences for suitability of habitat for nonnative fishes such as smallmouth bass. This is because flows will be low and water temperatures will naturally increase because transit times are increased and volumes of released water are reduced, allowing for more warming. That condition may induce smallmouth bass reproduction early in the post-peak period. This scenario places a premium on flow management, specifically, a flow spike, to reduce smallmouth bass reproduction. A flow spike following low base flow releases will have a larger relative effect in terms of increased stage and flow velocity as well as reduced water temperatures, and may create more certainty that most smallmouth bass have or will be attempting to spawn in the reach of interest when the disturbance is attempted. This scheme will also induce spawning earlier than might normally occur, so that the flow spike does not overlap with onset of Colorado pikeminnow larvae drift into the Green River. This scenario was discussed in Bestgen (2018). Effects of various flow management scenarios on nonnative fishes have been discussed, and monitoring programs are in place to detect those effects (Bestgen et al. 2018).

Reducing flows early in the season in the regulated reach of the Green River may have additional benefits for nonnative fish control (Zelasko et al. 2015; 2016). That is because northern pike *Esox lucius*, which spawn during high flow releases in the Browns Park area of the upper Green River, may be negatively impacted by early season flow reductions because of reduced survival of young. High abundance of young northern pike observed in both recent high and extended flow years in Browns Park (2011, 2017) indicates that pike respond positively to higher flows if they occur over extended periods. This may be because northern pike are attracted to spawn in areas of shallow submerged vegetation in the flood plain or the channel margin during higher flows in May and early June. If flows are reduced when sensitive eggs or larvae are present in the shallow floodplain or the channel margin, those life stages may be stranded or flushed to the river, resulting in lower survival.

**Uncertainties.** An important consideration for implementing Green River flow management actions is to identify if sufficient water is available to conduct all desired fish management releases in a single flow year, and if not, which action(s) have the highest priority for implementation. A key part of that determination is the hydrologic conditions present in the upper Green River basin and the Yampa River basin in a given flow year. For example, extensive floodplain inundation is achievable and important, but more difficult, in lower runoff years. Conversely, smallmouth bass flow disruptions may work best in lower flow years

(Bestgen 2018), given that such years are the ones best suited for bass survival and because those flow management events are short-term and relatively low volume releases. Summer base flow management water requirements are greatest in low flow years (LaGory et al. draft review) and most release scenarios and their drawdown effects are discussed there. The duration and magnitude of various flow prescriptions, the amount of water available in Flaming Gorge Reservoir, reservoir inflow forecasts, drought and storage trends, status or abundance of nonnative fish, and other competing uses for that water need to be considered as well. An advantage in this system is that Flaming Gorge Reservoir has a relatively large storage volume, and the amount of flow required in many years may be modest relative to the overall storage capacity and inflows into the system.

Another uncertainty is the effects of other flow management actions including LTSP spring flows, flow spikes to suppress smallmouth bass reproduction, as well as summer base flow management and other flow management activities on other resources such as nonnative vegetation (Friedman 2018). This includes the concern that elevated base flows with less interannual variability may promote the encroachment and stabilization of nonnative shrubby vegetation in the active river channel and eventually reduce Green River channel width and complexity, including suitable backwater habitat. A plan was developed by the National Park Service to monitor vegetation responses and channel changes over time so flow management effects can be assessed (Trammel et al. 2020). Findings of that study, this summer base flow evaluation, and other pertinent data will be considered annually by Recovery Program partners in development of the annual flow request letter and an operations plan developed for Flaming Gorge Dam.

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**Table 1.** Summer base flow levels proposed in Bestgen and Hill (2016a) for the middle and lower Green River, Utah. The higher upper ends of flow ranges in Muth et al. (2000) for the lower Green River reflect uncertainty about tributary inputs, while proposed targets represent preferred ranges.

| | Green River | |
|---|---|---|
| Hydrologic classification | Reach 2 | Reach 3 |
| Dry (10% of years, 0 to 10% exceedance) | 48-51 $m^3/s$ (1,700-1,800 $ft^3/s$) | 48-57 $m^3/s$ (1,700-2,000 $ft^3/s$) |
| Moderately dry (20% of years) | 51-57 $m^3/s$ (1,800-2,000 $ft^3/s$) | 57-65 $m^3/s$ (2,000-2,300 $ft^3/s$) |
| Average (40% of years) | 57-74 $m^3/s$ (2,000-2,600 $ft^3/s$) | 65-79 $m^3/s$ (2,300-2,800 $ft^3/s$) |
| Moderately wet (20% of years) | 62-79 $m^3/s$ (2,200-2,800 $ft^3/s$) | 74-91 $m^3/s$ (2,600-3,200 $ft^3/s$) |
| Wet (10% of years, 90 to 100% exceedance) | 68-85 $m^3/s$ (2,400-3,000 $ft^3/s$) | 79-108 $m^3/s$ (2,800-3,800 $ft^3/s$) |

**Table 2.** Characteristics and conditions for summer base flow management to promote higher survival of early life stage Colorado pikeminnow in the Green River downstream of Flaming Gorge Dam, Colorado and Utah.

