REVIEW OF FISH STUDIES WITH INTERIM FLOW RECOMMENDATIONS FOR ENDANGERED FISHES OF THE WHITE RIVER, COLORADO AND UTAH

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TABLE OF CONTENTS

LIST OF TABLES iii

LIST OF FIGURES iii

LIST OF APPENDICES v

ACKNOWLEDGEMENTS vi

EXECUTIVE SUMMARY vii

1. INTRODUCTION 1-1

1.1 Purpose 1-1

1.2 Study Area 1-2

1.3 Importance of the White River in Recovering Endangered Fishes 1-4

2. WHITE RIVER – FISH BIOLOGY SUMMARY 2-1

2.1 General Overview 2-1

2.2 Native Fish Communities in the White River 2-2

2.2.1 Colorado Pikeminnow 2-2

2.2.2 Razorback Sucker 2-6

2.2.3 Other Native Fishes, Including Bluehead Sucker, Flannelmouth Sucker, and Roundtail Chub 2-7

2.3 Nonnative Fishes 2-13

2.4 Summary 2-16

3. IMPORTANT CHARACTERISTICS OF THE WHITE RIVER FLOW REGIME .. 3-1

3.1 Spring Peak Flows 3-1

3.2 Base Flows 3-5

4. FLOW RECOMMENDATIONS 4-1

4.1 Objectives of these Recommendations 4-1
4.2 Methodology 4-2
4.3 Peak Flows Analyses and Recommendations 4-3
4.4 Shoulder Peak Flows Analyses and Recommendations 4-5
4.5 Base Flow Analyses and Recommendations 4-6
4.6 Assumptions and Uncertainties 4-13
4.7 Implementation Considerations 4-16
LITERATURE CITED 5-1

Cover photo: Colorado pikeminnow caught in the White River, by Mathew J. Breen, UDWR

LIST OF TABLES

1. Recommended annual peak and shoulder peak flows, by hydrologic year type.
2. RHABSIM data generated for 49 field-measured White River transects from River Mile 1 to 104 by Haines et al. 2004.
3. Recommended irrigation-season base flows, by hydrologic year type.
4. Recommended non-irrigation-season base flows, by hydrologic year type.

LIST OF FIGURES

1. The White River in Colorado and Utah, including the locations of Taylor Draw Dam and the USGS gage near Watson, Utah.
2. Captures of sub-adult and adult Colorado pikeminnow per hour of electrofishing effort.
3. Fish community composition from randomly designated river miles where all species were collected during cataraft electrofishing surveys.
4. Length-frequency distribution of bluehead sucker (a), flannelmouth sucker (b), and roundtail chub (c) captured during cataraft electrofishing surveys by year in the White River, Utah.
5. Catch-per-unit-effort (CPUE) during autumn seining surveys for young-of-year fishes in the White River, Utah.
6. Location of two tributaries to the White River: Piceance Creek and Coal Creek.
7. Distribution of flows (mean daily discharge) as measured by the USGS White River near Watson, Utah gage (#09306500) for the period 1923-2016.
8. Cottonwood groves along the lower White River.
9. Woody debris in the lower White River after the high flows of 2011.
10. Flow duration curve for White River at Watson gage from August 15 to October 31 of four 'wet' years (1983, 1984, 1985, and 2011) compared to distribution of recommended wet year flows

11. Flow duration curve for White River at Watson gage from August 1 to October 31 of eight 'moderate wet' years (1975, 1978, 1979, 1986, 1993, 1995, 1997, and 1998) compared to the distribution of recommended moderately wet year flows.

12. Flow duration curve for White River at Watson gage from July 15 to October 31 of 16 'average' years (1976, 1980, 1982, 1988, 1991, 1996, 1999, 2000, 2003, 2005, 2006, 2008, 2009, 2010, 2014, and 2015) compared to the distribution of recommended average year flows.

13. Flow duration curve for White River at Watson gage from July 1 to October 31 of eight 'moderately dry' years (1981, 1989, 1990, 1992, 2001, 2004, 2007, and 2013) compared to the distribution of recommended moderately dry year flows.

14. Flow duration curve for White River at Watson gage from June 15 to October 31 of four 'dry' years (1977, 1994, 2002, and 2012) compared to the distribution of recommended dry year flows.

LIST OF APPENDICES

A. White River StateMOD Technical Memorandum (Wilson Water Group)

B. White River Base Flow Recommendations During the Irrigation Season – Rationale for Recommended Flows under Drier Hydrologies (U.S. Fish and Wildlife Service)

C. White River Base Flows and Water Quality (U.S. Fish and Wildlife Service)

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Many Recovery Program stakeholders contributed to this document and helped review the information therein, including the Colorado Division of Parks and Wildlife; the Colorado Water Conservation Board; the Nature Conservancy; the Rio Blanco Water Conservancy District, the Bureau of Reclamation; the Utah Department of Natural Resources; Utah's Division of Water Rights; the Colorado River Water Conservation District; the upper basin water users community, and the Ute Indian Tribe of the Uintah and Ouray Reservation. Nevertheless, any errors in this document are the responsibility of the authors. We also thank the Recovery Program Biology, Water Acquisition, and Management committees for their reviews and comments. Katherine Busch assisted with formatting this document.

EXECUTIVE SUMMARY

The White River plays an essential role in the conservation of native fish in the upper Colorado River basin, including recovery of federally endangered Colorado pikeminnow (*Ptychocheilus lucius*) and razorback sucker (*Xyrauchen texanus*). The substantial and persistent populations of these endangered and other native fish in the White River is likely related to the relatively unaltered White River flow regime and preservation of natural flow variation that continues to benefit native fishes.

This document reviews studies documenting the use of the White River by endangered and other native fish. It also provides interim flow recommendations for the lower White River derived from a review of studies demonstrating the biological importance of the White River to endangered fish recovery, an analysis of the White River flow regime under current development conditions, and a consideration of information provided by two technical flow studies conducted on the White River in the 1990s.

Based on these reviews and analysis, the U.S. Fish and Wildlife Service (Service) recommends a suite of peak flow targets intended to maintain satisfactory channel conditions for native and endangered fish. These recommendations include annual spring one-day peak flows of 1,000 to 5,250 cfs, and shoulder peak flows sustained for 10 to 30 days annually between 700 and 3,700 cfs, depending upon the hydrologic year type. In addition, the Service recommends a suite of irrigation and non-irrigation season base flows, also varying with the hydrologic year type, to protect flows vital for fish passage, forage, and shelter. As interim recommendations, the flow targets described herein are subject to further revision as relevant studies are completed.

The hydrologic regime of the White River still largely meets these recommendations. The Service believes that protecting these flows in the White River to the extent feasible is a prudent course of action for protection and recovery of the endangered Colorado pikeminnow and razorback sucker, and for reducing the possibility that other native fish may require protection under the Endangered Species Act.

1. INTRODUCTION

1.1 Purpose

This document provides flow recommendations for the lower White River[1] in Colorado and Utah that, based on best available information, are considered flows that will promote a thriving native fish community and aid the recovery of Colorado pikeminnow (*Ptychocheilus lucius*) and razorback sucker (*Xyrauchen texanus*). Both of these species are listed as federally endangered pursuant to the Endangered Species Act of 1973 (ESA; 16 U.S.C. §1531 et seq)[2], and recovery of their populations in the upper Colorado River basin (UCRB)[3] is supported through implementation of the Upper Colorado River Endangered Fish Recovery Program (Recovery Program), established in 1988 as a partnership of local, state, and federal agencies, water and power interests, and environmental groups (coloradoriverrecovery.org), and through the activities of the San Juan River Basin Recovery Implementation Program (fws.gov/southwest/sjrip).

The flows recommended here should sustain a rich forage base, provide fish passage and cover, and help maintain channel habitat diversity and availability for these endangered fish in the White River. The recommendations are based on an analysis of the flow regime of the White River under current (circa 2015) levels of development, and a consideration of information provided by two technical flow studies conducted on the White River (Schmidt and Orchard 2002, and Haines et al. 2004). A review of field data demonstrating the biological importance of the White River to endangered fish recovery is included.

This document has three main parts: a detailed synopsis of fish biology studies pertaining to the White River (Section 2), underscoring the importance of existing White River flow regimes to the Colorado pikeminnow, the razorback sucker, and other native species; a discussion of important characteristics of the White River flow regime for endangered fish (Section 3); and U.S. Fish and Wildlife Service (Service) recommendations for adequate annual peak and base flows to sustain favorable conditions for recovery of the endangered fishes (Section 4).

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[1] For purposes of this document, the "lower White River" refers to the portion of the river between Taylor Draw Dam (River Mile 104 in Colorado) and its confluence with the Green River near Ouray, Utah.

[2] In 2018, a five-year review of the status of the razorback sucker led the Service to propose downlisting the species to "threatened" status. The Service expects to soon publish a proposed federal rule to downlist *Xyrauchen texanus*.

[3] In this document, "upper Colorado River basin" or UCRB refers to the entire Colorado River system draining to Lake Powell (including the Green River and San Juan River basins).

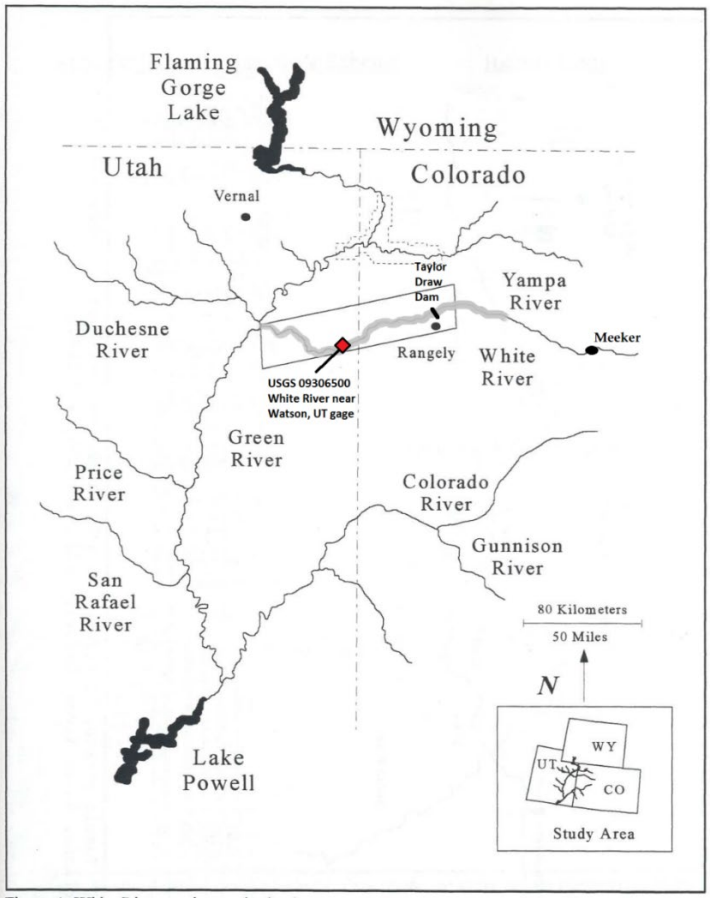

Figure 1. The White River in Colorado and Utah, including the locations of Taylor Draw Dam and the USGS gage near Watson, Utah. The shaded trace over the river channel denotes designated critical habitat in the White River drainage. The boxed area shows the reach of the White River studied by Haines et al. 2004 in 1995 and 1996.

1.2 Study Area

The White River is a major tributary to the Green River, second only to the Yampa River in annual discharge under current conditions of development. It is more than 200 miles long and drains nearly 5,120 square miles in western Colorado and eastern Utah, merging with the Green River in northeastern Utah approximately 98 river miles downstream from the Yampa River confluence, and two miles downstream from the Duchesne River confluence (Figure 1).

Most runoff derives from high elevation snow accumulation and melt. Under current conditions, average runoff volume in the White River is about 508,000 acre-feet annually, based on measurements at the U.S. Geological Survey (USGS) gages near Watson, Utah (#09306500) and near the Colorado State Line (#09306395) from 1975 to 2015. Median flows vary from around 350 cubic feet per second (cfs) in late summer to well over 3,000 cfs during the peak of spring snowmelt runoff.

The White River, over the period identified above, contributed on average about 13% of the total annual flow in the lower Green River as measured at the USGS gage at Green River, Utah (#09315000).

The hydrology of the White River is affected by various water diversions and uses within the river basin, and by one substantial mainstem impoundment, Taylor Draw Dam, at River Mile 104 near Rangely, Colorado. However, compared to most other major rivers in the upper Colorado River system, the hydrology of the White River remains relatively unaltered. Recent estimates indicate approximately 26,000 to 28,000 irrigated acres in the basin in Colorado, with a

corresponding average consumptive annual irrigation water requirement[4] between 32,634 and 45,740 acre-feet (CWCB 2015; AMEC and Hydros, 2015). Almost all of this irrigation is provided by surface water; groundwater pumping in the basin is relatively minor. Surface water diversions to meet irrigation needs averaged about 288,000 acre-feet annually from 1950-2013, with no obvious trends in these amounts over that period, but with considerable year-to-year variation attributed to variations in snowpack and water supply (CWCB, 2015).

The White River basin is sparsely populated; AMEC and Hydros (2015) estimated a municipal and industrial diversion demand for water in Colorado's Rio Blanco County in 2008 (including the towns of Rangely and Meeker) of only 2,000 acre-feet/year. This does not include any industrial oil, oil shale, natural gas or coal development that may have occurred since that time.[5] Nor does it include evaporative losses from reservoir storage within the White River basin. The Colorado Division of Water Resources (1994) estimated 1,643 acre-feet of annual depletion due to evaporation from Kenney Reservoir in 1992-1994.

Collectively, the above numbers suggest that, on average, roughly 10% of the natural flow of the White River is depleted annually by human uses. The Colorado Division of Water Resources estimated a cumulative depletion from 1992 to 1994 of 11.4% of the total basin yield (Lentsch et al. 2000). While these depletions are modest in magnitude relative to those in other major rivers in the upper Colorado River system[6], these water uses do significantly affect the timing of flow in the White River. In particular, while a substantial portion of the water diverted for agricultural purposes eventually makes its way back to the river as surface or subsurface return flow, those returns may be delayed by days, weeks or months.

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[4] Irrigation water requirement (IWR) is defined as potential crop evapotranspiration minus effective precipitation used by the crop. It does not include losses accrued through ditch seepage and via field application.

[5] We are not aware of reliable estimates of total water use for oil and gas development, however the depletive impacts of these activities as of 2018 were considered relatively minor. The Bureau of Land Management (BLM), in 2017, based on "professional judgement from the BLM petroleum engineers and private industry professionals working in the Action Area" projected that 720 wells would be drilled on lands under their jurisdiction in the White River basin over a ten-year period, equating to a maximum average freshwater consumption of 538 acre-feet/year (AF/yr) (BLM, 2017). BLM subsequently estimated that a total of 77 AF of fresh water (*i.e.*, water not reused or recycled) was used to drill wells permitted by BLM in the White River basin of Colorado in 2018, and 0.7 AF in 2017 (BLM 2019, BLM 2018). The State of Colorado (CWCB 2019) estimated a substantially higher '2015 Baseline' demand for water for energy development in the Colorado portion of the White River basin of 1,600 AF/yr, however the amount representing water reused, recycled, or otherwise developed in a non-depletive manner is not specified.

[6] For comparison, studies suggest that an average of around 1,029,000 acre-feet annually of flow is depleted in the Colorado River above the Gunnison River confluence (CWCB 2008) out of an average natural flow since 1975 of around 3,500,000 acre-feet annually (USBR, 2017), or roughly 30%. For the Duchesne River in Utah, CH2M Hill (1997) suggests that approximately 270,000 of the estimated 768,000 acre-feet/annually of natural flow is now depleted by human use, or roughly 35%. For the Gunnison River in Colorado, current and "reasonably foreseeable" depletions are estimated at 450,000-537,000 acre-feet per year (USBR 2012b) out of an average natural flow since 1975 of around 2,280,000 acre-feet annually (USBR 2017), equating to roughly 20-24%.

Taylor Draw Dam (which impounds Kenney Reservoir) is a run-of-the-river project, and as such passes large spring peaks. The Dam was established in 1983, and modified in 1991 to accommodate a hydroelectric facility installed in 1993. The reservoir serves multiple purposes, including alleviating the occurrence of floods caused by White River ice jams, generating hydroelectric power, and providing for public recreation. Its design storage is 13,800 acre-feet, however present capacity is closer to 3,800 acre-feet due to ongoing accumulation of sediment in the reservoir at an estimated rate of 315 acre-feet annually (GEI 1999). While the quantity of flow stored behind the dam is modest relative to total river discharge, it does create a barrier to approximately 47 miles of river habitat upstream designated as critical habitat for Colorado pikeminnow by the Service.

