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Aspects of the Yampa River Flow Regime Essential for Maintenance of Native Fishes

Final Report submitted to the National Park Service, The Nature Conservancy, and Western Resource Advocates. Department of Fish, Wildlife, and Conservation Biology, Colorado State University, Fort Collins. Larval Fish Laboratory Contribution 181

Natural Resource Report NPS/NRSS/WRD/NRR—2015/962

ON THE COVER
Endangered Fish Spawning Bars, Yampa River, Dinosaur National Monument
Photograph National Park Service

ON THE TITLE PAGE
Lower Yampa River, Dinosaur National Monument
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Executive Summary

Maintaining various components of the natural flow regime of the Yampa River is essential to create habitat and preserve the native and endangered fishes it supports. Further, the Yampa River provides the downstream Green River with a more natural flow and water temperature pattern, and creates essential connections between the river and floodplain wetlands so native fishes can benefit. This report describes those essential components of the Yampa River flow regime, recognizing that all elements of the flow regime are important and losses or alterations would negatively affect ecosystem integrity. The following statements are excerpted from summary paragraphs located at the end of this report, with the corresponding topical section headers presented in bold. Information presented in this report is based on existing literature, data, and professional opinion, regarding aspects of the Yampa River flow regime thought essential for preservation of native fishes. A full reading of the report is encouraged so the reader understands the context under which these statements were developed.

Maintain the natural flow patterns of the Yampa River

- An optimal Yampa River flow regime would maintain the natural regime of the Yampa River in its entirety.

- Maintaining peak flows and enhancing base flows from present reduced levels would support many processes in the life history of native fishes, including providing spawning cues, physical habitat creation, and substrate cleansing.

- Maintenance of natural flows and relatively high peak and base flows will also promote reproduction and survival of native fishes, and reduce reproduction and abundance of most nonnative fishes.

Maintain peak flows

- Peak flows provide important physical habitat maintenance functions in the Yampa River including sediment transport from the stream channel, substrate mobilization for spawning habitat formation and maintenance, and sand transport and deposition for secondary channel and backwater formation.

- High flows may also provide a signal for fishes to prepare for or begin reproduction.

- High flows on floodplain surfaces or in tributary mouths provide relatively warm and low velocity off-channel habitat where fishes can increase body condition when Yampa River flows are high and cold.

- Peak Yampa River flows also provide amplitude and volume to spring flows in the downstream Green River. Those flows rejuvenate physical habitat, provide that regulated system with a more natural hydrograph shape and pattern, and connect the river with the extensive floodplain.

- Floodplain connections in the Yampa River and especially the downstream Green River are important for adult life stages of bonytail, Colorado pikeminnow, and razorback sucker as well as early life stages of razorback sucker because wetlands are warm and food rich relative to the cold and relatively unproductive main channel.

Maintain or enhance base flows, especially in late summer

- Base flows are, at present, the most altered aspect of the Yampa River hydrograph and based on one-day annual low flows have declined by 37% from 1922-2013. Low base flows reduce riffle habitat depth and area and reduce food and habitat availability.

- Riffles are important food production and foraging areas for all native fishes, and are also important for fish passage because large-bodied native fishes must traverse riffles to move throughout the Yampa River.

- Base flows also provide important habitat for early life stages of native fishes in nearshore areas, such as backwaters and secondary channels, including in the Green River.

- Higher base flow levels may also provide a thermal regime that is more favorable overall for the native fish community as a result of reducing nonnative predator fish growth, particularly for smallmouth bass.

Maintain post-peak, descending limb flows

- Descending limb Yampa River flows are important because that is when most native fishes reproduce.

- Increasing warming rates via descending limb flow reductions may disrupt adaptations for reproductive isolation and spawning chronology of native fishes and increase hybridization of native suckers with nonnative white sucker in the Yampa and Green rivers.

- Descending limb flows provide main-channel spawning fishes with clean gravel riffles for egg deposition, and sweep away fine sediments to maintain interstitial water flow, which is important for successful development of embryos and larvae over relatively long post-spawning periods of native fishes.

- Increasing the rate of warming during descending limb flows in spring by reducing flow volumes will also promote earlier spawning and faster growth of deleterious nonnative fishes such as smallmouth bass and small-bodied nonnative cyprinids.

Maintain as much of ascending limb flows as possible

- Flow alterations and water diversion from the Yampa River during the ascending limb of the hydrograph may be least damaging to the fishes and their habitat than any other time of year.

- Ascending limb flows of the spring hydrograph may also play a role in signaling timing for reproduction by native fishes, including in the downstream Green River.

- Increasing warming rates via flow reductions on the ascending limb of the hydrograph may disrupt adaptations for reproductive isolation and spawning chronology of native fishes and increase hybridization of native suckers with nonnative white sucker.

- Flow reductions during the ascending limb of the Yampa River hydrograph may increase water temperatures of the Yampa River. However, the potential for impacts to temperature signals for fishes in early spring, from ascending limb flow reductions in the Yampa River, seems relatively low if base flow or higher flow levels are maintained during that relatively cool season.

- Sediment transport occurs on the ascending, peak, and descending limbs of the hydrograph in the Yampa and Green River systems and early season transport capacity may be reduced.

- It is uncertain if some ascending limb flows were removed, if sufficient flows for sediment transport would be available during pre-peak and peak flow periods for clearing and rejuvenation of substrate in spawning areas.

Minimize short-duration flow fluctuations

- Minimize short-term and frequent flow releases that elevate river stage and discharge that can be disruptive to fish communities, especially if early life history stages of fish are present. Infrequent fluctuations to disrupt reproductive success of invasive species may be beneficial.

- Minimize base flow fluctuations in winter that may disrupt habitat stability and create potentially stressful conditions that reduce energy reserves and potentially survival of fish.

- Formation of ice cover provides a relatively stable riverine environment so flow fluctuations or base level increases that break ice cover should be avoided.

Maintain water temperature regimes

- The stream fish community in the Yampa River downstream of Craig, Colorado requires a summer-warm thermal regime that should be maintained.

- High water temperatures in the Yampa River are not deleterious to native fishes, but they also increase smallmouth bass growth rates, and subsequently, bass predation pressure on native fishes.

- Water temperature increases to very high levels in flow-depleted systems should be avoided.

Frequency and timing of recommended flow patterns

- Flow patterns recommended for peak, ascending limb, descending limb, and base flows need to continue in perpetuity.

- It is recognized that flow volumes will vary year to year based on snowpack and other hydrologic conditions, and that more geomorphic work may be completed in higher flow years than others.

- The timing of flow events should be largely dictated by the natural hydrograph.

Maintain natural peak flow durations

- Peak flows perform useful geomorphic work and create important fish habitat but the duration of peak flows needed to perform physical habitat formation and maintenance is less certain.

- The natural hydrograph will dictate much in terms of peak duration, which will typically be longer in higher flow years, and shorter in lower flow years.

- Accurate predictions of the onset of the three peak flow segments, ascending, peak, and descending portions, are needed to maintain the most valuable functions of flows in the Yampa River and the downstream Green River.

Maintain turbidity patterns

- Water turbidity, caused by suspension of fine clay particles in the water column, is a natural part of Yampa River flows.

- The interplay of turbidity on predation and growth and survival of native fishes may be important to understand the ecology of native and nonnative fish interactions in the Yampa and Green rivers.

Maintain or increase nonnative fish management efforts to reduce long-term effects

- Nonnative fishes, especially large-bodied piscivorous species such as smallmouth bass and northern pike, have the potential to undo many flow management activities undertaken for the benefit of native fishes in the Yampa River system.

- Nonnative fish removal effects are short-term because occasional flow events create large year-classes of various nonnative fishes that are apparent for several years in the river, and require several years of mechanical removal effort to suppress. Also, flow patterns do not affect nonnative fishes in similar ways.

- The specter of additional introductions and establishment of other species is real and ongoing as new species invade the system on a regular basis. This is sobering given that already established nonnative fishes are widespread and abundant, difficult to control, and have documented negative effects on native fishes.

- Ongoing management activities should be supported, with the view towards long-term solutions including controlling source populations, and more effective mechanical control techniques where and when populations are most susceptible.

- It is also important to keep a longitudinal perspective when considering present and future issues with nonnative fishes. This is because the lower Yampa River is positioned between upstream and downstream of river segments that differ with respect to problematic fish species and because fishes are mobile, with distributions and abundances shifting with environmental regimes and the state (early or late) of ongoing invasions.

Maintain or enhance flow and other management efforts in the Green River to aid the Yampa River fish community

- The co-dependency of Yampa River and Green River processes and fish communities is evident and strong.

- Processes that maintain or strengthen the co-dependency of the systems should be fostered, but are incompletely known.

- A relevant example is the interplay of the higher and later flow releases from Flaming Gorge Dam to promote connections of the Green River with the Uintah Basin floodplain for recruitment of young razorback suckers. Yampa River flows are an integral part of that process, especially the peak and descending limb flows and, as such, should be maintained.

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Introduction

The mostly unregulated Yampa River is widely recognized as rare among rivers in the western United States because flows are only minimally impacted by reservoir storage (Muth et al. 2000). The high resource value of the river in its minimally altered state, and recognition that water may be available for future development, prompted the National Park Service and environmental groups (Western Resource Advocates, The Nature Conservancy) to begin a process to better understand and maintain the natural attributes of the Yampa River, principally in Dinosaur National Monument below the confluence with the Little Snake River. Focal areas for investigation included stream channel geomorphology, riparian corridor, and aquatic biota (mainly fishes), each of which is closely linked through a common set of hydrologic processes. A main goal was to understand the role of hydrologic processes in maintaining natural Yampa River attributes and how its high resource value may be maintained.

Native biota are thought adapted to the flow regime of a particular system (Poff et al. 1997; Bunn and Arthington 2002; Brown and Ford 2002; Yarnell et al. 2010). For example, flow regime and associated water temperature patterns are thought to signal onset of reproduction of various fishes in the Colorado River Basin (Bestgen et al. 1998; Bezzerides and Bestgen 2002; Bestgen et al. 2011a; Bestgen 2011b). Flows also create or modify physical habitat by transporting and depositing sediment, which creates clean spawning riffles and low velocity nearshore environments for early life stages of fishes. High flows also connect seasonal habitat such as flooded tributary mouths and floodplain wetlands, which are important for adult and early life history stages of native fishes. Because altered regimes sometimes do not provide all aspects of flows necessary for maintenance of native fish communities and their habitat, it is useful to define those critical flow regime attributes. Therefore, the purpose of this report is to define aspects of Yampa River flows that are essential to maintain aquatic biota in that system, mainly fishes. Others have attempted to develop flow recommendations for the Yampa River, which is an admirable but difficult goal to attain. That is because in its essentially unregulated state, recommendations have been to maintain the natural flow regime. In other words, it is difficult to make flow recommendations for a river where flows are mostly controlled by natural processes such as snowpack accumulation and runoff. Base flows are recognized as one part of the Yampa River flow regime that is influenced by human activities.

In keeping with the overall goal of the project, I describe the distribution, abundance, and status of fishes in the Yampa River basin, including several problematic nonnative species, and the role of geomorphic and hydrologic processes that influence those fishes. To put the importance of the Yampa River system in better perspective, it is first necessary to describe the status of native fishes in the Colorado River basin, and discuss reasons for their decline, including effects of habitat change and nonnative fishes. I then use conceptual life history models to describe the ecology of several endangered fishes, and comment on the life history of all other native warm water fishes in the Green River subbasin, of which the Yampa River is a part, to understand specific factors that affect their distribution and abundance. This is important because the Yampa and Green rivers form a continuous linear riverine ecosystem, upon which resident and migratory fishes in the Yampa River rely. That discussion includes information specific to the fishes and processes in the Yampa River. I then focus on the Yampa River basin (beginning page 25, Importance of the Yampa River) and use data gathered since previous flow recommendation investigations to describe importance of specific portions of the flow regime to life history processes for native and nonnative fishes. Inclusion of nonnative fishes is essential because their distribution and abundance impacts native kinds and they are also affected by stream flow and water temperature patterns.

I discuss effects on fishes of the two main pieces of the Yampa River flow regime downstream of the Little Snake River, base flows and peak flows. Where possible, I separate potential effects of three portions of the Yampa River peak flows, the ascending limb, the peak, and the descending limb. The ascending limb encompasses a relatively long time period, usually from March through mid-May, which has flows higher than occur during the base flow period but lower than the peak period (Appendix I). The peak flow period is a relatively short, 1-2 week window that encompasses the maximum magnitude flow portion of the hydrograph including the peak, which usually occurs in late May or early June, and the high shoulder flows just pre-peak and post-peak. The descending limb of the hydrograph is typically shorter in duration and lower in volume than the ascending limb. In most years, the transition from descending limb flows to the base flow period in the Yampa River is in early to mid-July; only in high flow and relatively cool years (e.g. 1995 and 2011) is the transition later.

Separation of the peak flow period into the three segments is useful because distinct biological and geomorphological processes important to fishes may occur within each. Understanding when those processes occur and the importance of flows driving them may assist with understanding what aspects of the Yampa River hydrograph are most important to maintain. I have also assumed that any flow alteration would be from direct diversion without storage or a diversion(s) to an off-channel or tributary storage reservoir rather than a mainstem dam on the Yampa River.

The report closes with summary statements, supported by life history descriptions and best available knowledge, that describe the importance of various flow-related and other physical processes, and which of those need to be maintained to protect native fishes in the Yampa River.

Colorado River basin and fishes

The Colorado River basin drains portions of seven states in the southwest United States and the Mexican states of Sonora and Baja California (Figure 1). The Colorado River basin is divided into the upper and lower Colorado River basins at Lee Ferry, just downstream of Glen Canyon Dam and Lake Powell. The lower Colorado River basin drains portions of Utah, Nevada, California, Arizona, New Mexico, and a portion of the Republic of Mexico. The Little Colorado River, Virgin River, and Gila River subbasins represent major drainage units of the lower basin. The upper Colorado River basin drains portions of the states of Arizona, New Mexico, Colorado, Utah, and Wyoming and is divided into the San Juan River, Colorado River, and Green River subbasins.

The Colorado River basin supports relatively few native fishes compared to other drainages of comparable or smaller size in the United States (Minckley 1973; Minckley et al. 1986). This is due in part to the harsh environment of streams in the Colorado River basin, which are seasonally laden with suspended sediment (turbid), have extreme high and low flows, variable water temperatures, and other physical and chemical properties that fluctuate widely on daily or seasonal scales. Major portions of the basin were connected, with few impediments to movement of fishes among them. Consequently, Colorado River basin streams and rivers offered few opportunities for isolation and subsequent diversification of species. In addition, isolation of the entire drainage by high elevation divides limited exchange via stream captures with fish faunas of adjoining basins that are more species rich (Minckley et al. 1986). Isolation from adjoining basins over long time spans (perhaps millions of years) enabled evolution of several endemic species. Long isolation also led to morphological and life history traits of some species that are apparently adaptations to the environmental extremes of the basin. For example, streamlining of body forms and development of humps on the dorsal surface of at least two species is thought to stabilize them in high velocity flows (Minckley 1973; Figure 2).

The Colorado River basin has one of the highest proportions of rare and endangered native fishes in the world (Stanford and Ward 1986; Carlson and Muth 1989). Of the 35 or so species or subspecies considered native, three are extinct, 18 are listed as threatened or endangered under the Endangered Species Act (ESA) by the U.S. Fish and Wildlife Service, and the remainder are listed by most states where they occur as needing conservation action. Three minnow species, humpback chub *Gila cypha*, bonytail *Gila elegans*, Colorado pikeminnow *Ptychocheilus lucius*, and razorback sucker *Xyrauchen texanus* were historically widespread and common in both the lower and upper Colorado River basins; all are endemic to the Colorado River basin. Each is relatively large-bodied and historically occurred mainly in the larger rivers of the basin. All are listed as endangered by the U.S. Fish and Wildlife Service. Colorado pikeminnow and humpback chub were listed in 1967, and given protection under the ESA in 1973 (U.S. Fish and Wildlife Service 1967; listing decisions and other information cited in U.S. Fish and Wildlife Service 2002a; 2002b; 2002c; 2002d; http://www.coloradoriverrecovery.org/general-information/program-history/program-history.html). Bonytail was listed in 1980 and razorback sucker was listed in 1991. All four taxa are also listed as species in need of conservation action (endangered or threatened) by the states in which they reside.

Other large-bodied big river fishes, flannelmouth sucker *Catostomus latipinnis*, bluehead sucker *C. discobolus*, and roundtail chub *Gila robusta*, formerly occurred throughout many reaches of the Colorado River basin (Bezzerides and Bestgen 2002). Flannelmouth sucker and roundtail chub were widespread throughout the upper and lower Colorado River basin, but in the lower Colorado River basin, bluehead sucker was common only in the Colorado River in Grand Canyon. Small-bodied speckled dace *Rhinichthys osculus*, was widespread in small and large-river habitat throughout the basin.

Reasons for reduced range and abundance of native fishes in the Colorado River basin, particularly big river fishes, vary widely but can be grouped generally under two main factors: habitat change and effects of invasive species. Habitat changes are mainly from dam construction and subsequent reservoir water releases that alter natural streamflow patterns, reduce water temperatures, diminish sediment supply of rivers downstream, and enable establishment of nonnative woody vegetation.

Dam alterations to flows are particularly important because high flows reset and form the physical template of the river channel for aquatic biota that rely mainly on that habitat type. Some fishes use seasonally inundated floodplain habitats to complete their life history (Welcomme 1985; Junk et al. 1989; Welcomme 1995; Modde et al. 1996, Bestgen et al. 2011a). Storage of snowmelt runoff in reservoirs has reduced incidence of flows that overtop river banks and severs connections with wetlands and the river. Dams also block movements of fishes. Thus, several fish species and life stages in the Upper Colorado River basin that use floodplain wetlands to complete their life cycle or move long distances are negatively affected by dams (Welcomme 1985; 1995; Modde 1996; Modde et al. 1996; Valdez and Nelson 2004; Bestgen et al. 2011a).

More nonnative fishes (> 60) now occur in the Colorado River basin than natives, 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). Nonnative fishes are typically abundant as well, often representing > 90% of fishes in backwater and floodplain wetland habitats (Haines and Tyus 1990; Modde et al. 2001; Christopherson et al. 2004; Modde and Haines 2005, Skorupski et al. 2013). The result is often a negative outcome for native fishes due to competition for food or predation of natives by nonnative fishes. Even small nonnative fishes, with body lengths of 75 mm total length (3") or less, consume early life stages of endangered fishes that occur in the same habitat (Ruppert et al. 1993; Bestgen et al. 2006; Markle and Dunsmoor 2007). Nonnative white sucker *Catostomus commersonii*, a common invasive species, continues to expand its range in the upper Colorado River basin. White sucker hybridizes with native bluehead and flannelmouth suckers, sometimes to the point where only hybrid swarms remain, and endangered razorback sucker is also at risk (Bezzerides and Bestgen 2002).

Negative effects of habitat change and nonnative fishes on native fishes are most pronounced in the lower Colorado River basin, where numerous dams, especially on the mainstem Colorado River and its major lower basin tributary, the Gila River, have dramatically altered riverine habitats to the detriment of native fishes. For example, in its 300-mile course downstream of Lake Mead (impounded by Hoover Dam), the Colorado River has no fewer than five, large mainstem water storage facilities and few or no native fishes reside in those lentic habitats (Minckley 1983; Mueller and Marsh 2002; but see Albrecht et al. 2010). Elsewhere in the lower basin, reduced streamflows and abundant nonnative fishes have eliminated large-bodied big river fishes in most remaining riverine habitat; only isolated and geographically restricted populations of native fishes remain (Mueller and Wydoski 2004; Albrecht et al. 2010).

As a result of severe habitat changes and abundant nonnative fishes, the lower Colorado River basin no longer supports populations of most large-bodied native fishes including Colorado pikeminnow and bonytail (bonytail occurs only as introduced populations in highly managed off-channel ponds along the lowermost Colorado River; Mueller and Marsh 2002). The remaining razorback suckers are limited mainly to lakes Mead and Mohave (Minckley 1983; Albrecht et al. 2010) and humpback chub exists as a single population in the Colorado River in and near its confluence with Little Colorado River in Grand Canyon. Range of flannelmouth and bluehead suckers and roundtail chub has been reduced by 50% or more throughout the Colorado River basin and most severely in the lower Colorado River basin (Bezzerides and Bestgen 2002). Presently, both species are widespread and relatively abundant only in the Colorado River in Grand Canyon, although a repatriated population of flannelmouth sucker occurs downstream of Lake Havasu (Mueller and Wydoski 2004). Roundtail chub remains in some smaller tributaries of the lower Colorado River basin, particularly in the Gila River drainage (Minckley and Marsh 2009).

In contrast to the lower Colorado River basin, habitat change has been less severe in the upper Colorado River basin. Fewer mainstem dams exist in warm water portions and long river reaches remain where migratory species still reside (Muth et al. 2000). For example, the warm water reach of the Green River flows essentially unimpeded for about 588 river kilometers (RK, 365 river miles) from Lodore Canyon in northwest Colorado downstream to its confluence with the Colorado River in eastern Utah, and additional connected habitat is in its large tributaries (e.g., 169 RK in the White River and over 225 RK in the Yampa River; Bestgen et al. 2007a). Flow regimes in those tributaries are minimally altered and mostly intact. Flow regime and water temperature recommendations have been implemented in river reaches downstream of dams to meet stream flow and habitat needs of native warm water fishes (e.g., Green River downstream of Flaming Gorge Dam; Muth et al. 2000). Fewer nonnative fish species occur in the upper than lower Colorado River basin, but they are numerically abundant and problematic in many reaches (e.g., Johnson et al. 2008).

As a result of differences in habitat and fish communities, the upper Colorado River basin is considered the last stronghold for several large river fishes native to the Colorado River basin. For example, wild populations of Colorado pikeminnow persist in the Green River and Colorado River subbasins and some larger tributaries, including the Yampa River (Bestgen et al. 2007a; 2010; Osmundson and White 2014). Colorado pikeminnow is also found in the San Juan River but population augmentation by stocking hatchery-reared individuals is necessary to maintain it there (Platania et al. 1989; Franssen and Durst 2014). Humpback chub recently existed in at least five locations in the upper Colorado River basin, including two in the Green River subbasin (U.S. Fish and Wildlife Service 2002d). Bonytail have been widely stocked and survive in modest numbers, but with no evidence of reproduction, those populations will not be sustained (Badame and Hudson 2003; Bestgen et al. 2008). Finally, razorback suckers, which disappeared as naturally sustaining populations in about 2000 in the upper Colorado River basin, have been stocked widely in warm water rivers (Bestgen et al. 2002; Zelasko et al. 2010). Reproducing populations are now present in the San Juan and Colorado rivers (including the tributary Gunnison River), the middle and lower portions of the Green River, as well as the White and Yampa rivers (Tyus 1987; Tyus and Karp 1990; Holden 1999; Bestgen et al. 2002; Osmundson and Seal 2009; Bestgen et al. 2009; Zelasko 2008; Zelasko et al. 2009; 2010; 2011; Bestgen et al. 2012; Bottcher et al. 2013; Webber et al. 2013). Flannelmouth and bluehead suckers and roundtail chubs are relatively widespread in the upper Colorado River basin, except roundtail chub is rare in the San Juan River (Bezzerides and Bestgen 2002). Speckled dace remains widespread and comparatively common in the upper Colorado River basin. Thus, the upper Colorado River basin is an important area for conservation of several native Colorado River fishes.

Critical Habitat, the habitat deemed necessary for recovery of a federally protected species, is typically determined during the listing process or after being listed under the ESA. By merit of existing fish distributions and potential for recovery, most designated Critical Habitat for the four large river endangered fishes is located in the upper Colorado River basin (Maddux et al. 1993, U.S. Fish and Wildlife Service 2002a-d). Designated Critical Habitat includes the entire reach of the Green River downstream of the Yampa River to the confluence with the Colorado River (about 555 river kilometers [RK], 345 RM), the lower 169 RK of the White River, as well as the lower 225 RK (140 RM) of the Yampa River. Those reaches also support important populations of flannelmouth and bluehead suckers, roundtail chub, and speckled dace.

The Green River subbasin fish community

While upper Colorado River subbasins differ in physical attributes and extent of human modification, each supports two or more endangered fishes as well as populations of bluehead and flannelmouth sucker, roundtail chub, and speckled dace. The Green River, which depends on flows from the Yampa River, supports the largest populations of endangered as well as non-listed native fishes (Figure 3; Tyus 1987; Platania et al. 1989; Bestgen 1990; Tyus 1990; Bezzerides and Bestgen 2002; Bestgen et al. 2007a; 2008; 2010; Zelasko et al. 2010). This is a function of both larger overall habitat size and greater population densities. For example, about 900 RK of mainstem and tributary habitat in the Green River subbasin is occupied by Colorado pikeminnow. In contrast, Colorado pikeminnow in the mainstem Colorado River occupy only about 322 RK (Osmundson and Burnham 1998; Osmundson et al. 1997; Osmundson et al. 1998; Osmundson and White 2014). Populations of Colorado pikeminnow in the San Juan River, about 282 RK long, are present mainly as stocked individuals with only modest documented recruitment to the adult life stage (Platania et al. 1989; Holden 1999; Franssen et al. 2014).

Specific reasons for reduced distribution and abundance of native fishes in the upper Colorado River and Green River subbasins are varied and depend in part on the life history of the species. Short narratives for the four endangered fishes illustrate the complexity of life histories (the life cycle of the species and factors that affect it) and provide insight into factors that affect their distribution and abundance.

Conceptual life history models for endangered fishes in the Green River subbasin (Figures 4-7), some presented elsewhere (Bestgen et al. 2006; Bestgen et al. 2007b; Zelasko 2008; Valdez et al. 2011), illustrate differences among them. Conceptual models were developed from life history information available in published papers and agency reports, ongoing research, and personal observations (Bestgen et al. 2006; 2007b) and are diagrammatic representations of factors that may affect survival of each species as it progresses from egg to adult life stage. Factors controlling abundance and survival of various life history stages are divided into both biotic (e.g., competition and predation) and abiotic (streamflows, habitat, water temperatures, and pollutants) components to provide focus for management and mitigation of discerned negative effects. The arrows connecting the boxes show the logical development sequence from egg to adult and inter-relationships among life stages.

Separate biotic and abiotic limiting factors that affect abundance and survival of each species and life stage are presented, recognizing that some of the most important limiting factors likely represent interactions among two or more factors. For example, warm water positively affects growth of a fish larva, an abiotic factor, which interacts with predation, a biotic factor, because slow growing larvae will be susceptible to predation by other fishes longer than fast-growing larvae (see Bestgen et al. 2006).

Several compartments in the life-history model detail factors limiting the early life stages of these species. This was done to underscore the dramatic changes in physical ability that relatively small, weak-swimming, and vulnerable early life stages of fishes undergo and to highlight the diversity of habitat needed to support these life stages over a broad spatial scale. For example, the time required in the period from embryo deposition, hatching, and downstream drift, to a larva colonizing a backwater or floodplain habitat may be less than two weeks. However, during that period the 5-10 mm long organism occupied interstitial spaces in spawning gravel in turbulent and turbid canyon river flows, drifted downstream in swift river currents 10-150 RK or more, and eventually established itself in the margin of a large river with a shifting channel margin so it could swim or be entrained into a low velocity nursery habitat.

In addition, because of their small size and limited energetic reserves, early life stages of fishes are susceptible to a greater variety of harsh conditions and factors that control their distribution and abundance compared to juvenile and adult fish. Some later life stages were combined in conceptual models either because they have similar habitat and limiting factors (e.g., large juveniles and adults), or because their life history requirements and controlling factors were poorly understood (e.g., larvae to juveniles for razorback sucker; age-0, age-1 Colorado pikeminnow in winter habitat). The models end with variable-sized cohorts of adult fish. However, the models should be viewed as circular rather than terminating with adults, and represent a continuous life history cycle, because abundance of adults affects the quantity and quality of embryos that begins each annual cycle. The sum of annual production cycles reflects the current distribution, abundance, and status of the respective species, and also portrays the interconnectedness of various fish life history stages across the river landscape, including the linearly connected Yampa and Green river systems.

In this next section, I focus particularly on details of fish life histories in the Yampa-middle Green River area, where populations of humpback chub, Colorado pikeminnow and razorback sucker reside and habitat was ranked of highest importance (LaGory et al. 2003; Valdez et al. 2011); too little was known about bonytail for rankings to apply. Habitat rankings also recognized the critical reciprocal linkage between physical and biological processes in the Yampa and Green rivers.

Colorado pikeminnow distribution and life history

Colorado pikeminnow, once abundant throughout the Colorado River basin, is a large–bodied, long-lived (>30 years) species that historically reached nearly 2 m in length and up to 40 kg in weight (Tyus 1991a; Quartarone 1995; Osmundson and Burnham 1998; Bestgen et al. 2007). Lower basin populations were extirpated by the mid-twentieth century (Minckley and Marsh 2009) and wild populations persist only in the Green and upper Colorado River subbasins. In the upper Colorado River subbasin, Colorado pikeminnow now occur only in the mainstem, but as recently as the mid-

1990s Colorado pikeminnow were still spawning upstream of a diversion dam barrier (< 3 RK upstream of the Colorado River confluence) in the tributary Gunnison River. In the Green River subbasin, Colorado pikeminnow occupy the lower 600 RK of the Green River, extending as far upstream as upper Browns Park, CO (personal observation; Upper Colorado River Endangered Fish Recovery Program annual reports, Project FR-115), and lower reaches of the Yampa and White rivers (Bestgen et al. 2007a; 2010a; Figure 8). The species also occurs occasionally in smaller tributaries, including the Duchesne, San Rafael, and Price rivers (Bestgen et al. 2007a; Bottcher et al. 2013). Collectively, occupied reaches of the Green River subbasin provide over 900 RK of habitat.