| Aspect of Base flow | Expected Range | Determining Factors |
|---|---|---|
| **Onset Timing for Base flows** | Mid-June – late July | • Type of flow year (earlier implementation in years with lower flows and warmer temperatures)<br>• Predicted and observed Colorado pikeminnow spawning and first presence date |
| **Magnitude of Flaming Gorge release** | Variable, 23-71 $m^3$/sec (800-2,500 $ft^3$/sec) | • Release changes to accommodate variable flows of the Yampa River, likely lower in early portion of summer and increasing later, to maintain flows in preferred range<br>• Yampa River flows and changes in flow may affect magnitude of the required FG release<br>• Desired timing and magnitude of releases may be refined following observations of effects on young Colorado pikeminnow survival |
| **Duration of release** | Late spring-early summer until 30 September | • Base flow duration should be from base flow onset date until 30 September |
| **Change of release magnitude and rate** | Up to 56.6 $m^3$/sec (2,000 $ft^3$/sec) per day, per LaGory et al. (in review) | • Change to base flow and winter conditions per magnitudes and rates prescribed in LaGory et al. (in review) |
| **Frequency of implementation** | Annually | • Water available to conduct base flow management, and priority of summer base flows relative to other releases for fish management<br>• Years in which the Yampa and Green River hydrologies differ greatly may affect how flows are achieved but should not affect the annual implementation |
| **Feasible lead time to onset of base flow conditions** | 7-14 days | • Accuracy and reliability of pikeminnow hatching and first presence models<br>• Pikeminnow sampling and detection<br>• Release scheduling announcements |
| **Number of years implemented** | Minimum of 8 years with suitable base flow releases (timing, magnitude, and average or greater abundance of larvae) and evaluations; depending on results, more may be needed | • Success of the summer base flows to improve survival of Colorado pikeminnow and increase recruit and adult abundance, each has different time horizons<br>• Neutral or negative (not positive) responses detected in nonnative fish |

**Table 3**. Proposed monitoring activities for Green River summer base flow management studies to improve survival of young Colorado pikeminnow in the Green River downstream of Flaming Gorge Dam, Colorado and Utah.

| PARAMETERS | FIELD/GAGE ACTIVITIES | PURPOSES |
|---|---|---|
| **Physical Habitat:** | | |
| **Flow timing and magnitude monitoring in Green and Yampa rivers**<br><br>**Temperature**<br><br>**Sediment load in nursery habitats** | • Determine water year type (wet to dry)<br>• Monitor temperatures in Yampa and Green rivers at gaged sites and on site<br>• Monitor turbidity events and flow spikes using flow and sediment gage data | • Determine relative flow levels to assess summer flow management options<br>• Monitor water temperature differences between the Green and Yampa rivers during pikeminnow drift to reduce opportunities for differences > 5° C, which may cause mortality<br>• Monitor condition of backwater habitats via field observation or flow / sediment transport events from gage data to determine if storms negatively affected survival of age-0 Colorado pikeminnow. |
| **Biological Measurements:** | | |
| **Presence & abundance of Colorado pikeminnow larvae**<br><br>**Presence and abundance of larvae and other life stages of all species**<br><br>**Mid-summer backwater sampling, Middle Green River, to assess pikeminnow survival and abundance**<br><br>**Autumn backwater sampling, Middle Green River, to assess pikeminnow survival and abundance**<br><br>**Density of young SMB and other taxa** | • Predict timing of first pikeminnow presence using model estimates and empirical data<br>• Drift net sampling in lower Yampa River throughout the entire period of larval drift<br>• Mid-summer and autumn backwater sampling to assess pikeminnow survival and abundance<br>• Mid-summer and autumn backwater sampling to assess survival and abundance of other taxa, including nonnative fishes | • Determine first probable pikeminnow presence; verify first occurrence with drift net sampling<br>• Summer-long drift net sampling used to estimate drift abundance index<br>• Assess effectiveness of summer base flow management to mid-summer and autumn Colorado pikeminnow survival and abundance and compare to other years<br>• Assess effectiveness of summer base flow management to mid-summer and autumn survival and abundance of other fishes, including nonnative taxa and compare to other years |

**Table 4.** Base flow experiment evaluation components. Columns describe five criteria and scoring metrics for each annual experiment to derive an overall score for suitability of conditions to promote survival of age-0 Colorado pikeminnow in the Middle Green River, Utah.

| [1]Larval Production | | Temp (°C, avg daily) Δ @ the confluence | | Timing: Reach 2 Avg Daily Base flows relative to 1st larval capture | | [2]Nursery Period Avg Daily Flow in Reach 2 | | Reach 2 Daily Flow Stability through Nursery Period | | [3]Total Score |
|---|---|---|---|---|---|---|---|---|---|---|
| 100% or more of long-term average annual larval density = 1 | + | <5°C for the entire period of larval drift = 1 | + | Technical Working Group (TWG) base flow target achieved 4 days or more prior to 1st capture = 1 | + | ≥90% of mean daily flow days in chosen annual hydrologic category, beginning at base flow onset until 30 September = 1 | + | The "no more than 0.1 m stage change" recommendation achieved ≥95% of nursery period days = 1 | = | Values could range from 0 – 5. A score of 4 out of 5 is needed for the year to count in the total number of years needed for evaluation of managed summer base flows. |
| 25-99% of long-term average annual larval density = 0.5 | | Exceeds 5°C for <10% of the days during the period of larval drift = 0.5 | | TWG base flow target achieved within 3 days before or 7 days after 1st capture = 0.5 | | <90% of days in chosen annual hydrologic category= 0 | | The "no more than 0.1 m stage change" recommendation achieved <95% of nursery period days = 0 | | |
| <25% of long-term average annual larval density = 0 | | Exceeds 5°C for >10% of the days during the period of larval drift = 0 | | TWG base flow target achieved more than 7 days after 1st capture = 0 | | | | | | |

[1] Would not influence whether or not to proceed with a base flow experiment in any given year, but could retrospectively influence the quality of the experiment.
[2] Nursery period = date of 1st larval Colorado pikeminnow capture through Sept. 30.
[3] A suitable base flow experiment is years when ≥4pts are assigned; it is not possible to have a suitable base flow experiment when no larvae are captured.