The hydroelectric facility at Taylor Draw Dam operates 100% of the time as a run-of-the-river operation. Power generation frequently shuts down in late July/August, and periodically in September, late January and/or February due to diminishing flows. The hydroelectric facility remains shut down until flows are adequate to resume power generation. Kenney Reservoir is operated as a run of the river facility where outflow from the dam is the same as reservoir inflow, and no additional releases are made during periods of low flows. Short-term spikes in upstream flow from summer thunderstorms tend to be partially attenuated by the temporary reservoir storage. Kenney Reservoir is limited to a two-foot drawdown, unless a special permit allowing otherwise is issued by the Federal Energy Regulatory Commission.

Appendix A includes a summary of White River diversions and associated consumptive demands within the state of Colorado. By comparison, current consumptive use of White River flows in Utah is minimal, likely less than 500 acre-feet annually (James Greer, Utah Division of Water Rights, personal communication, September 2018). An additional unspecified quantity of reserved but as-yet unexercised water rights associated with the Ute Uintah and Ouray Indian tribal lands adjacent to the White River in Utah is not included in the Appendix A summary.

1.3 Importance of the White River in Recovering Endangered Fishes

While the Colorado River basin generally is one of the most altered aquatic ecosystems in North America (Minckley and Deacon 1968), the White River continues to host abundant populations of native fish (see Section 2.2.3), including the presence of endangered fishes in its lower reaches (see Sections 2.2.1 and 2.2.2). The Service considers the White River to be an essential component for the conservation of native fish in the UCRB, including recovery of endangered Colorado pikeminnow and razorback sucker, because it provides high quality shelter, forage, and breeding habitat. The river is listed as critical habitat for Colorado pikeminnow from

the Green River confluence to Rio Blanco Reservoir (river mile [RM] 150) and for razorback sucker throughout the lower 18 miles.

The White River was ranked highly for its contributions in maintaining a natural hydrograph and supplementing the input of sediment to the Green River in an evaluation of the role of several tributary streams for recovering endangered fishes in the upper Colorado River (Tyus and Saunders 2001).[7] The authors determined that the White River provided annual, base, and peak flows that could support endangered fish recovery and stressed the importance of adult Colorado pikeminnow habitat in the White River. Further studies emphasized the contribution of this pikeminnow population to the overall Green River sub-basin population, including resident adults that migrate to a spawning bar in the Yampa River (Lentsch et al. 2000; Haines et al. 2004).

Note that the above studies into the White River's direct role in recovering endangered fishes were focused on adult pikeminnow. Newer information regarding use of the White River by razorback sucker, along with evidence of Colorado pikeminnow spawning, demonstrates that the White River is even more important than previously assumed. This newer information includes the detection of larval razorback sucker in the White River for the first time in 2011, and increasing numbers of razorback sucker encountered in the White River, including continued colonization by suckers stocked in other locations. Moreover, recent studies indicate that the White River supports all life stages of the Colorado pikeminnow. This newer information is detailed in Section 2.

[7] The U.S. Geological Survey has continued to collect suspended sediment and other water quality data at multiple sites in the White River system since 2001, although a comprehensive summary of these data through 2018 does not appear to be available.

2. WHITE RIVER – FISH BIOLOGY SUMMARY

2.1 General Overview

The White River has a unique combination of fish community attributes: substantial populations of federally endangered Colorado pikeminnow and razorback sucker (Sections 2.2.1 and 2.2.2); abundant populations of other native large-bodied fish (bluehead sucker, flannelmouth sucker, and roundtail chub; Section 2.2.3); and the presence of only a few nonnative fish species, one of which is currently considered to be particularly problematic (section 2.3).

Studies of the White River fish community began in the 1970s as proposals for oil shale development emerged and information was needed to assess potential impacts of water impoundments for these projects. Crosby (1975) described the species composition and relative abundance of fish found in Utah portions of the White River. From the mid- to late-1970s, he found several species of small-bodied nonnative cyprinids along with roundtail chub (*Gila robusta*), flannelmouth sucker (*Catostomus latipinnis*), bluehead sucker (*C. discobolus*), speckled dace (*Rhinichthys osculus*), common carp (*Cyprinus carpio*), channel catfish (*Ictalurus punctatus*), black bullhead (*Ameiurus melas*), and smallmouth bass (*Micropterus dolomieu*). Carlson et al. (1979) summarized fish community data from multiple studies on the White River above the present day location of Kenney Reservoir to assess the status of sportfish and potential fishery impacts from coal and oil shale development. They also conducted thorough baseline studies at Piceance Creek and near Spring Creek, above what is now Kenney Reservoir. Native fishes comprised the majority of fish collected in both sites, with flannelmouth and bluehead suckers, speckled dace, mottled sculpin (*Cottus bairdii*), and roundtail chub represented. Lanigan and Berry (1981) conducted a study from the Colorado/Utah state line to the Uintah and Ouray Indian Reservation. They found similar species composition as previous studies, but were also able to illustrate a shift from native to nonnative species as their sampling progressed downstream.

White River studies in the 1980s focused on endangered fishes and the impacts of Taylor Draw Dam on those species. As Taylor Draw Dam was being constructed, several studies were conducted to assess effects on the White River fish community, particularly Colorado pikeminnow. The most immediate effects of dam closure in 1984 were the creation of a barrier to fish movement and a reduction in downstream turbidity. Taylor Draw Dam blocks access to 47 miles of river habitat historically occupied by Colorado pikeminnow (Martinez 1986; Chart 1987) and prevents other native fishes from moving upstream. Notably, adult Colorado pikeminnow have been observed congregating at the base of the dam, presumably in an attempt to move upstream (Martinez 1986; Irving and Modde 1994, 2000).

Reduced turbidity is apparent in the tailrace area below the dam due to sediment capture in Kenney Reservoir. Chart (1987) and Chart and Bergersen (1992) found that flannelmouth sucker moved out of the tailrace area below the dam, presumably in response to reduced turbidity and cover. They hypothesized that turbidity and deep pool habitats were important in providing cover from predators and protection from sunlight, pointing out that some native species, such as those in the genus *Gila*, have been shown to actively avoid sunlight (Deacon and Minckley 1974) and other species are sensitive to injury from exposure to sun (Minckley and Itzkowitz 1967; Minckley and Barber 1971). From upstream to downstream, turbidity increases from sediment input by small tributary streams and intermittent washes (Martinez 1986; Fiorelli and Breen 2014).

As described in Chapter 1, Taylor Draw Dam and its associated hydropower facility are operated as a "run of the river" project where outflow is roughly equal to inflow to the reservoir. As a result, flows were not dramatically altered when comparing pre- and post-dam discharge (Martinez 1986; Chart 1987; Chart and Bergersen 1992). Furthermore, the dam was found to alter summer maximum temperatures only slightly (Wullschleger 1990, Chart and Bergersen 1992).

2.2 Native Fish Communities in the White River

2.2.1 Colorado Pikeminnow

Colorado pikeminnow once were abundant in the mainstems of the Colorado and Green rivers and most of their major tributaries in Colorado, Wyoming, and Utah, including the White River (Banks 1964; Vanicek 1967; Seethaler 1978). Today, two wild populations of Colorado pikeminnow are found in the Colorado River basin upstream of Lake Powell, one in the mainstem Colorado River system and one in the Green River system. The mainstem Green River, along with two major tributaries, the White and Yampa rivers, currently supports the largest remaining population (Osmundson and White, 2017).

The White River is likely an important component for persistence and recovery of this species. Surveys have demonstrated that the lower White River (below Taylor Draw Dam) has exhibited the highest catch rates of Colorado pikeminnow in the UCRB (Figure 2; Bestgen et al. 2018; Bestgen et al. 2010; McAda et al. 1994). Moreover, the collection of all age classes of Colorado pikeminnow in the White River (discussed below), albeit sometimes in low numbers, indicates that this river supports the entire life history of this species, and provides quality habitat for juvenile and older life stages. As discussed later in this section, the White River contributes numerous adults that spawn in other UCRB rivers before returning to their White River home ranges.

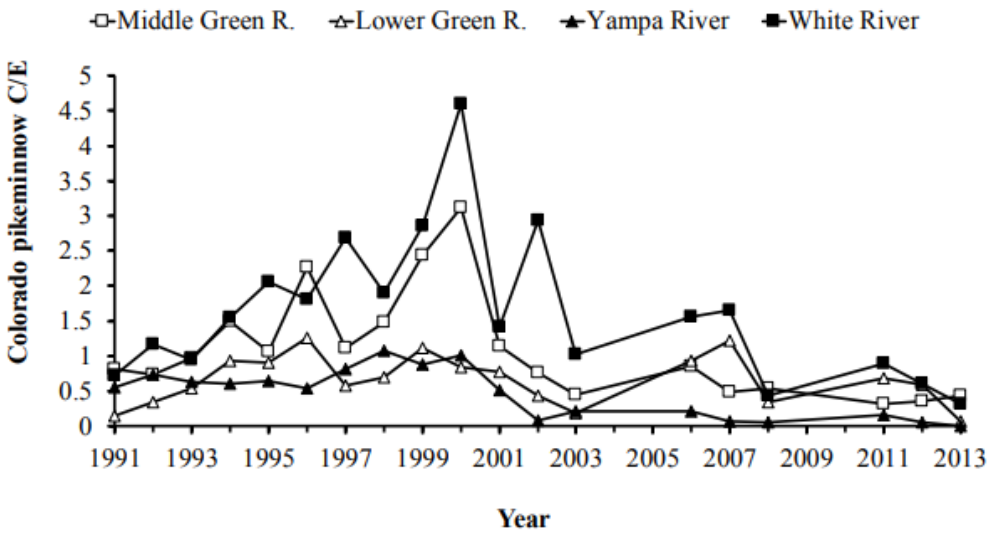

Figure 2. Captures of sub-adult and adult Colorado pikeminnow per hour of electrofishing effort (C/E). This was usually highest in the White River (Interagency standardized monitoring program for the Green River basin 1991 to 2003, 2006 to 2008, and 2011-2013 Bestgen et al. 2018).

The White River has been recognized as important habitat for Colorado pikeminnow since research on the species was initiated. Since 1978, researchers have repeatedly reported capturing Colorado pikeminnow in lower reaches of the White River (Carlson et al. 1979; Lanigan and Berry 1981; Miller et al. 1982; Radant et al. 1983; Tyus and McAda 1984; Martinez 1986; Chart 1987; Martinez et al. 1994; McAda et al. 1994; Irving and Modde 1994; Elmblad 2000; Bestgen et al. 2005, 2010; Breen and Hedrick 2009, 2010, 2012; Johnson and Breen 2012; Breen et al. 2013; Fiorelli and Breen 2013, 2014, 2015, 2016, 2017; Webber et al. 2013a, 2014; Smith et al. 2015, 2016, 2017).

The lower White River has exhibited some of the highest catch rates of Colorado pikeminnow in the upper Colorado River basin. Although specific pikeminnow spawning areas have not been identified in the White River, adults from the White River system appear to contribute to spawning stock in the Green River subbasin. The White River provides habitat for adults and sub-adults, while the Green River provides spawning habitat and essential rearing habitat for larval and age-0 fish.

Areas between Taylor Draw Dam and the Utah/Colorado border and the lower 24 river miles both have been identified as specific concentration areas for pikeminnow (Miller et al. 1982; Martinez 1986; Irving and Modde 1994; Elmblad 2000; Bestgen et al. 2010). Irving and Modde (1994) conducted a mark-recapture population estimate of

pikeminnow concentrated in the reach just downstream of Taylor Draw Dam and estimated 26 and 37 adult fish in 1992 and 1993, respectively, in the first 0.25 miles. Bestgen et al. (2010) estimated 660 adult (total length (TL) $\geq$ 450 mm) Colorado pikeminnow in the 104 miles of river sampled below Taylor Draw Dam, and 3,672 adults estimated for the entire Green River sub-basin (509 miles sampled). For comparison, pikeminnow population estimate sampling conducted in warm-water reaches of the mainstem Colorado River upstream of the Green River confluence (176-181 mile sampling reach) from 1991-2013 has rarely produced estimates of greater than 600 adult individuals (Osmundson and White 2017).

Despite consistently high catch rates of adult Colorado pikeminnow (Bestgen et al. 2010), investigators have caught very few age-0 fish in the White River, indicating that it may provide limited spawning and age-0 nursery habitats (Miller et al. 1982; Tyus and Saunders 2001; Breen and Hedrick 2010; Webber et al. 2013a). Even before construction of Taylor Draw Dam and its resulting barrier to upstream movement for native fishes, efforts to document reproduction of Colorado pikeminnow in the White River were unsuccessful (Miller et al. 1982; Radant et al. 1983). Reproduction was first documented during the high-flow year 2011 from a larval Colorado pikeminnow captured in light trap samples from the lower White River (Webber et al. 2013a). Further evidence for reproduction in the White River included capture of an age-1 fish in 2011, indicating potential reproduction in 2010, and capture of several ripe adults in spring 2012 and 2013 from near Kenney Reservoir downstream to RM 24.

Although specific pikeminnow spawning areas have not been identified in the White River, adults from this system do appear to contribute to spawning stocks in the Green River sub-basin. Radant et al. (1983) were the first to report adult Colorado pikeminnow leaving the White River to spawn in other locations. Several other researchers have used radio-telemetry to document spawning migrations for Colorado pikeminnow collected in the White River (Miller et al. 1982; Wick et al. 1983; Tyus and McAda 1984; Martinez 1986; Tyus 1990; Irving and Modde 1994, 2000; Lentsch et al. 2000). Irving and Modde (1994, 2000) documented movements of 12 adult Colorado pikeminnow captured and radio-tagged below Taylor Draw Dam. These fish spent most of the year in the White River, but made long-distance migrations to either the Yampa or Green River spawning areas during high flows.

This partitioning of Colorado pikeminnow life stages between the White and the Green Rivers has led to suggestions that pikeminnow populations in the two rivers be managed conjunctively (e.g., Miller et al. 1982). The White River provides habitat for adults and sub-adults (Bestgen et al. 2018), while the Green River provides spawning habitat and essential rearing habitat for larval and age-0 fish (Breen et al. 2015; Bestgen and Hill 2016b), Colorado pikeminnow larvae hatch after the spawning period and drift downstream into alluvial stretches of

the Green River approximately 24-124 river miles from spawning areas (Nesler et al. 1988; Tyus and Haines 1991; Bestgen 1996; Bestgen et al. 1998; Bestgen and Hill 2016b). As young fish grow, they move upstream and establish home ranges in the Green, Yampa, and White rivers (Bestgen et al. 2007).

Adult and juvenile Colorado pikeminnow use the White River throughout the year, with some adults leaving to spawn during spring (Miller et al. 1982; Martinez 1986; Irving and Modde 1994, 2000). It appears adults exhibit fidelity to their White River home range outside of the spawning season (Miller et al.1982; Radant et al. 1983; Wick et al. 1983; Martinez 1986; Tyus 1990; Irving and Modde 1994, 2000).

When the basin-wide population of Colorado pikeminnow increased in each year of a 2006 through 2008 study (Bestgen et al. 2010), numbers in the White River showed a concomitant rise, indicating that despite minimal levels of reproduction in the White River, it does attract and retain adult fish.[8] In this respect the White River serves an important function in providing quality habitat, thus contributing to sustaining the overall basin Colorado pikeminnow population.

Although overall Colorado pikeminnow abundance has declined in recent years (Bestgen et al. 2018), the percentage of Green River basin adults in the White River remains high. Since adult Colorado pikeminnow in the White River largely migrate to the Green and Yampa Rivers to spawn, this population contributes to reproduction and recruitment on a basin-wide scale. These adults also contribute towards the Green River basin abundance estimates used to measure the species' progress towards recovery. For the period when abundance estimates are available (2000-2013) the average density of Colorado pikeminnow in the White River equaled that for the Green River subbasin overall, despite the fact that the White River is the smallest tributary where abundance sampling occurs. A reduction in carrying capacity for Colorado pikeminnow in the White River would influence basin-wide population dynamics, and possibly reduce the total number of adults in the system and the spawning stocks available to maintain the population. Also, reducing adult numbers in the White River would require offsetting the loss of those individuals with increased populations elsewhere in the basin.