Abundance estimates for Colorado pikeminnow ≥450 mm total length (TL) in the mainstem upper Colorado River varied between about 450 individuals in the early 1990s to nearly 900 by 2005, but populations declined by 2010 and are nearly back to levels found in 1992 (Osmundson and Burnham 1998; Osmundson and White 2014). Abundance estimates for the Green River subbasin, ranged from over 4,000 adults (those ≥ 450 mm TL) in 2000 to just over 2,000 in 2003, but rebounded in 2006-2008 to levels similar to those in 2000. Recent capture rates were very low and estimates from data collected from 2011 through 2013 may be substantially lower than the 2003 estimate (Bestgen et al. 2007a; Bestgen et al. 2010a; 2013). This is especially true for the Yampa River, where the population has declined from over 300 resident adults to six and eight individuals captured in each year during 2012 and 2013.

There are substantial Colorado pikeminnow population age- and size-structure differences among three reaches of the Green River (middle Green River, Desolation-Gray Canyon, and lower Green River) and Yampa and White rivers. Downstream Green River reaches (lower Green River and Desolation-Gray Canyon reaches) typically support 20-50% of adults (5 to 8 years old) in the Green River subbasin, while middle Green River, White River, and Yampa River reaches support the remainder of adults (Osmundson 2006; Bestgen et al. 2007). Almost all juvenile and younger Colorado pikeminnow are found in the downstream Green River reaches, but the middle Green River reach was, and sometimes still is, an important nursery area. Absence of early life stages of Colorado pikeminnow in the Yampa River illustrates its dependence on recruitment of large juveniles and adults from downstream reaches.

Habitat use by adult Colorado pikeminnow is variable and depends on flow conditions. At summer base flow, Colorado pikeminnow use moderate velocity run or pool type habitat (0.1-0.7 m/sec) that is moderately deep (0.7-1.5 m). During high flow periods, typically in spring, large juvenile and adult Colorado pikeminnow are found in the main channel but prefer low velocity habitat in eddies, pools, inundated tributary mouths, and floodplain wetlands. Such areas offer warm water and abundant prey that enhance condition of adults in spring prior to spawning in early summer (Muth et al. 2000; Bestgen et al. 2006). During winter, adult Colorado pikeminnow occupy runs, embayments, and pools in relatively restricted home ranges in ice-covered rivers (Wick and Hawkins 1989). Occupied areas in winter were typically 0.6-1.0 m deep but sometimes shallower waters in channel margin backwaters.

Colorado pikeminnow adults migrate in late spring or early summer to spawning areas in upper Colorado River basin streams when snowmelt flows are declining and water temperatures are increasing (Tyus 1991b; Bestgen et al. 1998; McAda 2003). In the Colorado River, Colorado pikeminnow exhibit only short-range movements for reproduction, and spawn at widely scattered localities, mostly in reaches upstream of Westwater Canyon. In contrast, Green River subbasin Colorado pikeminnow move long distances, sometimes > 725 RK round-trip, to two main spawning areas, one in Gray Canyon of the Green River, and one in lower Yampa River, Yampa Canyon, in Dinosaur National Monument (Figure 9). The Yampa Canyon spawning population has been monitored for many years and production from that area is variable and low in low flow years but at a high level in most years (Bestgen et al. 1998, Figure 10).

The life cycle of Colorado pikeminnow consists of five distinct life phases, with each having a host of biotic and abiotic controlling factors (Figure 4). Colorado pikeminnow spawn in late spring and early summer when flows are descending and water temperatures warming to 16°C or greater (Bestgen and Williams 1994; Bestgen et al. 1998), usually in mid- to late June. The spawning season typically begins in late June, and extends about 3-8 weeks, often into August in the Yampa River. Eggs are deposited in clean gravel and cobble riffles in the lower Yampa River following re-assortment of substrate by elevated spring flows. Eggs are deposited into spaces between substrate particles, where they adhere to clean rock surfaces. Eggs that do not attach are lost downstream and die or are consumed by other fishes. The loose cobble riffles created by high spring flows creates optimal rearing environments for eggs because interstitial spaces allow for flow of oxygenated water. Embryos hatch in 4-7 days at water temperatures of 18-30°C, and developing larvae remain in the substrate for 4-8 days post-hatching. Thus, warm water spawning Colorado pikeminnow have a relatively long period (8-15 days) for egg incubation and post-hatching larval development. Larvae that are 5.5-7 mm TL emerge from spawning riffles and drift downstream 40-100 RK to nursery river reaches, such as the Uintah Basin of the middle Green River that are typically low-gradient and sand-bedded and have abundant low-velocity channel margin backwaters (Tyus and Haines 1991; Bestgen and Williams 1994; Day et al. 1996; Bestgen et al. 1998). The higher-gradient reaches of the lower Yampa River and the Green River directly downstream (Whirlpool Canyon, Island-Rainbow Park, Split Mountain Canyon) provide only limited backwater and channel margin habitat so young Colorado pikeminnow are relatively uncommon in these reaches.

In the Green River, the two main nursery habitat reaches where young Colorado pikeminnow are common are each 40-100 RK downstream of spawning areas, one in the middle Green River, and one in the lower Green River (Figure 11, Tyus 1991b; Tyus and Haines 1991; Trammell and Chart 1999; Day et al. 1999). The lower Green River reach is the most productive nursery habitat for young Colorado pikeminnow. This is because there is a clear link between abundance of juvenile pikeminnow from that reach that eventually recruit to adult size (Bestgen et al. 2007a; 2010a). The middle Green River Colorado pikeminnow nursery habitat reach, which is supplied with larvae from the upstream Yampa River site, has been less productive during recent years. That reach once supported large numbers of age-0 pikeminnow, but its production has declined since 1994 and may be contributing to reduced recruitment to adult life stages in the Green River subbasin. There is no apparent reason for observed reduction in larval Colorado pikeminnow numbers in this reach (Bestgen and Hill, draft report). Levels of reproduction in the Yampa River appear to be sufficient to sustain larger numbers of larvae and juveniles than documented. The recruitment process takes at least 5 and perhaps as many as 8 years, for a Colorado pikeminnow larva to grow to reproductive size, males maturing before females. Larvae occupy low-velocity nearshore backwaters through autumn and into the next year and eventually transition to main channel runs and pools as they grow. Juvenile Colorado pikeminnow 250-450 mm TL move upstream apparently in response to increased productivity of forage fishes, and eventually establish home ranges in mainstem Green River or tributaries such as the Yampa River (Osmundson et al. 1998; Bestgen et al. 2007).

Bonytail distribution and life history

Bonytail is a large minnow that grows to nearly 500 mm TL (20") and is long-lived, exceeding 30 years in age. It was once widespread and abundant throughout the Colorado River basin, including the Yampa River (Quartarone 1995; Bestgen et al. 2008). The conceptual life history model depicts only four distinct life stages and is relatively sparse in terms of well-understood controlling factors because so little is known about the ecology of the species. This is because studies on bonytail — the rarest native fish in the Colorado River basin — began only after the species had already declined dramatically in distribution and abundance. Only a few bonytail specimens have been collected in the past 30 years, and wild populations may be extirpated (Vanicek and Kramer 1969; Vanicek et al., 1970; Minckley 1973; Holden and Stalnaker, 1975*a*; 1975*b*; Kaeding et al., 1986; Holden 1991; U.S. Fish and Wildlife Service, 2002; Bestgen et al. 2008). Last verified captures of wild bonytail occurred in mainstem habitat of the Colorado River, Colorado, and the Green and lower Yampa rivers, Colorado and Utah, including reaches in Dinosaur National Monument. A few suspected bonytails were captured in the Colorado River, Cataract Canyon, Utah, in the late 1980s (U.S. Fish and Wildlife Service, 2002a). Reasons for demise of the formerly widespread and abundant bonytail are poorly understood (Vanicek and Kramer 1969; Holden and Stalnaker 1975*a*). In general, native fishes have declined due to disruption of natural flow and temperature regimes by main-stem dams and negative effects of non-native fishes and these conditions likely affected bonytails (Dill 1944; Vanicek and Kramer 1969; Holden and Stalnaker 1975*a*; Carlson and Muth 1989; U.S. Fish and Wildlife Service 2002a; Olden et al. 2006; Bestgen et al. 2008).

The paucity of wild bonytails requires stocking of hatchery-produced individuals to advance its recovery. Recent stockings in the upper Colorado River basin were of relatively large individuals (ca. >150 mm total length) in river reaches where last-known wild individuals were captured. For example, during 1996-2004, 44,472 bonytails implanted with passive-integrated-transponder (PIT) tags were released throughout the upper Colorado River basin, and many other, mostly smaller, coded-wire-tagged individuals also have been released. Large numbers of bonytail have also been released in the Green River, including in Echo Park, Dinosaur National Monument. Although survival of stocked individuals is low, some fish apparently have moved upstream into the lower Yampa River and downstream reaches of the Green River (Jones 2013).

Bonytails have been captured in floodplain wetlands and off-channel habitat during high flows, and grow quickly in productive floodplain wetlands that are warm and food rich (Christopherson et al. 2004; Modde and Haines 2005). Such areas are relatively warm and have high food resources relative to the colder mainstem river environment, and may represent important conditioning habitat for adults.

Humpback chub distribution and life history

Humpback chub attain lengths of nearly 500 mm TL (20 inches) and is relatively long-lived, with some individuals known to live more than 20 years. Humpback chub have a restricted distribution, and are found almost exclusively in canyon-bound reaches of warm water rivers. Their extreme morphology, with deeply embedded scales, large fins, and humped dorsal surface are thought adaptations to the fluctuating, high velocity, and turbid environment of large canyon-bound rivers. Only six populations are known, one from the lower Colorado River basin in the Colorado and Little Colorado rivers in Grand Canyon and the remainder in the upper Colorado River basin. Upper basin populations are found in Black Rocks, Westwater, and Cataract Canyon reaches of the Colorado River. A small population may yet reside in the lower Yampa River and Green River in Whirlpool Canyon reach and another occurs in Desolation-Gray Canyon in the lower Green River (Figure 12). The Yampa River population of humpback chub was formerly larger and consisted of stereotypical morphology fish (Tyus 1998), but specimens are rare in recent sampling (Haines and Modde 2002, U.S. Fish and Wildlife Service 2002d; Finney 2006; Valdez et al. 2011). Humpback chubs, as well as roundtail chubs, have also declined in abundance in the Green River downstream of the Yampa River in Whirlpool Canyon (Bestgen et al. 2006; 2007d). As recently as 2003, nearly 2,000 adult roundtail chubs were estimated in this reach, but only a handful have been captured more recently. The declines were coincident with several low water years and increased abundance of smallmouth bass *Micropterus dolomieu*, a predator of all chub species and life stages (Bestgen et al. 2008). The conceptual life history model for humpback chub is divided into five main stages, which emphasize early life history. Limiting factors information for humpback chub is not well-known, particularly for early life history stages. Lack of information about that life stage, which is mostly based on the inability to distinguish among species of larval and small juvenile chubs, limits assessment of factors that influence year-class strength and subsequent recruitment and abundance dynamics of adults.

Humpback chub spawn shortly after spring runoff crests at water temperatures of 16-22°C (Muth et al. 2000). Aggregations of adults spawn over cobble and gravel substrates. The eggs incubate among interstitial spaces and hatch in about 5 days. The larvae remain for several days in spawning gravel before presumably drifting short distances to shallow, protected shoreline habitats (Muth et al. 2000).

Timing and magnitude of runoff can influence habitat conditions and water temperature for reproduction and incubation of eggs, although there is evidence that humpback chub can spawn in a wide range of flows and temperatures (Muth et al. 2000). Substrate characteristics, sediment deposition, and oxygen in spawning cobbles and gravels are critical factors for survival of embryos and larvae. Elevated sediment loads and low oxygen can suffocate embryos. Discharge fluctuations can strand or desiccate incubating eggs or kill larvae, and stochastic events (e.g., floods and pollutants) can kill adults. Heavy rainfall over burned landscapes with recently applied fire retardant has resulted in floods with large kills of fishes in Desolation Canyon (Valdez et al. 2011), including humpback chub.

Chub larvae commonly occur along warm, sheltered shoreline habitats. They may be found in backwaters, although these habitats are less common in canyon reaches. Early life stages of chubs, like other native Green River fishes, are susceptible to predation, competition, and starvation (Papoulis and Minckley 1990; 1992; Bestgen 1996; Bestgen et al. 2006). Age-0 and juvenile humpback chub continue to use shallow, warm, productive, nearshore habitats that they entered as larvae. They may use backwaters, if available. Backwaters are used by young humpback chub in Grand Canyon where these habitats provide warm refuge from cold Glen Canyon Dam hypolimnetic releases (Muth et al. 2000; Valdez et al. 2011). A major controlling factor of humpback chub populations is predation on young by a variety of nonnative fish species. Important abiotic controlling factors include discharge and habitat availability, discharge fluctuations and habitat stability, water temperature, and natural stochastic events (Muth et al. 2000). Larger juvenile and adult humpback chub dramatically shift habitat use in their second or third years of life, moving from shallow, sheltered shorelines to large main-channel recirculating eddies (Muth et al. 2000).

Razorback sucker distribution and life history

Razorback sucker is a large-bodied species reaching nearly a meter in length and up to 6 kg in weight and was once very abundant throughout warm water streams of the Colorado River basin. Razorback suckers are also long-lived; individuals have been aged by counting annual marks deposited in otoliths (fish ear bones) at 44 years old or more (McCarthy and Minckley 1987). Currently, only small populations exist in the lower Colorado River basin in Lake Mohave and Lake Mead, with the latter being the only known self-replacing (juveniles recruit to adult size in sufficient numbers to compensate for adult mortality) population in the entire basin (Albrecht et al. 2010). Reproduction of razorback sucker was recently documented in lower Grand Canyon, upstream of Lake Mead (personal communication. S. P. Platania, American Southwest Ichthyological Researchers, L.L.C, Albuquerque, NM). Scattered individuals occur elsewhere in the lower Colorado River basin in tributary rivers and canals as a result of stocking (Minckley 1983). When listed in 1991, upper Colorado River basin populations were much reduced from historical levels (Bestgen 1990; U.S. Fish and Wildlife Service 2002b; Bestgen et al. 2002; Zelasko et al. 2010). Earliest studies of razorback sucker ecology focused on populations in the lower Yampa River (McAda and Wydoski 1980). The Green River population, including individuals in Yampa River, thought in 1990 to be the largest remaining wild population in the upper Colorado River basin, was believed extirpated by 2000 (Bestgen 1990; Modde et al. 1996; Bestgen et al. 2002, Bestgen et al. 2012). Because numbers were so depleted before extensive research began, and because few or no juvenile-sized fishes were observed, the life history and flow and habitat requirements of this species were largely unknown and thus rendered difficult formulation of conservation strategies.

A razorback sucker stocking program was initiated in 1996 in the upper Colorado River basin beginning with release of a few hundred individuals per year (Bestgen et al. 2002; Zelasko 2008; Zelasko et al. 2010). Stocking of up to 30,000 fish per year per river restored the species in much of the upper Colorado River basin, including the mainstem San Juan, Colorado, and Green rivers. For example, razorback suckers now occupy the lower 575 RK of the Green River, extending as far upstream as Lodore Canyon (Figure 13). Tributary populations are also expanding in some locations including the lower White River (Green River subbasin; Webber et al. 2013) and scattered individuals are captured in the lower San Rafael and Yampa rivers (Bottcher et al. 2013; Bestgen et al. 2013; Jones 2013). Survival rates of stocked fish are typically low (5-10%) in their first year after stocking even though fish are relatively large (> 250 mm total length) but annual survival rate increases after that to about 80% (Bestgen et al. 2009; Zelasko et al. 2010).

In the Colorado River subbasin, movement patterns for adult razorback suckers during the reproductive season are not well known (Osmundson and Seal 2009). Razorback suckers in the Green River subbasin move to spawning areas in spring when flows are ascending or have peaked and water temperature is 10°C or greater (Muth et al. 2000; Bestgen et al. 2011a; 2012). Green River subbasin razorback suckers move long distances in spring, sometimes >100 RK round-trip, to two main spawning areas (Razorback Bar and Escalante Ranch, Figure 13; Tyus 1987; Karp and Tyus 1990; Hedrick et al. 2009; Bestgen et al. 2011a; 2012), both in the middle Green River. Spawning areas may also exist in the lower Green River and in Desolation-Gray Canyon (Chart et al. 1999; Bestgen et al. 2012; T. Jones, pers. comm., U.S. Fish and Wildlife Service, Vernal, Utah). Spawning areas also occur in the lower White River and the lower Yampa River, Yampa Canyon, in Dinosaur National Monument (McAda and Wydoski 1980; Bestgen et al. 2012; Webber et al. 2013; Bestgen et al. 2013). The lower White River locality was discovered in 2011 and reproductive razorback sucker adults have gathered annually at that location since its discovery. Adult razorback suckers have recently been captured in spring in the lower Yampa River as well and are the likely source of larvae captured in drift nets at the mouth of the Yampa River (Jones 2013).

The spawning season for razorback suckers typically begins in late April (lower Green River) or mid to late May (middle Green River), and extends about 3-6 weeks, sometimes into early July if water temperatures remain cold (Muth et al. 2000; Bestgen et al. 2002; Bestgen 2011a; Bestgen 2012). Spawning begins earlier in the lower Green River and typically before spring runoff because water temperatures warm earlier downstream. Spawning in the middle Green River, and presumably the lower Yampa River, is later, typically coincident with peak spring runoff (Bestgen et al. 2011a). Eggs are deposited in clean gravel and cobble riffles following re-assortment by elevated spring flows. Eggs are deposited into spaces among substrate particles, where they adhere to clean surfaces. Eggs that do not attach are lost downstream and die or are consumed by other fishes. The loose cobble riffles created by high spring flows provide optimal rearing environments for eggs because interstitial spaces allow for flow of oxygenated water. Eggs deposited in gravel and cobble riffles develop in 6-10 days at water temperatures of 10-20°C, and hatched larvae develop in the substrate another 9-15 days post-hatching. Thus, early life stages of razorback sucker may remain in the spawning gravel for 15-25 days. Larvae then emerge from spawning habitat at 9-11 mm TL and drift downstream 10 to >100 RK during high spring flows until they settle in low velocity channel margin nursery habitat (Figure 7; Hedrick et al. 2009; 2010; Bestgen et al. 2011a).

The larvae-to-juvenile life stage in floodplain wetlands and main channel backwaters is the most critical life stage for the razorback sucker. This is due, in part, to the numerous biotic and abiotic factors that influence this life stage (Figure 7). Biotic factors include predation by fish and birds, growth rate, condition, food abundance, intra- and inter-specific competition, water quality extremes (especially low dissolved oxygen and high temperatures), toxicants, size-related energy stores, and size-related swimming ability. Abiotic factors include magnitude and duration of peak and antecedent discharge effects on main channel and floodplain habitat connections, transport rate of larvae to suitable nursery habitat, discharge fluctuations, flood plain habitat availability, water temperature, stochastic events (e.g., drought, floods and pollutants), and spring hydrology the next year with associated dispersal pathways from and to the main channel. In particular, predation on early life stages of razorback sucker, combined with slow growth in sub-optimal habitat, is thought a primary effect of non-native fishes that limits recruitment (Minckley 1983; Bestgen 2008; Bestgen et al. 2011a).

As a result of the many controlling factors at an early life stage, restoration efforts for razorback sucker in the Green River subbasin have emphasized remediation of physical habitat alterations and reduction of negative effects of introduced fishes. In the Green River subbasin, flow reduction due to storage of spring runoff in Flaming Gorge Reservoir, effects of channelization and levee placement, and reduced frequency and duration of floodplain inundation are the primary controlling factors. Programs have been established to re-connect important floodplain habitat with the river mainstem during spring peak flows. Floodplain enhancement programs were designed to entrain razorback sucker larvae into warm, food-rich wetlands that are important as rearing and resting habitat for early and adult life stages, and thus enhance recruitment (Modde et al. 1996; Muth et al. 2000; Bestgen et al. 2002; Bestgen et al. 2011a). Recruitment in cold, food-poor, and high-velocity main channel habitat in spring is thought low in most years. Thus, a main factor limiting razorback sucker recruitment and recovery is related to floodplain wetland or other high quality nursery habitat availability, which is a function of spring flow levels in both the regulated Green River and the unregulated Yampa River. Since closure of Flaming Gorge Dam, the main driver for spring flow levels needed for connection of the main channel of the Green River and the floodplain wetlands, and recruitment of razorback suckers, is flow from the Yampa River (Muth et al. 2000).

Nursery habitat locations in high flows are typically flooded side channels or washes, backwaters, or floodplain wetlands, the latter of which are especially valuable but are connected with the river only during higher flows. High spring flows that inundate either terrace or depression floodplain wetlands are optimal springtime habitat for rearing of razorback sucker larvae because they are low-velocity, warm, and food-rich compared to high velocity and cold main channel habitat (Modde 1996; Modde et al. 2005; Bestgen et al. 2011a). For example, Bestgen (2008) found growth of razorback sucker larvae just post-hatch was positively related to water temperature, and larvae reared at 25.5°C grew about twice as fast in length and four times as fast in weight as those reared at 16.5°C. Faster growth of larvae, and larger body size, aids swimming ability because body length and swimming speed for most fishes are usually positively related (e.g., Bestgen et al. 2010b). Accelerated growth also confers an advantage because larvae remain susceptible to predation for a briefer time from abundant small-bodied predators. For example, time required for razorback sucker larvae to exceed 25-mm TL, a potentially important threshold for reduced predation, was 30 days at 25.5°C and with abundant food but increased to 41 days (post-hatch) at 16.5°C (Bestgen 2008). Larger and faster growing larvae are also less prone to starvation because they have higher energy stores to withstand periods of low or no food availability (Papoulias and Minckley 1990; 1992). Thus, floodplain wetland habitat is a critical habitat feature to increase survival of larvae, enhance growth to the juvenile life stage, and eventually transition to adult life stage.

In the Green River subbasin, razorback sucker larvae are typically produced each year in the lower and middle Green River reaches. Adults are also present in most main channel reaches and are currently relatively abundant, at least partially a result of stocking (Bestgen et al. 2012). Abundance of larvae in both the middle and lower Green River reaches has recently increased (Figure14), as has presence of razorback sucker larvae in the lower Yampa River. However, throughout the Colorado River basin, including the Green River subbbasin, survival of larvae to the juvenile life stage, ones that eventually replace adults that die, are nearly unknown (Bestgen 1990; Gutermuth et al. 1994; Zelasko et al. 2010; Bestgen et al. 2011a; Bestgen et al. 2012). Without survival and recruitment of juveniles, populations are not self-replacing and prospects for long-term population persistence are negligible; because they are long-lived, presence of individuals gives an illusion of persistence. The few locations in the upper Colorado River basin where juvenile-sized fishes have been documented are floodplain wetlands, mostly in the middle Green River (Figure 15), selected riverine locations in the lower Green River, some as long ago as 1992 and some as recently as summer 2013 (Gutermuth et al. 1994, Modde 1996; Modde et al. 1996; Bestgen et al. 2011a; Bestgen et al. 2012; Skorupski et al. 2013) and recently, the lower Colorado River near Moab, Utah (T. Francis, U.S. Fish and Wildlife Service, Grand Junction Colorado Project 127 annual report, Upper Colorado River Endangered Fish Recovery Program). Thus, increased survival and abundance of juvenile razorback suckers, and protection of the habitat they are produced in, is a main objective of Recovery Program actions to recover razorback sucker.

Provision of suitable habitat for razorback sucker early life stages has required several connected management actions from many Recovery Program focal areas including nonnative fish control, flow management from Flaming Gorge Dam including providing peak flows that are high enough and at the correct time to support the dominant Yampa River spring peak flows, floodplain acquisition and management, and fish culture and stocking programs to restore wild populations. Floodplain wetland management is particularly important as floodplain wetlands provide high growth environments for larvae that enhance survival to juvenile life stage, and ultimately maintains adult numbers.

Other native fishes are also present in warm water reaches of the upper Colorado River basin that are more abundant than the endangered fishes. However, less is known about the life history of species such as flannelmouth and bluehead suckers and roundtail chub so conceptual life history models are not available for these taxa (but see Bezzerides and Bestgen 2002). Flannelmouth sucker spawns just after razorback sucker and bluehead sucker a short time later. Because flows are typically at their peak or decreasing when flannelmouth and bluehead suckers emerge from spawning areas, their use of floodplain wetlands in the middle Green River is less. Instead, they rely more on in-channel nearshore habitat for early life stage rearing. Roundtail chub is probably most similar to humpback chub in terms of life history traits, in that both species use similar habitat and spawn at about the same time of year (Kaeding et al. 1990; Bestgen et al. 2008). Roundtail chub spawn relatively late in the year and rely on late descending limb flows for spawning as well as base flows to provide backwater or channel margin nursery habitat. Speckled dace is a common and small-bodied main channel cyprinid species. Speckled dace reproduce in gravel riffles in late spring and early summer and are frequently captured in the Yampa River. Relatively little is known about its life cycle in the Yampa River.

Importance of the Yampa River

Yampa River flow and sediment

The Yampa River, the largest tributary of the Green River of the upper Colorado River basin, is one of the last mostly free-flowing rivers in the Colorado River basin. Yampa River basin flows derive from snowmelt runoff from April-June in high elevation areas of north-central Colorado and south-central Wyoming. Some flow is impounded by small reservoirs in the upstream portions of the Yampa River and tributaries including Stagecoach and Catamount reservoirs (upper Yampa River), Steamboat Lake (Willow Creek of the Elk River drainage), and Elkhead Reservoir (Elkhead Creek). Lack of large mainstem dams downstream and the largely unaltered hydrograph makes the Yampa River one of the most important tributaries in the Upper Colorado River Basin for recovery of four endangered fishes and provides important habitat for other native fishes as well. The Yampa River is also considered essential to maintaining suitable habitat conditions for endangered and other native fish populations in the Green River downstream from their confluence (Holden 1979; 1980; 1991), due to its relatively unaltered patterns of flow and sediment transport (Andrews 1986; Tyus and Karp 1989; 1991; Modde and Smith 1995). Holden (1980) concluded that flows from the Yampa River, especially spring peak flows, were crucial to the maintenance of the Green River's "large-river" characteristics and, therefore, very important to maintaining suitable conditions in the Green River downstream of the confluence. He speculated that loss of natural flows from tributaries of the Green River, especially the Yampa River, could push the endangered fish species closer to extinction and recommended against regulating Yampa River flows with mainstem dams (Holden 1980). Because of those important attributes, Tyus and Saunders (2001) ranked the Yampa River first out of 13 major tributaries in the upper Colorado River basin in terms of its potential contribution to recovery of native fishes.

Flows in the Yampa River upstream of the Little Snake River average about 1,124,000 acre-feet (AF) per year but vary both between and within years (U. S. Geological Survey [USGS] gauge # 09251000, 1917-2013, calendar years). From 1917 through 2013, the highest mean daily flow recorded at the Maybell gauge (25,100 cfs) was on 17 May 1984, whereas the lowest annual peak flow (3,620 cfs) was recorded on June 5, 1977. Annual mean daily peak flow of 6,000 to 12,000 cfs occurred at Maybell in 63 out of 98 years (64%). Peak flows greater than 12,000 cfs occurred in 27 of 98 years (28%), while peaks less than 6,000 cfs occurred in 6 of 98 years (8%). Seasonal extremes range from average spring peaks of nearly 10,500 cfs to mean minimum daily late-summer base flows of about 130 cfs, roughly two orders of magnitude less than average peak flows. Mean annual minimum base flows (1-d duration) at the Maybell gauge from 1999-2013 (since Muth et al. 2000) were only 95 cfs (1.8-312 cfs), reflecting drought conditions in the last 15 years. Between years, extremes are greater by as much as four orders of magnitude, from 25,100 cfs in 1984 to low flows less than 2 cfs in 1934 and 2002, both extremely dry years.

The Little Snake River, the largest tributary to the Yampa River and the last significant one downstream of Maybell, Colorado, joins the Yampa relatively far downstream at RK 80 in Lily Park, Colorado. Other Yampa River tributaries upstream have been considered in the discussion of flow and sediment contributions (as measured at the Maybell gauge) so will not be discussed further. The Little Snake River watershed covers roughly as large an area as that of the Yampa River upstream from their confluence. However, with an average annual discharge of 412,000 AF (USGS gauge # 09260000, 1922-2013, calculated from USGS records), it yields only about 27 percent of the average annual volume of water (1,510,000 AF) that the Yampa River historically delivered to the Green River at Echo Park. A main contribution of the Little Snake River is sediment, accounting for about 77 percent of the average annual sediment load to the Yampa River (O'Brien 1987). High spring flows are important for transporting this sediment through Yampa Canyon to the Green River and downstream. O'Brien (1987) concluded that the sediment budget of the Yampa Canyon is roughly in long-term equilibrium. However, he also stated:

> *The effect of reducing the discharge in the Little Snake* [River] *will be to reduce the sediment load in the canyon. Concomitantly, reducing the water supply in the Yampa River upstream of the confluence with the Little Snake River will have the effect of limiting the river's ability to transport the sediment load in the canyon.*

Thus, reduced Yampa River flows may have a serious effect on sediment flushing in Yampa Canyon and maintenance of important spawning and other habitat for native and endangered fishes.