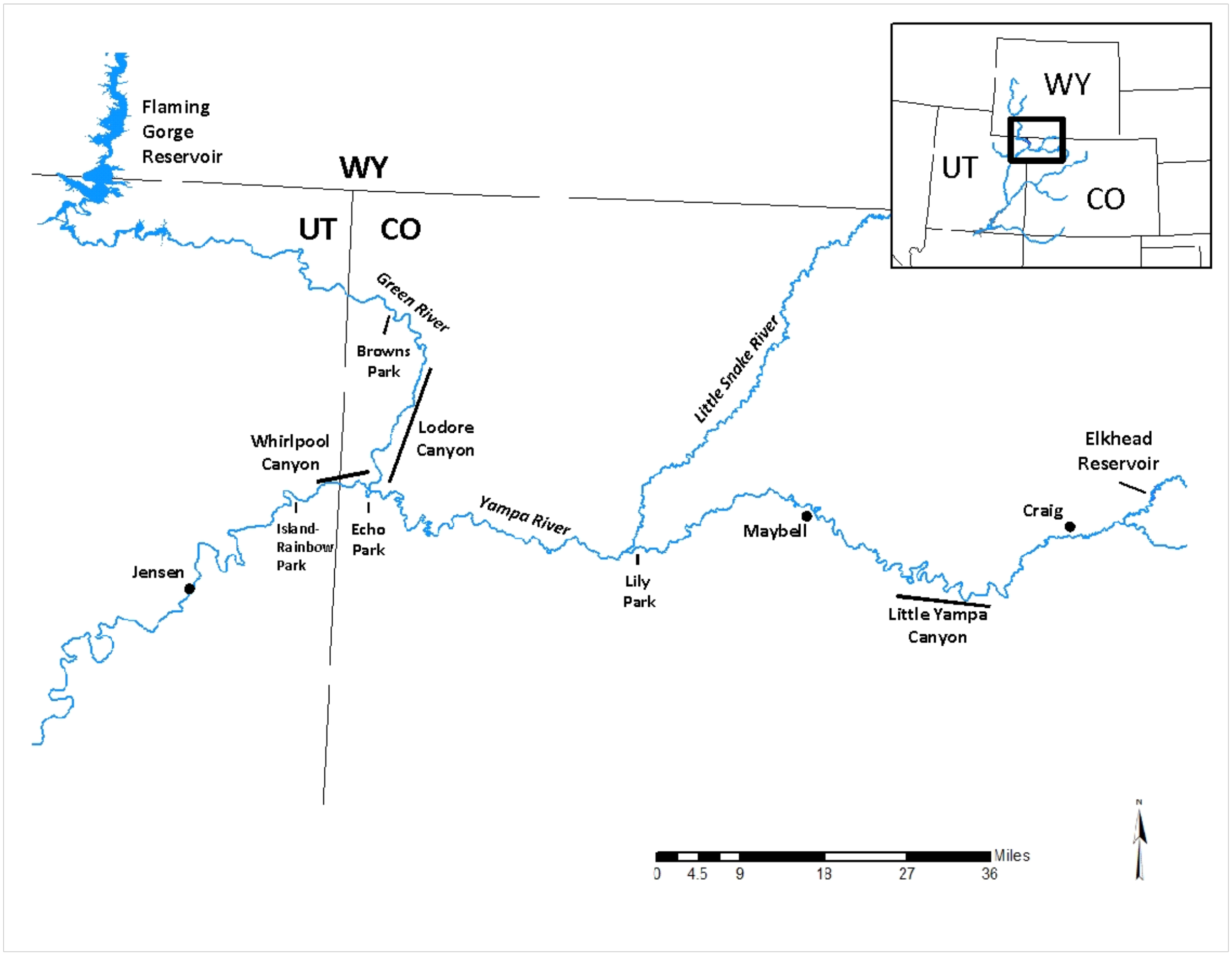



**Figure 1.** The upper Green River basin including the Yampa River-Green River confluence in Echo Park, Dinosaur National Monument. Reach 2 begins downstream of the Yampa-Green River confluence, and the main backwater nursery habitat study area for this experiment, begins downstream of Jensen, UT.

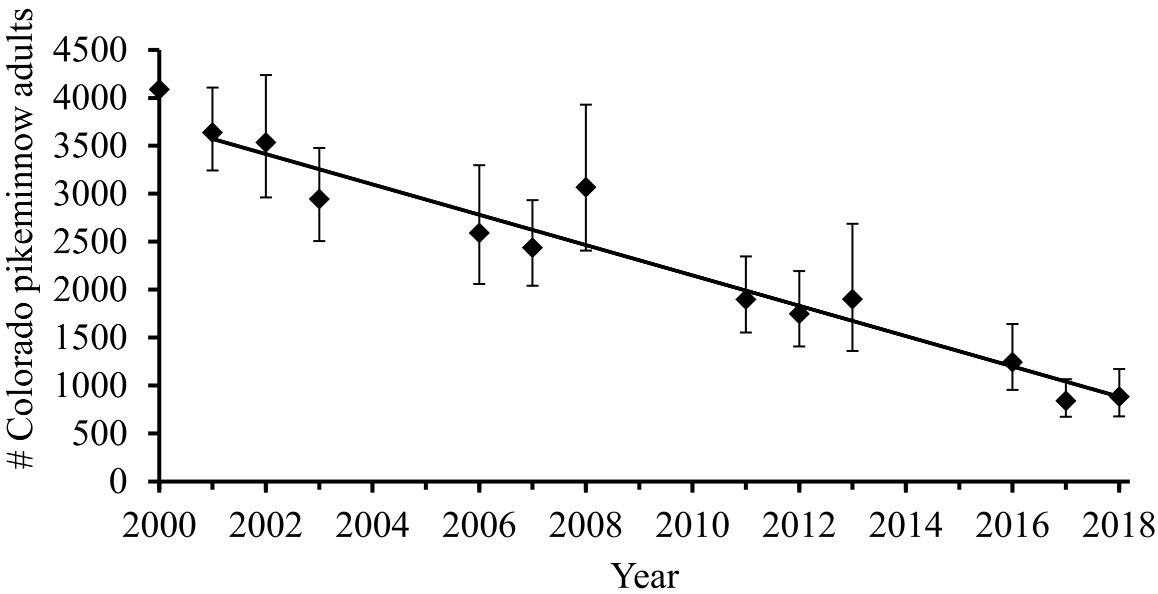



**Figure 2.** Estimated number of Colorado pikeminnow adults (≥ 450 mm TL), 2000-2018, Green River basin, Utah and Colorado. Abundance estimates are based on capture-recapture sampling in five reaches; error bars are 95% confidence intervals (from Bestgen et al. 2018 and unpublished data [2016-2018 estimates]).