[8] Colorado pikeminnow populations in the White River are estimated separately from those in the Green River, although the Green River population is partially a function of White River resident fish reproducing. Resident fish from the White River are included in population estimates used to measure progress toward recovery goals for the species (USFWS 2002).

2.2.2 Razorback Sucker

Historically, wild razorback sucker were widespread and common throughout the Colorado River and its larger tributaries, including the lower White River (Marsh 1996). Today all populations of razorback sucker above Lake Powell are supplemented with stocked fish. Although no razorback sucker have been stocked in the White River, extensive stocking efforts have occurred elsewhere in the UCRB on an annual basis, including the middle and lower Green River [9] (Zelasko et al. 2018), and individuals have immigrated from these other locations into the White River. Increased razorback sucker captures in recent years and progression in the upstream distance of captures (discussed below) provides strong evidence for population expansion into the White River.

Even though razorback sucker are not stocked in the White River, captures of adults have increased in recent years, with individuals traveling at least 59 river miles upstream from the river's mouth, suggesting this species is colonizing the habitat of the lower White. Furthermore, larval captures indicate that razorback sucker also spawn in the White River.

Few razorback sucker were reported in the White River through the early 2000s. As recently as 1998, there were no records of razorback sucker captures in the White River (Lentsch et al. 2000). Captures and other detections have been numerous in recent years. Installation of a passive integrated transponder (PIT) antenna at the Bonanza Bridge location (RM 59) in 2012 resulted in 66 detections of unique razorback suckers from 2013 through 2017. In addition, 18 razorback sucker were captured during Colorado pikeminnow population estimates from 2002-2008, predominantly in the lower 25 miles of the river (STReaMS Database 2018). These fish ranged from 225-480 mm TL (mean = 411 mm), and five were noted expressing gametes. The Utah Division of Wildlife Resources (UDWR) also caught one razorback sucker (TL = 357 mm) in April of 2010 as part of their native species sampling (Breen and Hedrick 2012). In 2011, 44 adult razorback sucker were collected on the White River between RM 34.8 – 0.0 during Colorado pikeminnow population estimate sampling (Doug Osmundson, USFWS-Colorado River Fishery Project – Grand Junction; personal communication, January 2018); a total of 160 razorback sucker were captured during this sampling from 2011 through 2013 (Bestgen et al. 2018). Additionally, seven adult razorbacks were collected during UDWR native species sampling from 2012-2016 (Fiorelli and Breen 2013, 2014, 2017), including a 501 mm fish captured at RM 43.5 (Fiorelli and Breen 2014). Five adults were captured during smallmouth bass removal efforts from 2014-2017 (Webber et al. 2014; Smith et al. 2015, 2016, 2017), including one individual captured even farther upstream, between RM 51.2 – 56.5.

[9] In the context of the Recovery Program, "middle Green River" refers to the reach between the Yampa River and White River confluences, while the "lower Green River" denotes the reach below the White River confluence.

Most importantly, 56 larval or early juvenile razorback suckers were captured from light traps at four of five sites in flooded backwater habitats between RM 18.2 – 1.4 in 2011, which constitutes the first documentation of spawning for this species in the White River (Webber et al. 2013a).

Increasing numbers of razorback sucker encountered in the White River and increased captures of hatchery fish suggest this species is colonizing the habitat of the lower river, and that suitable habitat conditions have attracted adults of this species. Documentation of recent spawning further underscores the value of White River habitat to razorback recovery.

Past analyses of the White River's role in recovery have considered only its importance to adult Colorado pikeminnow and occasional use by adult razorback suckers. However, the detection of larval razorback sucker by the Recovery Program for the first time in 2011 is significant for two reasons: First, documented spawning locations for razorback sucker throughout UCRB are very limited (e.g., Modde and Irving 1998). Second, continued colonization of the White River by fish stocked in other locations indicates that it offers habitat for the species' range expansion. The addition of this important life history component in the White River represents one of the more important scientific findings since the inception of the Recovery Program.

2.2.3 Other Native Fishes, Including Bluehead Sucker, Flannelmouth Sucker, and Roundtail Chub

In addition to federally endangered fishes, the White River supports a robust community of other native fishes, and has maintained a high native fish composition since at least the mid-1970s (Carlson et al. 1979; Miller et al. 1982; Lanigan and Berry 1981; Martinez 1986; Martinez et al. 1994; Breen and Hedrick , 2010, 2012; Johnson and Breen 2012; Breen et al. 2013; Fiorelli and Breen 2013, 2014, 2015, 2016, 2017; Fraser et al. 2017). Early studies found native fishes comprised the majority of samples in the upper reaches of the Utah portion of the White River in the mid- to late-1970s (Crosby 1975; Lanigan and Berry 1981). In the Colorado portion of the White River, native fishes also comprise a large percentage of the fish community (Miller et al. 1982; Martinez 1986; Chart 1987, Irving and Modde 1994; Martinez et al. 1994; Elmblad 2000; Fraser 2015; Fraser 2019; Colorado Parks and Wildlife (CPW) unpublished data 2014-2017).

Flannelmouth sucker, bluehead sucker, and roundtail chub, collectively referred to as the "three species" [10], comprise a large component of the White River fish community (Figure 3), and are encountered in a variety of size classes and life stages (Carlson et al. 1979; Lanigan and Berry 1981; Miller et al. 1982; Martinez 1986; Martinez et al. 1994; Elmblad 2000; Breen and Hedrick 2009, 2010 , 2012; Johnson and Breen 2012; Fiorelli and Breen 2013, 2014, 2015, 2016, 2017; Fraser 2015). Unlike much of the UCRB, the White River supports sustaining populations of all three species, including an abundance of all life stages, and catch rates for juveniles and adults that far exceed those of many drainages sampled elsewhere throughout their range (Breen and Hedrick 2009, 2010, 2012; Johnson and Breen 2012; Breen et al. 2013; Fiorelli and Breen 2013, 2014, 2015, 2016, 2017). Specifically, in the Utah portion of the White River all size classes of all three species are well represented (Figure 4) (Johnson and Breen 2012), including age-0 fish, demonstrating successful reproduction and recruitment. In Colorado, Elmblad (2000) electrofished a 10-mile reach below Taylor Draw Dam and found native fish comprised an average of 92% of the fish community over a three-year period, with flannelmouth and bluehead suckers being most

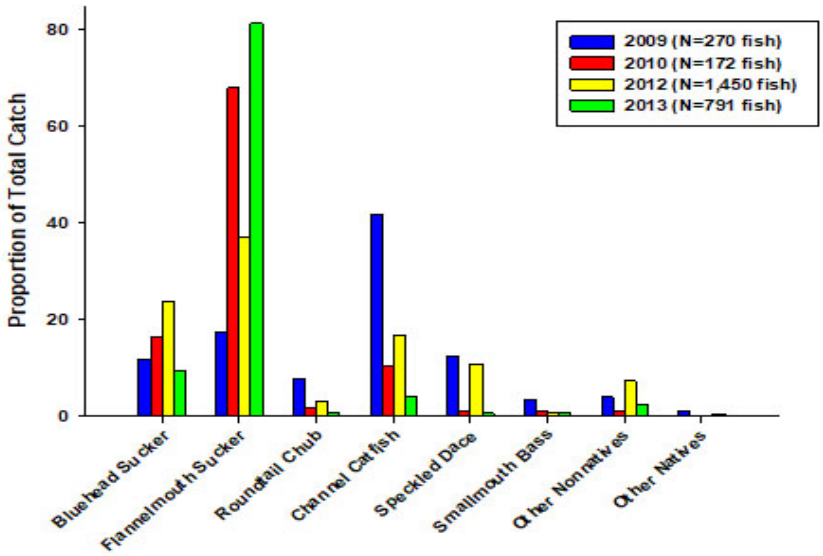

Figure 3. Fish community composition from randomly designated river miles where all species were collected during cataraft electrofishing surveys. Surveys in 2009 consisted of 4 miles sampled during 10 – 13 August; 2010 surveys consisted of eight miles sampled from 12 – 15 April; 2012 surveys covered 24 miles sampled from 20 May – 5 June; and 2013 surveys consisted of 16 miles sampled from 15 April – 2 May. "Other nonnatives" include common carp, fathead minnow, northern pike, redside shiner, red shiner, rainbow trout, sand shiner, and white sucker. "Other natives" include Colorado pikeminnow and razorback sucker. From Breen et al. 2013.

[10] These three species are the subject of a *Rangewide Conservation Agreement and Strategy* signed in 2006 amongst the states of Arizona, Colorado, Nevada, New Mexico, Utah, and Wyoming (UDWR 2006b), and renewed on a five-year basis three times since. The goal of the Agreement is to ensure the persistence of roundtail chub, bluehead sucker, and flannelmouth sucker throughout their ranges, and thus preclude federal listing of these species pursuant to the ESA.

abundant. In addition, CPW conducted multiple-pass surveys from 2014-2017 in a five mile reach approximately 10 miles downstream of Taylor Draw Dam (between river miles 93.4 – 87.5), and native fish still comprised a substantial majority (more than 72%) of the fish community in this reach, However common carp and channel catfish have notably increased in abundance since 2000, now comprising as much as 17% of the fish community in these sampling events (CPW 2018). While these surveys specifically targeted adult fish, all age-classes have been represented, indicating continued reproduction and recruitment of all of the three species.

Three-pass mark-recapture population estimates to measure juvenile and adult abundance were conducted in a 47.6 mile study reach of the lower White River in 2016 (Fiorelli and Breen 2017). The authors estimated 195 bluehead sucker (95% confidence interval [CI] = 160–275) and 221 flannelmouth sucker (CI = 182 - 313) per mile; too few roundtail chub were recaptured to provide a reliable estimate. Despite a lack of population estimates for roundtail chub, the White River is one of few drainages range-wide where they are fairly abundant (e.g., Fiorelli and Breen, 2014; Tildon Jones, U.S. Fish and Wildlife Service, personal communication July 2018). In the Colorado reaches of the White River, CPW surveys in 2014-2017 indicate that roundtail chub comprise on average 11% of the adult fish community (CPW 2018). Such refuges are crucial for preventing this species from becoming listed as federally endangered; it is already the most imperiled of the three species in Utah (Budy et al. 2015). Furthermore, a high juvenile-to-adult ratio indicates the White River provides essential rearing habitat, promoting recruitment of age-0 fish into larger size classes (Breen and Hedrick 2009).

Surveys also have been conducted in the mainstem White River upstream of Kenney Reservoir and > 90% of fish captured were native species, mainly bluehead and flannelmouth suckers (Fraser 2015). CPW surveys in the White River between Kenney Reservoir and Meeker, Colorado, in 2018, also indicate high abundance of native fish species, with mountain whitefish the most predominant, followed by flannelmouth sucker, bluehead sucker and roundtail chub (CPW unpublished data; Harry Crockett, personal communication, 2019). The absence of non-native sucker species and their hybrids in the White River upstream of Kenney Reservoir is notable, as few native sucker populations exist in western Colorado rivers free of non-native suckers. The non-natives are predominantly white suckers (*Catostomus commersonii*) along with some longnose suckers (*Catostomus catastomus*); hybridization with these non-natives is a primary threat to persistence of native sucker populations. (Douglas and Douglas 2003; Anderson and Stewart 2007; McDonald et al. 2008)

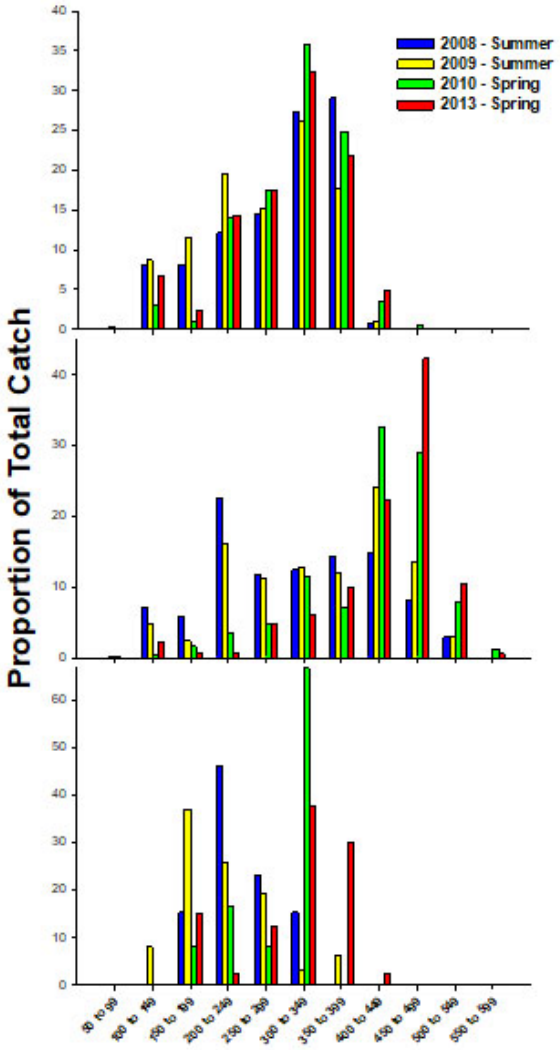

Figure 4. Length-frequency distribution of bluehead sucker (a), flannelmouth sucker (b), and roundtail chub (c) captured during cataraft electrofishing surveys by year in the White River, Utah. We chose representative sample periods from spring (2008 and 2009) and summer (2010 and 2013) to illustrate differences in size structure between spawning and resident populations. From Breen et al. 2013.

In addition, the White River provides important spawning habitat and is likely vital for long-term basin-wide recruitment of the three species metapopulations. In 2013 Fiorelli and Breen (2014) conducted two passes of spring electrofishing surveys in the reach between Cowboy Canyon (RM 66.5) and the Enron Boat Ramp (RM 24) that overlapped in time with the flannelmouth sucker spawning migration. Concentrations of adult fish expressing gametes were mapped to determine spawning areas, which encompassed > 25% of the entire study reach. Additionally, spring electrofishing surveys conducted in Utah portions of the White River continue to document large influxes of flannelmouth suckers during early spawning migrations. For example, 40% of recaptured flannelmouth in 2010 were originally tagged in the Green River (Breen and Hedrick 2012). Notably, four of nine bluehead suckers recaptured in the White River in 2016 also were originally tagged in the Green River (Fiorelli and Breen 2017).

The White River supports a robust community of native fishes, including flannelmouth sucker, bluehead sucker, and roundtail chub. These comprise a large component of the White River fish community, in a variety of size classes and life stages. Catch rates for both juveniles and adults far exceed those of many drainages sampled elsewhere throughout their range.

Recent surveys have provided valuable insights regarding three species reproduction and recruitment associated with various flow conditions. Following 2011 high flows (exceeding bankfull, with an extended duration of the peak), fall seining produced the highest catch rates of age-0 bluehead sucker, flannelmouth sucker, and roundtail chub since long-term fall recruitment surveys were initiated in 2009 (Figure 5; Johnson and Breen 2012). This emphasizes the importance of extended periods of inundation of a variety of habitat types (e.g., floodplains and other low-velocity riparian areas) to support successful spawning and rearing activities. In contrast, dry hydrologic conditions in 2012 and 2013 produced a relatively low runoff volume and short peak flow duration, severely limiting habitats important for various life stages of native fishes, and yielding the lowest observed levels of recruitment on record (Figure 5; Fiorelli and Breen 2013, 2014). This contrast between wet versus dry year observations illustrates how native fishes, especially catostomids (bluehead, flannelmouth, and razorback sucker), rely on high flow years to bolster recruitment of their populations through time.