The Yampa River contributes about the same average annual water volume, about 1,500,000 AF, as the discharge of the Green River above its confluence with the Yampa. Flaming Gorge Dam, located on the Green River about 105 RK upstream from the Yampa River confluence, impounds a 3,800,000 AF reservoir, which reduces peak flows and elevates base flows in the Green River downstream from the dam. As the largest tributary to the Green River, the Yampa River is important for providing both volume and shape to the Green River flow regime (as measured at Jensen, Utah). Undiminished by large dams and reservoirs or substantial out-of-basin diversions, the Yampa River is the only stream of its size in the upper Colorado River basin where spring peak flows have changed relatively little since water development began near the turn of the 20th century (Figure 16). Spring runoff typically begins as early as mid-March and wanes by late-July, with average flow maxima near Deerlodge Park, Colorado, occurring between April 25 and June 19 (Figure 17). However, more than 60 percent of peak flows historically occurred within a 3-week period (May 10–31), during which more than one-fourth of the average annual discharge passed the Maybell gauge (Muth et al. 2000).

A series of annual hydrographs (Appendix I) for the Yampa River was plotted by summing the gauge data (1922-2013) available from the Yampa River near Maybell, Colorado, and the Little Snake River, near Lily, Colorado. Those hydrographs show the annual variation in peak and base flows at Deerlodge Park at the head of Yampa Canyon and the overall magnitude of runoff in the basin. Low elevation snowpack typically melts in late March and April in the Yampa River basin and higher and more abundant snow melts later, typically in late May or early June, resulting in a double peak hydrograph. A scan of the hydrographs for the 91-year period of record (the period when both the

Yampa River and Little Snake River were reliably gauged so annual flows could be combined for a total discharge estimate) indicates it is rare to not have an early but relatively lower peak in April or early May that exceeds 5000 cfs, followed by a later and larger peak. Furthermore, substantial increases in base flow during that time also occur for a month or more prior to the main spring peak.

Since its completion in October 1962, Flaming Gorge Dam has significantly reduced peak flows in the Green River, while increasing base flows. Because the reservoir acts as a sediment trap for the Green River, sediment load at Jensen, Utah, has been reduced 54 percent since Flaming Gorge Dam was completed. Prior to 1962, the Green River contributed 3.6 million tons of sediment per year (Andrews 1986). However, Andrews (1986) also noted that, since 1962, an equilibrium existed between sediment supply and transport in the Green River, from the Yampa River downstream to Jensen, due to the significant sediment contributions of the Yampa River. Thus, Yampa River flows are important for simultaneously scouring sediment from Yampa Canyon and transporting it downstream to the Green River. Sediment transport to the middle Green River produces sand bars, secondary channels, and backwaters. These are important habitats for early life stages of native Green River fishes (Haines and Tyus 1990; Tyus and Haines 1991).

Flow regimes of most rivers, including the Yampa River, are responsible for the physical template of the stream channel and floodplain upon which resident biota rely (Sabo et al. 2012). Elements of flow regimes postulated important to physical and biological processes in the Yampa and Green rivers include frequency, magnitude, and duration of spring peak flows. For example, peak flows transport and scour cobbles in riffles, which serve as food production areas, rearrange cobble bars for spawning as well as resting habitat, and provide overbank flows in alluvial reaches where floodplain wetlands are present. Peak flows also transport sand and create circulating eddies and secondary channels that form low velocity backwaters when flows recede. Base flows occur from July through March of the following year and are also important to provide habitat for important life history processes such as spawning, via continued fine sediment scour and transport, and rearing of young.

As a continuous ecosystem, the Yampa and Green rivers provide important habitat for migratory native fishes that sometimes reside only temporarily in the Yampa River to complete critical life stages. For example, Colorado pikeminnow move long distances in spring from the Green River and its tributaries into the lower Yampa River to spawn in flood-formed gravel and cobble bars and then move back to their respective home ranges for the remainder of the year (Tyus 1990; Irving and Modde 2000). Early life stages of fishes, including Colorado pikeminnow and razorback sucker, drift from Yampa River spawning habitat during descending spring runoff flows, or during base flows, into downstream reaches of the Green River where they rear. Those same fish eventually grow to adults and may return to the same lower Yampa River spawning area as their parents. The importance of the largely unregulated flow pattern of the tributary Yampa River, to physical and biological processes in the downstream Green River, argues for treatment of the Green and Yampa rivers as a single ecosystem.

One aspect of the Yampa River flow regime that has changed substantially is base flows, especially in late summer and early autumn. Using the Indicators of Hydrologic Alteration (IHA) software (Richter et al. 1996; Poff et al. 2009), the lowest mean daily flow of the Yampa River (e.g., 1-day duration minimum flow) downstream of the Little Snake River (Little Snake River and Maybell gauge data summed) for each year was identified. That low flow always occurred in summer and usually in August or September. A regression relationship of the 1-day duration minimum flow as a function of year was estimated, and indicated a 37% decline over the period of record (Figure 18). That percentage decline value was achieved by solving the regression relationship for years 1922 and 2013, the earliest and latest years in the flow data series, such that the 1-day duration minimum flow was estimated to be 180 cfs in 1922, but only 113 cfs in 2013 (the % value was [180-113]/180 = 0.37*100, = 37%). The three-day (-32%) and seven-day (-27%) duration minimum flows also showed substantial declines (based on IHA estimates, no relationships shown; three-day and seven-day duration minimum flows were the lowest mean daily flows over a period of three or seven consecutive days, respectively, in the calendar year). The low base flow index also showed a substantial 27% decline over the period of record (Figure 18). This index indicated that the proportion represented by the lowest seven-day base flow in a year divided by the mean annual daily flow that same year was diminishing over time (e.g., the low flow period discharge is declining). Those declines in base flow were in spite of consecutive years of well above average summer flow in a relatively recent period (1982-1986), and when annual peak flow magnitudes were unchanged over the period of record. The base flow decline also occurred in spite of late summer or early autumn releases in recent years from Elkhead Reservoir, typically about 50 cfs per day for about 50 days (5,000 acre-feet total), which are designed to supplement low flows in the Yampa River. This decline also occurred in spite of slightly increased base flow from the Little Snake River over the period of record 1922-2013 (IHA analyses; Little Snake River 1-day duration minimum flow = 0.1631*year – 308.9). The 30-day minimum flow of the Yampa River estimated with IHA software indicated a slight decline over the period of record to about 190 cfs in recent times.

Yampa River fishes

Not only does the Yampa River provide important habitat for spawning by migratory native fishes that rear in downstream Green River reaches, but it also provides important habitat for resident native fishes. As with other upper Colorado River basin streams, the fish community of the Yampa River varies longitudinally. Historically, it supported 12 native fishes in an array of cold to warm water habitats that transition from high to low elevations, respectively. Upstream coldwater species in relatively small streams include cutthroat trout *Oncorhynchus clarkii* and mottled sculpin *Cottus bairdii*, and intermediate elevation and cool water reaches of moderate-sized streams supported those same fishes plus speckled dace, mountain sucker *Catostomus platyrhynchus*, and mountain whitefish *Prosopium williamsoni* (Table 1). Mid- to downstream reaches, typically larger rivers and streams with seasonally and naturally turbid water, are warm in summer, and support several cool water species plus large-bodied (as adults) humpback chub, roundtail chub, bonytail, and Colorado pikeminnow, as well as three sucker species, flannelmouth sucker, bluehead sucker, and razorback sucker (Bestgen et al. 2007c).

Distribution and abundance of Yampa River native fishes has changed over time for most species, declining everywhere but especially in upstream reaches. Coldwater species are largely precluded from the main lower Yampa River by warm water. However, mountain whitefish and mountain sucker are occasionally found in the Hayden to Lily Park reach, especially in years with colder or higher flows. The upstream and mid-reach fish community has been negatively affected by nonnative white sucker, which hybridizes with native suckers or otherwise displaces them. This was evident nearly 40 years ago, when Prewitt (1977) found mostly white sucker and flannelmouth sucker hybrids near Craig, Colorado, a trend that continues downstream. Currently, native flannelmouth and bluehead suckers are abundant only in the lower portion of the Yampa River near Deerlodge Park and downstream (drift net studies, Recovery Program Project 22f; Bestgen et al. 2007d; Jones 2012; 2013).

Similarly, upstream populations of roundtail chub are much reduced since the early 1990s, when large numbers of young and adult chubs could be captured near Hayden, Colorado. Roundtail chub are likely extirpated from the upstream reach, present but rare in the middle reach, and common or abundant only in Yampa Canyon. Speckled dace likely exhibit a similar pattern but less is known about upstream abundance of that species. Abundance of roundtail chub and speckled dace has increased in Little Yampa Canyon of the Yampa River since smallmouth bass control efforts were increased in 2005 but only during high flow years; populations in the low-flow years such as 2013 and 2014 were much reduced (Bestgen et al. 2007c; annual project reports, Upper Colorado River Recovery Program Project 140).

Colorado pikeminnow was relatively widespread and locally common in the Yampa River downstream of Craig, Colorado, through 2001 (Bestgen et al. 2007a). Currently, the resident adult Colorado pikeminnow population is much reduced, with only six and eight individuals collected in 2012 and 2013, respectively. This is in comparison with 2000 and 2001, when about 100 were captured each year and > 300 fish were estimated present (Bestgen et al. 2007). Bonytail was historically uncommon even in the 1970s, but apparently were more common before that (Holden and Stalnaker 1975a; Quartarone 1995). Bonytail currently inhabit the lower Yampa River near the confluence of Green River as stocked individuals; no reproduction has been noted for any bonytail population in the wild. However, stocked fish in riverside ponds in the lower Colorado River reproduce (Mueller and Marsh 2002).

Humpback chub were once thought relatively widespread in Yampa Canyon and locally abundant (Tyus 1998), but since 2000 none have been captured (Haines and Modde 2002; Finney 2006; Jones 2013). The few chubs captured in Yampa Canyon and in downstream Whirlpool Canyon had distinctive features of the species (small delicate head, slight nuchal hump, 10 anal fin rays), but some also contain morphological characteristics of roundtail chub (larger head, reduced nuchal hump, 9 anal fin rays, relatively small pectoral fins: Bestgen et al. 2007d; Bestgen et al. 2008). Razorback sucker was historically rare in most of the Yampa River, except near the Green River confluence (Holden and Stalnaker 1975a; 1975b; McAda and Wydoski 1980). There, a wild population was studied extensively and reproduction was thought occurring (McAda and Wydoski 1980). Stocked razorback suckers have since reinvaded the lower Yampa River and spawning over several years has been verified by capture of larvae in drift nets set mainly for Colorado pikeminnow larvae, most recently in 2012 and 2013 (Bestgen et al. Annual Project reports, Upper Colorado River Basin Recovery Program Project 22f).

The largely natural flow regime of the Yampa River has not precluded establishment of many nonnative fishes, such that in many reaches upstream of the Little Snake River, they are numerically dominant. This was true even in the early 1980s, when native fishes were 22-33% of the fish community in Little Yampa Canyon near, Craig, Colorado (Wick et al. 1985). Native fishes there continued to decline to < 1% of the fish community in some years following establishment of smallmouth bass around 1992, which are now the dominant species in many reaches of the Yampa River downstream of Craig, Colorado to the Little Snake River (Bestgen et al. 2007d; Breton et al. 2013). Native fishes are still relatively abundant in the lower reaches of the Yampa River downstream of the Little Snake River, and the natural flow pattern there is thought to benefit their wide distribution and abundance.

Yampa River fish and flow relationships studies

Flow recommendation studies

A number of studies have attempted to define the role of flows in the life history and ecology of fishes in the upper Colorado River basin, including those in the Yampa River. A number of those are qualitative, while others focus on specific aspects of a particular time of year and flow pattern on the distribution and abundance of fishes. In response to the recognized importance of Yampa River flows to native resident fishes, and those downstream in the Green River, efforts have been made to protect flows in this system. Holden and Stalnaker (1975a; 1975b) were among the first to suggest that protection of the Yampa River flows was of paramount importance to supporting endangered fishes in the entire Colorado River Basin and Green River subbasin (Miller et al. 1982). Recognition of the important role that Yampa River played in conservation of native fishes led to several efforts to formally preserve flows in the system. In 1990, the U.S. Fish and Wildlife Service developed interim flow recommendations for the Yampa River that were based on a review of existing biological data describing endangered fishes in the Green and Yampa rivers (Tyus and Karp 1989). Those interim recommendations called for preservation of a natural seasonal pattern of flows in the Yampa River, including spring peak flows that reflected the natural hydrologic regime and base flows equal to the 50% flow-exceedance level, as measured at the USGS gauge near Deerlodge Park. The recommended interim flows followed a “stair-stepped” pattern that reflected the use of mean monthly flows for a given period.

Harvey et al. (1993) identified the importance of flows to spawning areas for Colorado pikeminnow in the lower Yampa River below Little Snake River confluence in Yampa Canyon. High spring peak flows in the Yampa River (> 10,000 cfs) sort, clean, and redistribute gravel and cobble in locations suitable for spawning. Subsequent descending limb flows (500-4,000 cfs) in late spring and summer cut through loose cobble and create fresh spawning substrate with abundant interstitial spaces for eggs of Colorado pikeminnow and other native fishes that spawn in the main channel. Loose substrata in spawning areas allow movement of well-oxygenated water that is critical for successful egg incubation and subsequent hatching.

Modde and Smith (1995) and Modde et al. (1999) reexamined the interim recommendations in light of additional studies on endangered fishes in the Green and Yampa rivers. They identified a need to maintain natural variability by allowing flows to be driven by natural daily variability instead of average monthly flows. Additional recommendations for August–October base flows measured at the Maybell gauge, and needed by subadult and adult Colorado pikeminnow in the Yampa River above the Little Snake River, were made by Modde et al. (1999), recognizing that base flows were often low and may be limiting growth and survival in some reaches. Using a curve break analysis, they determined that 93 cfs was a minimum flow needed to maintain sufficient water depth in riffles to provide foraging habitat for Colorado pikeminnow. The recommended flow was later increased 33% to 124 cfs during winter months, to provide a buffer should the lower flow prove insufficient. That is a substantially lower flow level than the 30-day minimum flow level (190 cfs) estimated by the IHA, assuming minimal input from the Little Snake River. This higher flow is relatively consistent with the earlier finding by Wick and Hawkins (1989) that the diversity of low velocity habitats in this reach during the winter was best maintained by flows between 200-300 cfs. Stewart et al. (2005) also suggested that increasing Yampa River summer base flow to 300 cfs may increase biomass of native suckers.

Additional flow and water temperature recommendations were developed for the Green River downstream of Flaming Gorge Dam (Stanford 1994; Muth et al. 2000; U. S. Bureau of Reclamation 2005), which relied on the Yampa River's relatively intact flow regime. Similar to previous interim recommendations for the Green River (Tyus and Karp 1991), the new recommendations built specifically on flows of the mostly unmodified Yampa River. Spring peak and summer base flows were proposed that were contingent upon snowpack and anticipated runoff levels in the upper Green and Yampa River basins. Muth et al. (2000) assumed that flow targets downstream from the Yampa River confluence could be met despite expected water development to meet future demand in the Yampa Basin.

The Yampa River Basin Programmatic Biological Opinion (PBO) recognized the importance of Yampa River flows on native fishes. It also acknowledged that water depletions would cause adverse effects to endangered fishes and their designated critical habitats. Nonetheless, it concluded that implementation of the Recovery Action Plan for the Yampa Basin was sufficient to avoid the likelihood that adverse effects of existing depletions (not exceeding 167,854 AF on average per year) and new depletions (not exceeding 53,532 AF on average per year) would not jeopardize the continued existence of endangered fishes or adversely modify critical habitat. The PBO noted the pattern of the existing and future depletions was relevant to effects on biota and divided the covered depletions between those that would impact flows and habitat in the Little Snake River, Yampa River upstream of the Little Snake River, and Yampa River downstream of the Little Snake River. The PBO then assessed the impact of the covered depletions on both base and high flows in each of these reaches to conclude that the impacts of the covered depletions would not likely jeopardize the endangered fish or adversely modify critical habitat. After conducting this flow assessment, the PBO found that if water is used during the peak flow period in a "substantially different timing regime, re-initiation of consultation is required". The PBO also found:

Because reservoir storage to meet consumptive demand in the Yampa River Basin is limited, depletions are expected to have a proportionately greater impact on base flows, particularly July through October, than on peak flows. Percentage reductions in base flows are greater than those of peak flows, although absolute peak flow reductions from baseline flow conditions may be greater than absolute base flow reductions. For this reason, base flow augmentation is one of the key measures of the proposed action to minimize the impacts of depletions.

The PBO then developed an initial augmentation protocol that set target base flows at the Maybell gauge of up to 138 cfs from July to October and up to 169 cfs from November to February. The protocol was to release up to 50 cfs per day from 7,000 AF of storage at an enlarged Elkhead Reservoir, except in extremely dry years when the storage releases could be limited to 33 cfs. This initial protocol was based on the recommendations by Modde et al. (1999) to maintain a base flow of 93 cfs with the same frequency that such flows had occurred historically. The USFWS later refined this protocol to target maintenance of 93-134 cfs and preferably 120 cfs or greater at the Maybell gauge. The flow target was increased after noting that 93 cfs may not be enough to avoid a 50% risk of the flows in this reach being insufficient for Colorado pikeminnow movement and passage through riffles. In refining this protocol the U.S. Fish and Wildlife Service also considered the finding of Stewart et al. (2005) and Anderson and Stewart (2007) that base flow needed to maintain riffle habitat in this reach for bluehead and flannelmouth suckers was much higher than 134 cfs.

This protocol and the flow assessment for the PBO assumed that the historic flows at the Maybell gauge would not be depleted by more than 30,104 AF in the future and that the enlargement of Elkhead Reservoir would be the only storage added upstream of the Maybell gauge. The PBO also found that the existing depletions of 167,854 AF and new depletions of 53,532 AF on both the Yampa River upstream of the Little Snake and on the Little Snake River did not threaten the sediment equilibrium in the Yampa River in Yampa Canyon below the Little Snake River or the sediment transport needed to form nursery habitats in the downstream Green River.

Because it was difficult to estimate the number of individuals of the four fishes listed as endangered that could be affected (taken) by the water depletions addressed in PBO, a surrogate measure was developed that corresponded to the amount, distribution, and pattern of existing and future depletions whose flow impacts were assessed and determined not likely to jeopardize the endangered fishes or adversely modify critical habitat. This would exempt all take in the form of harm that would occur from an average annual 167,854 AF of existing water depletions and an average annual 53,532 AF of future water depletions. Water depletions above the amount addressed in the PBO would exceed the anticipated level of incidental take and those levels are not exempt from the prohibitions of section 9 of the ESA.

Most flow recommendations proposed for the Yampa and Green rivers attempt to link flows with fish habitat use patterns (e.g., use of floodplain wetlands inundated by high spring flow releases), the need for flows to accomplish specific geomorphic processes (e.g., high spring flows to create cobble spawning areas, sediment transport to create sand bars for backwater habitat at low flows), and use of professional judgment based on knowledge of fish life history in different basins with different flow patterns. A main limitation of such flow recommendations is that there is only a weak or non-existent link between actual flow levels proposed and the response by biota. This problem is especially difficult in the Colorado River Basin where many fishes are relatively long-lived and as a result, it takes several years for a population-level response by native fishes to affect adult life stages.

As an alternative, Stewart et al. (2005), Anderson and Stewart (2007) and Stewart and Anderson (2007) linked habitat use and availability patterns in the Yampa River upstream of the Little Snake River with flow levels through 2-dimensional habitat modeling. They then linked habitat and flow patterns with fish biomass levels, mostly for large juvenile and adult native flannelmouth and bluehead suckers, to determine flow needs for native fishes. In the Yampa River, they determined that native fish populations were flow limited mostly in summer. They recommended base flow levels of 650 cfs in the Yampa River, based on optimal flow-habitat-biomass relationships. However, they also recognized that those base flow levels were not always available and that base flows prior to 1999 were frequently between 250-300 cfs with a minimum of 200 cfs. They referenced the availability of base flows prior to 1999 because fish population sampling indicated that the post-1999 base flow regime was not adequate to maintain the native fish assemblage. Based on those observations regarding the historical magnitude of base flows in this reach, they recommended a minimum base flow of 200-300 cfs. This recommendation is based in part on the findings of Anderson and Stewart (2003) and Stewart et al. (2005) that flows < 200-300 cfs provided only minimal habitat for native suckers in the Yampa River. Stewart and Anderson (2007) and Anderson and Stewart (2007) made no specific recommendations for spring flow peaks for this reach, although they concurred that maintaining high spring flows appears to be important for native fish management in the Yampa River and for mitigating flow alteration in the Green River.

Below, additional data and studies that link Yampa River peak and base flow levels with metrics of fish abundance are considered. Most fish data available involve early life stages. Analysis of fish early life stages is useful because their abundance can be directly linked to flow conditions in the year they were produced. Because production of young is required to yield adults, and because abundance of young life stages is often positively linked with abundance of adults (Bestgen et al. 2007a; 2010a), these relationships are deemed particularly useful to inform flow management.

As described in the Introduction, and where possible, the influences of the ascending, peak, and descending limbs of the hydrograph, as well as base flows, on reproduction and distribution and abundance of fishes, will be elucidated. This was done to acknowledge that *if* future flow depletions occur in the Yampa River, it may be useful to identify time-specific portions of the flow regime that would most or least affect native or nonnative fishes, recognizing that any substantial flow depletions would likely reduce the integrity of the Yampa River ecosystem. Most of the data presented derives from research conducted through the Upper Colorado River Endangered Fish Recovery Program, and most was during or since the last flow recommendations studies were completed.

Colorado pikeminnow larvae abundance is positively linked with Yampa River flows

Larvae of Colorado pikeminnow were collected with drift nets in the lower Yampa River downstream of the Little Snake River from 1990-2013 (except for 1997, Bestgen et al. 1998, in part). That sampling was conducted to document year-class strength of larvae produced in the Yampa

River each year and could be used to assess status of Colorado pikeminnow populations as well as relate its abundance to environmental conditions, including Yampa River flow attributes. Yampa River flows might affect abundance of Colorado pikeminnow larvae produced at spawning areas in at least two ways. First, high flows create high quality spawning substrate for Colorado pikeminnow and other native fishes. This occurs when substrate of spawning areas is redistributed to allow flushing of fine sediment in spaces amongst cobble and gravel that might otherwise reduce survival of incubating eggs. Also, spawning gravel and cobble are scoured of algae and debris when mobilized. This results in clean spawning substrata that provide suitable attachment surfaces for eggs. All warm water native fishes in the upper Colorado River basin produce adhesive eggs that adhere to clean substrata; eggs flushed downstream die or are consumed by other fishes (e.g., Bestgen and Williams 1994). Second, during the descending limb of spring runoff and in the base flows period, it is essential that oxygenated water moves through interstitial spaces of cobble bars where eggs are incubating and just-hatched larvae are developing. After hatching, larvae develop in spawning riffle substrate for 4-7 days. If descending flows decline too rapidly portions of spawning areas might be dewatered thereby exposing eggs and larvae. After larvae emerge from spawning areas, they are transported downstream varying distances, depending on flow levels and distance from suitable nursery habitat. In the Yampa River, Colorado pikeminnow larvae that emerge from spawning gravel are transported downstream to backwaters in the middle Green River, a distance of 40-200 RK. Descending limb or base flows that are very low either inhibit emergence or are not sufficient to carry larvae downstream to suitable nursery habitat, and result in low year class abundances (Bestgen et al. 1998; Bestgen and Hill 2014).

The relationship of peak flow of the Yampa River downstream of the Little Snake River to an index of Colorado pikeminnow larvae abundance was positive (Figure 19). The index of larvae abundance adjusts the number captured in drift nets by flow level to allow equitable comparisons across years with variable flow levels, recognizing that when no larvae are captured no adjustment is possible. In several years including 1994, 2002, and 2007, low peak flow magnitudes (< 10,000 cfs) resulted in relatively low or near zero production and transport of Colorado pikeminnow larvae downstream; in only 3 of 9 years (33%) was the transport abundance index > 10,000 when spring peak flow was less than 10,000 cfs. Peak flows at higher levels typically resulted in higher abundance of Colorado pikeminnow larvae that were hatched and transported downstream. For example, in 12 of 13 years (92%) the transport abundance index was > 10,000 when spring peak flow exceeded 10,000 cfs.

Relationship of descending limb and base flows of the Yampa River downstream of the Little Snake River during summer, to an index of Colorado pikeminnow larvae abundance, were also positive (Figure 19). Mean July-August base flow levels < 500 cfs often resulted in low downstream transport of Colorado pikeminnow larvae; in only 3 of 10 years (30%) was the index > 10,000. In contrast, mean base flows > 500 cfs in the July-August period generally resulted in higher transport abundance of Colorado pikeminnow larvae. For example, in 12 of 12 years (100%) the transport abundance index was > 10,000 when mean July-August base flow exceeded 10,000 cfs.

In most years when summer transport abundance of larvae was low, autumn abundance of age-0 Colorado pikeminnow in downstream middle Green River, Utah, backwaters was also low. Because high peak flows and base flows are positively correlated in the lower Yampa River, the exact mechanism of higher flow levels to promote stronger year classes is not certain. However, for species that use main channel gravel substrate for spawning, both high peak flows (spawning substrate preparation) and base flows (adequate incubation and transport conditions and riffle habitat for forage in upstream reaches) can be reasonably invoked as having important positive effects.

Higher Yampa River flows positively linked with age-0 native fish abundance and negatively with nonnative fish abundance

There is also evidence that higher peak and base flows in the Yampa River downstream of the Little Snake River resulted in higher abundances of other native fishes (Figures 20 and 21). Age-0 native and nonnative fish in backwaters of Yampa Canyon were seine sampled in late summer from 1980-1984 (Muth and Nesler 1993). Those five years had both high (1984) as well as relatively low flows (1981), plus intermediate flow years. Those abundance data were plotted as a function of peak and base flows in those years for four native and four nonnative fishes that were relatively common in samples. Importantly, all native fishes spawn in main channel riffles in late spring or early summer on descending limb flows, and similar to Colorado pikeminnow, are potentially influenced by levels of spring peak flows via scour of spawning substrate. Nonnative fishes spawn later in summer when water is warmer and at base flow levels, and mostly in low velocity backwaters. Those areas are affected by peak flows that create side channel backwaters, but are not directly affected by main channel substrate cleansing action.

Abundance of bluehead and flannelmouth sucker and speckled dace increased in years with higher spring peak flows. Because native suckers spawn or emerge in peak flows or on the descending limb of the hydrograph in relatively shallow spawning riffles, abrupt reductions in descending limb flows may desiccate portions spawning riffles in some years. Roundtail chub, which spawns later than native suckers in June and July, showed a slight decline in abundance with high flows but it was very abundant at all flow levels, and more so than any other native fish in the Yampa River in Yampa Canyon. Abundance of all nonnative fishes declined in years of high peak flows, but especially red shiner *Cyprinella lutrensis*. This is important because red shiner is a known predator on native fish larvae in the Green River system (Ruppert et al. 1993; Bestgen et al. 2006) and other small-bodied nonnative fishes such as fathead minnow *Pimephales promelas* also prey on fish larvae (Markle and Dunsmoor 2007).

Abundance of bluehead and flannelmouth sucker and speckled dace was also higher in years with higher Yampa River base flows (Figure 21). Roundtail chub showed a slight decline in abundance with higher base flows but again, it was more abundant than any other native fish in the Yampa River in Yampa Canyon so flows are thought to have a negligible effect over the abundance levels observed.

Abundance of all nonnative fishes declined in years of higher base flows. Reduced abundance of all small-bodied nonnative fishes including red shiner was likely due to reduced spawning season length in higher flow years. This was likely because higher flows remain cooler later in summer and inhibit early season reproduction by the small-bodied, warm water-spawning nonnative fishes. Effects of increased flows in late summer due to summer monsoon rainstorms are not well understood.

Razorback sucker reproduction increased in lower Yampa River

Razorback sucker have also been documented to spawn in the lower Yampa River in recent years, including 2013, based on captures of larvae in drift nets set in mid-June and presence of ripe adults (Jones 2013). This reproductive activity is doubtless a result of widespread stocking of razorback suckers throughout the Green River Basin and subsequent upstream dispersal. For example, of the four razorback sucker adults captured in the lower Yampa River in 2013, all were stocked 40 RK or more downstream; two of the four fish captured were apparently in breeding condition. The site of recent captures of larvae and adult razorback suckers overlaps closely with a historical site where adult fish gathered and were thought reproducing (McAda and Wydoski 1980). While specific flows and water temperatures to maintain or increase reproductive success of razorback suckers in the lower Yampa River are not known, apparently conditions there are suitable in at least some years. Reproduction by razorback sucker there may be underestimated, as drift net sampling in the lower Yampa River is mainly to collect Colorado pikeminnow larvae and occurs after most sucker reproduction has been completed.