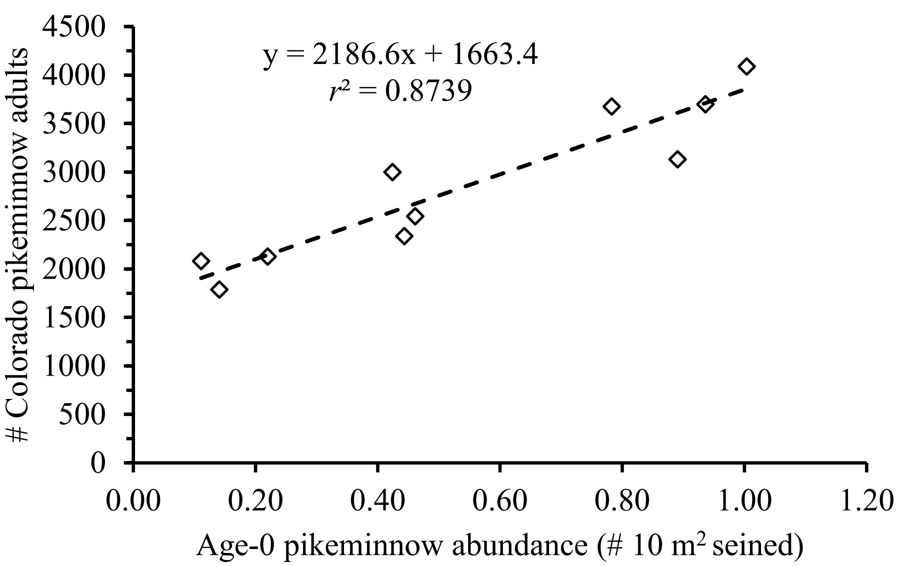
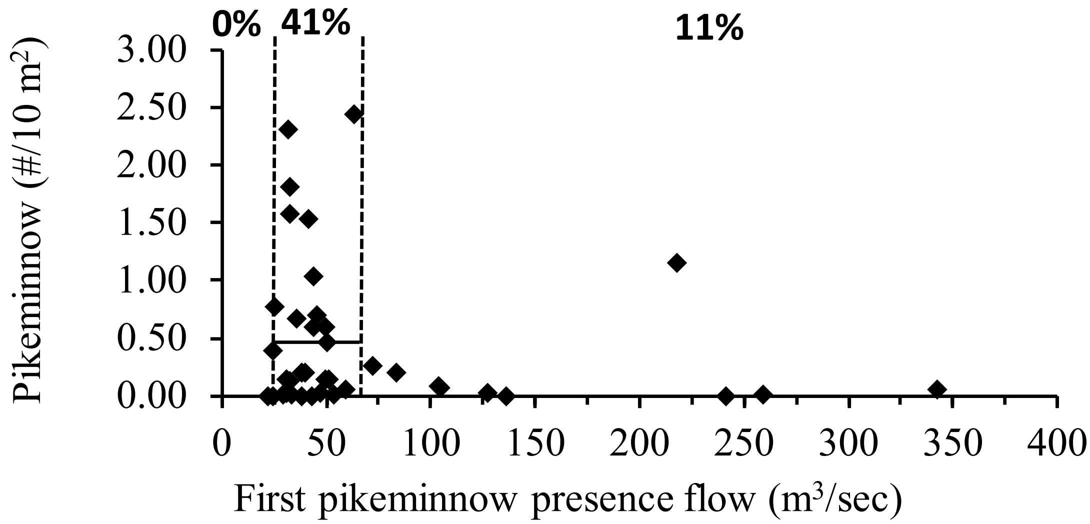



**Figure 3.** The relationship between annual abundance of adult Colorado pikeminnow in the Green River basin, Utah and Colorado, as a function of mean abundance of age-0 Colorado pikeminnow in Green River backwaters sampled in autumn 7, 8, 9, and 10 years prior. For example, the highest abundance of adult Colorado pikeminnow of > 4,000 individuals was in 2000 and was a product of age-0 pikeminnow mean abundance in the years 1990, 1991, 1992, and 1993.

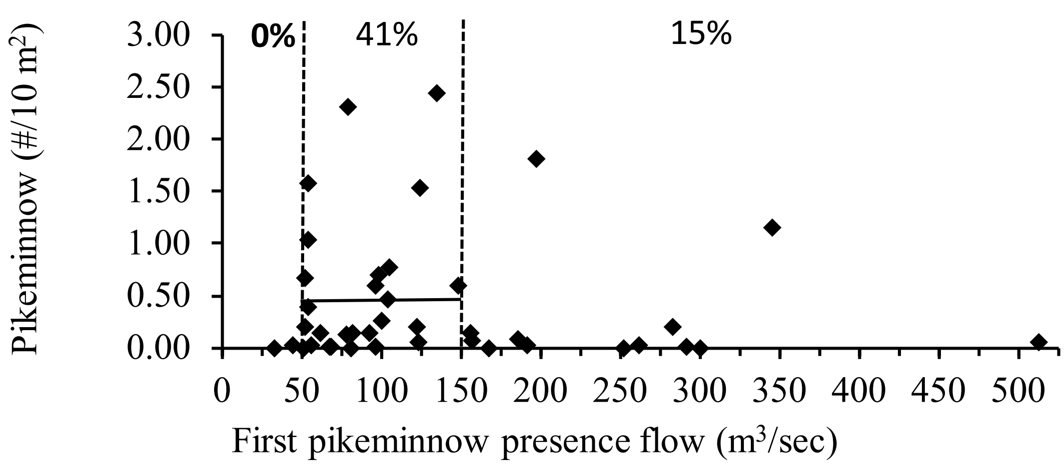
Age-0 pikeminnow density & first presence
Flaming Gorge Dam flow, 1979-2019