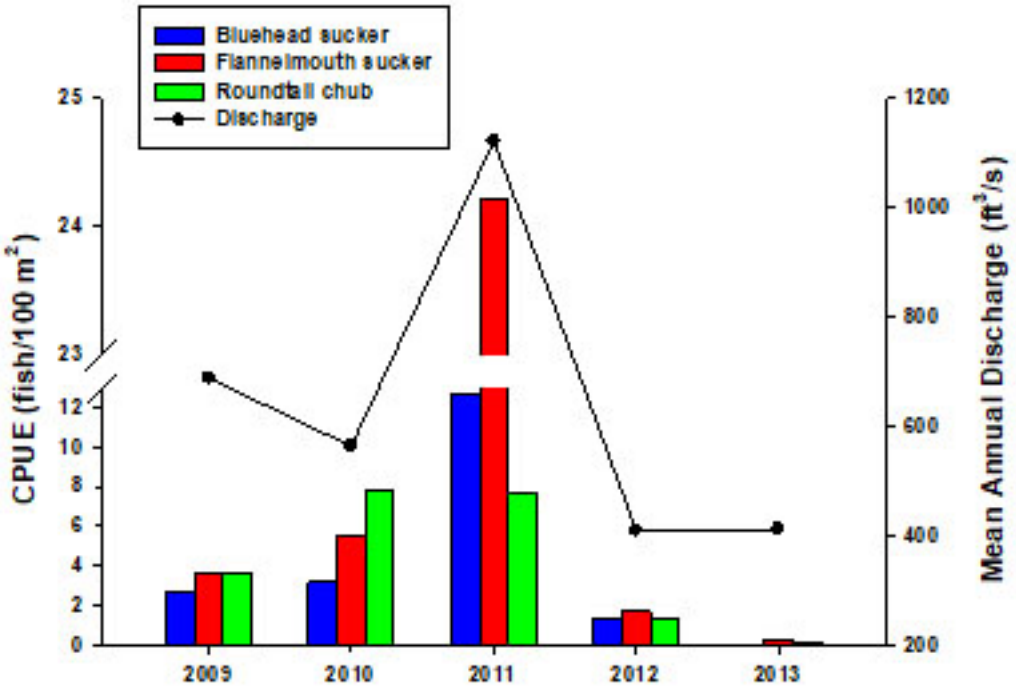

Figure 5. Catch-per-unit-effort (CPUE) during autumn seining surveys for young-of-year fishes in the White River, Utah. Mean annual discharge is plotted on the right y-axis. From Breen et al. (2013).

The importance of flow conditions also was underscored by Fraser et al. (2017), who studied spawning migrations of adult flannelmouth and bluehead suckers in perennial tributaries of the upper White River (Figure 6). They found that movement of spawning adults was not observed into Piceance Creek, whereas Coal Creek was readily occupied by both species for spawning purposes. Although these two watersheds are similar, Coal Creek sustains a more natural hydrograph than Piceance Creek, because flows in the latter are more heavily impacted by irrigation withdrawals (Fraser et al. 2017).

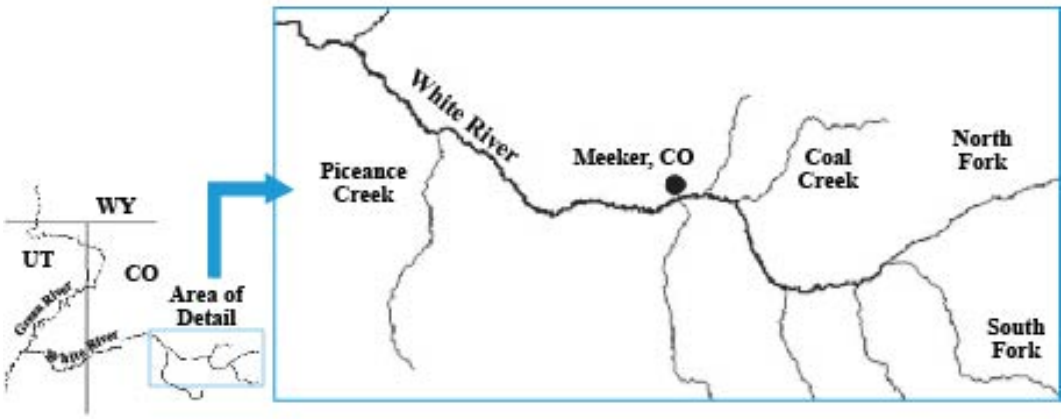

Figure 6. Location of two tributaries to the White River: Piceance Creek and Coral Creek

The relatively unaltered flow regime in the White River promotes better growth of bluehead and flannelmouth suckers than other drainages in the UCRB, promoting stable populations of these species (Klein et al. 2017). Persistence of a robust, diverse, and predominantly native fish community in the White River implies that it maintains an adequate flow regime, temperatures, and habitat to support native fishes, and this also likely benefits endangered fishes adapted to similar conditions (e.g., razorback sucker). Habitat factors that likely contribute to native fish success include the higher turbidities and deep pools maintained by periodic high flows which provide cover for native fishes (Martinez 1986; Chart and Bergerson 1992).

Populations of the three species are important to consider because they have similar ecological requirements as razorback sucker and Colorado pikeminnow (i.e., similar spawning, foraging, and habitat needs). Additionally, native fishes serve as indigenous prey for Colorado pikeminnow, and the abundance of native fishes in all size categories likely benefits pikeminnow foraging.

2.3 Nonnative Fishes

About 65 nonnative, invasive fishes now occur in the Colorado River basin, outnumbering native species by a ratio of 2:1 or more in most locations (Carlson and Muth 1989; Olden et al. 2006; 2008; Gido et al. 2013).. These include top predators introduced as sport fish, fish introduced for vegetation control, and smaller-bodied fish introduced as forage. Non-native fish now comprise more than 95% of small-bodied fishes found in Green River backwaters, important nursery habitats for native species (McAda et al. 1994).

Large-bodied nonnative fish are a concern because they often prey on smaller native fishes (Johnson et al. 2011), have the ability to alter food webs and the carrying capacity for all species in a river system (Naiman et al. 2012), and compete for similar food sources as native species, potentially reducing the overall prey base for other predatory species such as the Colorado pikeminnow. In the UCRB, three nonnative predators are the primary species of concern: northern pike (*Esox Lucius*), walleye (*Sander vitreus*), and smallmouth bass (*Micropterus dolomieu*). These species are especially problematic because of their ability to consume large numbers of native fish across their entire life history (Johnson et al. 2008).

In the White River, smallmouth bass, red shiner (*Cyprinella lutrensis*), sand shiner (*Notropis stramineus*), fathead minnow (*Pimephales promelas*), and channel catfish (*Ictalurus punctatus*) are the most common nonnative fishes (Carlson et al. 1979; Miller et al. 1982; Lanigan and Berry 1981; Martinez 1986; Martinez et al. 1994; Breen and Hedrick 2010, 2012; Johnson and Breen 2012; Breen et al. 2013; Fiorelli and Breen 2013, 2014, 2017).

Other potentially problematic nonnative species in the White River include walleye and northern pike. To date, only one walleye has been collected in the White River (Webber et al. 2014), despite high densities in other nearby river reaches (Michaud and Francis 2017). Northern pike, a voracious predator found in other UCRB locations, have been caught only occasionally in the White River below Taylor Draw Dam, despite a population upstream in Rio Blanco Reservoir since at least the 1990s (Irving and Modde 1994; Breen and Hedrick 2012; Webber et al. 2013b, 2014; Smith et al. 2016, 2017). More recently, northern pike were documented in Kenney Reservoir after being illegally introduced. Anglers reported catching northern pike from that reservoir during the 2018 fishing season, and CPW confirmed their presence during standardized reservoir sampling in the fall of 2018. In April 2019, CPW personnel collected multiple size classes of northern pike while the fish attempted to spawn in the reservoir. Northern pike catch rates (number of fish collected per hour of gill net sets) have declined since CPW began lethal removal efforts in early 2019, along with an angler cash harvest incentive for each northern pike caught and removed from the reservoir, the White River, and any other waters within the boundaries of the Rio Blanco Water Conservancy District (Lori Martin, Colorado Parks and Wildlife, personal communication, October 2019).

Smallmouth bass recently began establishing in the White River below Taylor Draw Dam and are now of particular concern. Nevertheless, this species has never been collected in Kenney Reservoir or the White River upstream of that reservoir despite considerable monitoring, including sampling in 2002-2004, 2011-2013, 2015, 2018 (CPW 2018 and Fraser 2015). Hence, smallmouth bass appear to have invaded from downstream, eventually encountering conditions favorable for

reproduction and recruitment below the dam, with the dam likely contributing to those conditions. Although reported in the White River as early as 1975 (Crosby 1975), their numbers remained relatively low compared to other Green River tributaries until about a decade ago (Miller et al. 1982; Martinez 1986; Breen and Hedrick 2009, 2010, 2012; Johnson and Breen 2012).

An increase in bass densities below Taylor Draw Dam around 2010 prompted additional removal efforts to determine the extent of bass presence in 2012 (Breen et al. 2012). This initial investigation showed high densities nearest the dam, with decreasing numbers in a downstream gradient. Adults were abundant in the upstream reach, and captures of age-1 and age-0 bass demonstrated that reproduction is occurring there. Drought conditions and low flows in 2012 appeared to favor smallmouth bass spawning and recruitment, similar to findings in other river reaches during the dry conditions of 2007 (Badame and Jones 2008; Jones 2008; Bestgen et al. 2009; Hawkins et al. 2009). In the Yampa River, Bestgen (2015) noted that an increase in summer water temperatures, such as might occur with reduced summer streamflow, promotes earlier spawning, faster growth, and more robust development of smallmouth bass over an extended growing season, all of which tends to enhance the over-winter survival of these predatory fish.[11] Moreover, because young smallmouth bass grow 2-3 times as fast as native fishes, warm temperatures stimulating their growth means that for much of the summer they may more easily be able to capture and consume young native fishes produced in the same year. Over the past decade, catch rates of smallmouth bass in the White River have remained high in the reach below Taylor Draw Dam and they are now spreading downstream into the Utah portion of the river (Smith et al. 2017).

The nonnative fish composition in the White River is low compared to that of other rivers in the upper Colorado River basin, such as the Duchesne. However, smallmouth bass populations recently became better established in the White River below Taylor Draw Dam, and are now a particular concern.

In spite of these concerns associated with smallmouth bass, comparisons of the diversity and abundance of nonnative fishes in other UCRB tributaries demonstrates the relative health of the White River fish community. In contrast to the low nonnative fish composition in the White River (Breen et al., 2013), the Duchesne River, whose confluence with the Green River is only about two river miles from that of the White, is dominated by nonnative fishes including smallmouth bass, white sucker and channel catfish (Finney and Groves 2006; Groves and Fuller 2009; Breen and Hedrick 2010). In fact, recent surveys determined that the lower Duchesne River has some of the highest

[11] Conversely, observations by Bestgen and Hill (2016a) suggest that a timely natural 'flow spike' in the Yampa River in July 2015 (on the order of a 1,200 cfs increase in flow over five days, followed by a similar five-day decline) resulted in substantial mortality of pre-emergent and larval smallmouth bass in that river, likely due to the effects of elevated flow velocity and increased turbidity on the nests guarded by adult bass.

densities of smallmouth bass (Staffeldt et al. 2017) and walleye (Michaud and Francis 2017) in the entire UCRB. The Service's 2003 flow recommendations for the Duchesne River (Modde and Keleher 2003) were for a relatively modest minimum base flow of 50-115 cfs; however the relatively high summer water temperatures associated with these flows apparently have created conditions favorable for nonnative fishes (e.g., more slow-velocity, pool-like habitat that heats up more quickly than areas with more substantial flow). This experience suggests that further reductions to base flows in the White River beyond those naturally occurring during drought conditions would likely be advantageous for smallmouth bass and other nonnative fishes.

The lesser diversity and lower density of nonnative species in the White River compared to other Colorado and Green River tributaries, along with the river's relatively natural hydrograph and habitat, make it an important refuge for native and endangered fishes.

2.4 Summary

The relatively high abundance of adult Colorado pikeminnow, and other native fishes in the White River, along with increasing numbers of razorback sucker in the lower White River, indicate this river plays an important role in endangered species recovery and conservation of other native fishes. The lower White River harbors the highest densities of Colorado pikeminnow of all tributaries in the UCRB. Additionally, the lower White River supports reproduction by hatchery-reared razorback sucker and, perhaps to a lesser extent, wild Colorado pikeminnow. Recent expansion of non-native smallmouth bass populations in the White River raises concerns, but the White River generally contains lower numbers of predatory nonnative fish than other major tributaries across the range of the two endangered species. The current flow regime of the river is believed to promote this relatively favorable species composition.

3. IMPORTANT CHARACTERISTICS OF THE WHITE RIVER FLOW REGIME

As described previously, the White River currently supports robust populations of endangered and other native fish species, while being appreciably impacted to date by only one predatory nonnative fish, smallmouth bass. This demonstrates that existing habitats and flow regimes are adequate to support healthy native fish populations. Protection of the current flow regime would be expected to continue supporting native fish recovery efforts, and would likely reduce the need for compensatory restoration efforts elsewhere in the Colorado River basin.

The current hydrologic regime of the White River includes the annual occurrence of relatively robust spring peak flows (Figure 7, and Appendix A) which, together with the current magnitude and timing of base flows, have been adequate to provide and maintain habitat characteristics that sustain Colorado pikeminnow and razorback sucker populations. Relevant characteristics of these peak and base flows are discussed below.

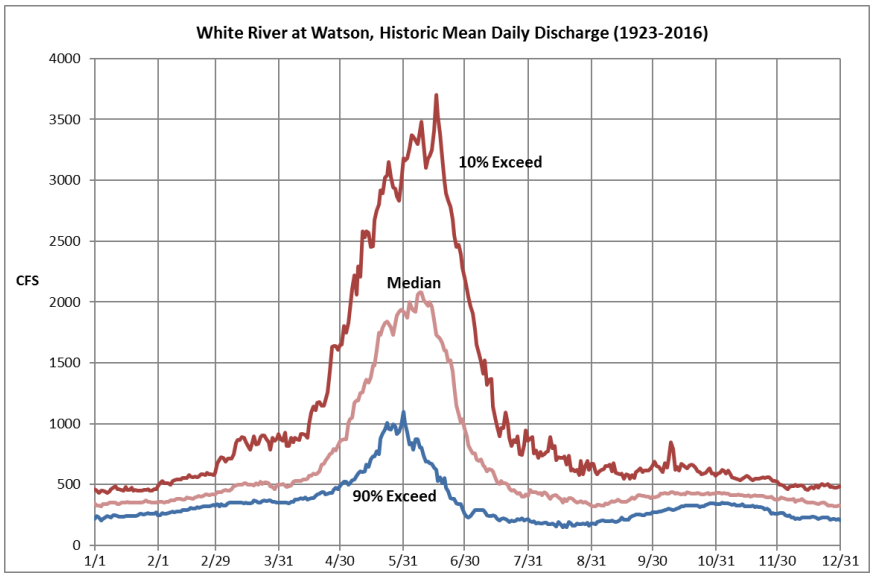

Figure 7. Distribution of flows (mean daily discharge) as measured by the USGS at the White River near Watson, Utah gage (#09306500) for the period 1923-2016 (missing 1980-1985). The traces illustrate 90% exceedance, 50% exceedance, and 10% exceedance values for each individual date over the period of record.

3.1 Spring Peak Flows

Spring peak flows are important for creating and maintaining in-channel habitats by scouring, mobilizing and re-depositing sediments within the river channel. High flows protect the

quality of riffles by removing accumulated fine sediments, preventing the accumulation of interstitial fine sediments in gravels, and maintaining gravel looseness. Open interstices between cobbles and gravels improve conditions for spawning and provide habitat for aquatic invertebrates which are an important forage base for fish (Flecker and Allan, 1984; Wood and Armitage 1997). In addition, high flows restore or enhance pools by preventing the accumulation of fine sediment (Schmidt and Orchard 2002). Deep pools provide cover and cool, oxygenated water for fish survival during hot, low-flow months, and offer refuge in the winter.

Annual high flows can include channel-forming flows capable of eroding banks, moving large substrate sediments, shifting cobble and gravel bars, and scouring vegetation (Pitlick et al. 1999). These dynamics help maintain active channel widths and contribute to the complex channel morphology and mix of habitats preferred by Colorado pikeminnow and other fishes. The Colorado pikeminnow has occupied a variety of habitats throughout the lower White River including eddies, backwaters, main channels, runs, side channels, pools, shorelines and riffles (Lentsch et al. 2000).

Disturbance by floods also is crucial in promoting the diversity and quantity of aquatic vegetation, invertebrates, and fish, in association with the entrainment and movement of bed material (Mosely 2001). Lentsch et al. 2000 note that diversity of the overall fish community in the White River has been positively correlated with habitat diversity. Additional biological benefits of high spring flows include providing physical cues for the initiation of spawning migrations and spawning readiness for Colorado pikeminnow (Stanford 1994; Stanford et al. 1996; Poff et al. 1997).