Nonnative large-bodied fish predators and flow effects

Another aspect of Yampa River flows that needs to be considered is effects on nonnative fishes that are large-bodied and predaceous. The main predaceous species of interest in the Yampa River are channel catfish *Ictalurus punctatus*, northern pike *Esox lucius*, and smallmouth bass (Johnson et al. 2008). Each preys on juvenile or adult life stages of all native fishes in the Yampa River.

Channel catfish is mainly restricted to the lower portion of the river, with a few larger adults present upstream of Yampa Canyon. The lower Yampa River is also a known spawning area for channel catfish, as larvae are captured in most years in drift nets set to monitor Colorado pikeminnow larvae abundance. Abundance varies by year, with higher reproductive success in low flow years compared to higher flow years with colder water later in the year. For example, in the low flow and relatively warm year 2012, 1,482 channel catfish larvae were captured in lower Yampa River drift nets in summer. Based on capture of larvae, the reproductive period was from 15 July to 11 August. In contrast, only three channel catfish larvae were captured in the high flow and relatively cold year 2011. All were captured late in the year on 18 August (unpublished data, Upper Colorado River Basin Endangered Fish Recovery Program annual report Project 22f).

Northern pike is relatively uncommon in downstream reaches of Yampa River, such as Yampa Canyon, but increases in abundance in an upstream direction (Johnson et al. 2008; Jones 2013; Webber 2013; Zelasko et al. draft report). In the Yampa River, they are most commonly associated with alluvial river reaches with adjoining floodplain wetlands, where northern pike spawn relatively early in the year, typically on the ascending limb of the hydrograph. Northern pike is less abundant in floodplain-restricted reaches such as in Yampa Canyon in the lower Yampa River and Lodore and Whirlpool canyons of the Green River (Bestgen et al. 2007; Jones 2012; 2013). Northern pike also reproduce in upstream reservoirs (Catamount and Stagecoach) in the Yampa River drainage, as well as in Elkhead Reservoir on Elkhead Creek. When high Yampa River flows inundate floodplain wetlands and lake margins (e.g., 2008 and 2011), large year-classes of northern pike are often noted although large year-classes are also produced in lower flow years (Zelasko et al. draft report, Recovery Program Project 161b). Movement of these fish to the river, as well as recruitment of young fish from within the floodplain, creates a substantial predatory threat to native fishes. The same situation has been observed in the upper Green River in Browns Park, Colorado, where larger than typical numbers of northern pike were produced in the high and extended flow year of 2011 compared to lower flow years (Bestgen et al. 2007d; unpublished data, Upper Colorado River Basin Endangered Fish Recovery Program annual report, Project Report 115).

Northern pike is a substantial problem because even modest-sized adults can capture and consume, or injure, almost any native fish in the upper Colorado River basin, including adult Colorado pikeminnow. Predation on adult Colorado pikeminnow by northern pike has been documented (J. Hawkins, pers. comm., Colorado State University), as well as on other native fishes (Tyus and Beard 1990; Bestgen et al. 2007d). Northern pike bite marks on all native fishes, including large Colorado pikeminnow and roundtail chub, were observed with high frequency before extensive northern pike removal by the Recovery Program began in upstream reaches (Hawkins et al. 2009; Zelasko et al. draft report). Some bites were infected and likely resulted in mortality of injured fish. Because of its documented impact on native fishes, northern pike are subject to extensive mechanical removal efforts in upstream reaches, which likely reduces numbers in downstream reaches, such as Yampa Canyon. In 2012-2013, relatively few northern pike (5 and 16, respectively) were captured in Yampa Canyon sampling (Jones 2012; 2013). Reduced abundance of northern pike has also been observed in lower Lodore Canyon on the Green River since extensive Yampa River removal efforts began (Bestgen et al. 2007d; unpublished data, Upper Colorado River Basin Endangered Fish Recovery Program annual report, Project Report 115). Reductions in northern pike removal efforts in upstream Green or Yampa River reaches will likely result in increased abundance of northern pike in lower reaches of the Yampa River where Colorado pikeminnow spawn in riffles in late spring and early summer (Bestgen et al. 1998).

Smallmouth bass colonized the upper reaches of the Yampa River in about 1992, after Elkhead Reservoir was drained and its substantial smallmouth bass population was flushed downstream into the Yampa River (Breton et al. 2013). Smallmouth bass abundance increased dramatically after 1999, when a series of low flow and warm years ensued that enhanced reproductive success (Anderson and Stewart 2005; Anderson and Stewart 2007; Stewart and Anderson 2007; Bestgen et al. 2007c; Hawkins et al. 2009). Anderson and Stewart (2005) found a strong correlation ($r=0.985$) between degree days and the number of days that flows were less than 200 cfs and that the strong trend in increasing numbers of age-1 smallmouth bass in 2003 and 2004 closely followed the degree day trend. Since 1999, smallmouth bass have spread mostly downstream of the Elkhead Creek-Yampa River confluence, and are now common or abundant, especially in river reaches with rocky shoreline substrate. Such habitat is most common in canyon-bound reaches including Little Yampa Canyon, Lily Park, portions of Lodore Canyon, and downstream Whirlpool and Split Mountain canyons of the Green River (Hawkins et al. 2009; Breton et al. 2014).

Smallmouth bass are especially problematic because they occur in a wide variety of habitats, and are abundant and piscivorous. For example, small-bodied smallmouth bass prey on fish larvae in backwaters whereas adults are documented predators of relatively large chubs, including bonytail

(Bestgen et al. 2008). Occurrence of numerous and large smallmouth bass in Whirlpool Canyon around 2003 preceded a subsequent decline of roundtail chub there (Bestgen et al. 2006; 2007d; annual FR-115 project reports, Bestgen et al. 2003-2013). Young smallmouth bass are now typically the most abundant species in shallow, nearshore habitats in upstream Little Yampa Canyon (Bestgen et al. 2007c; Hawkins et al. 2009). There, they compete with or prey on native fishes and are believed a major reason for the near collapse of the once relatively abundant native fish fauna (Wick and Hawkins 1985; Bestgen et al. 2006; Anderson and Stewart 2007; Stewart and Anderson 2007).

Similar to northern pike, strong year-classes of smallmouth bass in the Yampa River downstream of the Little Snake River are closely linked with the hydrologic cycle, but in an opposite manner. In years when flows are relatively low and water temperatures are about 16°C (e.g., 2006-2007, 2012-2013), smallmouth bass spawn as early as late May (Bestgen et al. 2007c; Hill and Bestgen 2014). In such years, smallmouth bass in the Yampa River near Craig, Colorado, and downstream have a relatively long growing season and reach mean TL of 100 mm, or more, by September (Figure 22). Rapid declines or reductions in descending limb spring flows benefits smallmouth bass by promoting earlier spawning and by providing a longer growing season. Large size confers a decided benefit on overwinter survival, as larger age-0 smallmouth bass have greater energy stores (Shuter et al. 1980). Additionally, based on an age-structured simulation model for smallmouth bass in the Yampa River, those larger smallmouth bass are responsible for subsequent strong year classes (Breton et al., draft report).

Conversely, high flow years with extended periods of cooler base flows (e.g., 2008 and 2011) reduced smallmouth bass reproductive success and year class strength. For example, in 2011, smallmouth bass spawning did not begin until late July because water remained < 16°C. Smallmouth bass that hatched late also grew slowly and averaged 40 mm TL or less in September. The small individuals produced that year had low overwinter survival, based both on observations of bass abundance the next year as well as simulation model output (Breton et al. draft report). Thus, extended peak and descending limb flows that last longer into summer would inhibit reproduction by smallmouth bass and shorten their growing season.

Downstream Green River fish benefit from high Yampa River flows

As others have indicated, the natural flow regime of the Yampa River subsidizes the flow-regulated Green River, and is a key reason it is a stronghold for native fishes (conceptual models; Tyus and Karp 1991; Muth et al. 2000). The role of Yampa River peak and descending limb flows is especially important. Those flows may provide cues for initiating spawning or motivating movements related to reproduction for many species. High flows also provide links between the main channel Green River and floodplain wetlands, which are used by adult bonytail and Colorado pikeminnow, and are especially critical for rearing and recruitment of young razorback sucker.

The need for a sustained high and unaltered Yampa River peak was particularly evident after it was found that optimal timing and release volumes for Flaming Gorge Dam releases needed to be adjusted to benefit razorback sucker recruitment (Muth et al. 2000; Green River Study Plan *ad hoc* Committee 2007; Bestgen et al. 2011a). Flaming Gorge Dam releases had been timed to match the

Yampa River peak to achieve maximum magnitude flooding in the middle Green River. That time, however, was typically before any or most razorback sucker larvae were present to access floodplain wetlands created by high flows. Consequently, recommendations were made and a program implemented to provide Green River flows when larvae were present, and this was usually after Yampa River flows had peaked (Bestgen et al. 2011a; LaGory et al. 2012). Success was achieved in 2012, 2013, and 2014 in terms of abundant larvae accessing at least one floodplain wetland in the middle Green River, Utah. More importantly, in 2013, more than 600 juvenile razorback suckers returned to the river from Stewart Lake wetland (Skorupski 2013) and in 2014, more than 700 were captured (R. Schelley, Utah Division of Wildlife Resources, Vernal, Utah). Those are the largest groups of juveniles ever documented for a wild population of razorback suckers in the upper Colorado River basin. Juvenile razorback suckers were also observed in other floodplain wetlands in those same years in the middle Green River. The importance of preserving Yampa River peak flows and, particularly, the natural flow recession pattern to maintaining wetland connections in the middle Green River is critical to successful razorback sucker spawning and recruitment.

The Yampa River also plays a role, albeit smaller, in extending spring runoff recession and maintaining base flows in middle and lower Green River reaches. Those base flows are important for sustaining backwater habitats for young Colorado pikeminnow (Bestgen et al. 2007a; 2010a). Loss of these nursery habitats diminishes number of individuals recruiting into the adult population. Moderate flows apparently provide conditions for maximum growth, survival, and recruitment of young Colorado pikeminnow in both the lower and middle Green River (Figure 23; Bestgen and Hill, draft report; Trammell and Chart 1999).

Higher flows benefit native fishes and disadvantage nonnative fishes

Yampa River flows are an important driver of abundance of resident native as well as nonnative fish in the Yampa River as well as in the downstream Green River. There also seem to be consistencies in these patterns whereby a goal to provide suitable conditions for native fish recruitment would be complemented by conditions that reduce abundance of problem nonnative fishes. Elevated flows enhance reproductive success of native fishes and eventual recruitment in a two-stage process. First, stream geomorphology is reset during high flows to provide important physical habitat maintenance functions for main-channel-spawning native fishes. Colorado pikeminnow is the best studied example of this, but this process seems important for all main-channel gravel-riffle-spawning native fishes. Gravel and cobble in riffles are re-arranged and cleaned to provide attachment surfaces for eggs. Maintaining water and clean interstitial spaces amongst substrate in relatively shallow spawning areas during post-peak recession flows is important because spawning seasons are relatively long at 3-6 weeks for each species, and spawning for all native taxa is temporally separated. Thus, duration of spawning for all sucker species in the lower Yampa River could be as long as two months, and over the course of a reproductive season, a single riffle may be used continuously by reproducing native fishes over a nearly three-month-long period.
Further, eggs and larvae spend relatively long time periods among gravel of spawning riffles. For example, bluehead suckers spawn when water temperatures are relatively cool at 12-18°C. Embryos may develop for 8-12 days prior to hatching and larvae then spend an additional 8-15 days in the spawning gravel, where development time is inversely related to water temperature. Thus, total

residence time in spawning gravel for early life stages of bluehead sucker may be 2-4 weeks. Colorado pikeminnow likewise have a relatively long period for embryo incubation and post-hatching larvae development in the gravel of 9-15 days. Post-peak flows in the Yampa River typically recede quickly to base flows, which reinforces the need to maintain descending limb flows as long as possible to protect early life stages of fish in spawning areas. Reduction in quality of spawning areas at low flows is likely a reason Colorado pikeminnow produced weak year classes in 1994, 2002, and 2007.

In general, higher peak flows and higher base flows reduce reproduction, growth, and recruitment of most nonnative fish species by attenuating the period of optimal spawning temperatures. This was true for small-bodied species such as red shiner and fathead minnow in primary channel shoreline habitats (Muth and Nesler 1993). Main-channel-spawning channel catfish and smallmouth bass also had reduced reproductive success in years with higher and cooler peak, recession, and base flows. Conversely, low flows meant a longer reproduction period, a longer growing season, and higher overwinter survival for larger age-0 smallmouth bass. Enhanced survival of young smallmouth bass during years of low-flow conditions was evident 2-4 years after those fish were produced (Breton et al. 2014). Successive years of low base flow in the Yampa River in the early 2000s were thought the mechanism for smallmouth bass to become established and flourish (Anderson and Stewart 2005; Anderson and Stewart 2007; Bestgen et al. 2007c; Hawkins et al. 2009).

The nonnative species that may sometimes benefit from a high peak flow scenario in the Yampa River is northern pike. This is mainly because high flows inundate the floodplain which may subsequently be used for reproduction. However, little is known about the timing of successful reproduction related to when floodplain inundation occurs and for how long. A synthesis of capture-recapture data from the Yampa River shed additional light on the population dynamics of northern pike related to flow and ongoing management actions designed to reduce effects of that species on native fishes (Zelasko et al. draft report, Recovery Program Project 161b). That study found no link between high flows and recruitment of northern pike in the Yampa River, as large year-classes were produced in both low and higher flow years. Most, perhaps all, northern pike reproduction occurs in off-channel habitats (floodplain wetlands and reservoirs) prior to peak flows and controlling escapement from these may be more manageable and certain than flow manipulation to reduce in-stream spawning success of a species like smallmouth bass. In addition, general restriction of northern pike to upstream reaches means a smaller area of attention.

Conclusions

Maintain the natural flow pattern of the Yampa River

An optimal Yampa River flow regime would be maintenance of its natural flow pattern in its entirety. This would involve preservation of spring peak and summer-winter base flows that have many functions in the life history of native fishes, including providing spawning cues, physical habitat creation, and substrate cleansing. Maintenance of natural flows and relatively high peak and base flows will also enhance reproduction and survival of native fishes, and reduce reproductive success and abundance of many nonnative fishes.

Maintenance of high peak flows and preservation of a natural flow regime mirrors recommendations of the earliest investigators in the system (Vanicek et al. 1970; Holden and Stalnaker 1975a; 1975b; Holden 1980) and the general prevailing paradigm regarding flow patterns needed for conservation of riverine ecosystems. For example, the Natural Flow Paradigm (Poff et al. 1997; Bunn and Arthington 2002; Yarnell et al. 2010) posits that riverine flows and patterns that closely mimic those in the unregulated state provided the best conservation prescription. That is because those patterns provided the environment that resident biota evolved with and may also serve to limit the distribution and abundance of nonnative species, thus providing a dual role in native aquatic species conservation.

Positive attributes of natural flows and the merits of maintaining a natural snowmelt runoff with high peak and base flows are also consistent with previous attempts to define or protect flow needs for native fishes in the Yampa River (Tyus and Karp 1989; Modde et al 1999; U.S. Fish and Wildlife Service 2005; Anderson and Stewart 2007). For example, Tyus and Karp (1989; 1991) recommended maintenance of the Yampa River peak flows, in support of both the resident fish community, and the one in the downstream Green River.

Maintenance of a natural flow regime in the Yama River is also supported by observations of flows and the fish community of the nearby White River, Colorado and Utah, also a tributary to the Green River. The White River has a mainstem impoundment, but flows downstream are only minimally affected because Kenney Reservoir is a run-of-river facility; flows pass through the reservoir in a mostly unaltered pattern although sediment is retained. Unlike the Yampa River, base flows in the White River are minimally altered from historical patterns, because of few diversions. This may be a reason that the White River native fish community thrives (Bezzerides and Bestgen 2002; Webber et al. 2014); effects of a recent smallmouth bass invasion on native fishes are yet unknown.

More detailed information on the dynamics of native and nonnative fish populations relative to particular aspects of the Yampa River flow regime would be useful. The ecology and connection of various life history stages of native fishes to the linearly arrayed habitats in the Yampa and Green rivers is well-understood for Colorado pikeminnow, but less so for other taxa. For example, understanding downstream transport and the most important areas for rearing and recruitment of native suckers and chubs could help guide future management actions.

Maintain peak flows

Peak flows, the 1-2 week window of highest flows that include the maximum magnitude flow, provide important physical habitat maintenance functions in the Yampa River. These include sediment transport from the stream channel, substrate mobilization and re-arrangement for spawning habitat formation and maintenance, transport of particles from the floodplain into the main channel, and sand transport and deposition for secondary channel and backwater formation. Those processes are important for spawning site preparation, nursery habitat formation, and also rework substrate for invertebrate communities to thrive. High flows may also provide a biological signal for fishes to prepare for or begin reproductive activities. High flows on floodplain surfaces, in tributary mouths, or tributary streams provides relatively warm and low velocity off-channel habitat where fishes can increase body condition when Yampa River flows are high and cold. Floodplain inundation may also entrain nutrients and organic matter to enrich the riverine ecosystem (Welcomme 1985; 1995).

Peak Yampa River flows also enhance amplitude and volume of spring flows in the downstream Green River. Those flows also rejuvenate physical habitat, provide that regulated system with a more natural flow, and connect the river with extensive floodplains. Floodplain connections are important for adult bonytail, Colorado pikeminnow, and razorback sucker as well as early life stages of razorback sucker because wetlands are warm and food rich relative to the cold and comparatively unproductive main channel.

Maintain or enhance base flows, especially in late summer

Base flows are, at present, the most altered aspect of the Yampa River flow regime and have declined by about 37% over the period 1922-2013. Various investigators of minimum flow needs for native and endangered fishes recognized deficiencies in the river's base flow (e.g., Modde et al. 1999; Anderson and Stewart 2007). A main problem with low base flows is reduced habitat of all types. In general, low flows reduce overall habitat depth and area as well as reduced food availability. Riffles are important food production and foraging areas for all native fishes; their reduction during low flows diminishes food availability, and are the habitat type most reduced by low flows because of shallow depth. Riffle depth is also important for fish passage because large-bodied native fishes must traverse riffles to move throughout the Yampa River. This may be important for routine movement among macrohabitats to obtain the best foraging and resting locations. It is also important for post-spawning Colorado pikeminnow that are moving upstream from lower Yampa Canyon spawning areas to home ranges scattered throughout warm water reaches of the upper Yampa River.

Base flows also provide habitat for early life stages of native fishes in nearshore areas, such as backwaters and secondary channels (Haines and Tyus 1990; Muth and Snyder 1995). Flows that are too low may dewater backwaters and make them unsuitable for native fishes.

Like for peak flows, the mostly unregulated nature of the Yampa River provides limited opportunities to increase base flows from their presently low level in late summer, the most problematic time for native fishes. Late summer base flows are lowest because that is when flows are naturally low and agricultural demands and evaporation are highest, all of which are exacerbated in hot, drought years.

Higher base flow levels may also provide a thermal regime that is more favorable overall for the native fish community as a result of reducing nonnative predator fish growth. This is because smallmouth bass grow much more quickly than native fishes, and increased growth in warmer water will enhance the predatory pressure of smallmouth bass on native fishes. The exact relationship of base flows to water temperature levels is not known precisely but could be investigated because simultaneous flow and air and water temperature data are available for several locations in the Yampa River.

If additional water development is pursued in the Yampa River basin, perhaps there would be opportunities to use flow releases to enhance base flows. This of course depends on the use of the water, the type of storage, seasonal demands by users, and many other factors. However, enhancing base flows during this low flow period, over and above measures already described, may be needed for conservation of native fishes. As others have indicated, base flows increased from present reduced levels, back to historical levels, perhaps 200-300 cfs or more at the Maybell gauge in all but the driest years, will benefit native fishes in the lower Yampa River.

Maintain post-peak, descending limb flows

Flows during ascending and descending limbs of the hydrograph have historically been less well-defined in terms of their influence on biological processes, and were grouped together with peak flows. However, the role of descending limb flows is important because that is when most native fishes reproduce in the Yampa River. Declining flows may cue fishes in terms of signaling timing for reproduction. Declining flows also warm in response to increasing atmospheric temperatures and reduced flow volume. If reductions in descending limb flows are too abrupt, such as might happen with large volume flow diversions, reproductive signals to initiate spawning movements or reproduction may be disrupted.

Further, increasing warming rates via increased flow reductions on the descending limb of the hydrograph may disrupt adaptations for reproductive isolation and spawning chronology of native fishes. For example, razorback suckers are the first native fish to spawn in spring, and in the middle Green and lower Yampa River that may occur just prior to, at, or just after peak flow depending on water temperature. Flannelmouth sucker spawning usually begins soon after, usually within 1-2 weeks after razorback suckers. Finally, bluehead sucker reproduction begins 1-2 weeks after that. Spawning seasons for each species overlap to some extent because each extends 3-6 weeks depending on flow and water temperature conditions. However, the peak of spawning activity of each taxa is separated in time, and even though they often use the same spawning areas, temporal separation may offer a mechanism to reduce the reproductive overlap and potential for hybridization among native sucker species. Shortening the duration and volume of descending limb flows, and associated increased warming rates of water, may result in increased spatial and temporal overlap of reproducing suckers at spawning areas and increased rates of hybridization. This is especially important now because of increased abundance of white sucker in the upper Colorado River basin, a species that readily hybridizes with flannelmouth and bluehead suckers. White sucker also has potential to hybridize with razorback sucker based on overlap in time of reproduction; white suckers are relatively cold water spawning fish similar to razorback suckers.

The role of descending limb flows on reproductive success of native fishes is also important. All are main channel spawning fish that rely on relatively clean and shallow gravel riffles for egg deposition. Those flows serve to maintain water over riffle habitat and sweep fine sediments away so reproductive success is enhanced. Descending limb flows also maintain interstitial water flow through gravel for successful development of embryos and larvae over relatively long post-spawning periods.

Increasing the rate of warming during descending limb flows in spring, which could be effected by reducing flows at that time, will also promote earlier spawning by nonnative fishes such as smallmouth bass and extend spawning seasons for small-bodied cyprinids. Reproduction in smallmouth bass is dictated by a temperature threshold, initiating spawning and first hatching of larvae when water temperatures reach 16°C. Even though this threshold always occurs on the descending limb of the hydrograph, and at different flow levels, the main driver is water temperature. Thus, if flow alterations create earlier warming and more favorable conditions for bass spawning and growth, smallmouth bass growth and survival will be enhanced with associated negative effects for native fishes.

Post-peak Yampa River flows also enhance amplitude and volume of spring flows in the downstream Green River. Those flows also rejuvenate physical habitat, provide that regulated system with a more natural flow volume and pattern, and maintain connections of the river with extensive floodplains. Importance of floodplain connections for various endangered fishes and life stages was elaborated just above.

Maintain as much of ascending limb flows as possible

Flow alterations and water diversion during the ascending limb of the hydrograph may be least damaging to the fishes and habitat of the Yampa River than any other time of year. The time prior to runoff for most fishes is relatively quiescent. Fishes have emerged from winter and are perhaps responding to increasing water temperatures following ice-off by feeding at a higher level. This is also a time when gametes are developing, so occupation of relatively food-rich and warm areas for developing reproductive products is needed. Thus, this is an important time of year for fishes. However, some flow reductions may not necessarily affect processes associated with reproductive readiness.

Ascending limb flows of the spring hydrograph may also play a role in signaling timing for reproduction by native fishes. This link is poorly understood however, because flows vary through time even in non-reproductive periods. Thus, it is difficult to imagine a mechanism for disruption of reproductive cues that may be based on reduced ascending limb flows.

Flow reductions during the ascending limb of the Yampa River hydrograph may affect water temperatures of the Yampa River. This may happen because reduced water volume may warm more quickly than higher volumes. Changes in the thermal regime may promote gamete development and reproductive readiness in native fishes that is out of synch with runoff patterns and habitat readiness. For example, in the Dolores River downstream of McPhee Dam in southwestern Colorado, the very low flows (about 30 cfs) present in spring warm quickly and may promote reproductive readiness in native suckers very early in the year. Higher and colder runoff flows then commence and may stall or stifle the reproduction process, which could be a reason why native sucker abundance there is low (Bestgen et al. 2011b). However, it is unlikely that lower Yampa River flows would get so low that water temperature would change dramatically. This is because a large quantity of early flows would likely remain; excessive withdrawals that cause temperature changes should be avoided. Also, early spring flows are mostly low elevation snow melt runoff, so are typically relatively cold. Thus, the potential for impacts to temperature signals for fishes in early spring, from pre-runoff flow alterations in the Yampa River, seem relatively low if typical base flow or higher flow levels are maintained.

A caveat to the assumptions above is that the life history of native Yampa river fishes is poorly understood, especially in the spring, pre-peak period. A better understanding of the role of flow and possible temperature alterations in spring on fish ecology would be useful.

Sediment transport certainly occurs on the ascending, peak, and descending limbs of the hydrograph function in the Yampa and Green River systems. Removal of ascending limb flows would surely disrupt some of that sediment transport function. Ascending limb flows are presumably efficient transporters of sediment because sand and other fine materials are present in the largest amounts in the channel due to accumulation since the last runoff period. What is less clear is if some ascending limb flows were removed, would there still be sufficient flows for sediment transport during that time and at peak periods for clearing and rejuvenation of substrate in spawning areas. The timing is important because some native fishes such as razorback sucker begin reproduction prior to, during, or just post-peak in the lower Yampa and middle Green River reaches. Thus, presence of adequate spawning areas that are clear of sediment is important. Sediment-flow dynamics and effects of timing, magnitude, and duration of runoff flows, on creation of spawning habitat are not well studied.

Flows competent to transport sediment downstream also perform other habitat formation functions. For example, runoff flows also transport sand downstream to form secondary channel and backwater habitat in some locations of the Yampa River and more importantly, in the middle Green River. Those places are important habitat for early life stages of native fishes. Potential changes in timing or quantity of sediment transport in spring with reduced ascending limb flows are poorly understood, especially if peak flow magnitude and duration, and their associated sediment transport capacity, is maintained.

Minimize short-term flow fluctuations

Short-term flow releases that elevate river stage and discharge can be disruptive to fish communities, especially if early life history stages of fish are present. Thus, high volume releases that substantially and frequently increase base flow levels should be avoided. However, native fishes are adapted to flow fluctuations and seem capable of tolerating some levels of disruption. Flow fluctuations may be useful to disadvantage early life stages of smallmouth bass. Embryos and weak-swimming larvae of smallmouth bass occur in low velocity habitat. Increased river flows may entrain those early life stages and displace them, which reduces their survival. Abrupt flow reductions caused by diversions or other water infrastructure should also be avoided.

Minimize winter base flow fluctuations

Winter habitat use by adult Colorado pikeminnow was related to flow patterns and ice cover in the Yampa River upstream of the Little Snake River (Wick and Hawkins 1989). Colorado pikeminnow winter habitat use in this reach was mainly runs, pools, embayments, and backwaters, relatively low velocity and deep habitat. Flows were relatively low during winter base flow and when ice cover forms, effective depth in certain habitat types is low and declines as ice accumulates. Such situations are potentially stressful and may reduce energy reserves and potentially survival of fish. Formation of ice cover provides a relatively stable riverine environment so flow fluctuations or base level increases that may break ice cover should be avoided. Flows of 200-300 cfs provided relatively diverse habitat in this reach for adult Colorado pikeminnow in winter. Those flow levels are similar to those indicated by Anderson and Stewart (2007) for summer base flow level.

Maintain water temperature regimes

The Yampa River downstream of Craig, Colorado supports a warm water fish community. Native fishes tolerate relatively high water temperatures in the Yampa River and mortality associated with natural temperature levels are rarely an issue with these species. Smallmouth bass also tolerate relatively warm water temperatures in the Yampa River. Warm water also stimulates growth of young smallmouth bass, which grow 2-3 times as fast as native fishes. As a result of fast growth rates and large body size, young smallmouth bass are easily able to capture and consume young of native fishes produced the same year for much of the summer. Thus, any increase in summer water temperatures, such as might occur with reduced summer stream flow, will increase water temperatures, smallmouth bass growth rates, and their predation pressure on native fishes. Extremely cold hypolimnetic releases from dams have negative effects on all warm water fishes.

Frequency and timing of recommended flow patterns

Flow patterns recommended for spring runoff, including ascending, peak, and descending flows, and base flows need to continue in perpetuity. It is recognized that discharge will vary year to year, based on snowpack and other hydrologic conditions, and that more physical re-arrangement of the substrate and channel will occur in higher flow years than others. That, however, does not obviate the useful functions performed by lesser flows that remain essential for maintenance of spawning and other habitat.

There is a lingering perception that long-lived Colorado River basin native fishes do not need to produce successful year-classes in most years, and instead can maintain populations based on only occasional recruitment. That has been demonstrated a false premise (Bestgen et al. 2007a) and suggests that some populations of Yampa River fishes require regular recruitment to sustain populations. For example, during a period of adult Colorado pikeminnow population stability or expansion in the Green River basin, moderate to large cohorts of sub-adult fish were produced in seven of 10 years. In contrast, population abundance of adult Colorado pikeminnow in the Green River basin declined nearly 50% from 2000 to 2003, when few fish recruited to adult size classes. Thus, population response to low recruitment even in long-lived species occurs in a short time frame. Similarly, old, long-lived razorback sucker populations that had little apparent recruitment were functionally extirpated from the Green River basin around 2000 (Modde et al. 1996; Bestgen et al. 2002; 2011a).