A




Age-0 pikeminnow density & first presence flow,
Middle Green River, 1979-2019

B



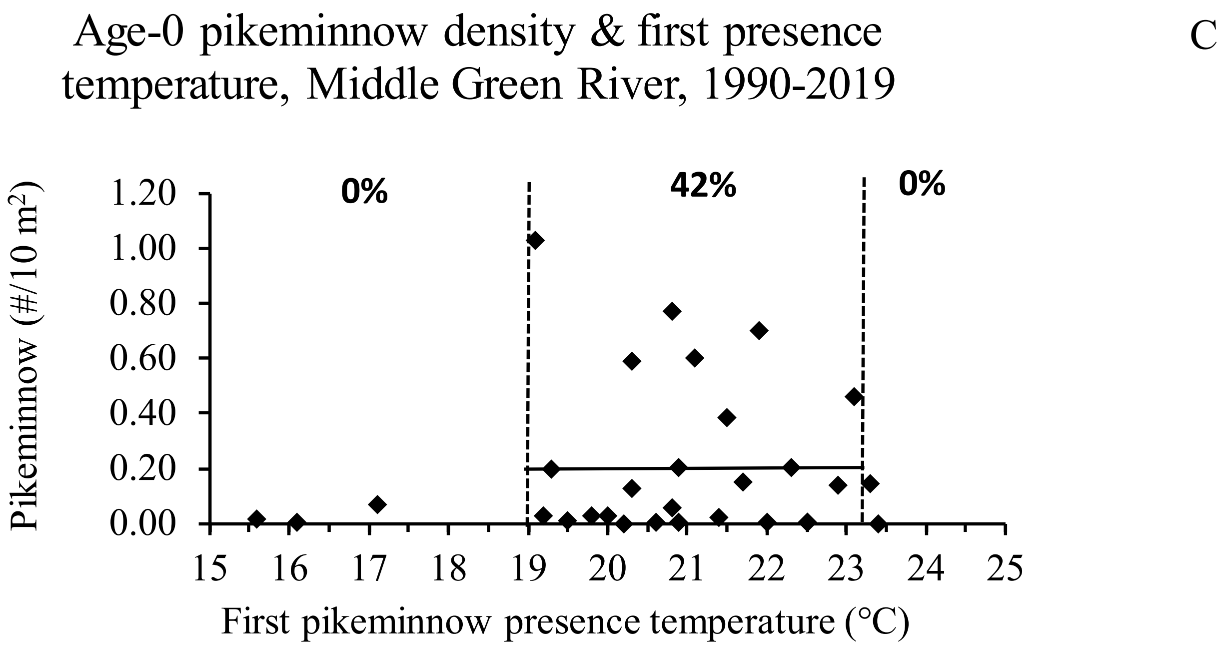



**Figure 4.** Age-0 Colorado pikeminnow density measured in Green River autumn backwater sampling as a function of flow on the first day of larvae annual presence; flow was measured at Flaming Gorge Dam (panel A), and the middle Green River, Jensen, Utah (panel B), with greater Jensen reach flows due to the input of the tributary Yampa River. Age-0 Colorado pikeminnow density measured in Green River autumn backwater sampling as a function of mean daily water temperature on the first day of larvae annual presence in the middle Green River, Jensen, Utah (panel C). Horizontal crossbars represent the mean abundance of age-0 Colorado pikeminnow for the period of concern; mean abundance was higher for the 1979-2019 dataset because of several large year-classes in the 1980's. The %'s are the number of years that pikeminnow year class abundance was above average when flows or water temperatures were in the relevant window. For example, when water temperatures were 19-23.1°C, 42% of year-classes were of average or higher abundance than the mean; no year-classes were of average or higher abundance when water temperatures were higher or lower.