The White River's high suspended-sediment load and large proportion of bed covered by fine sediment (Lentsch et al. 2000) highlight the habitat maintenance value of flows sufficient to periodically transport suspended sediment through the lower river. Sediment mobilization and suspension also may be important for the success of native fish that have evolved in and adapted to high turbidity streams such as the White River. In addition, and importantly, the large amount of suspended sediment delivered by the White River (Tobin 1993) represents a significant contribution to the Green River's sediment load, helping ensure the maintenance of habitats downstream in the Green River essential for endangered species recovery (e.g., backwaters and sand bar complexes). Examining data from 1975 through 1988, Tobin (1993) determined that annual sediment loads in the White River near Rangely (USGS gage site #09306290, the most downstream of six sites he evaluated), were around 2 million tons annually. Of that, 1.3% or less was determined to be bedload (versus suspended sediment load). Tyus and Saunders (2001) later estimated suspended sediment delivery to the Green River from the White River to be more than 3.7 million tons annually, about equal to that of the Yampa River (3,506,000 tons), and many times

that of the Duchesne and Price Rivers (135,000 and 424,000 tons, respectively). They concluded the White River input represented nearly one-third of the total sediment load to the Green River below Flaming Gorge Dam.

As described in Section 2.2.3, high-flow years bolster recruitment of native fish populations in the White River. Conversely, in nearby Green River tributaries like the lower Yampa, low-flow years have been shown to correspond to lower numbers of spawning Colorado pikeminnow (Bestgen, 2015). In general, backwater areas are relatively uncommon in the White River in average or lower flow years (Webber et al. 2013a), but in high-flow years their increased occurrence can aid in supplementing favorable habitat for Colorado pikeminnow. Inundation of a variety of riparian habitat types (*e.g.*, floodplains, temporary pools) are important for the successful recruitment of native fishes, especially the catostomids (bluehead, flannelmouth, and razorback sucker) that serve as important forage for Colorado pikeminnow. Researchers (e.g., Junk et al. 1989; Welcomme 1995; Modde et al. 1996; Bestgen et al. 2011) note that several native UCRB fishes use seasonally inundated floodplain habitats to complete their life history. Conversely, dry hydrologic conditions severely limit the habitats available for various life stages of native fishes, and these low-flow years historically have corresponded to the lowest levels of recruitment for bluehead sucker, flannelmouth sucker, and roundtail chubs. As described in Section 2.2.1, reproduction of Colorado pikeminnow was observed in the White River for the first time in the unusually high-flow year of 2011.

Periodic overbank flows (floods) also are biologically important because they reconnect the river with coarse organic matter, invertebrates, and vegetation in the floodplain, which allows riverine organisms to exploit rich food sources that otherwise would be unavailable (Benke 2001). Floods further aid in the establishment of riparian cottonwood forests (Figure 8) which provide bank stability and contribute woody debris and nutrients to the hydrologic system (Lytle and Merritt 2004). Large woody debris (Figure 9) is important because it adds more instream habitat structure and diversity for fish, altering flow hydraulics and often reshaping the channel itself (Abbe and Montgomery 1996). Native cottonwood recruitment in riparian areas of the western United States is highest under free-flowing conditions, declining abruptly when flows are modified (Merritt and Poff 2010).

Figure 8. **Cottonwood groves along the lower White River. Photos by Justin Jimenez, BLM.**

Figure 9. Woody debris in the lower White River after the high flows of 2011. Photo by Mathew Breen, UDWR.

3.2 Base Flows

Adequate base flows are important to protect the needs of adult Colorado pikeminnow, which include passage through riffle reaches to move up and down the White River, protection of their resting and foraging habitat, and maintenance of riffle habitat which contributes to biological productivity and a healthy forage base. While juvenile Colorado pikeminnow movements are usually concentrated in localized areas, adults have been documented to undertake spawning movement of hundreds of kilometers (Tyus and McAda 1984). As noted in Section 2.2.1, there is evidence that radio-tagged pikeminnow in the White River make long-distance spawning migrations to sites in the Yampa and Green rivers and return to the White River after spawning, demonstrating home range fidelity. For this reason, providing relatively unrestricted passage for species migration throughout the year is important.

As described in Haines et al (2004) and summarized in Section 4.5 of this document, when White River flows decline below certain thresholds, the wetted channel of the river narrows, fewer riffle reaches remain passable by adult Colorado pikeminnow, and eddies become fewer, all of which tends to trap these fish within smaller reaches and make them more vulnerable to predation and damaging sun exposure. Drying of the river channel during very low flows, especially if this

persists for more than a few days, also reduces the benthic invertebrate population that provides an important forage base for pikeminnow and other native fishes. As described in Section 2.3, reductions in base flow magnitudes and frequencies beyond those naturally occurring during drought conditions are likely to provide competitive advantages to nonnative fishes. During the very low flows of late summer 2018 (less than 100 cfs mean daily discharge was measured at the Watson gage on 15 days between July 28 and August 20), multiple reaches of river channel between Taylor Draw Dam and Enron Bridge (RM 104 to 24) were observed to transmit only an inch or two of water, and many of the remaining pools had native and nonnative fishes confined together at high densities in isolated habitats (Alden Vanden Brink, Rio Blanco Water Conservancy District, and Tildon Jones, U.S. Fish and Wildlife Service, personal communications, 2018). These conditions, even where instream flow may have exceeded the base flow recommendations described in Section 4.5, were clearly not advantageous for the endangered fish.

Various water quality parameters have the potential to affect endangered fish in the UCRB, including metals (such as mercury, cadmium, lead, and zinc), other elements (such as selenium), petroleum products, pesticides, pharmaceuticals, and elevated water temperatures. Because concentrations of some constituents tend to increase with decreasing flow due to the reduced effect of stream dilution, this raises the possibility that diminished base flows could impact water quality and temperature in ways detrimental to native fish. An analysis of the available water quality data (Appendix C) suggests that mercury, selenium, and periodically elevated stream temperatures are likely to be the most significant water quality concerns relevant to Colorado pikeminnow and razorback sucker in the White River. However, that analysis also suggests that modestly elevated base flows may do little to moderate these concerns.

An additional base flow consideration is that low flows tend to magnify the impact of sudden, unanticipated disturbances to the aquatic environment: e.g., from a summer thunderstorm delivering ash and sediment from a recently-burned area, or from an oil spill entering surface waters. Reducing the frequency and duration of very low flows in the White River correspondingly reduces the vulnerability of native fish to these kinds of unpredictable habitat disruptions.

4. FLOW RECOMMENDATIONS

4.1 Objectives of these Recommendations

The endangered fish flow recommendations described herein reflect important characteristics of the White River's natural flow regime that, in the Service's opinion, should be preserved to the greatest extent practicable to help conserve and recover endangered fish in the UCRB system, particularly the Colorado pikeminnow and razorback sucker. These include an adequate magnitude, duration, and frequency of annual spring high flows, and adequate base flows during the annual low-flow period.

As noted in the previous discussions, multiple observations suggest the value of preserving as much of the White River's natural flow regime as possible. These include:

- The persistence of a predominantly native fish community in the White River (including Colorado pikeminnow and razorback sucker), and a relatively low density of nonnative fishes compared to other tributaries in the UCRB. This suggests the river maintains an adequate flow regime, temperatures, and habitat to support this species assemblage;
- A concern that water development activities that substantially reduce base and peak flows enhance opportunities for problematic nonnative species to become established and thrive, based on observations in other tributaries of the upper Colorado River system such as the Duchesne River;
- Recognition that the White River continues to make important biological, physical, and chemical contributions to the Green River as it has historically, being one of the least-altered major tributaries to the Green (Lentsch et al. 2000); and
- The recommendation by Haines et al. (2004) that current flow patterns be maintained to protect the Colorado pikeminnow until additional information becomes available to recommend otherwise.

In light of these observations, the Service believes that preservation of a White River flow regime mimicking natural flow magnitudes and variability will support protection and recovery of Colorado pikeminnow, razorback sucker, and other native fishes. Moreover, by promoting healthy populations of the "three species" (flannelmouth sucker, bluehead sucker, and roundtail chub), this reduces the likelihood that one or all of these species could become federally listed as threatened or endangered.

4.2 Methodology

The natural flow regimes of most tributaries in the UCRB are dominated by a spring snowmelt peak (or multiple peaks) followed by a pronounced decline in the annual hydrograph, until a relatively stable base flow level is reached that is supported primarily by subsurface inflows throughout the stream network, intermittently augmented by short-term storm runoff spikes. Adequately protecting both the spring peak and the base flow is vital for the recovery of endangered fish and the protection of other native fish communities, for reasons described in Section 3.

To characterize the flow regime of the White River under current levels of water development in the basin, Wilson Water Group (WWG) worked with the Service and other White River basin interests[12] to develop a daily flow model (derived from the monthly StateMod model) based on a 40-year period of record from April 1, 1975 to March 31, 2015 (Appendix A). StateMod is a water allocation and accounting model capable of analyzing water distribution, consumption, availability, and shortages, and is useful for assessing historic and future water availability and shortages on a watershed level. It operates by allocating available water to demands (e.g., irrigation diversions, reservoir storage, and instream flows) based on water right priority. Using a modified version of StateMod[13], several time series of flows simulating various water development scenarios in the White River basin were developed and analyzed, including a 'Baseline scenario' simulating current (circa 2015) levels of basin development. These simulated baseline flows, modeled at a daily timestep, are hereafter referred to as the "Baseline Condition".

*For purposes of this report, **'Baseline Condition'** refers to the StateMod results that simulate White River diversions, storage, and flows based on current conditions of water development and current water rights in the basin. These Baseline simulations were used extensively in the development of the Service's flow recommendations.*

The White River StateMod model's simulation of the Baseline Condition incorporated current irrigated acres and crop types to represent irrigation demand for the 40 year period of record. A full crop irrigation requirement was used to quantify demands at the corresponding points of diversion, and the model simulated lagged return flows from these agricultural diversions.

[12] The 'White River Planning Team' that was convened for these discussions included representatives from U.S. Fish and Wildlife Service, Rio Blanco Water Conservancy District, basin water users (Water Consult Engineering and Planning), the Colorado Water Conservation Board, The Nature Conservancy, the State of Utah, and the Ute Indian Tribe of the Uintah and Ouray Reservation.

[13] WWG used StateMOD Version 15, modified by the State of Colorado in 2015.

To represent municipal demands, current levels of demand were replicated for each year over the full period modeled.

Diversions for oil and gas development in the basin also were included in the modeling, however Wilson Water Group has indicated they don't consider the aggregate quantities to be particularly significant (personal communication, August 2019). The White River Mesa Ditch, which diverts for oil and gas production, is modeled as generating about 520 acre-feet/year of depletions. Additional depletions may be occurring where some of the water diverted under irrigation rights (accounted for in the model) is in fact used for energy development (in which case the modeled depletions may be underestimated). However, the Division Engineer's office does not consider these uses to represent a substantial amount of water when considered at the basin scale (Wilson Water Group, personal communication, August 2019).

These simulated Baseline Conditions for the White River basin, along with historic gage records, were evaluated by the Service in conjunction with the flow recommendations proposed by Schmidt and Orchard (2002), and Haines et al. (2004), to develop the suite of peak flow and base flow recommendations described below.

4.3 Peak Flows Analyses and Recommendations

Schmidt and Orchard's work studying White River peak flows (2002) was provided as a draft report to the Recovery Program but was never approved by the Program as a final product. Nevertheless, their report represents the best information available at this time on the geomorphic effects of high flows in the White River, and it provides useful threshold values for characterizing the current White River high-flow regime. Various shortcomings of their report are described in Section 4.6 of this report, Assumptions and Uncertainties.

Schmidt and Orchard used two approaches to determine peak discharges needed to maintain channel complexity. First, they evaluated channel bed movement, sediment transport, and scour and fill of river beds along the reach designated as critical habitat. In addition, they examined historic discharge and depth records measured at the USGS gage White River near Watson, Utah (#093065000) for 26 years (1967 to 1979, and 1985 to 1997; refer to Figure A-23 in Schmidt and Orchard 2002). They found that the annual rise in the hydrograph is accompanied by as much as a meter decrease in bed elevation. After a large annual peak passes, the river bed returns to approximately the same elevation as prior to the peak. This scouring and subsequent filling of the bed represents a pulse of sediment transport. Data showed that scour and movement of fine bed sediment occurred at approximately 1,400 cfs, bedload movement that transformed

bedforms occurred around 1,800 cfs, and gravels embedded in bars became entrained at around 3,700 cfs.

Subsequent hydrophone and acoustic doppler current profiler (ADCP) investigations of bedload movement in 2017 by Minear (2017) generally confirmed the findings of Schmidt and Orchard (2002), with slight differences. Minear made his measurements during spring peak flows in May and June 2017 from the USGS White River near Watson gage (#093065000) down to the Enron Bridge takeout (about 35 river miles total), and also in the 16-mile reach downstream of Taylor Draw Dam. In the first (lower) reach, fresh coarse bedload deposits were observed one week following flows of around ~1,600 cfs, but no active bedload transport was observed at flows of around 900 cfs. Later in the same reach, at higher flows of ~1,450 cfs, local coarse bed sediment transport was observed but was not widespread. These results suggest that while the findings of Schmidt and Orchard (2002) likely hold for large-scale sediment transport, localized fine and coarse bed sediment transport does occur at lower flows than described in that report. In the 16-mile reach below Taylor Draw Dam, almost no coarse sediment bedload was observed, suggesting that this dam-affected reach may require higher flows to mobilize sediments than the lower 35-mile reach below the Watson gage. (J.T. Minear, University of Colorado, Boulder, personal communication, June 2018).

To develop peak flow recommendations that reflect current basin conditions, we analyzed the simulated Baseline Condition data for the White River near Watson Utah gage location, along with data on historic gaged peak flows at that location. Five hydrologic year type categories were defined based on the runoff volume exceedance during the "forecast year" [14], and forecast years 1975 through 2015 were grouped into corresponding categories. The five categories are Wet (0 to 10 percent exceedance), Moderately Wet (10 to 30 percent exceedance), Average (30 to 70 percent exceedance); Moderately Dry (70 to 90 percent exceedance), and Dry (90 to 100 percent exceedance).

The Service's median, one-day peak flow recommendations are those that occurred in fifty percent of the years within each category. These are listed in Table 1 and further described in Appendix A.

[14] For analyses summarized in this report, 'Forecast Year' statistics were used (April 1 through March 30) rather than the traditional 'Water Year' period of October 1 through September 30. This preserves the hydrologic influence of the spring and summer high flow months on the subsequent fall and winter base flow months of the same year analyzed.

4.4 Shoulder Peak Flows Analyses and Recommendations

Shoulder flows refer to elevated flows occurring in the spring at lower magnitudes than peak flows but with longer durations. They are important because their magnitude and duration induce sustained sediment transport and channel reworking processes important for creating and maintaining desirable endangered fish habitat. Note that in most rivers, transport rates for both fine and coarse sediments increase nonlinearly with discharge, such that small increases in flow can disproportionately increase the sediment transport (Pitlick 2007).

All of the Service's shoulder peak flow magnitude recommendations, except those for Dry years, are based on the geomorphologic functions of these flows as described by Schmidt and Orchard (2002), and summarized below. The recommended durations of the shoulder peaks are based on the simulated durations occurring for the Baseline Condition level of water development in the watershed at each of these corresponding flow magnitudes:

- For Moderately Dry years, the shoulder peak flow of 1,400 cfs was chosen, because Schmidt and Orchard observed that at this flow, bed scour and movement of 70 percent of the fine bed sediment occurs, and some exposed gravels are entrained.
- Shoulder peak flow magnitude recommendations for Average and Moderately Wet years are 1,700 cfs and 2,900 cfs, respectively, because Schmidt and Orchard determined that effective discharge (i.e., the discharge that on average transports the largest proportion of the annual sediment load) is between these two rates of flow.
- A shoulder peak flow of 3,700 cfs (which approximately corresponds to bankfull flow at the Watson gage location) is recommended for Wet years, as Schmidt and Orchard determined that embedded gravels in bars entrain at this flow, ensuring scour and fill of bed materials.

To derive recommended flow durations for these shoulder peak flows, the Service, working with WWG, calculated for each of the five hydrologic categories the median number of days annually that exceeded the recommended shoulder peak flow over the period April 1 to July 31 in the simulated Baseline Condition data. The results from this analysis also are listed in Table 1.

Table 1. Recommended annual peak and shoulder peak flows, by hydrologic year type.