Natural patterns of stream flow and sediment discharge prevail on the Yampa River because there are no large volume water storage facilities in the basin. Thus, in low flow years, runoff peaks and higher water temperatures will occur earlier than in higher flow years. Accordingly, patterns of native fish reproduction will follow those vagaries in flow regimes, with reproduction beginning earlier in low flow and warm years and later in higher flow and cooler years. This occurs because of the close association of fish reproduction with flows but especially water temperatures. Thus, biological processes will follow natural flow and water temperature patterns. Nevertheless, a more complete disentangling of effects of various flow and water temperature patterns, and perhaps effects of day length, on reproduction of native fishes would assist managers with flow management decisions to benefit those species.

Maintain natural peak flow durations

Peak flows perform useful geomorphic work and create and maintain important fish habitat. What is less certain is the duration of peak flows needed to perform necessary physical habitat formation and maintenance. Like many other aspects of Yampa River flows, the natural flow regime, especially during spring, is driven by snowpack volume and dynamics of snowmelt. Thus, if flow alteration occurred during the ascending limb of the hydrograph, water removal would have to be brief to avoid attenuating or diminishing duration of peak flows.

As previously suggested, relationships between timing of sediment transport and flow dynamics are uncertain in the Yampa River system, and more so if a portion of the ascending limb flows were removed. This is because ascending limb flows are responsible for transporting a large portion of the sediment stored in the river channel since the last runoff period. This is also important because the timing of sediment movement may overlap with spawning periods of some native fishes, which may reduce spawning success.

Accurate predictions of the onset of the three spring runoff segments, ascending, peak, and descending portions, are needed if water development proceeds and withdrawals are specified to affect only a certain portion of the flow regime. For example, if water withdrawals were specified only for the ascending limb of the flow regime, prediction of onset of peak flows would signal when withdrawals would stop so peak flows remain unaffected. Predictions of runoff timing and volumes are difficult because those are predicated not just on snowpack amounts, which can be measured to some extent, but also on climatic patterns and unusual events (unseasonal warming, rain on snow events, dust deposition that enhances snowmelt rates). However, improved runoff forecasting may be needed to maintain valuable Yampa River flow functions and native fishes.

Maintain turbidity patterns

Water turbidity, caused by suspension of fine clay particles in the water column, is a natural part of Yampa River flows. Turbidity levels are highest in spring during increasing runoff and also in summer following rainstorm runoff in small drainages that erode and transport soil to the river. At other times of the year, particularly during base flow, turbidity levels are relatively low. Turbidity likely impedes ability of sight-feeding predators, including invasive northern pike and smallmouth bass. High turbidity and increased flow levels following a summer thunderstorm were also associated with periods of low growth of young Colorado pikeminnow in backwaters of the lower Green River (Bestgen et al. 2006), although the mechanism was unclear (e.g., lack of food, lack of backwater habitat).

Water turbidity patterns in the Yampa River may also affect reproduction and dispersal of early life stages of native fish. For example, during an extreme turbidity event due to a summer monsoon rainstorm, samples of Colorado pikeminnow included relatively young, 4-day-old larvae, an age not typically found in drift nets (Bestgen et al. 1998). Those larvae had not yet developed their swim bladder or substantial musculature so were weak swimmers, compared to the 6-8 day-old larvae usually captured. Early emergence of larvae from spawning gravel may have been a response to a stressful environment in that low-flow year, when sediment particles apparently infiltrated the gravel substrate where larvae were developing. Thunderstorm-caused turbidity events are also related to high downstream transport of Colorado pikeminnow larvae, perhaps because it is stressful and also because larvae may lose visual orientation.

The preponderance of clay soils in the Yampa River basin suggests that flows will always be seasonally turbid. Understanding better the interplay of turbidity on predation and growth and survival of native fishes would be useful to better understand the ecology of native and nonnative fish interactions. Regardless, turbidity likely interferes with predation by sight-feeding nonnative predators. The two-fold effects of this are to directly reduce predation on native fishes, as well as slow their growth, which may have implications for length-dependent survival processes.

Maintain or increase nonnative fish management efforts to reduce long-term effects

Unless nonnative fishes, especially smallmouth bass and northern pike, are suppressed or controlled, other efforts to enhance and improve recovery potential for endangered fishes may be compromised if not negated. Currently, mechanical removal of nonnative fishes is the most effective solution, but such programs are expensive and seemingly, a short-term solution. Removal effects are short-term because occasional flow events create large year-classes of various nonnative fishes that are apparent for several years in the river, and require several years of effort to suppress. Some flow attributes that enhance native fish reproductive success may also improve that for some problematic nonnative fishes. For example, northern pike reproduction may benefit from high flows in some but not all years, so a better understanding of those mechanisms would be useful. In this instance, the only short-term viable management option is focused suppression of problem species with mechanical removal. The obvious longer-term solution seems to be reduction of source populations, wherever they exist.

The specter of introduction and establishment of additional species is real and ongoing as new species invade the system on a regular basis (Modde 1996; Walford and Bestgen 2008; Webber and Jones 2013; Breton et al. 2013; Breton et al. 2014; Martinez et al. 2014). This is sobering given that already established nonnative fishes are widespread and abundant, difficult to control, and have documented negative effects on native fishes. Ongoing management activities should be supported, with the view towards long-term solutions including controlling source populations, and more effective mechanical control techniques where and when populations are most susceptible. Additional species introductions should be avoided.

It is also important to maintain a longitudinal perspective when considering current and future issues with nonnative fishes. This is because the lower Yampa River is located between river segments that differ with respect to problem fish species and because fishes are mobile, with distributions and abundances shifting with environmental regimes and the state (early or late) of ongoing invasions. For example, white sucker and hybrids have been common for many years in the Yampa River upstream of Craig, Colorado and native suckers are nearly absent (Prewitt 1977). Conversely, abundance of native suckers is relatively high in the Yampa River in Lily Park and downstream and abundance of white sucker and hybrids is low. A similar pattern is observed in the Green River in Lodore Canyon (Bestgen et al. 2006). Maintaining the present distribution of suckers would seem important to conservation of the native kinds, and water temperatures may be a key, but those relationships are poorly understood. Understanding the role of flow and water temperature regimes in maintaining such species distributions would be useful, and may be instructive to avoid future issues involving razorback sucker. In the meantime, suppression of white suckers may be useful to forestall further downstream dispersal.

In addition to more efficient suppression and source control, a better understanding of nonnative fish ecology and relationships with flows patterns may assist with disadvantaging invasive predaceous fishes. For example, how to best use releases of Recovery Program water from Elkhead Reservoir to benefit native fishes and disadvantage nonnative fishes is not clear but worthy of investigation. It does seem clear that continued suppression of nonnative fishes by whatever means possible, is needed, until additional strategies emerge.

Maintain or enhance flow and other management efforts in the Green River to aid the Yampa River fish community

The co-dependency of Yampa and Green River processes and fish communities is evident and strong. For example, adult Colorado pikeminnow in the Yampa River are the product of young reared in downstream, Green River nursery habitat. It is also likely that if razorback sucker recruitment is restored in the middle Green River that the Yampa River populations will benefit from subadult and adult fish moving upstream. Yampa River flows transport sediments that form backwater habitat for young Colorado pikeminnow in downstream reaches and also supplement Green River flows to enable river-floodplain connections that allow drifting razorback sucker larvae access to quality nursery habitats. Yampa River flows are an integral part of that process, especially the peak and descending limb flows, and should be maintained.

In spite of challenges from introduced populations of nonnative predaceous fishes, the Yampa River in its mostly free-flowing state is essential habitat for recovery of endangered fishes including Colorado pikeminnow, humpback chub, bonytail, and razorback sucker, as well as other native fishes. Elsewhere in the upper Colorado River basin, both flow restoration as well as nonnative fish management actions are required to enhance distribution, abundance, and recovery of native fishes. Loss of the mostly natural flow regime will compromise the value of the Yampa River and diminish recovery prospects for native and endangered fishes.

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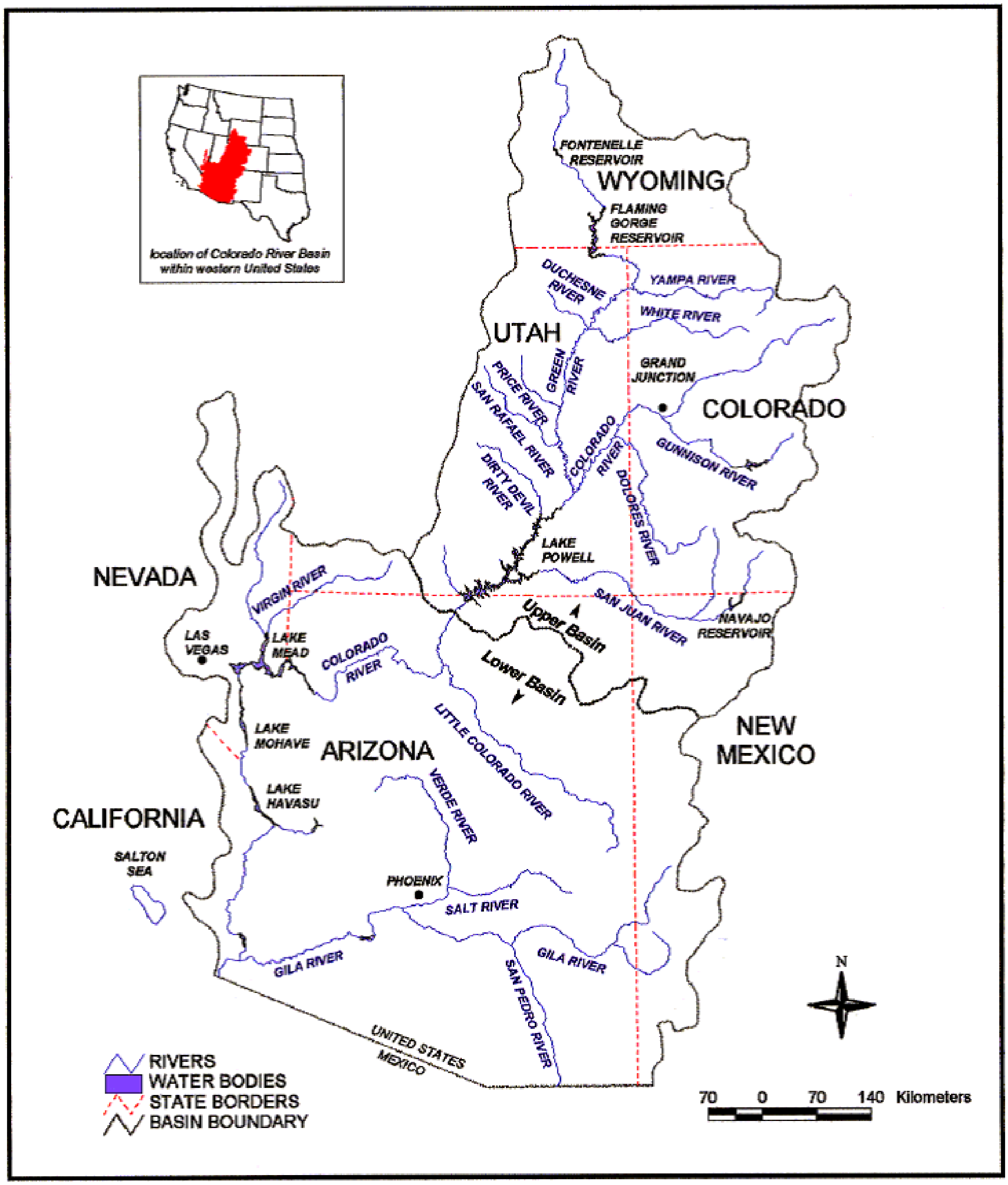


Figure 1. Map of Colorado River basin rivers and major water storage structures (from Muth et al., 2000). The upper and lower portions of the basin are demarcated by the heavy line just downstream of Lake Powell.

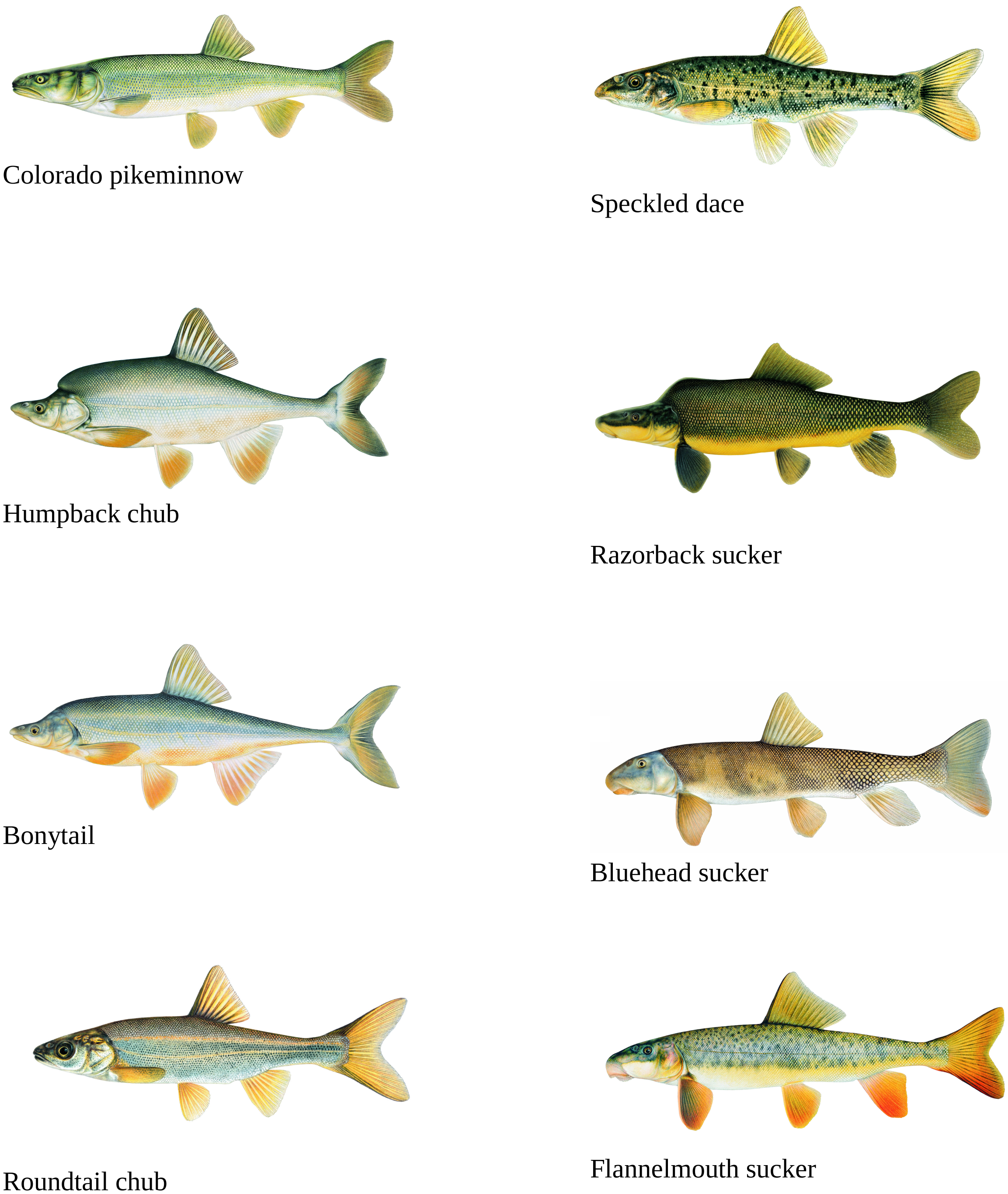


Figure 2. Illustrations of native fishes that occupy warm water reaches of the lower Yampa River, Colorado (illustrations by Joseph R. Tomelleri).

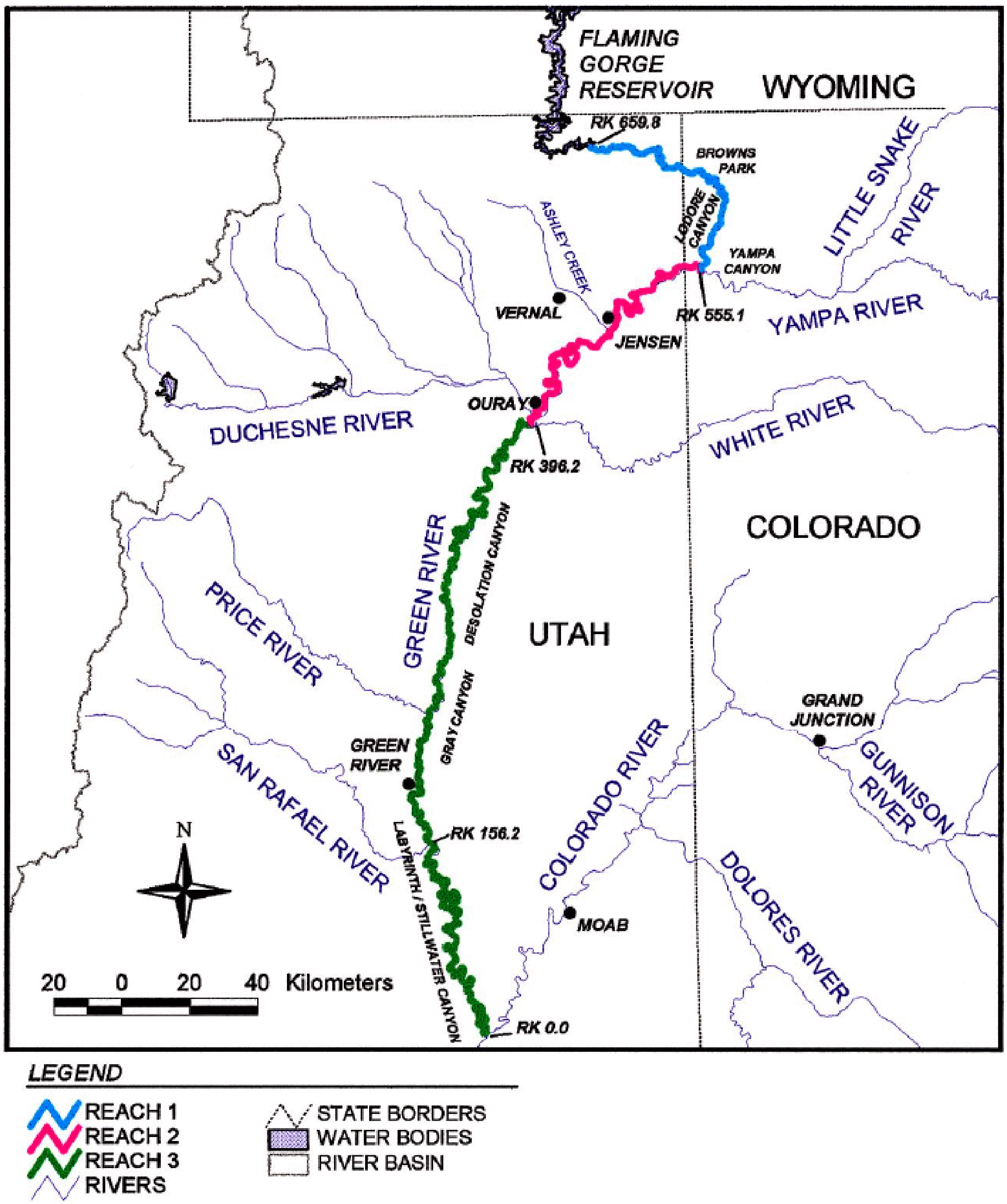


Figure 3. Map of Green River subbasin rivers and major water storage structures (from Muth et al., 2000). The three main reaches of the Green River (1, upper Green River; 2, middle Green River; and 3, lower Green River). River kilometer (RK) designations depict important landmarks or confluence points.

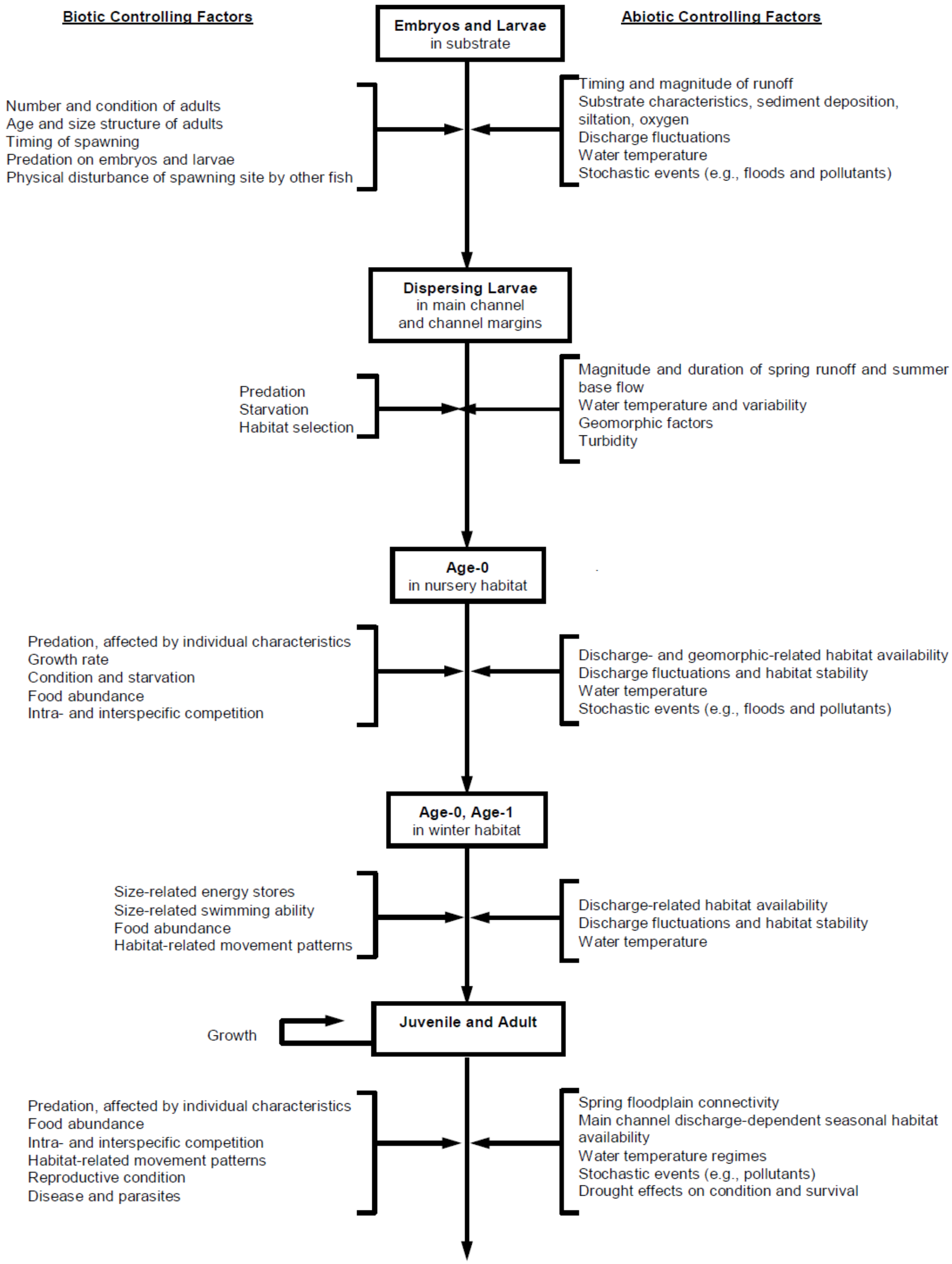


Figure 4. Conceptual life history model of Colorado pikeminnow recruitment to various developmental stages, and important biotic and abiotic controlling factors that affect them.

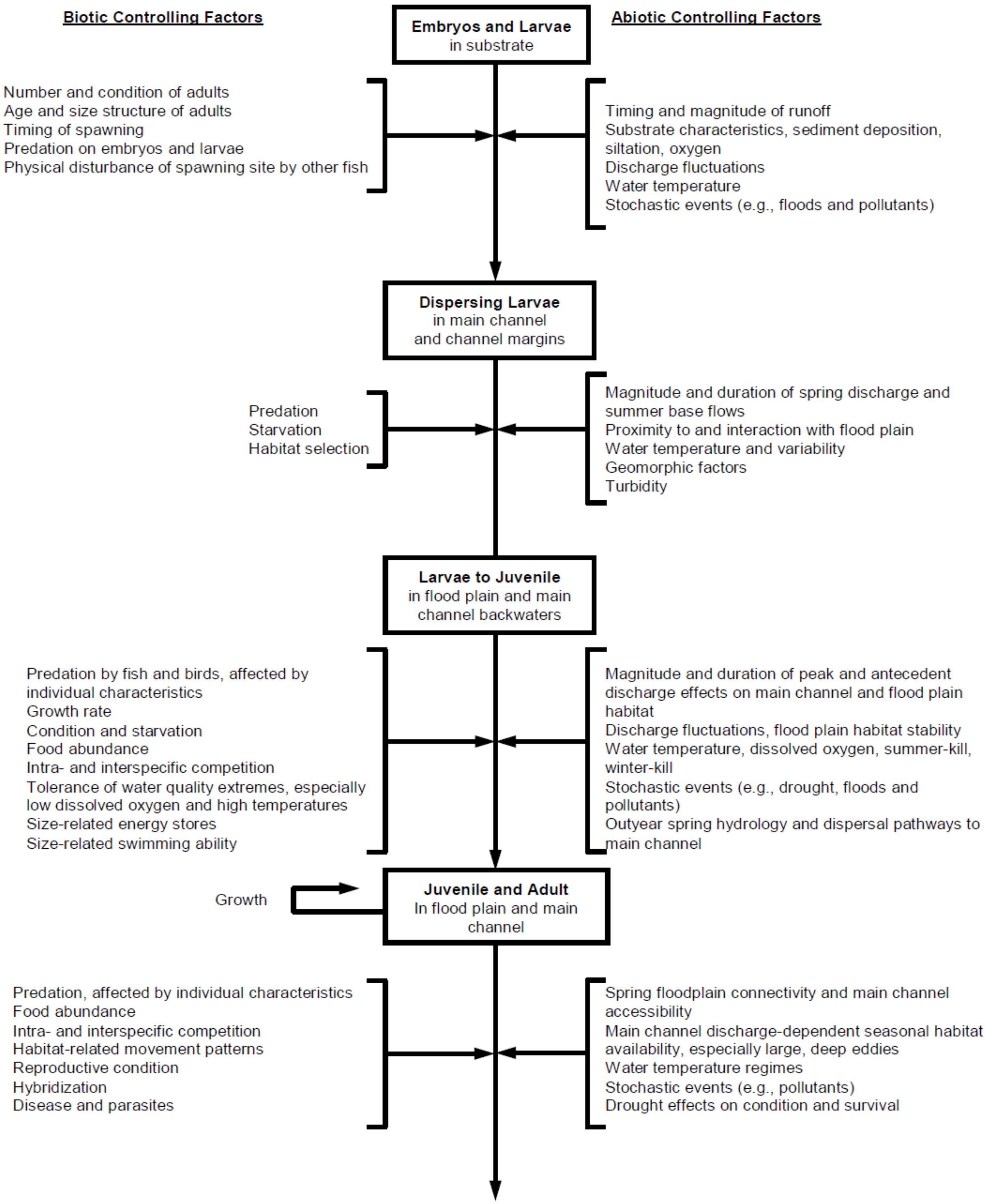


Figure 5. Conceptual life history model of bonytail recruitment to various developmental stages, and important biotic and abiotic controlling factors that affect them.