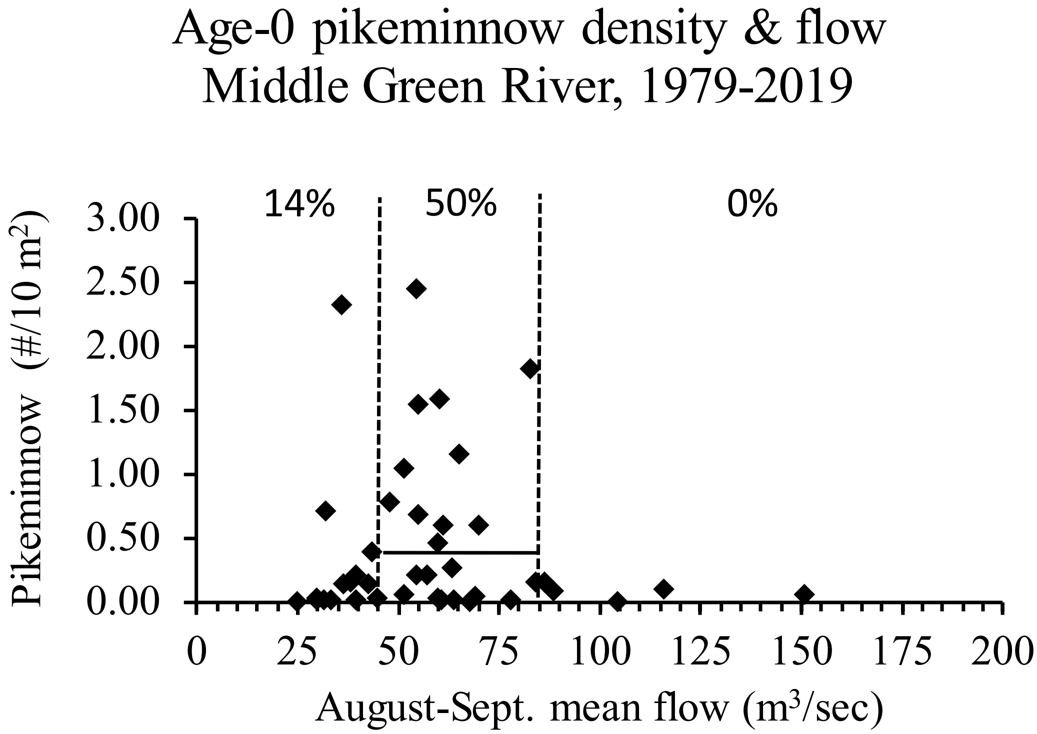



**Figure 5.** Age-0 Colorado pikeminnow density measured in Green River autumn backwater sampling as a function of mean daily August-September flow measured for the middle Green River, Jensen, Utah. The horizontal cross-bars represent the mean abundance of age-0 Colorado pikeminnow for the period of concern; mean abundance was higher for the 1979-2019 dataset because of several large year-classes in the 1980's. The %'s are the number of years that pikeminnow year class abundance was at or above average when flow was in the relevant window. This graph is modified from the one in Bestgen and Hill (2016a), which had data only through 2012, and because recent-year pikeminnow densities have been low, the mean for the period is slightly lower (0.44 fish/10 $m^2$ seined compared to 0.51 for the earlier period).

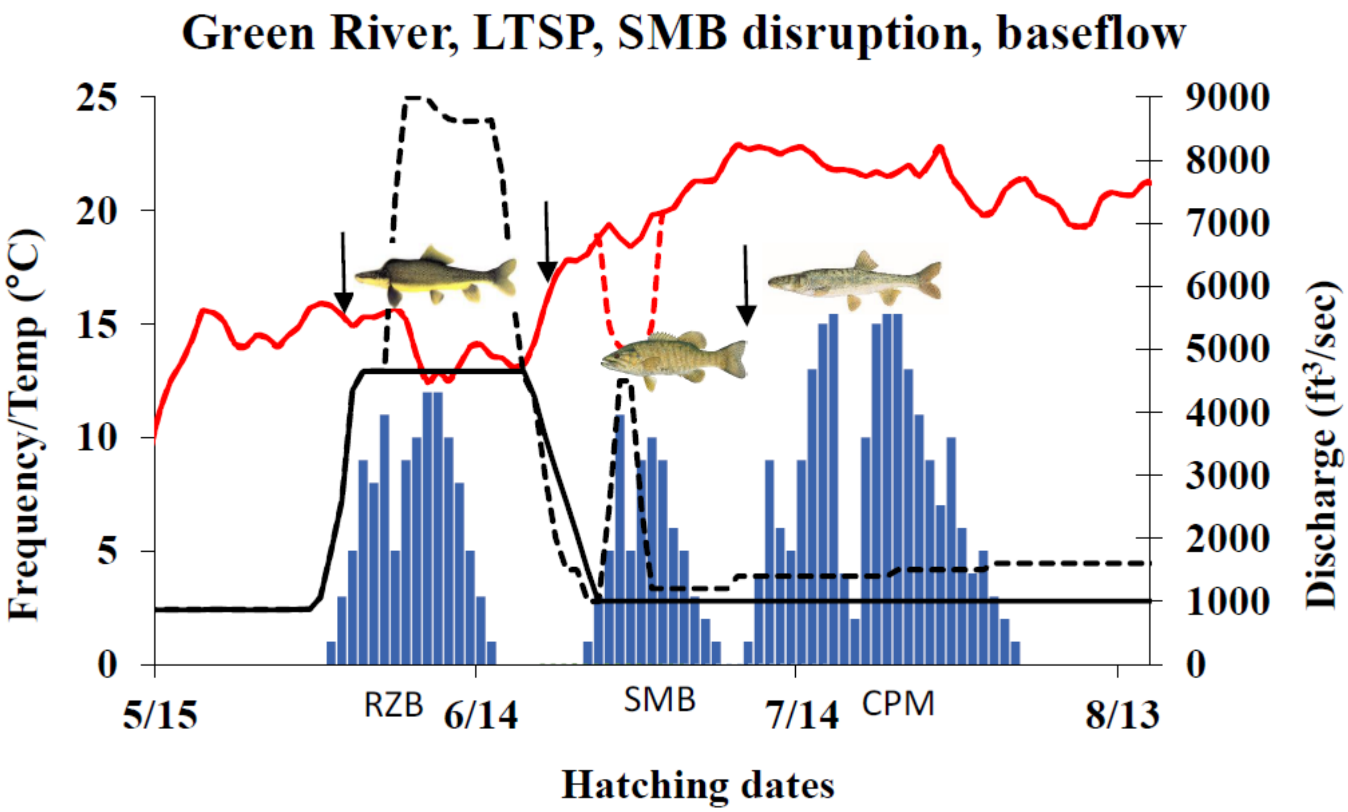



**Figure 6.** Conceptual diagram showing temporal sequencing of flow and water temperature regimes to benefit native razorback sucker (RZB) and Colorado pikeminnow (CPM) and disadvantage invasive smallmouth bass (SMB) in the Green River, downstream of Flaming Gorge Dam. Hatching dates for each species (indicated by arrows) are well-known and used to trigger flow management actions at appropriate times. Solid black line indicates a standard flow release from Flaming Gorge Dam under the 2006 Record of Decision. The dashed line indicates proposed (and presently implemented) higher magnitude flows for razorback sucker in spring under the Larval Trigger Study Plan to promote floodplain connection with the Green River, the flow spike in late June designed to disadvantage the early portion of smallmouth bass reproduction, and managed base flows in summer designed to benefit age-0 Colorado pikeminnow in Green River nursery backwaters. The water temperature decline associated with the late June flow during smallmouth bass hatching could be effected either by reduced water warming as higher flows proceed downstream more quickly, or by releasing colder water from the variable elevation penstocks at Flaming Gorge Dam.