	Hydrologic Year Type				
	Wet (10%)	Mod Wet (10-30%)	Ave (30-70%)	Mod Dry (70-90%)	Dry (100%)
Median Annual peak (1-day)	5,250 cfs	4,100 cfs	3,300 cfs	1,700 cfs	1,000 cfs
Shoulder peak magnitude	3,700 cfs	2,900 cfs	1,700 cfs	1,400 cfs	700 cfs
Shoulder peak duration in 50% of years (and range)	≥ 30 days (25 to 35 days)	≥ 20 days (15 to 40 days)	≥ 30 days (20 to 45 days)	≥ 10 days (1 to 30 days)	≥ 15 days (5 to 40 days)

4.5 Base Flow Analyses and Recommendations

Haines et al. (2004) completed for the Recovery Program a study of base flow habitat conditions in the White River for Colorado pikeminnow. They collected habitat data across a 105-mile study area of the river (Figure 1) in 1995 and 1996. They simulated changes in channel depth, velocity, and the availability of different habitat types (riffles, runs, pools) using version 2.0 of the RHABSIM model (Payne 1995). Results were used to analyze useable pikeminnow habitat for a stratified random sampling of habitat clusters across the study area, using three sets of habitat suitability indices: one developed from White River fish use observations, and two developed from Yampa River fish use observations.

In recognition of the importance of riffle habitat to the Colorado pikeminnow, Haines et al. (2004) developed riffle habitat-discharge relationships in two ways: First, they simulated wetted perimeter-discharge relationships using their hydraulic model for each cross-section where riffle was the only habitat type. Using a curve break approach (Gippel and Stewardson 1998), they determined the discharge at which habitat conditions deteriorated most rapidly, such that small reductions in discharge yielded a disproportionately large loss of stream riffle area. Second, they calculated riffle surface area for each habitat cluster, and expanded the results to the entire study area for each simulated discharge.

In recognition of the need for the White River to also allow for Colorado pikeminnow passage through riffle habitat, Haines et al. used their hydraulic model to determine the depth of flow in the deepest portion (thalweg) of the transect for 49 riffle cross-sections at various river discharges. A depth of 30 cm was assumed to be sufficient for Colorado pikeminnow passage, based on Burdick (1997) and Modde et al. (1999) observations.

From this analysis, Haines et al. found that there was a linear decrease, from 600 to 5 cfs, in useable habitat area for the adult Colorado pikeminnow. At flows below 150 cfs, riffle areas increased as a percentage of total area, and eddy area decreased. They suggested that the following low-flow thresholds are particularly significant for Colorado pikeminnow in the White River during the base flow period:

- **400 - 500 cfs**: In this range, 95% of the available surface area for most riffles is covered, which appears adequate to allow for near-maximum benthic invertebrate production during the base flow period.
- **300 cfs**: At this flow, adequate passage for adult Colorado pikeminnow appears to exist at 47 of 49 of the shallow riffle transects examined, if a 30 cm thalweg depth is considered adequate. (All 49 transects were passable if a 27 cm thalweg depth is considered adequate.)
- **150-161 cfs**: At around this rate of flow, there is a natural breakpoint in the relationship between wetted perimeter and discharge; at lower flows the available habitat for Colorado pikeminnow shifts markedly toward a narrowing of the wetted channel, more riffles, fewer riffles passable by adult Colorado pikeminnow (Table 2), and fewer eddies, all of which tends to trap the fish within smaller reaches. At 150 cfs, 43 of the 49 shallow riffle transects were determined to provide adequate passage for Colorado pikeminnow. (For comparison, at 100 cfs, only 35 of the 49 transects provided adequate depth of passage.)

Table 2: RHABSIM data generated for 49 field-measured White River transects from River Mile 1 to 104 by Haines et al. 2004. 30 cm is assumed to be adequate pikeminnow passage depth.

Flow in cfs	100	150	200	250	300
# of 49 transects with riffle thalweg depth ≥ 30 cm	35	43	45	46	47

Citing the flow studies by Haines et al., in January 2011 the State of Utah, in order to protect flows for endangered fish, stipulated that a White River water rights claim could not take its diversion (estimated at 2.86 cfs) when flow was less than 161 cfs at the Watson gage, recognizing that 161 cfs "appears to be a reasonable minimum flow to apply to this application based on protecting the riffle habitat" (UDNR, 2011).

The Service's base flow recommendations, which consider the Haines et al. (2004) research summarized above, are separated into two periods: irrigation and non-irrigation seasons.

The Service made this separation because data indicate that both the gaged and simulated historic flows in the White River fall short of various low-flow thresholds with significantly greater frequency during the irrigation season of Dry, Moderately Dry, and Average years than during the non-irrigation season of November 1 to March 31. This pattern reverses for simulated natural flow during these two periods (*i.e.*, flow that would have occurred in the absence of diversions and storage for human use), suggesting that low flows are substantially diminished by diversions during the irrigation season, while lagged returns from these diversions augment post-irrigation-season streamflow. The Service considers protection of the irrigation season base flows to be a higher priority, as White River flows tend to reach their annual minimum prior to November 1, maximizing during this period the threats to endangered fish associated with reduced instream habitat, vulnerability to predators, increased water temperatures, and increased solar exposure.

The Service assigned start dates to irrigation-season base flow recommendations that vary based on the hydrologic year type, with a common end date of October 31. These variable start dates (as early as June 15 for the Dry hydrologic condition, and as late at August 15 for the Wet hydrologic condition) reflect the historic timing of the onset of the annual low-flow period in the White River, and they match the start dates of base flow recommendations for the Green River established by Muth et al. 2000. In contrast, the Service's non-irrigation base flow season dates are fixed, beginning November 1 and ending March 31 in all years.

Recommended irrigation-season base flows, and the percentage of days they should be met or exceeded annually, are listed in Table 3. The Service believes that expressing the base flow recommendations in this manner – as 50%, 90%, and 100% exceedance values – appropriately characterizes the natural inter- and intra-annual variability in White River base flows likely to accommodate endangered fish survival and recovery.

Table 3. Recommended irrigation-season base flows, by hydrologic year type.[15]

Percent of days specified target met*:	Hydrologic Year Type				
	Wet (10%)	Mod Wet (10-30%)	Ave (30-70%)	Mod Dry (70-90%)	Dry (100%)
	Dates of Applicability				
	Aug 15 – Oct 31 (78 days)	Aug 1 – Oct 31 (92 days)	Jul 15 – Oct 31 (109 days)	Jul 1 - Oct 31 (123 days)	Jun 15 - Oct 31 (139 days)
50%	500 cfs (39 days)	490 cfs (46 days)	390 cfs (55 days)	280 cfs (62 days)	150 cfs (70 days)
90%	430 cfs (70 days)	305 cfs (83 days)	200 cfs (98 days)	150 cfs (111 days)	70 cfs (125 days)
100%	230 cfs (78 days)	200 cfs (92 days)	120 cfs (109 days)	100 cfs (123 days)	30 cfs (139 days)

*These percentages indicate targeted frequencies of exceedance; they do not establish legal or administrative requirements. The Service recognizes that current and future basin conditions may not support these recommended flows at the recommended frequencies.

Values in the unshaded boxes of Table 3 represent the exceedance values derived from the simulated Baseline Condition for the corresponding hydrologic year types, rounded to the nearest multiple of 5 cfs.[16] Values in the shaded boxes exceed the simulated Baseline Condition values. The Service considers the flows in the shaded boxes to be more appropriate for protecting the habitat needs of the endangered fish than the corresponding simulated Baseline Conditions flows, in part because they are more representative of flows actually observed at the Watson, Utah gage since 1975.

A more detailed description of the rationale for the Service's recommended flows for each of the seven shaded boxes in Table 3 is provided in Appendix B to this report. To cite one example, the Service recommends that 100 cfs in mean daily flow be maintained or exceeded for all days (i.e., 100% exceedance) from July 1 through October 31 in 'Moderately Dry' years. In contrast, the 100% exceedance 'Baseline Condition' flow simulated by WWG's White River StateMod analysis for these hydrologic year types was only 2 cfs. An analysis of flows measured at the Watson, Utah gage in the eight 'Moderately Dry' years between 1975 - 2015 reveals that, on average, flows dropped below 100 cfs in this irrigation season period less than one day annually, with a minimum recorded mean daily flow of 73 cfs on September 5, 2013. Thus, the Service

[15] The shaded boxes in this table denote recommended flows that exceed the corresponding simulated Baseline values. For a discussion of the rationale behind these higher values, see the corresponding footnotes for each of the shaded boxes in Appendix B to this document.

[16] This rounding recognizes the limited accuracy inherent in gage measurements. The one exception to the methodology of using WWG's modeled exceedance value to establish the value in the unshaded boxes is the Wet year, 50% exceedance recommendation of 500 cfs. The Baseline Condition analysis for Wet years indicates that 670 cfs is the 50% exceedance value; however because Haines et al. 2004 do not provide a compelling rationale for base flow protection in excess 500 cfs, this lower value is used.

recommends maintaining if possible a minimum of 100 cfs during the irrigation season of 'Moderately Dry' years to ensure reasonable protection of the habitat conditions beneficial for endangered fish while reflecting the flow regime actually observed in the White River over the modeled 40 years. The Service recognizes that flows higher than those identified in Table 3 for the very lowest flow conditions would likely benefit endangered fish. However, under current basin conditions, limited water is available for augmentation of White River flows, thus protecting the flows identified is a priority.

Flow duration curves for all measured irrigation-season flows at the White River near Watson gage from 1975-2015, categorized by hydrologic year type, are illustrated in Figures 10 through 14, together with corresponding Table 3 base flow recommendations. Areas where the flow duration curve (blue) is higher than the recommended minimum flow (dashed line) represents instream flow 'surplus' to the recommended flows. As flow surplus to the recommendations, the area above the dashed line is an example of water potentially available for development that is excess to targeted minimums. However it should be noted that multiple years of historic flows are aggregated in these plots; thus the 'surpluses' and 'shortages' to the recommended flows in any individual year may look quite different.

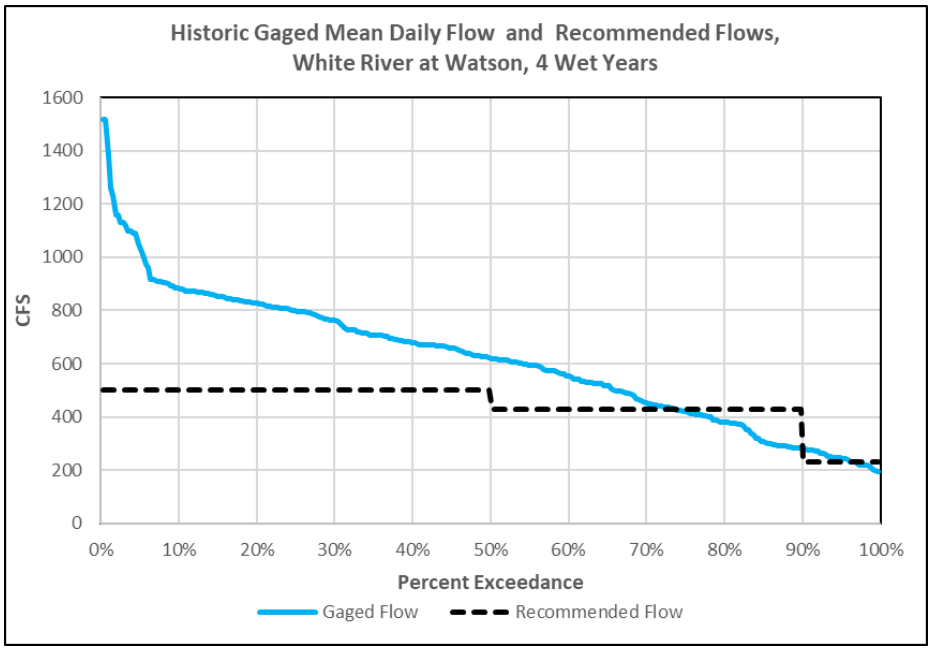

Figure 10. Flow duration curve for White River at Watson gage from August 15 to October 31 of four 'wet' years (1983, 1984, 1985, and 2011) compared to distribution of recommended wet year flows.

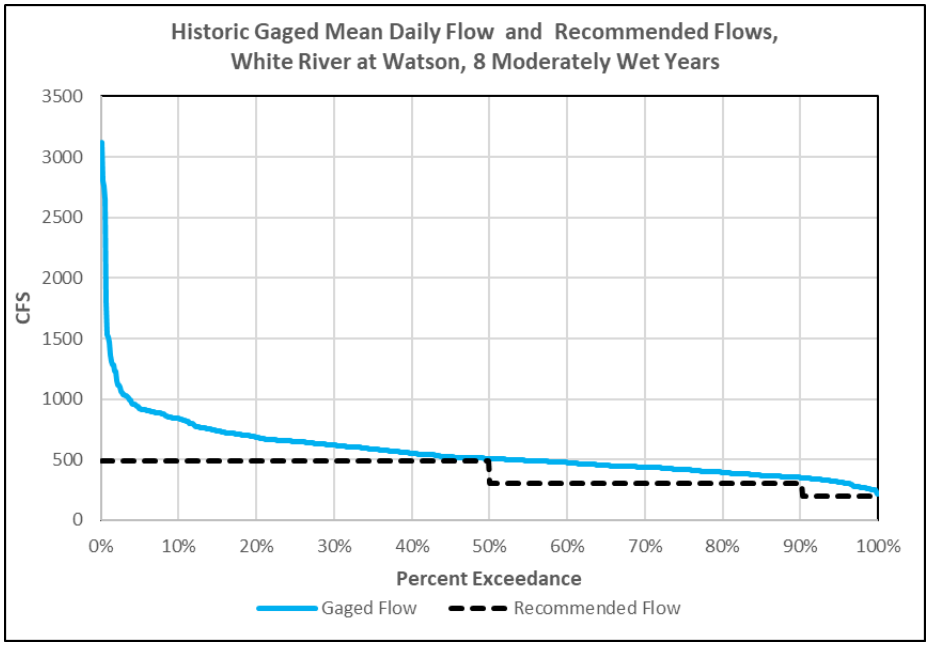

Figure 11. Flow duration curve for White River at Watson gage from August 1 to October 31 of eight 'moderate wet' years (1975, 1978, 1979, 1986, 1993, 1995, 1997, and 1998) compared to the distribution of recommended moderately wet year flows.

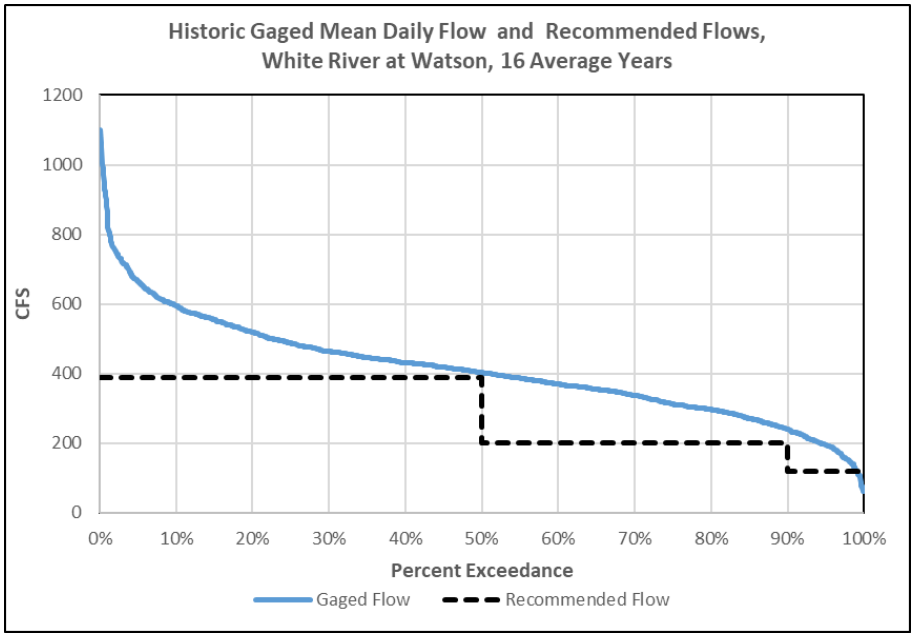

Figure 12. Flow duration curve for White River at Watson gage from July 15 to October 31 of 16 'average' years (1976, 1980, 1982, 1988, 1991, 1996, 1999, 2000, 2003, 2005, 2006, 2008, 2009, 2010, 2014, and 2015) compared to the distribution of recommended average year flows.