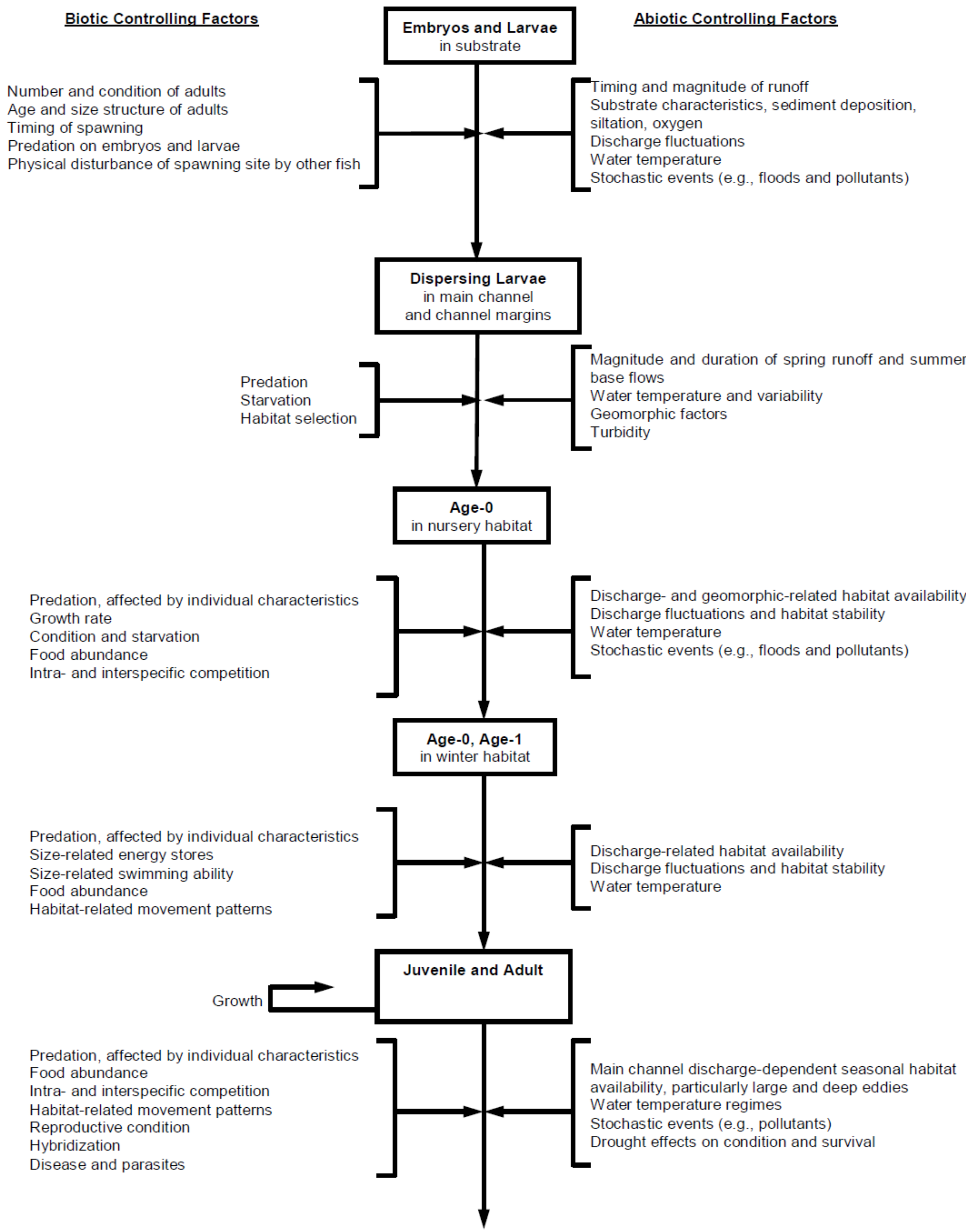


Figure 6. Conceptual life history model of humpback chub recruitment to various developmental stages, and important biotic and abiotic controlling factors that affect them.

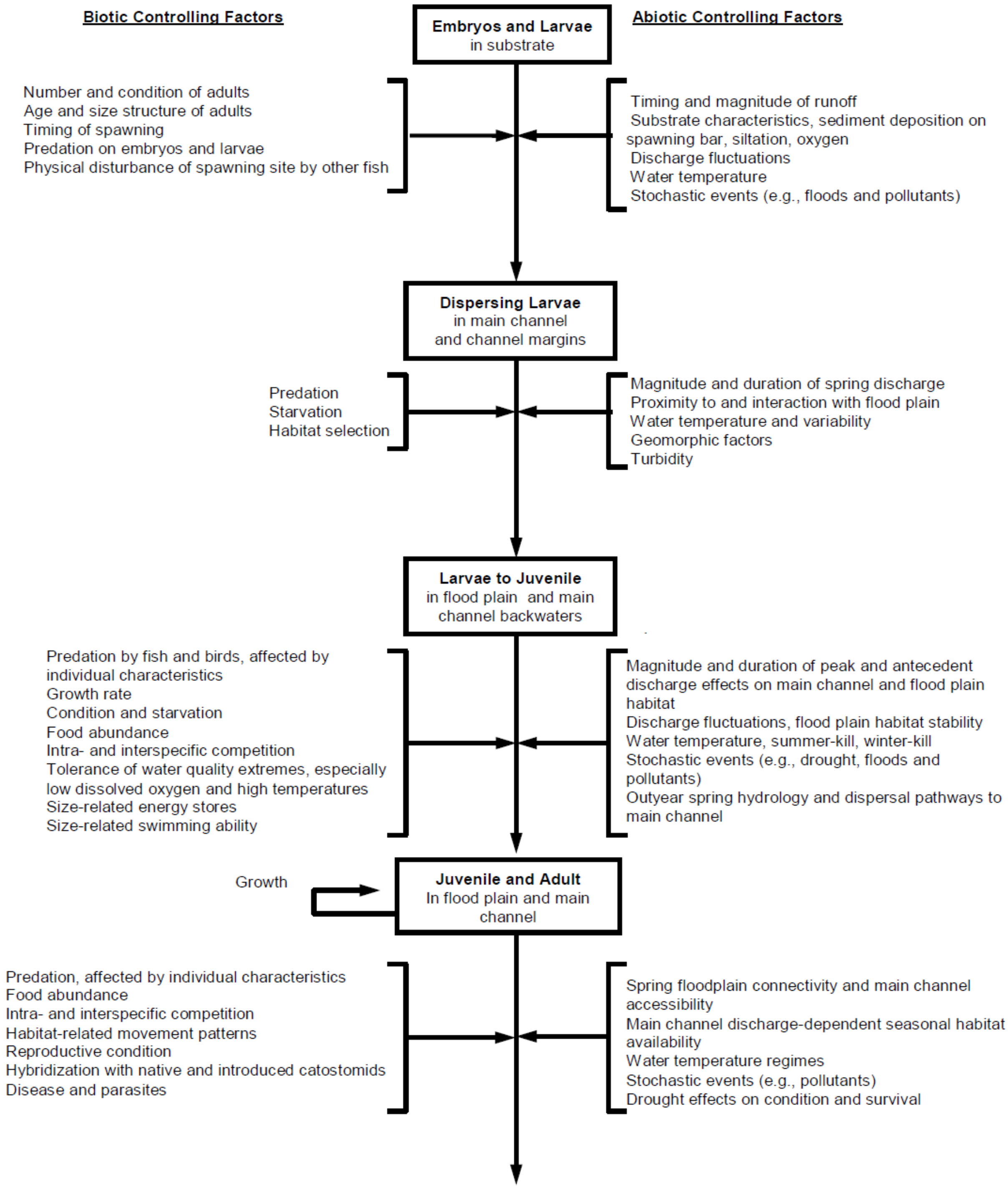


Figure 7. Conceptual life history model of razorback sucker recruitment to various developmental stages, and important biotic and abiotic controlling factors that affect them.

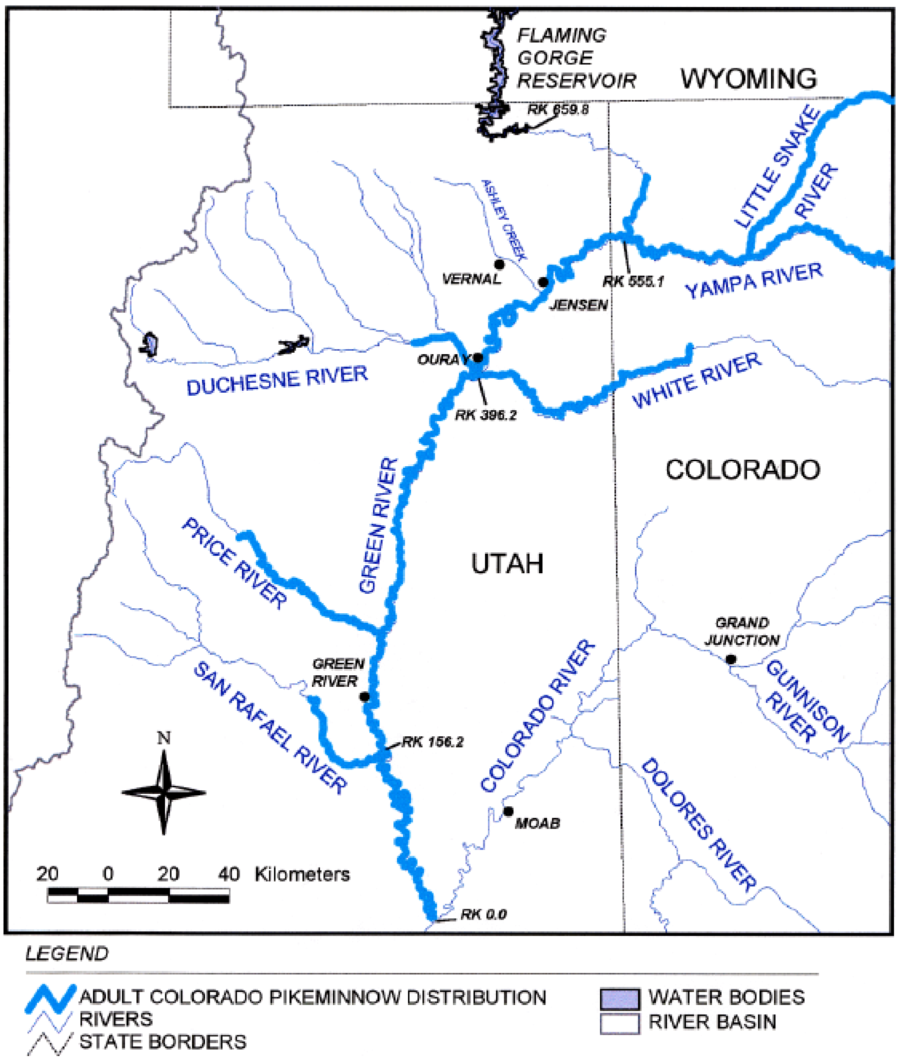


Figure 8. Distribution of adult Colorado pikeminnow in the Green River subbasin (from Muth et al. 2000, distribution remains essentially the same in 2014 as in 2000). Colorado pikeminnow also occur in Browns Park, upper Green River, Colorado and Utah.

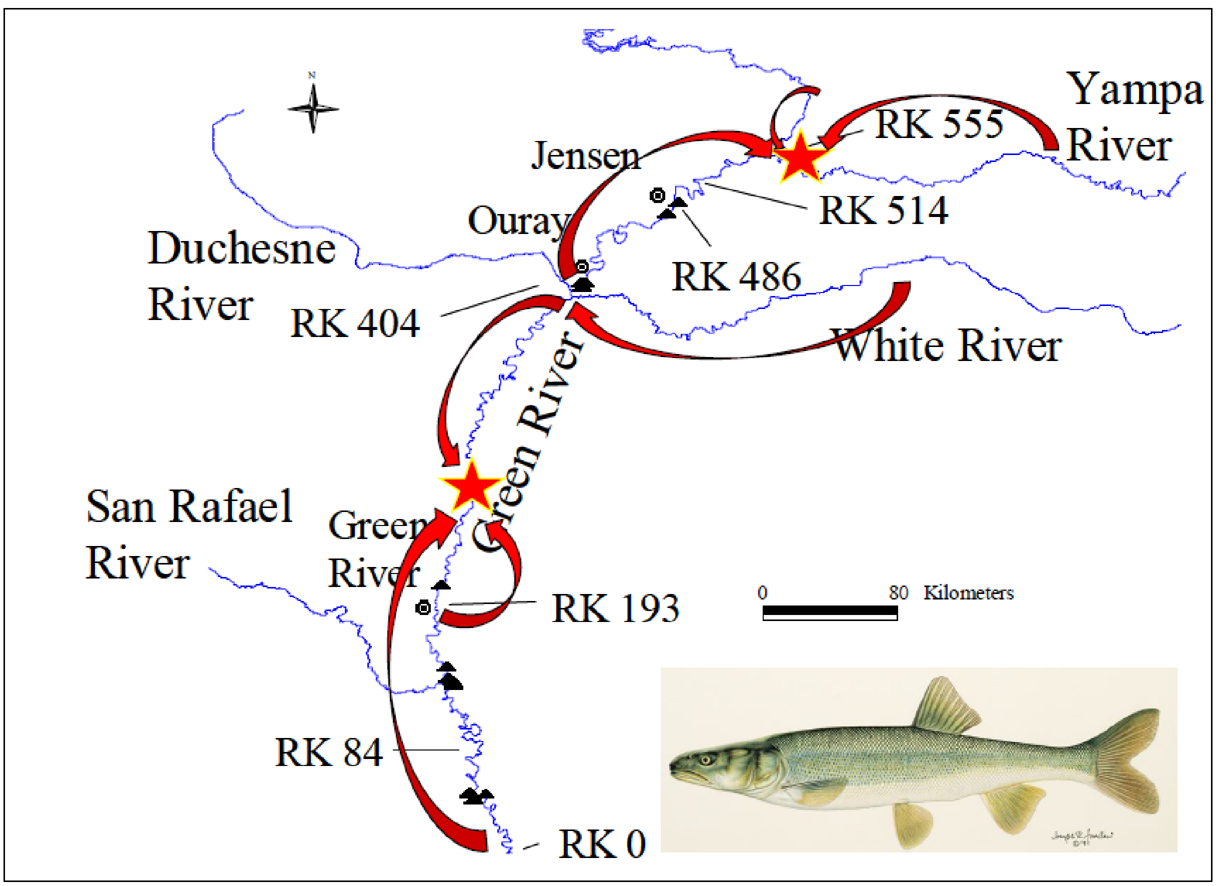


Figure 9. Movements by adult Colorado pikeminnow (arrows) from various reaches of the Green River subbasin to two known spawning areas (stars), one in Gray Canyon, lower Green River, and one in the lower Yampa River. Colorado pikeminnow return to home ranges after spawning.

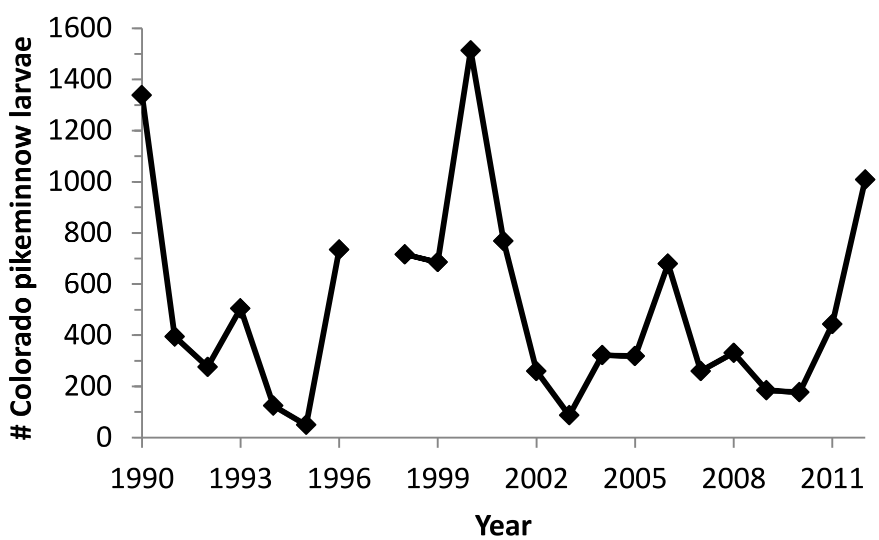


Figure 10. Number of Colorado pikeminnow larvae captured from 1990 to 2012 (no sampling in 1997) in the lower Yampa River, Colorado, during summer in drift nets.

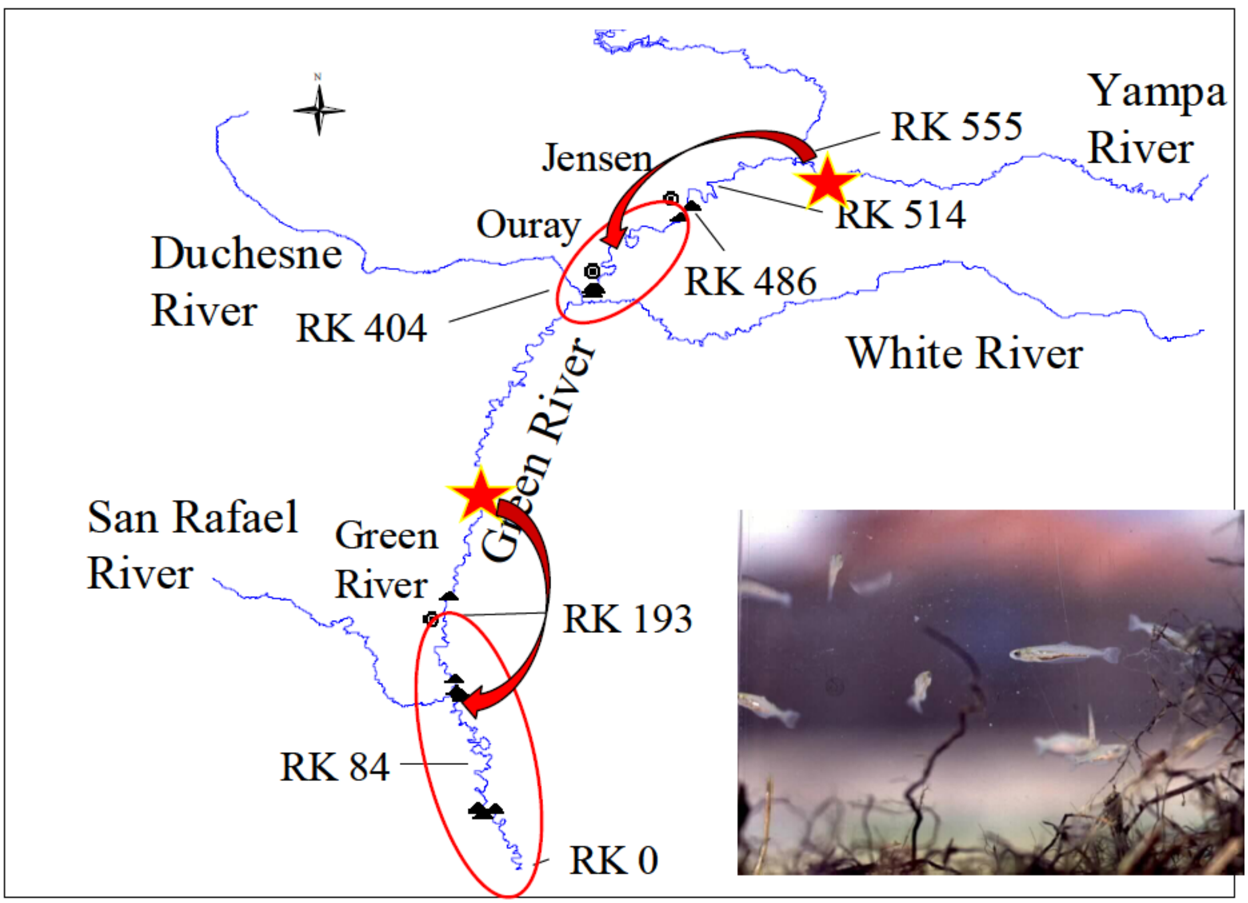


Figure 11. Drift of Colorado pikeminnow larvae from spawning areas (stars) downstream to nursery habitat (arrows) in the middle and lower Green River reaches.

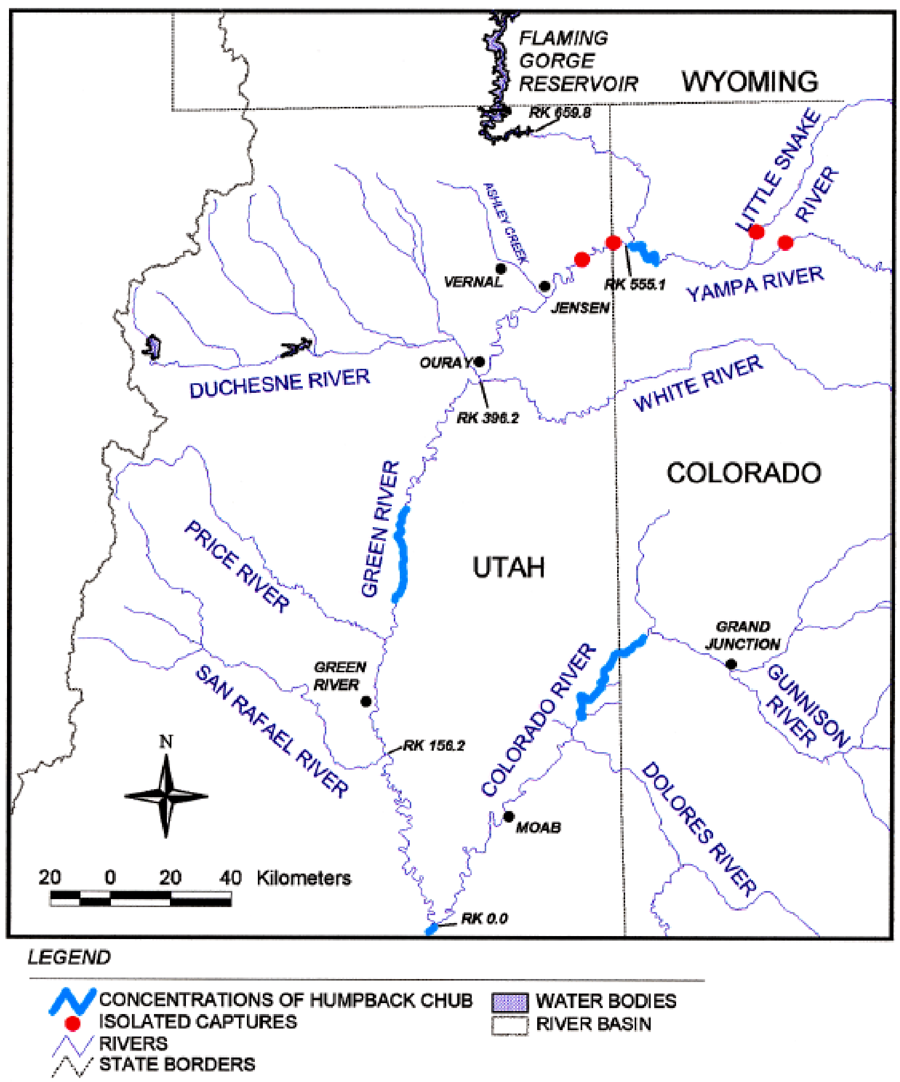


Figure 12. Distribution of adult humpback chub in the Green River subbasin (from Muth et al. 2000, distribution remains largely the same as in 2000, except lower Yampa River population is essentially extirpated).

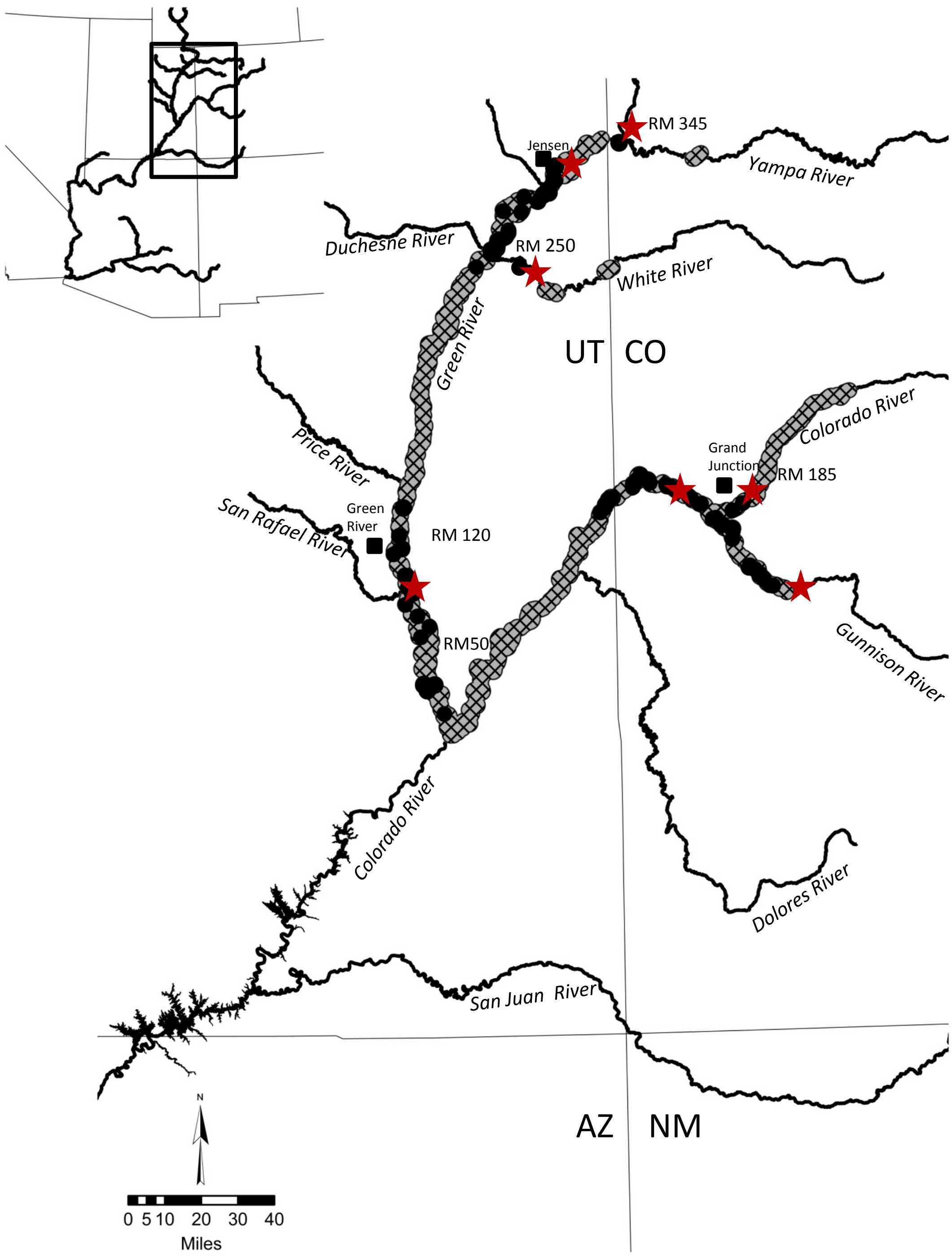


Figure 13. Distribution of adult razorback suckers in the Green and Colorado River subbasins (grey shaded and cross-hatched area), upper Colorado River basin. Filled black circles represent captures of razorback sucker larvae, stars represent known spawning areas for razorback suckers.

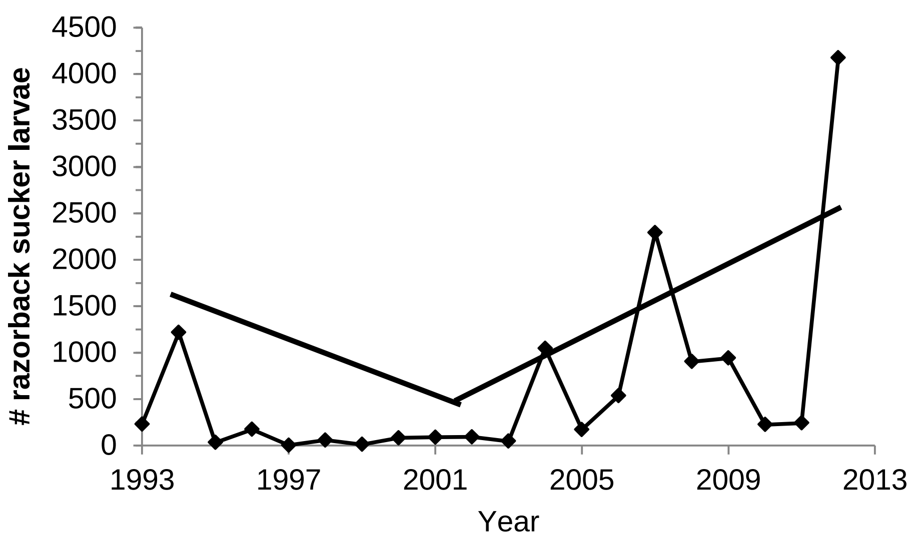


Figure 14. Number of razorback sucker larvae captured from 1993 to 2012 in the middle Green River, Utah, in light traps. Decline in abundance of larvae from 1993-2001 was due to reduced abundance of wild adult razorback suckers. Increased abundance of razorback sucker larvae since 2001 is indicative of Recovery Program efforts to stock adult razorback sucker and restore and recover the species in the Green River subbasin.