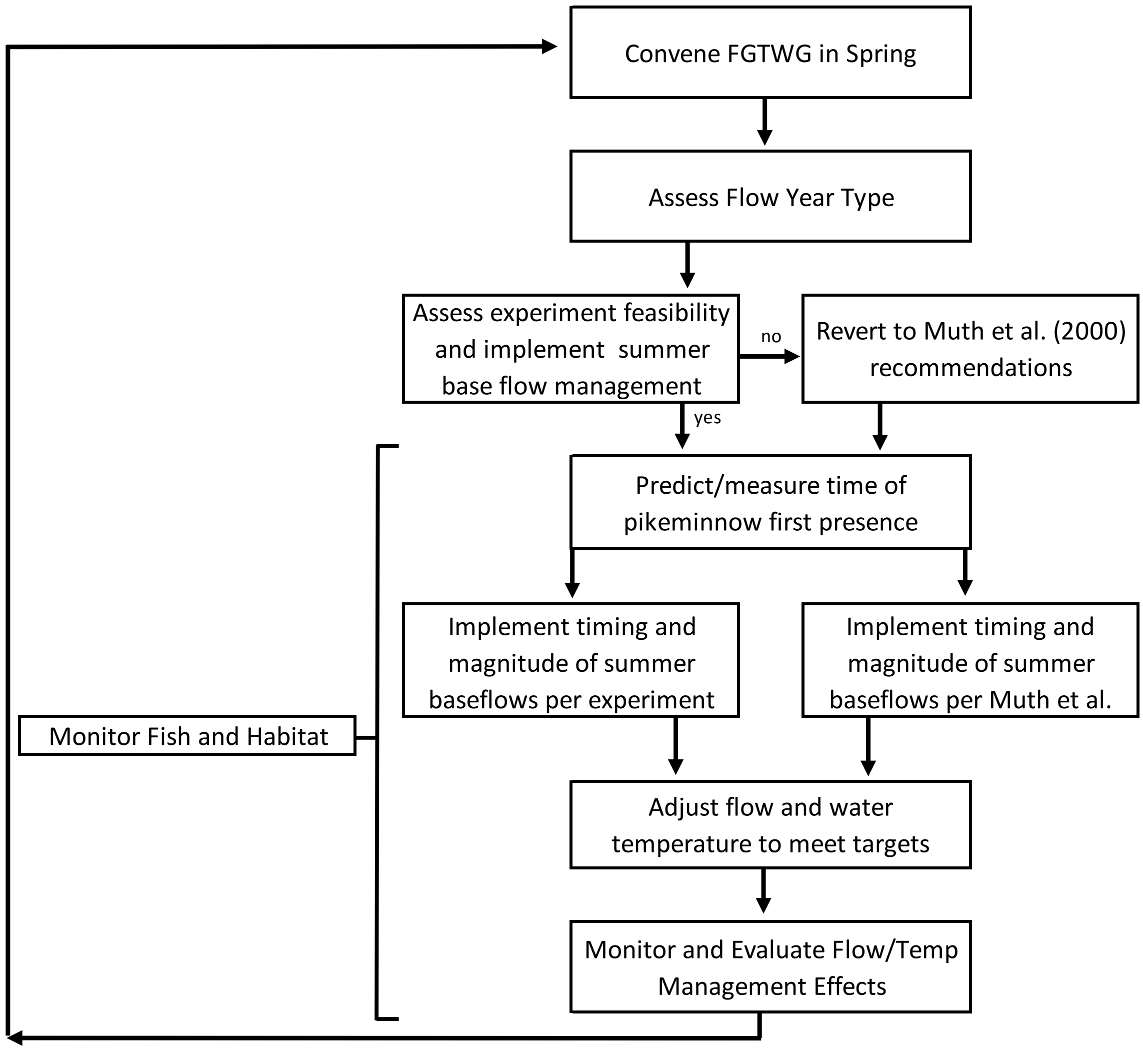



**Figure 7.** Flow chart describing the recommended annual process to schedule and monitor summer base flow management in the Green River downstream from Flaming Gorge Dam.

**Appendix I.** Procedure to estimate flows and water temperatures at first presence of Colorado pikeminnow, upper Green River basin.

Past analyses (Bestgen and Hill 2016a) described the relationship of Colorado pikeminnow abundance as a function of mean August-September flow in the middle Green River, Utah, from 1979-2012. That analysis was extended here to include data collected through 2019, and showed essentially the same pattern; that flows in the 1,700-3,000 cfs range resulted in above average survival abundance of age-0 Colorado pikeminnow in about 60% of years.

To complement that analysis, we conducted a similar analysis of flow and water temperature conditions when Colorado pikeminnow first presence was noted each year. This extended analysis was logical because there was clear evidence that early season conditions for Colorado pikeminnow were important and that survival of the fish hatched earliest in the year was often reduced or non-existent (Bestgen et al. 2006a; Bestgen and Hill 2016a; Bestgen et al. annual reports for Project 22f). Dates of first presence were known based on drift net captures of Colorado pikeminnow larvae in the lower Yampa River each year from 1990-2019; 1997 was an exception because no sampling was conducted. Dates of first presence were used to identify the relevant flow levels at Greendale and Jensen gages. Then, pikeminnow abundance in the autumn ISMP samples was plotted as a function of the flow levels at first presence for each gage. The plots of flow levels at each gage allowed us to separate flows from the Yampa River from relationships and gave insights into operations at Flaming Gorge Dam that may be used to benefit Colorado pikeminnow early life stage survival rates. We also plotted pikeminnow abundance as a function of water temperature at first presence, to better understand the possible role of the thermal environment on survival.