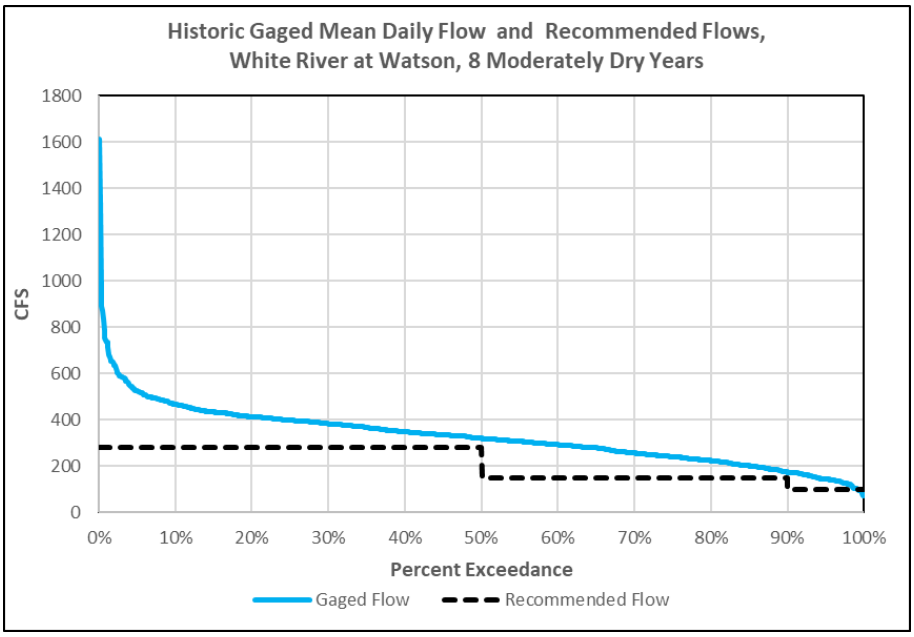

Figure 13. Flow duration curve for White River at Watson gage from July 1 to October 31 of eight 'moderately dry' years (1981, 1989, 1990, 1992, 2001, 2004, 2007, and 2013) compared to the distribution of recommended moderately dry year flows.

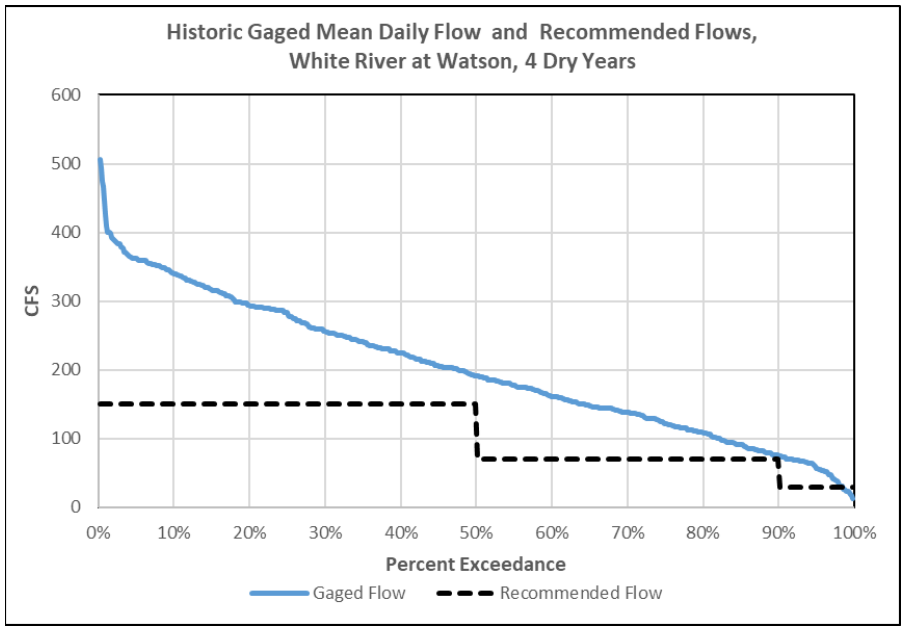

Figure 14. Flow duration curve for White River at Watson gage from June 15 to October 31 of four 'dry' years (1977, 1994, 2002, and 2012) compared to the distribution of recommended dry year flows.

Flow recommendations for the non-irrigation season (Table 4) reflect the importance of maintaining certain thresholds of future base flows at no less magnitude and frequency than occurs in the simulated Baseline Condition. The Service considers protection of these flows at the recommended magnitudes and frequencies to be a lower priority than protecting the annual peak flows and the irrigation-season base flows described above, as this period is less likely to create stresses for endangered fish as intense as those associated with very low flows of the irrigation season. Nevertheless, protection of these flows is considered important for fish recovery, and the rebound in post-irrigation-season flows typically observed in drier years may significantly benefit endangered fish that have been stressed by unusually low flows during preceding months. The following are flow recommendations to maintain the Baseline Condition.

Table 4. Recommended non-irrigation-season (November 1 through March 31) base flows, by hydrologic year type.

Percent of days specified target met:	**Hydrologic Year Type**				
	Wet (10%)	Mod Wet (10-30%)	Ave (30-70%)	Mod Dry (70-90%)	Dry (100%)
	Dates of Applicability: Nov 1 through Mar 31 (151 days)				
50%	500 cfs (76 days)	425 cfs (76 days)	390 cfs (76 days)	340 cfs (76 days)	300 cfs (76 days)
90%	360 cfs (136 days)	295 cfs (136 days)	265 cfs (136 days)	230 cfs (136 days)	165 cfs (136 days)
100%	220 cfs (151 day)	200 cfs (151 days)	145 cfs (151 days)	135 cfs (151 days)	105 cfs (151 days)

4.6 Assumptions and Uncertainties

A basic assumption underlying these Service flow recommendations is that it is important to mimic as much of the current pattern of annual and inter-annual flow magnitude and variation in the White River as practicable to promote the conservation and recovery of Colorado pikeminnow and razorback sucker. This is consistent with river protection and restoration strategies promoted elsewhere based on the paradigm that maintaining or restoring a relatively natural and dynamic river flow regime is typically the most effective means of benefiting large numbers of native riverine species adapted to pre-development river conditions (e.g., Stanford et al. 1996; Poff et al. 1997). It is also consistent with the observations by Martinez (1986) that spatial and temporal variability in the White River flow regime are important components of the river ecology. Bestgen (2015) specifically cites the White River's "mostly unaltered" flow regime

and its thriving native fish community as evidence that argues for maintaining as much of a natural flow regime as possible in the nearby Yampa River, where the flow regime has been more affected by development, and the native fish communities more adversely impacted.

Nevertheless, additional research is needed to better understand the specific physical and biological factors that determine successful reproduction, growth, recruitment, and survival of these endangered fish in the White River, and in the associated Green River system. This includes a need for research to better understand the impacts of water quality as well as habitat quality and availability on the fish communities of the White River. As noted by Kaeding and Osmundson (1989), because many interacting variables affect fish populations, no simple method exists for assessing the relationship between abiotic factors such as flow regime and channel morphology and faunal communities. For example, we assume flows that maximize the area of riffles and the quality of riffle substrate enhance benthic productivity in the White River, and therefore the prey base available for Colorado pikeminnow. However, specific studies relating channel productivity to the success of Colorado pikeminnow do not exist. In addition, the peak flows and base flows that optimize conditions for endangered fish in the White River likely vary from one year to the next, even under comparable hydrologic conditions, depending upon antecedent flows and other variables affecting real-time habitat conditions. Relevant variables include the prevalence and types of non-native species encountered locally.

Some additional uncertainties associated with these flow recommendations include:

<u>Biological</u>:

- With respect to razorback sucker in the White River, specific habitat needs such as spawning habitat requirements are unknown at this time and not specifically addressed by these flow recommendations. Similarly, spring flows necessary to provide razorback sucker nursery habitat along the White River, or transport sucker larvae to favorable habitats in the Green River, are unknown and not addressed here.
- With respect to the Colorado pikeminnow, further investigations are needed to determine the importance of the White River as spawning habitat, and identify flows that would help satisfy those spawning needs. To date, no specific pikeminnow spawning areas have been identified in the White River.
- Relationships between specific durations and magnitudes of flows and the biological benefits those flows provide to endangered fish in the White River are not well understood.
- Relationships between streamflow and water quality, and the potential impacts of various contaminants on the fish community, also are not well understood.

Physical:

Haines et al. (2004) recognized various uncertainties associated with their base flow study. These included:

- Their estimates of habitat areas are considered rough approximations, due to the limited range of flows evaluated, which constrain the confidence in their findings. For example, they describe as "suspect" their estimates of riffle wetted perimeters at flows of less than 134 cfs, due to problems of extrapolating beyond the measured range of flows. Collection of additional riffle habitat measurements at lower flows would be informative.

- Their site-specific habitat suitability curves for Colorado pikeminnow in the White River were based on information collected in the Yampa River, and in the White River prior to the closure of Taylor Draw Dam. Ideally, the authors would have developed their own habitat suitability curves for use in their PHABSIM analysis.

  - The authors note that the study design "should have included seasonal flows" for their evaluation of fish habitat use, not just base flows, and they specifically recommend that a study be conducted "that includes seasonal flow needs of Colorado pikeminnow including base flow needs, thus permitting determination of flow regimes that will maximize preferred habitats".

It is also worth noting that Schmidt and Orchard 2002 and Haines et al. 2004 conducted their field studies more than 20 years ago, raising uncertainties regarding changes in channel and habitat conditions over that time. For example, thousands of acre-feet of sediment have accumulated in Kenney Reservoir since it was first impounded in 1984 (Rio Blanco Water Conservancy District, 2018; GEI 1999). This deposition of sediment behind Taylor Draw Dam inevitably affects channel and habitat conditions downstream, but the implications for endangered fish flow needs are unknown, and not specifically considered here.[17]

Finally, impacts of water quality on the endangered fish, and by extension on recommended instream flows, were not considered in detail for this document nor by the cited supporting studies. Relevant variables could include water temperature, turbidity, and various constituents such as mercury and selenium that have the potential to affect particular life stages of the fish (see

[17] The Rio Blanco Water Conservancy District (personal communication, October 2019) notes that while Kenney Reservoir continues to capture significant amounts of sediment, sediment capture was more efficient early in the life of the reservoir. They note that with increased sedimentation, more sediment appears to be passing year-round through the reservoir and Taylor Draw outlet works, in contrast to a historic pattern in which the river below the dam would frequently exhibit little turbidity during periods of lower seasonal inflows.

Appendix C discussion). In addition, the proliferation of *Cladophora* algae in the White River in recent years has emerged as a substantial and growing concern. *Cladophora* began to proliferate in problematic quantities beginning around 2014, and has been a recurring problem in each subsequent year (Alden Vanden Brink, Rio Blanco Water Conservancy District, personal communication, July 2018). The factors leading to *Cladophora* proliferation are not yet well understood, however these extensive algal mats are likely to have problematic impacts on streambed habitat (e.g., aquatic invertebrate food base), water quality (including dissolved oxygen when this algae decomposes), and the ability to divert water for municipal and irrigation uses along the White River (due to clogging of diversion facilities). As additional information comes to light regarding the effects of water quality on various Colorado pikeminnow and razorback sucker life stages, corresponding adjustments to White River flow recommendations may be merited.

4.7 Implementation Considerations

The purpose of this document is to provide interim flow recommendations for the lower White River in Colorado and Utah that, based on the best information available, are believed to be flows that will aid recovery of endangered Colorado pikeminnow and razorback sucker, and promote a thriving native fish community in the White River. As interim recommendations, these are subject to change as studies further clarify relationships between streamflow and survival and recovery of the targeted species.

The Service recognizes that new water development in the basin – including new or expanded consumptive uses and new water storage projects – may render it impractical or impossible to meet all of these flow recommendations in the future. Moreover, warming temperatures in the UCRB are likely to make it more difficult to sustain the specified flows over time, in light of a trend toward earlier snowmelt, more precipitation falling as rain rather than snow, increased evapotranspirative demand by vegetation, and a reduction in annual runoff per unit of snow accumulation in the higher elevations of the Colorado River watershed (*e.g.*, USBR 2012a; Udall and Overpeck 2017; McCabe et al. 2017).

In light of the above, the Service recommends protecting the specified flows to the extent practicable as water resources are developed in the White River basin, recognizing that full protection may not be feasible. To the extent the recommended flows are not attainable, and in light of the assumptions and uncertainties cited in Section 4.6, the Service recommends that:

- Any new water development should consider and implement feasible mechanisms, operations, and protections to minimize impacts to these recommended flows, consistent

with the ability to develop its water rights under state and Federal law, interstate compacts, the Law of the River, and relevant Recovery Program Section 7 Agreements.

- Highest priority be given to protecting the recommended spring peak flows, including shoulder peak flows, and irrigation-season base flows, with lesser attention to protecting the recommended non-irrigation season base flows;

- To the extent that shortfalls to these recommended flows will occur as the result of water development in the basin, additional actions by the Recovery Program (both flow- and non-flow-related) should be implemented to offset adverse effects to endangered fish and their habitat;

- The Upper Colorado River Endangered Fish Recovery Program should implement a prioritized monitoring/data collection program to address the assumptions and uncertainties identified in Section 4.6, and address other significant deficiencies in the technical reports that were used as a basis for the current flow recommendations; and

- To the extent that actions are implemented to offset adverse impacts, biotic and abiotic conditions should be monitored to determine whether the offsetting actions are providing the intended benefits.

Finally, the flow recommendations presented here do not take into account the potential confounding effects of future changes in the basic ecological dynamics of the White River system – for example, introduction of new nonnative fish species, or proliferation of nonnative vegetation within the river channel or along the riparian corridor. A reevaluation of flow recommendations for the White River should occur in the future as additional data are collected and as such changes occur, or as additional information pertaining to such threats comes to light. For example, observations have been made that appropriately timed, short-duration spikes in flow can substantially reduce the emergence and survival of larval smallmouth bass in the Yampa and Green Rivers. As a result, recommendations have been made to experiment with controlled "flow spikes" in the Green River and possibly in other locations to reduce problematic predatory smallmouth bass populations (Bestgen and Hill 2016a; LaGory et al. in preparation). Similarly, it was observed that an experimental short-duration flow spike in July 2018 reduced, at least temporarily, the proliferation of problematic *Cladophora* algae in the White River below Taylor Draw Dam (Alden Vanden Brink, Rio Blanco Water Conservancy District, personal communication, August 2018).

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Appendix A

White River State MOD Technical Memorandum

Wilson Water Group

[Attached separately]

Appendix B

White River Base Flow Recommendations During the Irrigation Season: Rationale for Recommended Flows under Drier Hydrologies

U.S. Fish and Wildlife Service, June 2018

Recommended irrigation-season base flows in the unshaded boxes of Table 3 in *Review of Fish Studies and Flow Recommendations for Endangered Fishes of the White River, Colorado and Utah* (Flow Recommendations) represent exceedance values derived from the simulated 'Baseline Condition' for the corresponding hydrologic year type, rounded to the nearest 5 cfs. Values in the shaded boxes exceed the simulated Baseline values. The Service considers the flows in these shaded boxes to be more appropriate for protecting the habitat needs of the endangered fish than the corresponding simulated Baseline Condition flows, in part because they are more representative of the flows actually observed at the White River near Watson gage since 1975.

A more detailed description of the rationale for the Service's recommended flows for each of the seven shaded boxes in the table is provided below. For each, refer to the description indexed by the numbered parentheses.

The extraordinarily low flows generated by the White River StateMod Baseline simulations under unusually dry conditions (*e.g.*, simulated 0 cfs for the 100% exceedance condition in Average years) raised the question as to why these simulated flows are consistently more extreme than the corresponding measured historic flows. It appears that these StateMod simulations, which take into account all current water rights, simulate a fuller exercise of those rights under extreme low-flow conditions than has occurred historically. In that sense, the simulations may accurately reflect current opportunities to divert and utilize water consistent with recognized water rights in the White River basin. However, the full exercise of basin water rights is not indicated by the gaged, historic flows, and is not considered likely in the foreseeable future. Hence the higher recommended flows provided here.

Percent of days specified target met:	Hydrologic Year Type				
	Wet (10%)	Mod Wet (10-30%)	Ave (30-70%)	Mod Dry (70-90%)	Dry (100%)
	Dates of Applicability				
	Aug 15 – Oct 31 (78 days)	Aug 1 – Oct 31 (92 days)	Jul 15 – Oct 31 (109 days)	Jul 1 - Oct 31 (123 days)	Jun 15 - Oct 31 (139 days)
50%	500 cfs (39 days)	490 cfs (46 days)	400 cfs (55 days)	280 cfs (62 days)	150 cfs (1) (70 days)
90%	430 cfs (70 days)	305 cfs (83 days)	200 cfs (98 days)	150 cfs (2) (111 days)	70 cfs (3) (125 days)
100%	230 cfs (78 days)	200 cfs (4) (92 days)	120 cfs (5) (109 days)	100 cfs (6) (123 days)	30 cfs (7) (139 days)

(1) The simulated Baseline value for 50% exceedance in Dry years is 130 cfs. As described in Section 4.5 of the Flow Recommendations, 150 cfs is a significant low-flow habitat threshold (Haines et al., 2004), below which the available habitat for Colorado pikeminnow shifts markedly toward a narrowing of the wetted channel, more riffles, fewer riffles passable by adult pikeminnow, and fewer eddies, all of which tend to trap the fish within smaller reaches. In the four driest years since 1975 (1977, 1994, 2002, and 2012), measured flow at the Watson gage dropped below 150 cfs on average for 50 days.