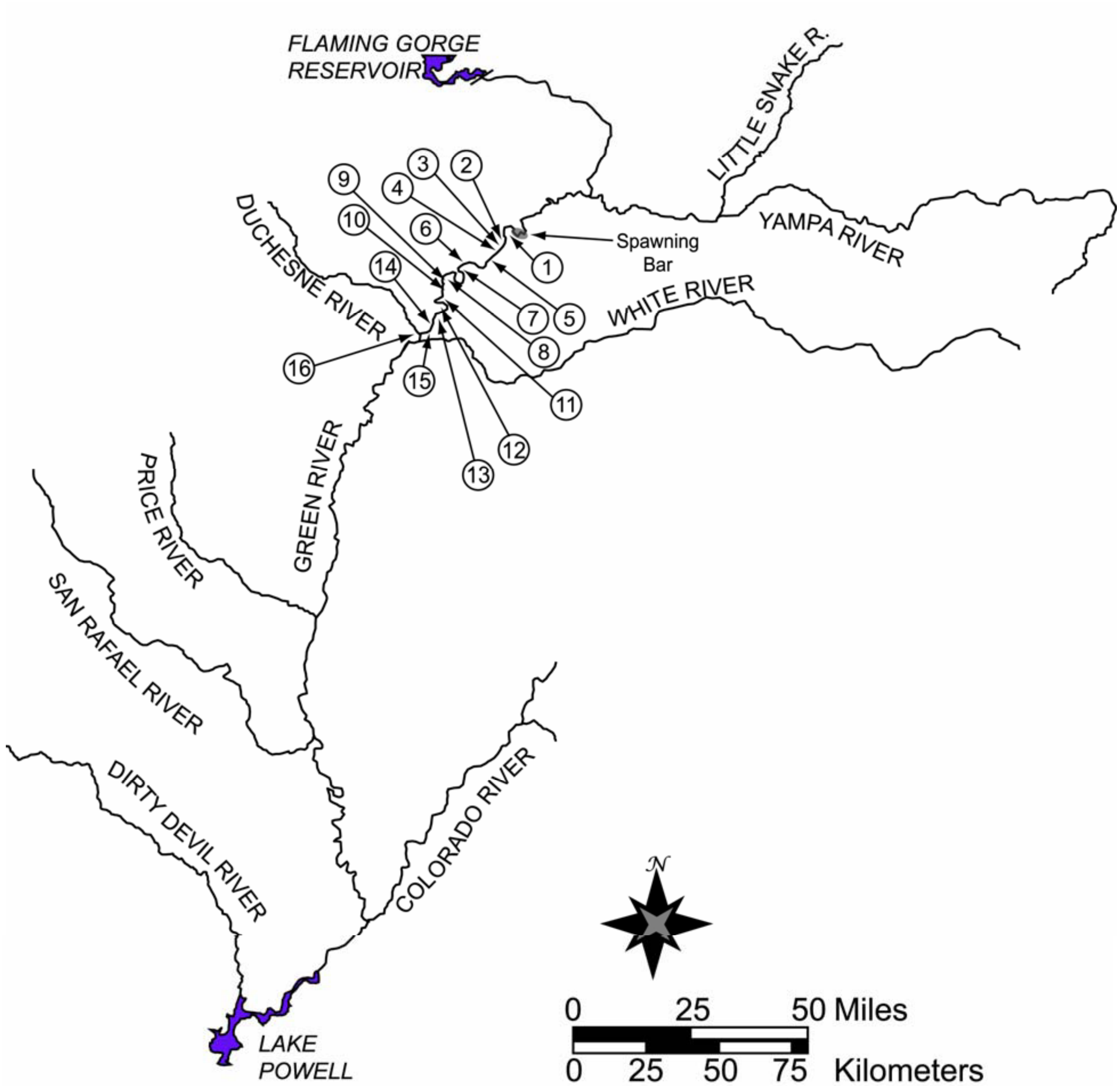


Figure 15. Green River study area showing locations of 16 priority flood plain wetlands (from Hayse et al. 2005, and Valdez and Nelson 2004). Location 1= Thunder Ranch, 2 = IMC, 3 = Stewart Lake, 4 = Sportsman's Lake, 5 = Bonanza Bridge, 6 = Richens, Slaugh, 7 = Horseshoe Bend, 8 = The Stirrup, 9 = Baser Bend, 10 = Above Brennan, 11 = Johnson Bottom, 12 = Leota ponds, 13 = Wyasket Lake, 14 = Sheppard Bottom, 15 = Old Charley Wash, 16 = Lamb Trust Property. From Hayse et al. (2005) with permission.

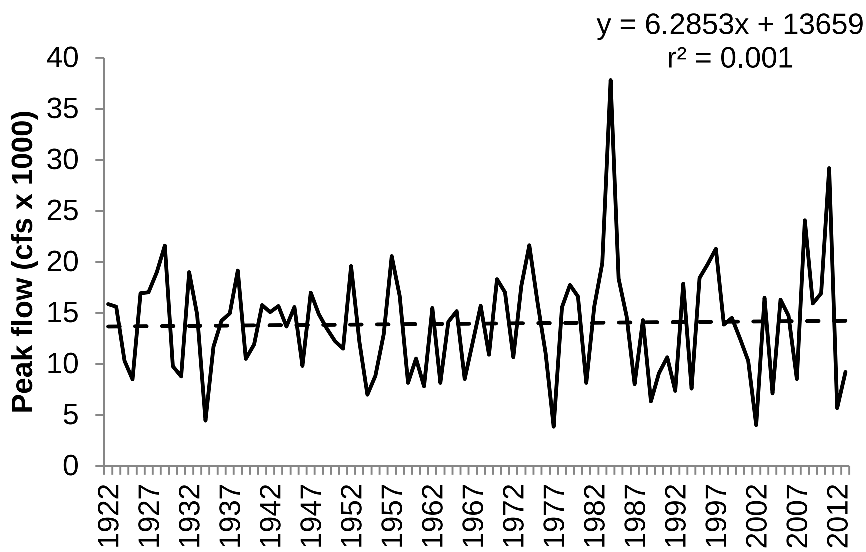


Figure 16. Maximum mean daily flow each year of the Yampa River for the period of record (1922-2012). Daily flow data from the Maybell gauge (U. S. Geological Survey gauge # 0925100), Yampa River, Colorado and the Little Snake River, Colorado (gauge # 09260000) were summed to obtain total Yampa River flow (Little Snake data was offset one day later than the Maybell gauge to account for downstream travel time). The regression shows that maximum Yampa River flows have not diminished over the period of record.

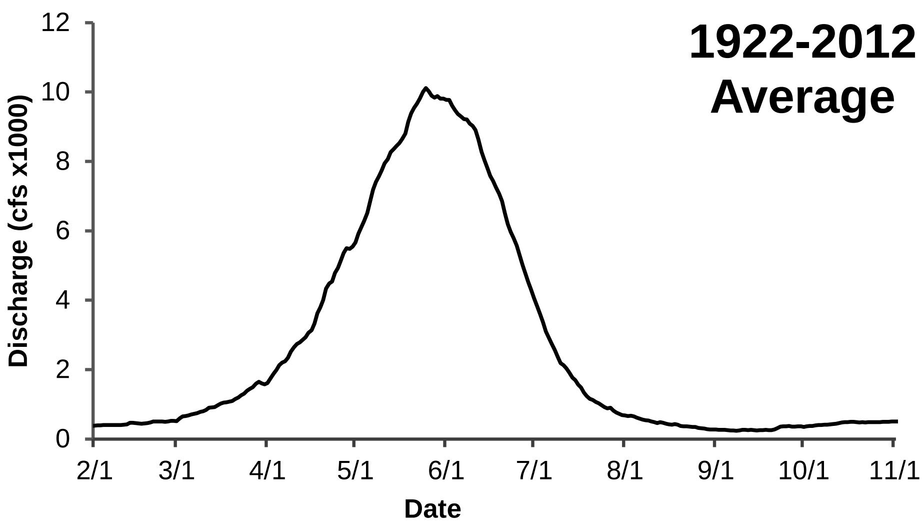


Figure 17. Mean daily flow of the Yampa River for the period of record (1922-2012). Daily flow data from the Maybell gauge (U. S. Geological Survey gauge # 0925100), Yampa River, Colorado, and the Little Snake River, Colorado (gauge # 09260000) were summed to obtain total Yampa River flow (Little Snake data was offset one day later than the Maybell gauge to account for downstream travel time).

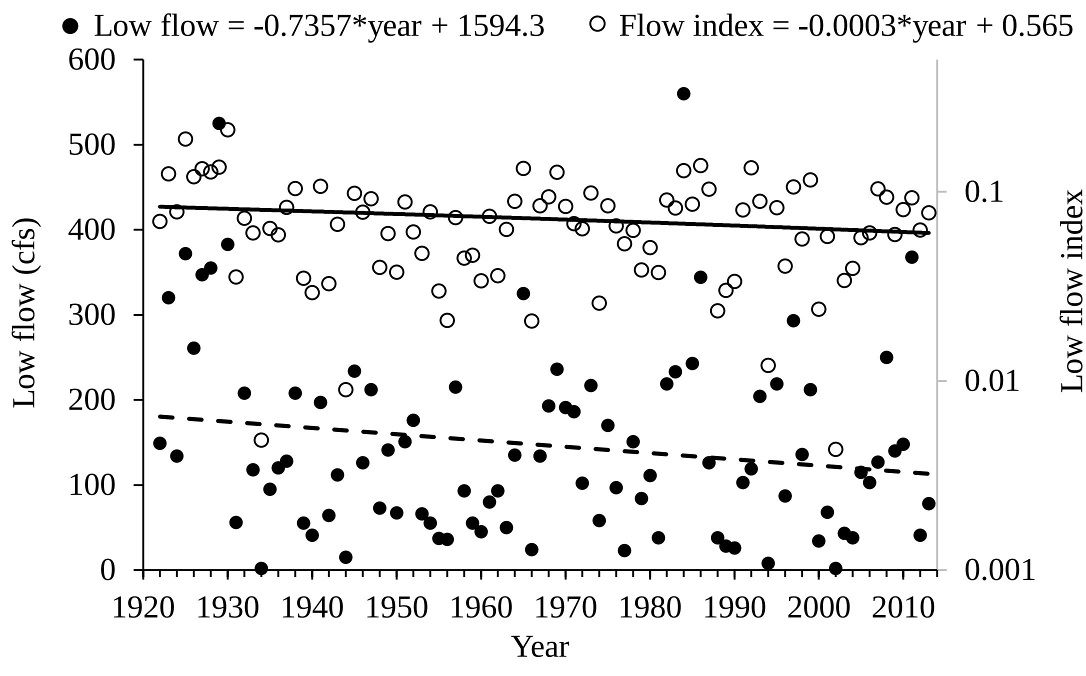
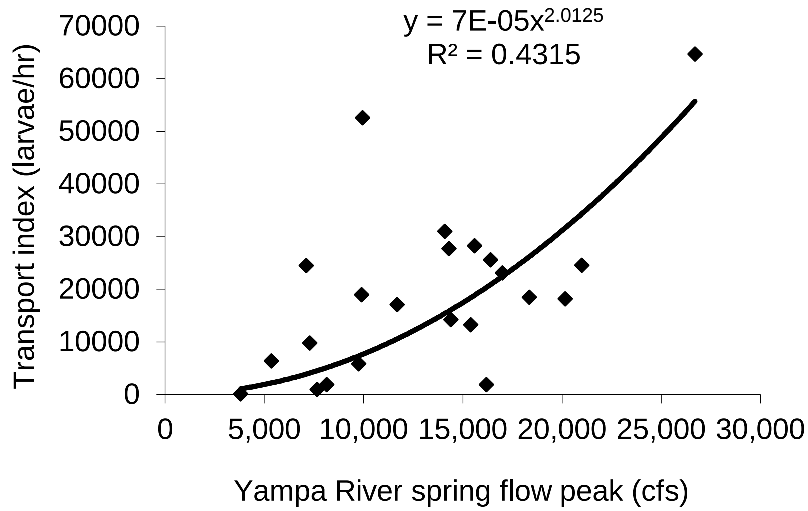


Figure 18. Minimum annual flow (one-day duration; left Y-axis, solid dots) and the low flow index (seven-day mean annual low flow/mean annual daily flow; right Y-axis; open dots) of the Yampa River for the period of record (1922-2013). Daily flow data from the Maybell gauge (U.S. Geological Survey gauge # 0925100), Yampa River, Colorado, and the Little Snake River, Colorado (gauge # 09260000) were summed to obtain total Yampa River flow (Little Snake data was offset one day later than the Maybell gauge to account for downstream travel time).



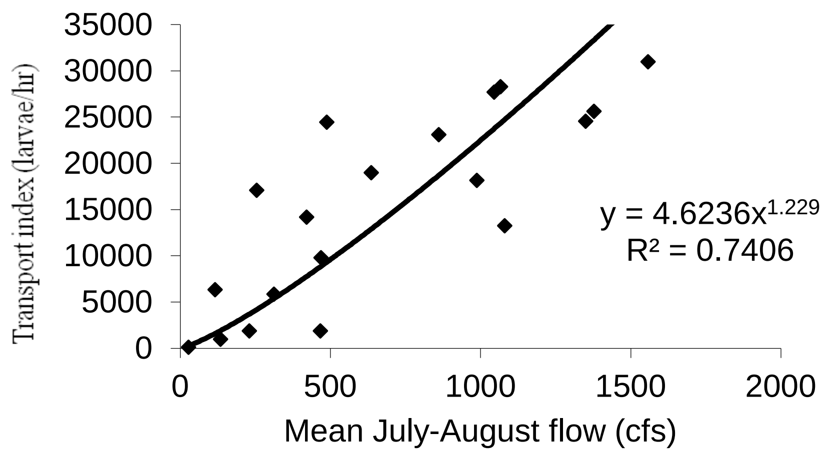
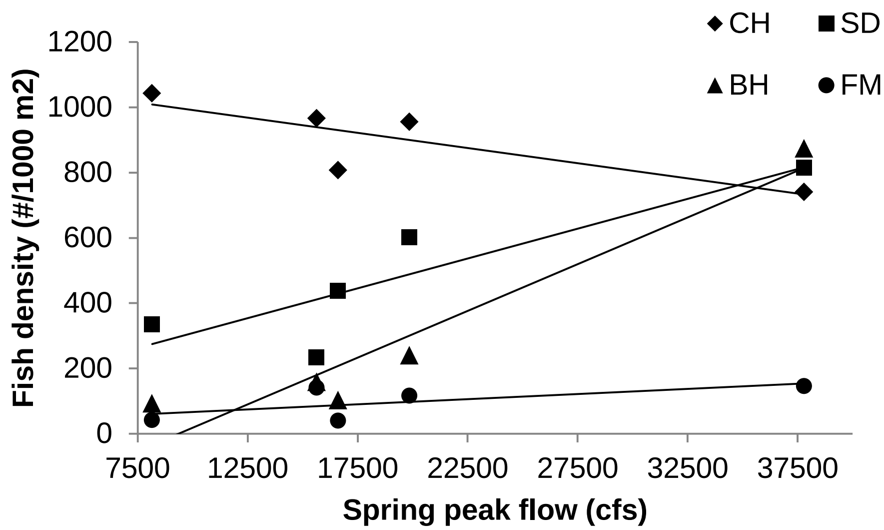


Figure 19. Annual transport of Colorado pikeminnow larvae downstream in the Yampa River as a function of spring flow peak (upper panel), and mean July-August flow (three high flow and transport values censored to show detail). The transport index is number of larvae captured per day at dawn in one hour by three drift nets and corrected for % volume of the river sampled to estimate transport past the site; daily values are then summed over the season.



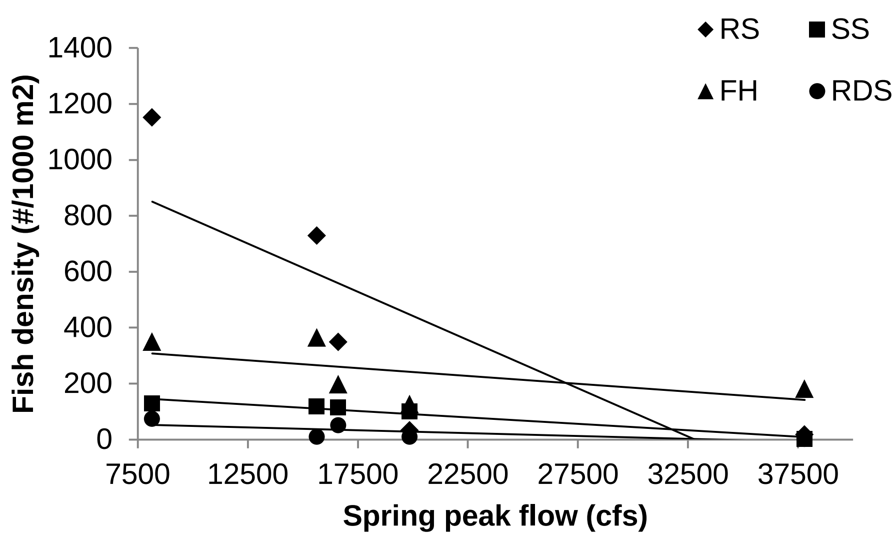
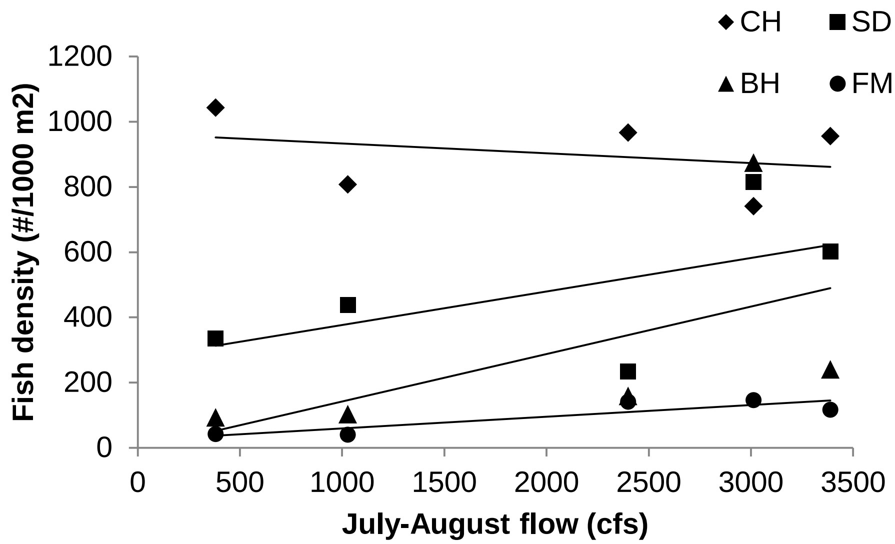


Figure 20. Density (fish per 1000 m2/seined) of age-0 native and non-native (upper and lower panels, respectively) fishes from summer and autumn seine samples in low-velocity channel margin habitat in the lower 73 RK of the Yampa River as a function of maximum mean daily spring flow, 1980-1984 (data from Muth and Nesler 1993). Daily flow data from the Maybell gauge (U. S. Geological Survey gauge # 0925100), Yampa River, Colorado, and the Little Snake River, Colorado (gauge # 09260000) were summed to obtain total Yampa River flow (Little Snake data was offset one day later than the Maybell gauge to account for downstream travel time). Native fishes: CH = Gila sp., SD = speckled dace, BH = bluehead sucker, FM = flannelmouth sucker. Non-native fishes: RS = red shiner, SS = sand shiner, FH = fathead minnow, RDS = redside shiner. Trendlines indicate general rates of change in population abundance by species as a function of flow and may or may not be statistically significant.



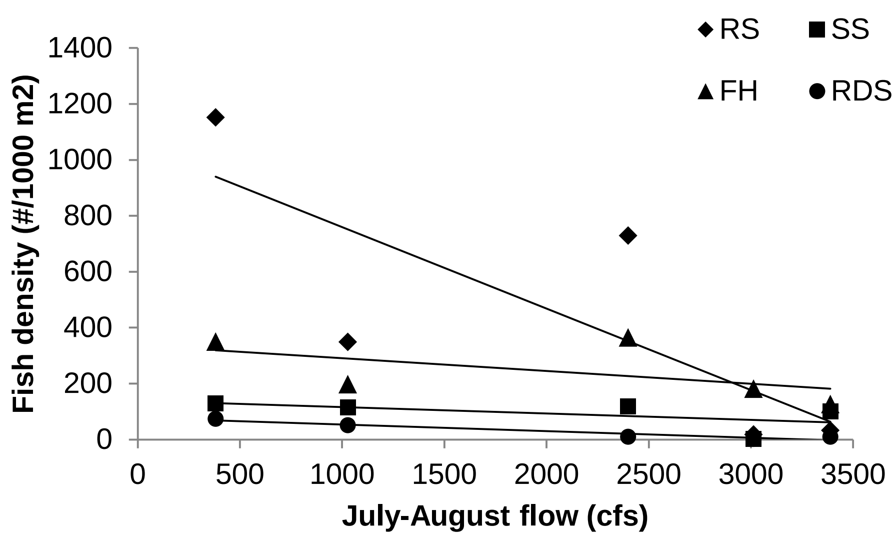


Figure 21. Density (fish per 1000 m^2/seined) of age-0 native and non-native (upper and lower panels, respectively) fishes from summer and autumn seine samples in low-velocity channel margin habitat in the lower 73 RK of the Yampa River as a function of mean daily flow in the July-August period, 1980-1984 (data from Muth and Nesler 1993). Daily flow data from the Maybell gauge (U. S. Geological Survey gauge # 0925100), Yampa River, Colorado, and the Little Snake River, Colorado (gauge # 09260000) were summed to obtain total Yampa River flow (Little Snake data was offset one day later than the Maybell gauge to account for downstream travel time). Native fishes: CH = *Gila* sp., SD = speckled dace, BH = bluehead sucker, FM = flannelmouth sucker. Non-native fishes: RS = red shiner, SS = sand shiner, FH = fathead minnow, RDS = redside shiner. Trendlines indicate general rates of change in population abundance by species as a function of flow and may or may not be statistically significant.

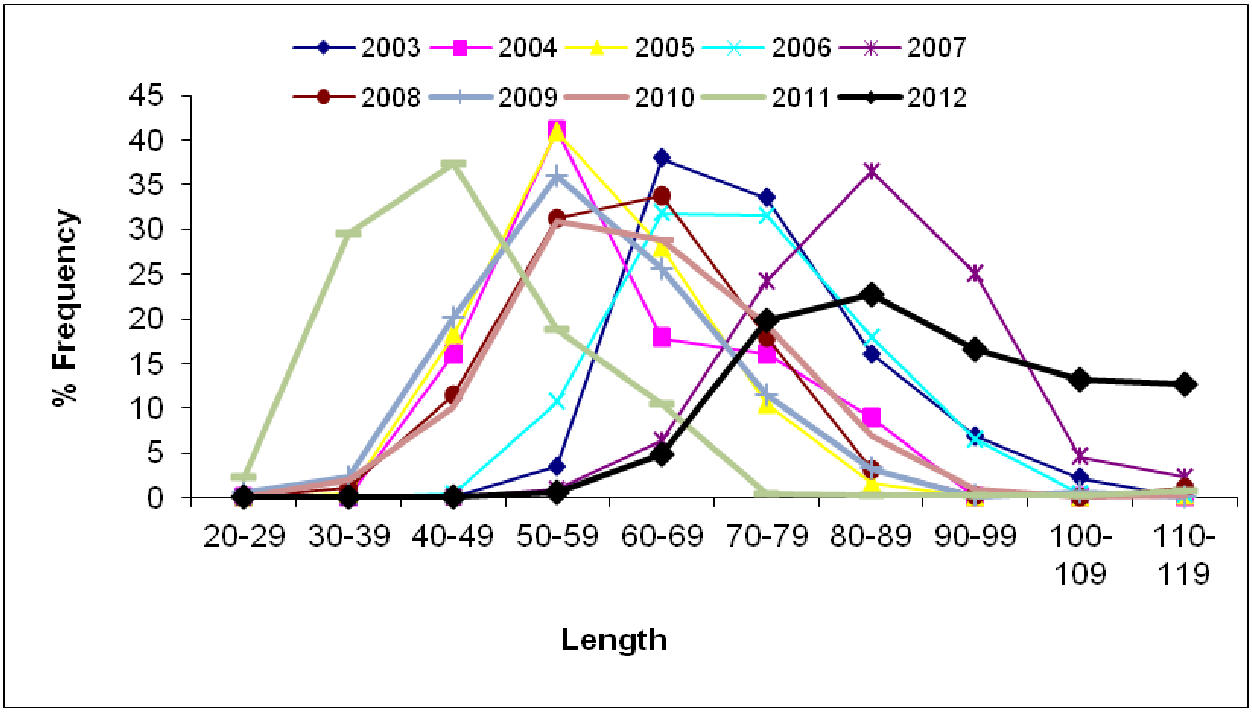


Figure 22. Annual growth in length of age 0 smallmouth bass in September, 2003-2012, in the Yampa River near Craig, Colorado. Low flow and warm years (e.g., 2007, 2012) result in high growth while higher flow and cooler years (e.g., 2011) result in lower growth.

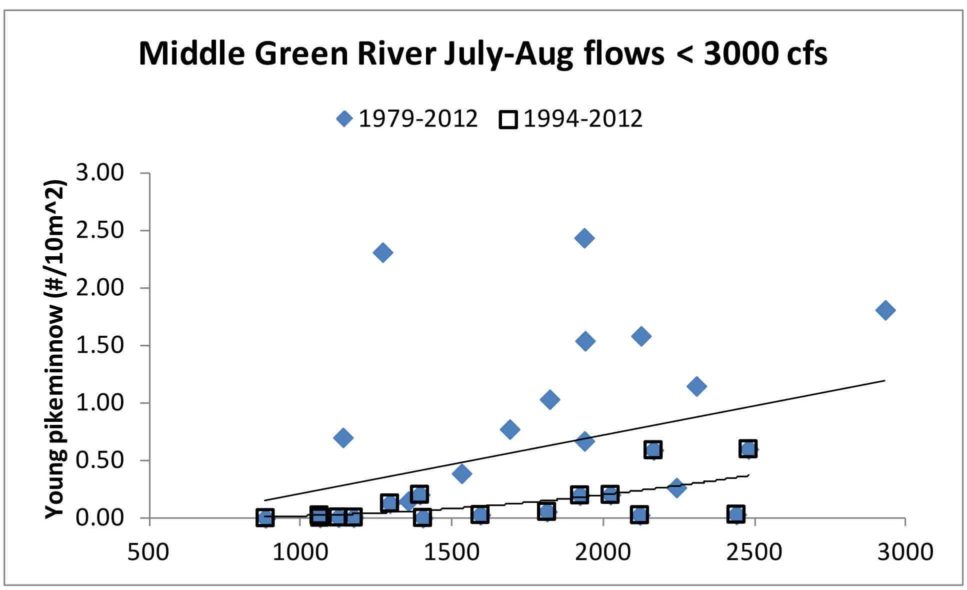


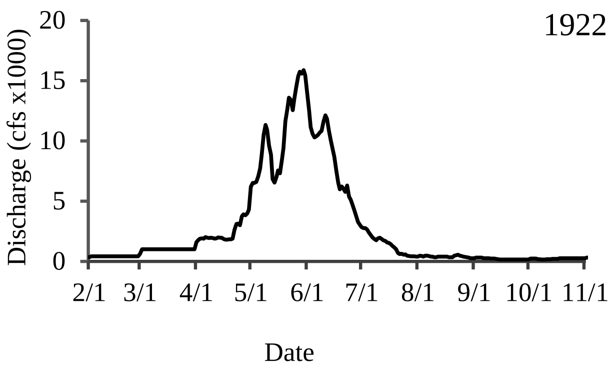
Figure 23. Density of young Colorado pikeminnow (per area backwater seined) as a function of middle Green River summer base flows, 1979-2012; very high flow years were excluded because no backwaters were present.

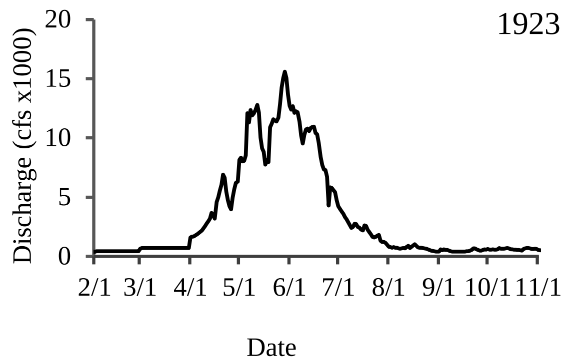
Table 1. Distribution and abundance of native fishes historically (H, pre-1985) and at present (P, 2014) in three reaches of the Yampa River, Colorado. Reaches are Upper = upstream of Hayden, Colorado, Middle = Hayden downstream to Lily Park, and Lower = Lily Park to confluence with the Green River. Abundant (A) = regular occurrence, high abundance, Common (C) = frequent occurrence, low abundance, Rare (R) = occurs infrequently, low abundance, Extirpated (Ex) or not found (Nf) = gone from area or historically absent, respectively.

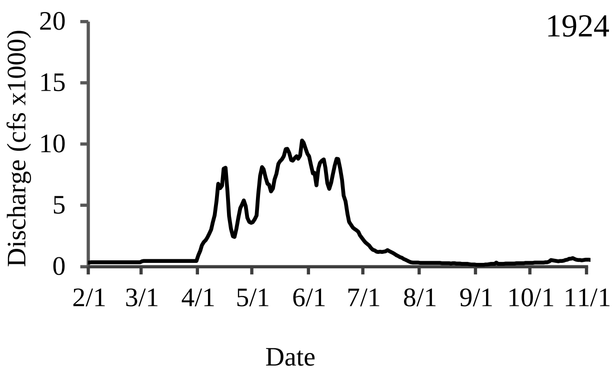
Species			Reach		
Common name	**Scientific name**	**Period**	**Upper**	**Middle**	**Lower**
cutthroat trout	*Oncorhynchus clarkii*	H	A	R	Nf
		P	Ex	Ex	--
mountain whitefish	*Prosopium williamsoni*	H	A	C	R
		P	C	R	Ex
mottled sculpin	*Cottus bairdii*	H	A	R	R
		P	R?	R	R
speckled dace	*Rhinichthys osculus*	H	C	A	A
		P	R?	R?	C
mountain sucker	*Catostomus platyrhynchus*	H	C	R	Nf
		P	R?	R	--
bluehead sucker	*Catostomus discobolus*	H	A	A	A
		P	R	C	A
flannelmouth sucker	*Catostomus latipinnis*	H	A	A	A
		P	Ex	R	A
Colorado pikeminnow	*Ptychocheilus lucius*	H	R	C	R-C
		P	R	R	R-C
roundtail chub	*Gila robusta*	H	C	A	A
		P	Ex	R	A
humpback chub	*Gila cypha*	H	Nf	Nf	C
		P	--	--	Ex
razorback sucker	*Xyrauchen texanus*	H	Nf	R	R-C
		P	--	R	R
bonytail	*Gila elegans*	H	Nf	R	R
		P	--	Ex	R

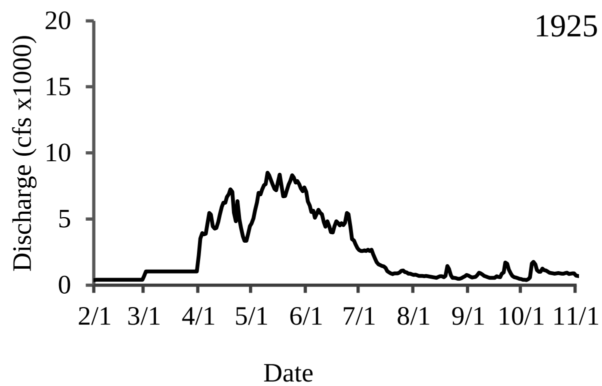
Appendix I.