Additional plots were constructed for the entire 1979-2019 period, to extend the analysis. Recall there was no first presence information for 1979-1989 and 1997 because larvae sampling was not conducted. First hatching dates for those years were calculated per the equation in Bestgen and Hill (2016a), and 12 days were added to that result to achieve predicted date of first presence; 12 days is the average time for embryos to hatch, and larvae to emerge and drift downstream to be captured in drift nets. The predictor variables were peak flow, an easily attainable statistic, and degree days, which were not available because temperature records were poor at that time. In lieu of temperature records for that early period 1979-1989, we compared flow data and chose two or three comparable flow years in the 1990-2019 period, and calculated the mean degree days for those flows. That value was then substituted into the first hatching equation to achieve first presence dates for the year in the 1979-1989 period; the 1997 estimate used temperature data for that year.

Results for 1990-2019 data indicate that when flows are in the window of 50-150 $m^3$/sec at first presence, there is nearly a 50% chance of achieving an average or better year class of YOY Colorado pikeminnow. Flows lower than 50 $m^3$/sec resulted in no above average year classes, and flows higher than 150 $m^3$/sec resulted in only a 1 in 9 chance (11%) of getting a higher than average year class abundance. After including the data beginning at 1979 (Figure 4, panel B) for the same flow window, the chance of achieving an above average year class abundance remain about the same, but two years (15%, 2 of 13 years) emerge as occasions when YOY pikeminnow production was above average when flows were high (1982, 1986). We used the mean abundance of pikeminnow in each year from autumn ISMP sampling to set the "crossbar" height on the goal posts, so recognize the crossbar magnitude increases from 0.20 fish/10 $m^2$ seined in the period 1990-2019 to 0.45 fish/10 $m^2$ using the full 41 years of data and when pikeminnow abundance was higher.

The temperature analysis for 1990-2019 (Figure 4, panel C) shows that average or higher abundances occur 42% of the time when Green River, Jensen, Utah, water temperature at first presence is > 19°C (19-23°C). In the three years when it was cold at first presence (1997, 2016, 2017), few pikeminnow survived to autumn, years which also had high or very high flow. We did not conduct the same retrospective analysis for water temperature by adding the 1979-1989 data, because there were no temperature data available to accommodate that.

To understand the effects of Flaming Gorge flows only on those same abundance relationships, we plotted the same density data for 1990-2019 as a function of Flaming Gorge Dam release levels on date of first presence. All but one average or greater than average abundance year was when FG flows were 25-50 $m^3$/sec (880-1760 cfs). The only average or higher than average survival year when Flaming Gorge Dam flows were higher was 1995; Yampa River flows were also high. A similar pattern results when that same analysis is extended to the entire 41-year data set, although the beneficial flow window expands slightly to 25-65 $m^3$/sec (Figure 4, panel A).

What is uncertain of course, is what would have occurred with Colorado pikeminnow abundance if Flaming Gorge releases were lower in the 8 years when flows exceeded the more "acceptable" range and when abundance was low (> 150 $m^3$/sec at Jensen); that is not knowable. However, in 5 of those 8 higher flow years when survival was poor (years 1997, 1999, 2011, 2016, 2017), Flaming Gorge releases averaged 71% (54-89%) of the flow volume at Jensen at pikeminnow first presence; in 1998, 2008, and 2019 Yampa flows were greater (74% of Jensen flows) than Green River flows. In 7 of those 9 total years when Jensen flows were higher than the 150 $m^3$/sec threshold, flows could have been better managed (reduced sooner, spillway use, etc.) to get below the 150 $m^3$/sec threshold identified; those years include 1997-1999, 2011, 2016, 2017, and 2019. We note that 4 of those 7 years have occurred relatively recently and in 4 of the last 9 years, and 3 of them were in the last 4 years. In the other 2 years of the 9 total years, 1995 and 2008, reduced released from Flaming Gorge Reservoir would not have been sufficient to reduce Jensen flow to more acceptable levels due to dominant Yampa River flows.

Collectively, these analyses indicate that to have about a 50% chance at an average or greater than average survival year, Green River flows and Flaming Gorge releases must be relatively low and warm when pikeminnow are first present, the unregulated Yampa River notwithstanding. The Yampa River will always be warm at first reproduction because those temperatures drive reproduction of fish that are resident in that system at the spawning bar. Also indicated is the notion that more management could have been done in most higher flow years, to reduce flow levels into the window that may enable higher survival of Colorado pikeminnow early life stages. Ideally, this would be followed with the base flow magnitude recommendations for the remainder of the summer. The high base flows and low temperatures at first presence of larvae in 2016, and 2017, 2 of the 3 years when temperatures were likely a problem, were also relatively recent.

There are those years when flows and water temperatures are in the ranges between the uprights but below the crossbar, which results in a majority of years that do not yield higher survival (e.g., above the crossbar). There are many possible reasons for that, including increased negative effects of invasive fish effects, measurement error when estimating autumn pikeminnow abundance, and low reproduction. Although there is not much to remedy these potential problems, a possible additional activity may be to evaluate efficacy of ISMP sampling to estimate pikeminnow abundance.

Also of interest are the two years in the full dataset, 1982 and 1986 (labeled on the graph, panel B), when high survival occurred when Jensen flows were also high. In 1986, flows were high from the Gorge (218 $m^3$/s) and high from the Yampa River, with total Jensen flow at first presence of >346 $m^3$/sec (12,200 cfs) and high survival (1.15 fish/10 $m^2$, when the mean is 0.45/10 $m^2$). In 1982, even higher survival occurred (1.81 fish /10 $m^2$ seined), but flows were low from the Gorge (33 $m^3$/sec) but higher from the Yampa River (Jensen flows nearly 200 $m^3$/sec (6960 total cfs). Perhaps larvae were very abundant in those years, and survived at average or higher levels, but that is speculation.

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