(2) The simulated Baseline value for 90% exceedance in Moderately Dry years is 100 cfs. 150 cfs is a significant low-flow habitat threshold as already described. In the eight 'Moderately Dry' years since 1975, gaged flow dropped below 150 cfs on average for only 4 days.

(3) The simulated Baseline value for 90% exceedance in Moderately Dry years is 3 cfs. Because of the rapid loss of channel width and passable riffles below 150 cfs, FWS proposes protecting flows more comparable to recently gaged flows. In the four Dry years since 1975, gaged flow dropped below 70 cfs on average for 11 days.

(4) The simulated Baseline value for 100% exceedance in Moderately Wet years is 148 cfs. FWS proposes protecting flows more comparable to recently gaged flows. In the eight 'Moderately Wet' years since 1975, gaged flow never dropped below 200 cfs within this date window; the lowest mean daily flow recorded was 216 cfs on 9/7/1978.

(5) The simulated Baseline value for 100% exceedance in Average years is 0 cfs. Because dry channel conditions would be highly injurious to the endangered fish, and in light of the rapid loss of channel width and passable riffles as flows fall below 150 cfs, FWS proposes protecting flows more comparable to recently gaged flows. In the 16 'Average' years since 1975, gaged flow dropped below 120 cfs on average for 1 day. The lowest mean daily flow recorded was 61 cfs on 8/10/2000.

(6) The simulated Baseline value for 100% exceedance in Dry years is 2 cfs. Because dry channel conditions would be highly injurious to the endangered fish, FWS proposes protecting flows more comparable to recently gaged flows. In the eight 'Moderately Dry' years since 1975, gaged flow dropped below 100 cfs on average for less than one day. The lowest mean daily flow recorded was 73 cfs on 9/5/2013.

(7) The simulated Baseline value for 100% exceedance in Very Dry years is 0 cfs. Because dry channel conditions would be highly injurious to the endangered fish, FWS proposes protecting flows more comparable to recently gaged flows. In the four 'Dry' years since 1975, flow dropped below 30 cfs on average for 2 days. The lowest mean daily flow recorded since 1975 was 13 cfs on 7/3/1977.

Appendix C

White River Base Flows and Water Quality
U.S. Fish and Wildlife Service, October 2019

Various constituents affecting water quality have the potential to affect endangered fish in the Upper Colorado River Basin (UCRB), including metals (such as mercury, cadmium, lead, and zinc), non-metals (such as selenium), petroleum products, pesticides, pharmaceuticals, and elevated water temperatures. Because concentrations of some contaminants tend to increase with decreasing flow due to the reduced effect of stream dilution, this raises the possibility that diminished base flows could impair water quality and water temperatures in ways detrimental to native fish.

Although multiple water contaminants exist in the Colorado River Basin (USFWS 2017), only the effects of mercury have been quantified for Colorado pikeminnow (USFWS 2015). Mercury likely inhibits Colorado pikeminnow population growth rates through reduced reproductive output and larval fish survival (Miller 2014). High concentrations of selenium also are documented to have adverse biological effects on fish, including both larval and adult razorback sucker (Hamilton 1998; B. C. Osmundson *et al.* 2000). The potential impacts of other pollutants on UCRB endangered fish are not well understood.

The U.S. Geological Survey recently undertook a more intensive water quality sampling effort in the White River (and the Yampa River) which includes more intensive sampling of mercury concentrations, at the request of the U.S. Fish and Wildlife Service. However, as of this writing, a summary of the information gleaned from these recent studies is not available.

Mercury

Atmospheric deposition of mercury occurs throughout the UCRB, including in the White River basin, with origins in both natural and anthropogenic sources. After entering the aquatic environment, elemental mercury converts to methylmercury and enters the aquatic food web, where it bioaccumulates, especially in longer-lived predatory fish such as the Colorado pikeminnow. Mercury is a neurotoxin and endocrine disruptor; its impacts to fish may include reduced ability to avoid predators, secure food, and reproduce.

Osmundson and Lusk (2019) assessed mercury concentrations in the muscle tissue of Colorado pikeminnow >400 mm in length collected in 2008 and 2009 (73 total) throughout their existing range in the UCRB, and determined that the highest mercury concentrations occurred in those pikeminnow (also roundtail chub) collected from the White River (Fig 1). Additionally, among fish sampled, Colorado pikeminnow from the White and the Green rivers had the highest

mean mercury concentrations and the lowest mean relative body conditions, the latter an indicator of overall health. The mean concentration of mercury in muscle tissue from the ten Colorado pikeminnow sampled from the White River, was 1.1 µg/g wet weight (95% CI = 0.79–1.31), which is higher than the means in fish sampled from the Yampa, Green and Colorado River segments, and more than three times the 0.31 µg/g "fish muscle toxicity guideline for fish health" that Osmundson and Lusk (2019) inferred from Beckvar et al.'s (2005) recommendations. Similarly, four of four Colorado pikeminnow taken from the White River for broodstock in 1986 (Krueger 1988) that subsequently died in captivity exhibited concentrations of mercury in muscle tissue at or above that guideline (0.31–0.96 µg/g wet weight). Osmundson and Lusk (2019) conclude that mercury exposure is affecting Colorado pikeminnow body condition, with some likely impacts in terms of impaired reproduction, reduced growth, and reduced survival.

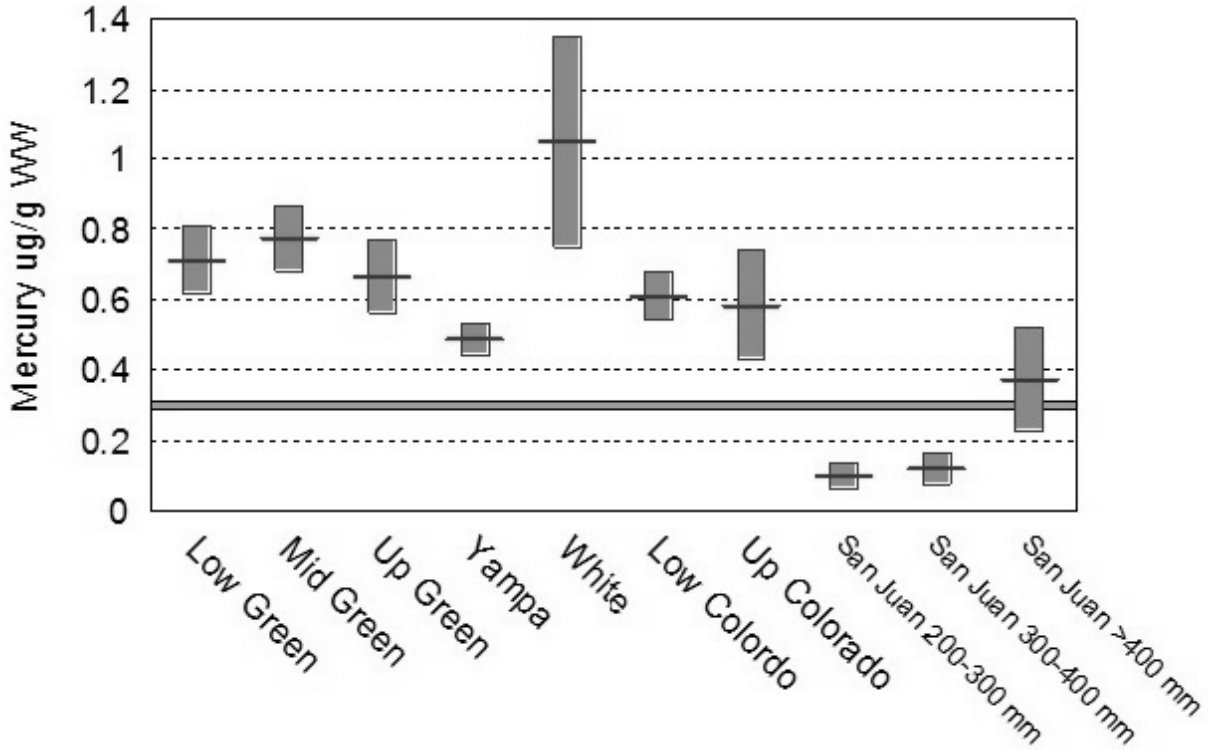

Figure 1. Mercury concentrations (mean and 95% confidence intervals) in Colorado Pikeminnow muscle plugs collected from Upper Colorado River Basin rivers (Green, Yampa, White, upper and lower portions of the Upper Colorado, and San Juan). Horizontal line identifies the USEPA's recommended tissue-based mercury water quality criterion of 0.3 µg/g wet weight. Figure from Osmundson 2012.

Some investigators have suggested that mercury toxicity in fish might be counteracted by selenium (Peterson et al. 2009; Penglase et al. 2014), although the role selenium may play in counteracting toxic effects is not currently known. Nevertheless 'surplus' selenium (i.e., present in fish tissue at a molar ratio to mercury greater than 1:1), which in Colorado pikeminnow may

protect against the effects of mercury, was highest in the Colorado River and lowest in the Yampa and White rivers among the UCRB rivers evaluated (see Table 1).

Tobin and Hollowed (1990) analyzed dissolved mercury in the water column at Kenney Reservoir in the mid-1980s. Concentrations ranged from <0.1 to 0.2 µg/l. A total of eight measurements (taken at two depths on four different occasions between January 1985 and August 1986) had a median concentration of 0.1 µg/L. This compares to a State of Colorado standard for total mercury in the water column of 0.01 µg/L (CDPHE 2018).

Selenium

Selenium occurs naturally in the environment and is required for normal growth and development of fish; however, at elevated levels it can have detrimental effects. If selenium bioaccumulates, toxic levels can cause deformities and decreased reproductive success in fish (Hamilton 2004).

Selenium has been documented in high concentrations in mainstem and wetland habitats of the UCRB since the 1930s, and its adverse biological effects on both larval and adult razorback sucker have been documented (Hamilton 1998; B. C. Osmundson *et al.* 2000). Selenium loads are generally higher in the Gunnison River, Dolores River, and lower mainstem Colorado River than in the White and Yampa rivers (Morford 2014).

Table 1 summarizes selenium concentrations sampled from Colorado pikeminnow muscle tissue by Osmundson and Lusk (2019) throughout the UCRB. As illustrated, considerably more selenium is found in fish tissue sampled from the Colorado River above the Green River confluence than in the Green River basin (including the White River). The effects of these concentrations on Colorado pikeminnow are not known at this time.[18]

Table 1. Average and range of selenium (mg/kg wet weight) in Colorado pikeminnow muscle tissues from Upper Colorado River Basin 2008-2009 (Osmundson and Lusk 2019).

River	Average Se in muscle tissue (min - max)
San Juan River (> 400 mm total length)	0.83 (0.74 – 1.00)
Middle Green River	0.98 (0.87 – 1.08)
Upper Colorado River	1.92 (0.93 – 2.16)
White River	0.93 (0.64 – 1.18)
Yampa River	0.62 (0.44 – 0.72)

[18] For comparison, the U.S. Environmental Protection Agency (2006) recommends no more than 11.3 mg of selenium per kg dry weight of fish muscle tissue, and a monthly average exposure of no more than 3.1 ug/L of selenium in the lotic water column once every three years as "protection of aquatic life" water quality criteria,

Hamilton et al 2003 cite unpublished data from the National Irrigation Water Quality Program indicating that selenium residues in muscle plugs of Colorado pikeminnow collected in the White River (mean 3.6 µg /g, *n* = 5) tended to be lower than in the Colorado River near Walter Walker State Wildlife Area, Grand Junction (4.4–8.5 µg/g), and in the lower Gunnison River (mean 4.9 µg /g, *n* = 7). They were comparable to those in the Green River (3.7 µg /g, *n* = 5), and greater than those in the Yampa River (2.3 µg /g, n = 5).

Tobin and Hollowed (1990) analyzed dissolved selenium in the water column at Kenney Reservoir in the mid-1980s. Concentrations ranged from 2-6 µg/L. Eight total measurements (taken at two depths on four different occasions between January 1985 and August 1986) averaged 3.4 µg/L concentration. Two of these measurements (both in April 1986) exceeded the 4.6 µg/L chronic water quality standard established for aquatic life in Class III waters in both Colorado and Utah.

Other Trace Elements

In addition to mercury and selenium, Tobin and Hollowed (1990) analyzed 20 other trace elements in Kenney Reservoir. None of these 20 appear to have exceeded either the acute or chronic water quality standards currently applicable in Colorado for aquatic life, when compared to Table III Metal Parameters in CDPHE 2018. However, as these trace metal data are now more than 30 years old, conditions in the river may have changed significantly over the intervening period.

Elevated Temperatures

Unusually high water temperatures can be disadvantageous for native fish. On other Green River tributaries, non-native and predatory smallmouth bass populations have been observed to increase rapidly in low-flow years (e.g., Bestgen 2015; see Figure 22), and one likely contributing factor is elevated water temperatures, as described in Section 2.3 of this document.

Data collected under unusually low-flow conditions in 2018 provide an opportunity to assess the possible effects of low flows on White River water temperatures. Analysis of unpublished data collected by USFWS in the White River at Cowboy Canyon (RM 67, approximately eight river miles upstream of the Watson, Utah stream gage and six miles downstream of the Colorado-Utah state line) indicate that stream temperatures briefly peaked at

84.0°F (28.9°C) on July 10, when flows at the Watson gage were approximately 230 cfs.[19] In contrast, stream temperatures at the same location on August 14, when flow reached its 2018 minimum (<30 cfs), peaked at a substantially lower temperature of 75.5°F (24.2°C). At least in this case, differences in ambient air temperatures and direct solar radiation appear to have had a greater influence on stream temperatures than differences in streamflow. Mean daily air temperatures measured at Rangely, Colorado, averaged 83°F (28.3°C) on July 7-9, and reached 84°F (28.9°C) on July 10. In comparison, the mean air temperature on August 14 was seven degrees cooler, 76°F (24.4°C), and averaged 77°F (25.0°C) over the three preceding days. Greater day length and higher angle of incident solar radiation in July also may have contributed to the higher stream temperatures. Whatever the physical drivers, under these 2018 conditions of diminished summer streamflow, a difference in streamflow of 230 versus 30 cfs did not appear to be the dominant factor controlling stream temperature.

An additional base flow consideration is that low flows tend to magnify the impact of sudden, unanticipated "shocks" to the aquatic environment: e.g., from a summer thunderstorm delivering ash and sediment from a recently-burned area, or from an oil spill entering surface waters. Reducing the frequency and duration of very low flows in the White River correspondingly reduces the vulnerability of native fish to these kinds of unpredictable habitat disruptions.

Summary

From a water quality perspective, extended periods of elevated stream temperatures in the White River and elsewhere are a concern because of the competitive advantages they appear to confer on problematic non-native species such as smallmouth bass. In addition, concentrations of mercury, and to some extent selenium, observed in the White River aquatic environment may have adverse effects on Colorado pikeminnow and/or razorback sucker. Occasionally, stream temperatures also appear to briefly exceed levels considered suitable by Colorado for razorback sucker.

It is unclear, however, to what extent elevated base flows could moderate the effects of these water quality concerns. As noted, peak summer stream temperatures appear to be more strongly controlled by factors other than the rate of streamflow, at least once flows fall below certain levels. Similarly, base flow magnitudes likely have little impact on the total mercury and

[19] It is worth noting the stream temperature at this location on July 10 and July 13 appears to have briefly exceeded the acute temperature standard of 28.6°C established in Colorado for "Tier II Warm Stream" river reaches, defined as applicable where razorback sucker or white sucker (among other species) are expected to occur. The same regulations (CDPHE 2018) establish a maximum "chronic" (i.e., mean 7-day) temperature standard of 27.5°C for these stream reaches. The maximum mean 7-day stream temperature recorded at this site in 2018 was 26.3°C from July 7 through July 13, thus did not exceed the chronic standard.

selenium loads in the White River system, suggesting they may have limited impact on the long-term accumulation of these two contaminants in fish tissues.

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