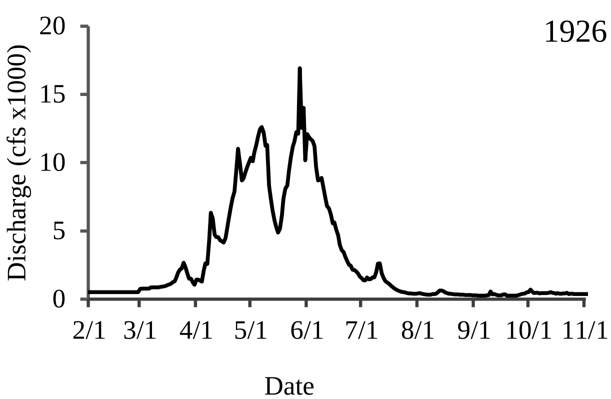
Mean daily flow each year for the Yampa River for the period of record (1922-2013). Daily flow data from the Maybell gauge (U. S. Geological Survey gauge # 0925100), Yampa River, Colorado, and the Little Snake River, Colorado (gauge # 09260000) were summed to obtain total Yampa River flow (Little Snake data was offset one day later than the Maybell gauge to account for downstream travel time)


1922
Discharge (cfs x1000)
20
15
10
5
0
2/1 3/1 4/1 5/1 6/1 7/1 8/1 9/1 10/1 11/1
Date


1923
Discharge (cfs x1000)
20
15
10
5
0
2/1 3/1 4/1 5/1 6/1 7/1 8/1 9/1 10/1 11/1
Date


1924
Discharge (cfs x1000)
20
15
10
5
0
2/1 3/1 4/1 5/1 6/1 7/1 8/1 9/1 10/1 11/1
Date


1925
Discharge (cfs x1000)
20
15
10
5
0
2/1 3/1 4/1 5/1 6/1 7/1 8/1 9/1 10/1 11/1
Date


1926
Discharge (cfs x1000)
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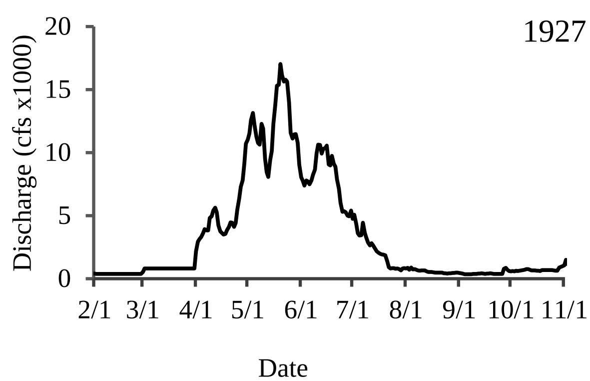
15
10
5
0
2/1 3/1 4/1 5/1 6/1 7/1 8/1 9/1 10/1 11/1
Date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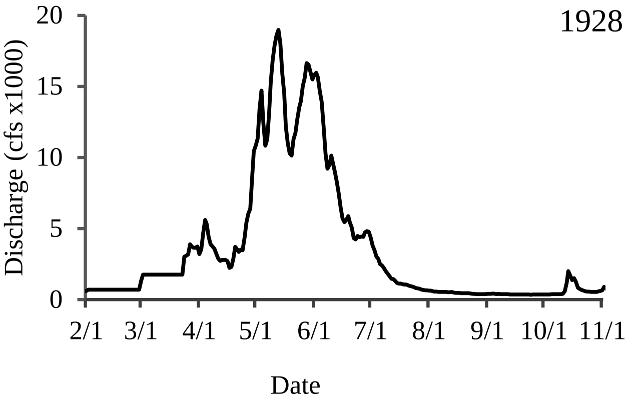
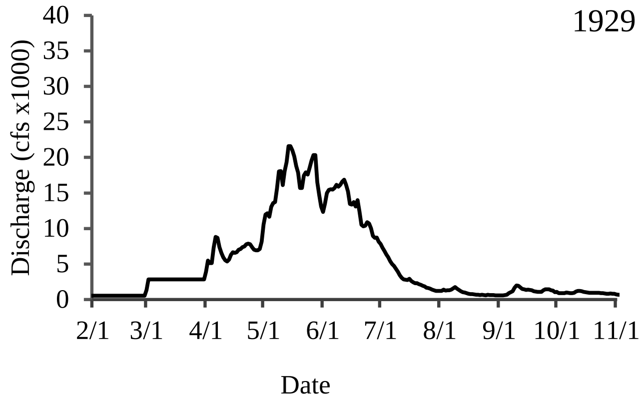
Discharge (cfs x1000)
20
15
10
5
0
2/1 3/1 4/1 5/1 6/1 7/1 8/1 9/1 10/1 11/1
Date


1928
Discharge (cfs x1000)
0
5
10
15
20
2/1 3/1 4/1 5/1 6/1 7/1 8/1 9/1 10/1 11/1
Date


1929
Discharge (cfs x1000)
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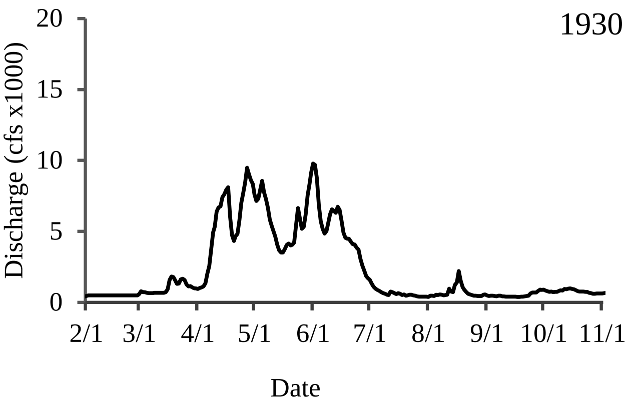
5
10
15
20
25
30
35
40
2/1 3/1 4/1 5/1 6/1 7/1 8/1 9/1 10/1 11/1
Date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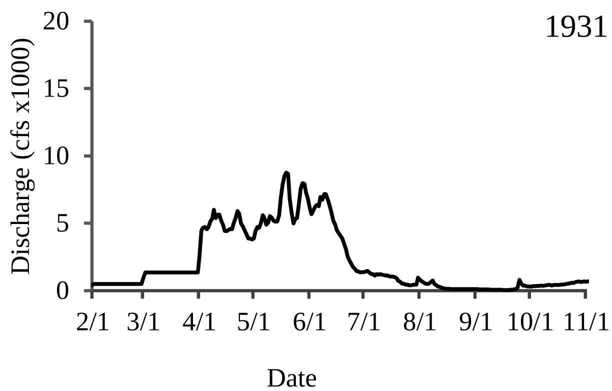
Discharge (cfs x1000)
0
5
10
15
20
2/1 3/1 4/1 5/1 6/1 7/1 8/1 9/1 10/1 11/1
Date


1931
Discharge (cfs x1000)
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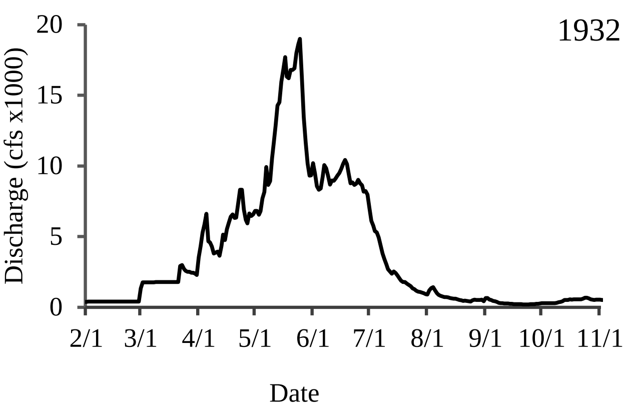
5
10
15
20
2/1 3/1 4/1 5/1 6/1 7/1 8/1 9/1 10/1 11/1
Date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Discharge (cfs x1000)
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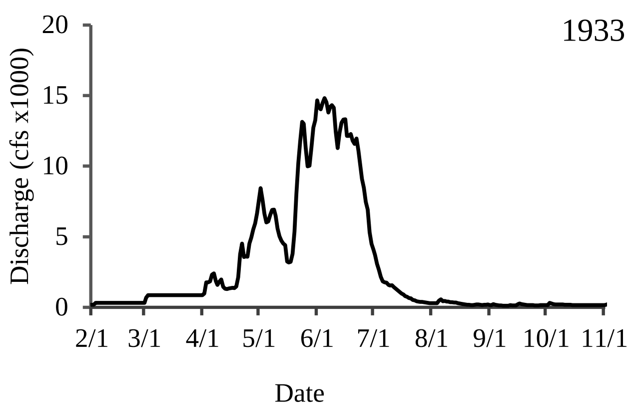
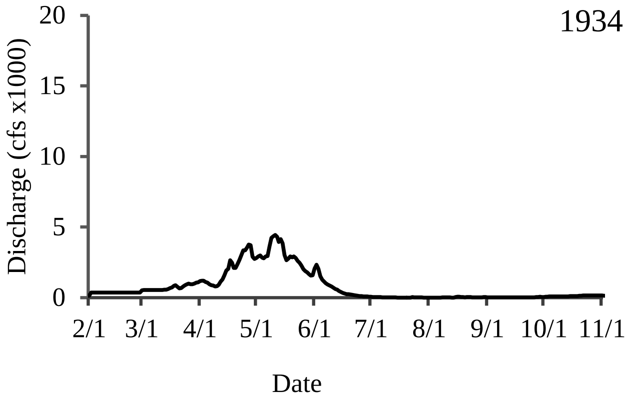
5
10
15
20
2/1 3/1 4/1 5/1 6/1 7/1 8/1 9/1 10/1 11/1
Date


1933
Discharge (cfs x1000)
0
5
10
15
20
2/1 3/1 4/1 5/1 6/1 7/1 8/1 9/1 10/1 11/1
Date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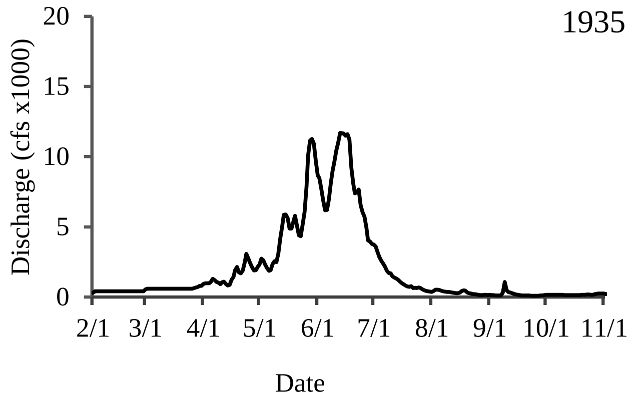
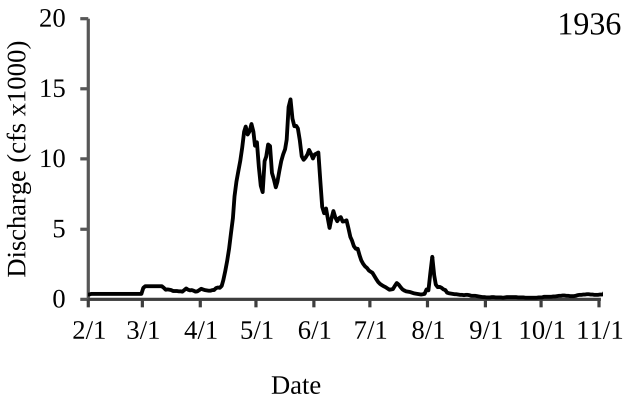
Discharge (cfs x1000)
20
15
10
5
0
2/1 3/1 4/1 5/1 6/1 7/1 8/1 9/1 10/1 11/1
Date


1935
Discharge (cfs x1000)
20
15
10
5
0
2/1 3/1 4/1 5/1 6/1 7/1 8/1 9/1 10/1 11/1
Date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Discharge (cfs x1000)
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15
10
5
0
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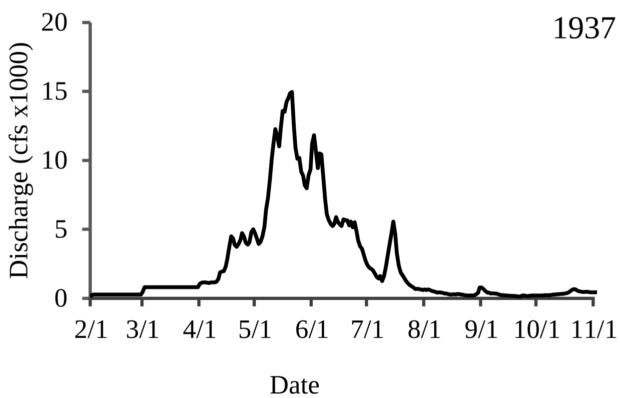
Date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Discharge (cfs x1000)
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15
10
5
0
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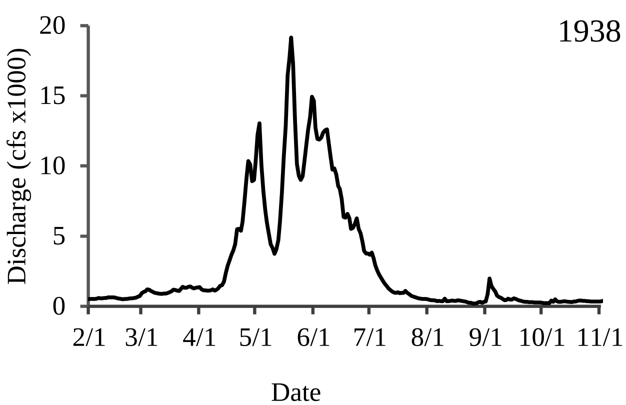
Date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Discharge (cfs x1000)
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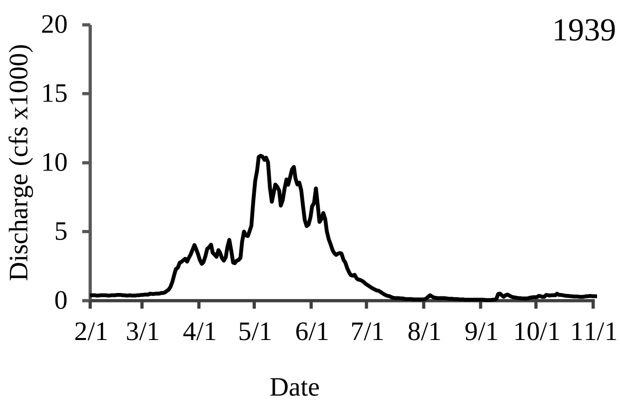
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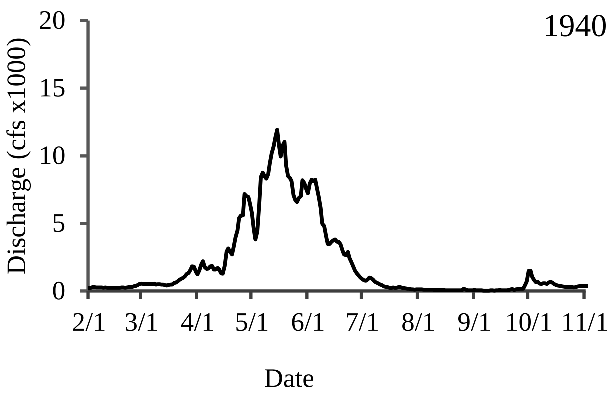
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Discharge (cfs x1000)
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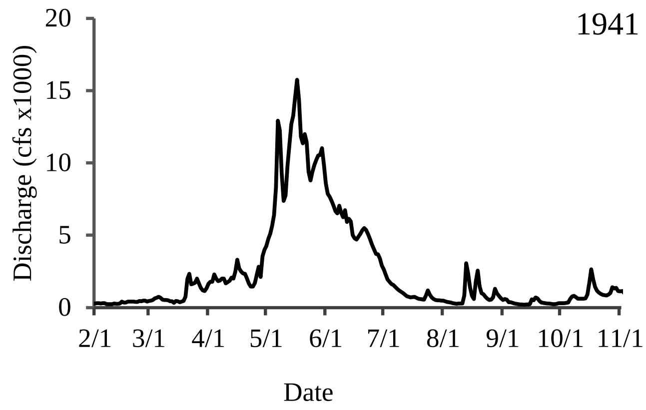
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Discharge (cfs x1000)
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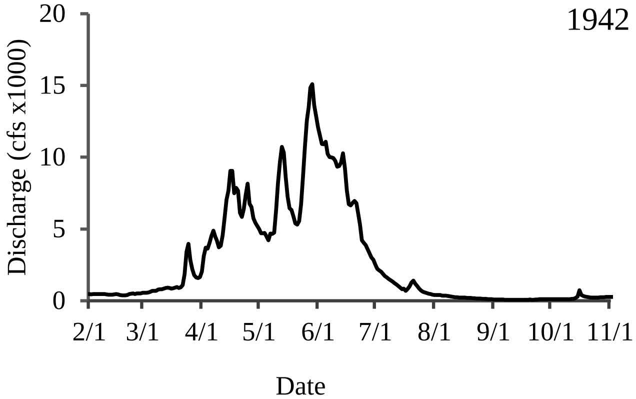
Date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Discharge (cfs x1000)
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10
15
20
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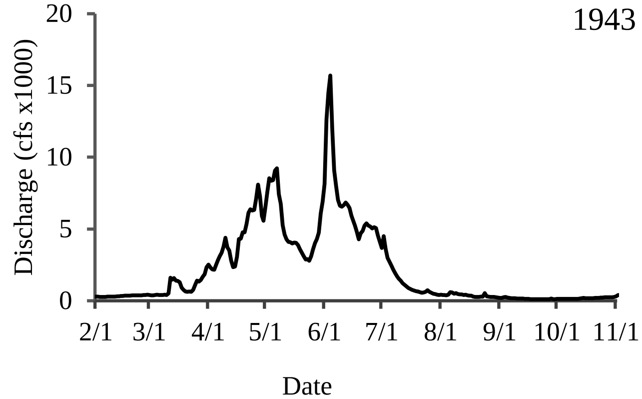
Date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Discharge (cfs x1000)
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10
15
20
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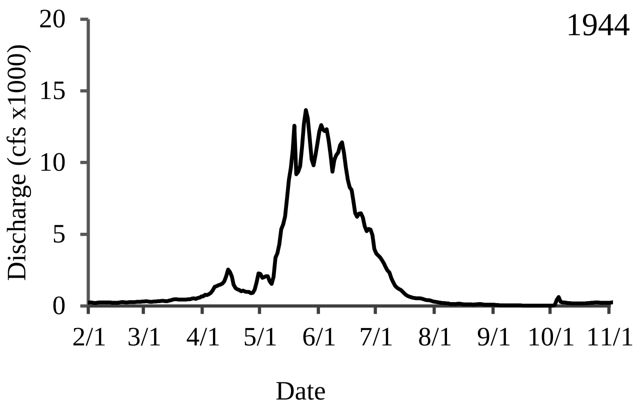
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Discharge (cfs x1000)
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5
10
15
20
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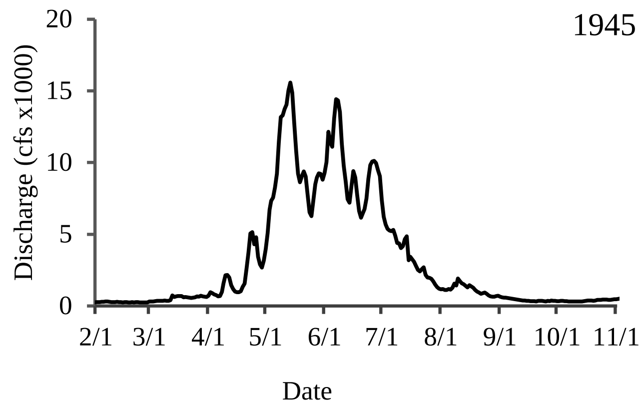
Date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Discharge (cfs x1000)
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10
15
20
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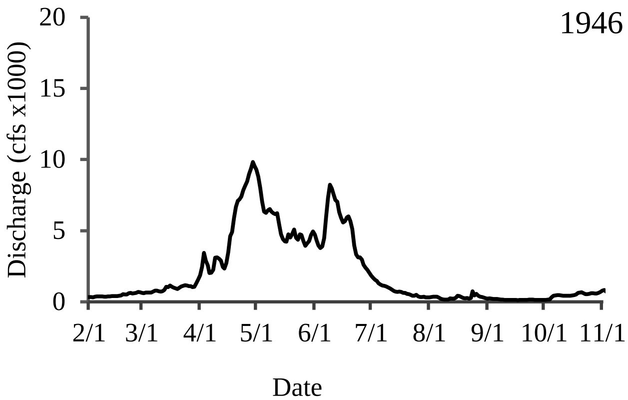
Date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Discharge (cfs x1000)
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5
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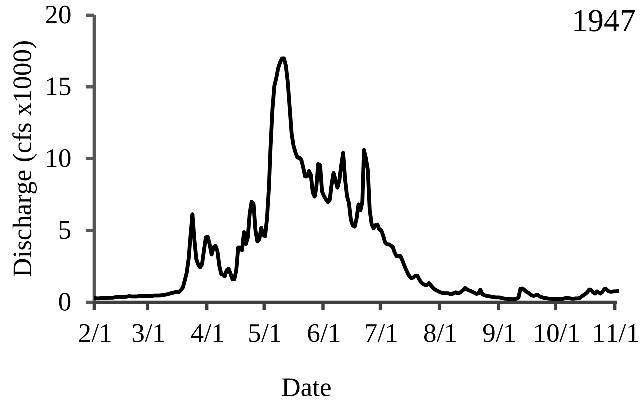
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Discharge (cfs x1000)
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10
5
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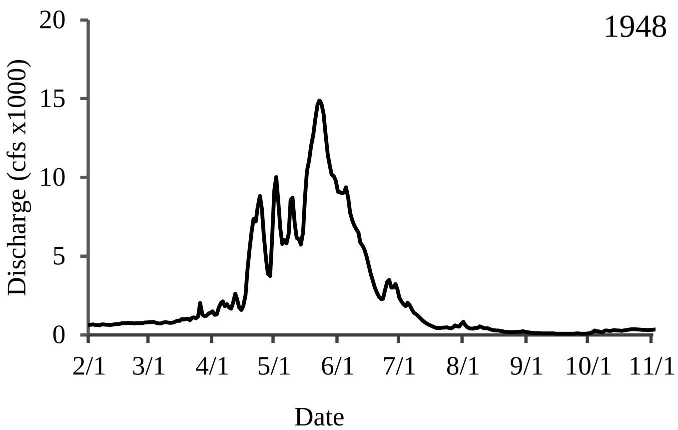
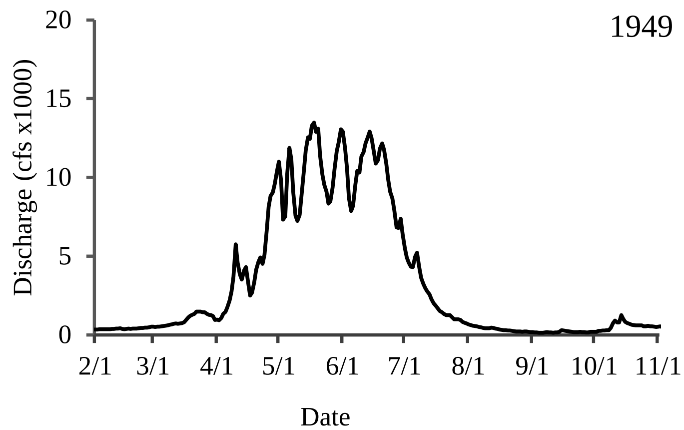
Date


1948
Discharge (cfs x1000)
20
15
10
5
0
2/1 3/1 4/1 5/1 6/1 7/1 8/1 9/1 10/1 11/1
Date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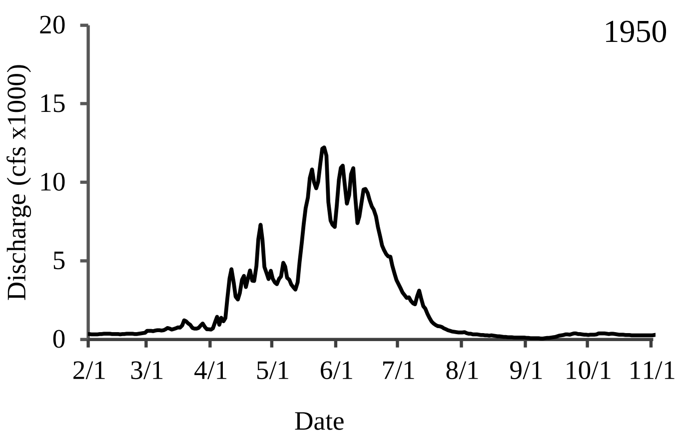
Discharge (cfs x1000)
20
15
10
5
0
2/1 3/1 4/1 5/1 6/1 7/1 8/1 9/1 10/1 11/1
Date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Discharge (cfs x1000)
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10
5
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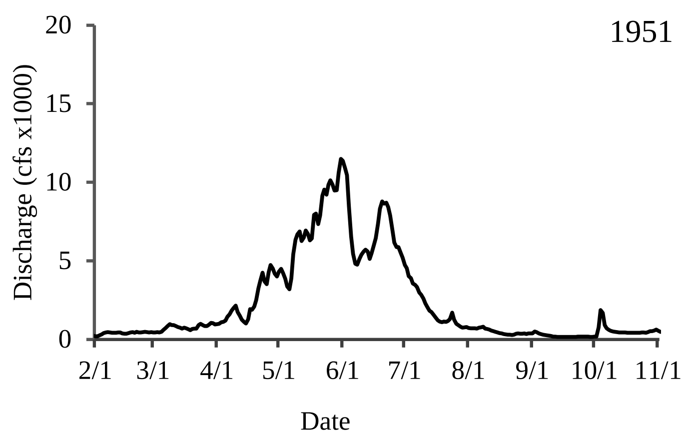
Date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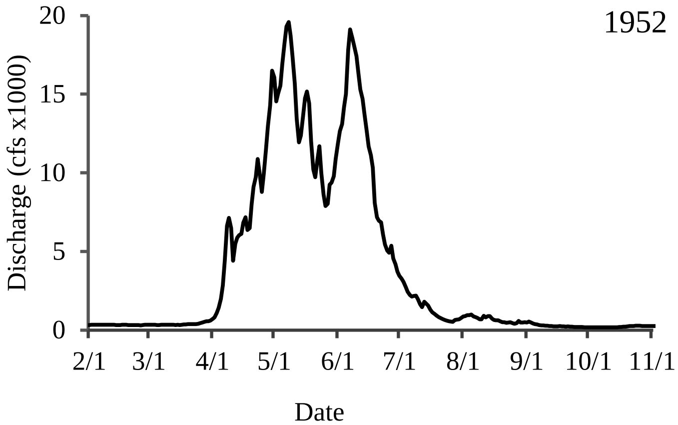
Discharge (cfs x1000)
20
15
10
5
0
2/1 3/1 4/1 5/1 6/1 7/1 8/1 9/1 10/1 11/1
Date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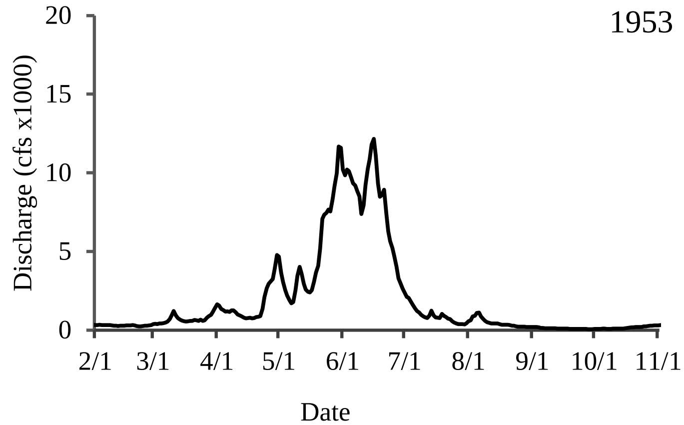
Discharge (cfs x1000)
0
5
10
15
20
2/1
3/1
4/1
5/1
6/1
7/1
8/1
9/1
10/1
11/1
Date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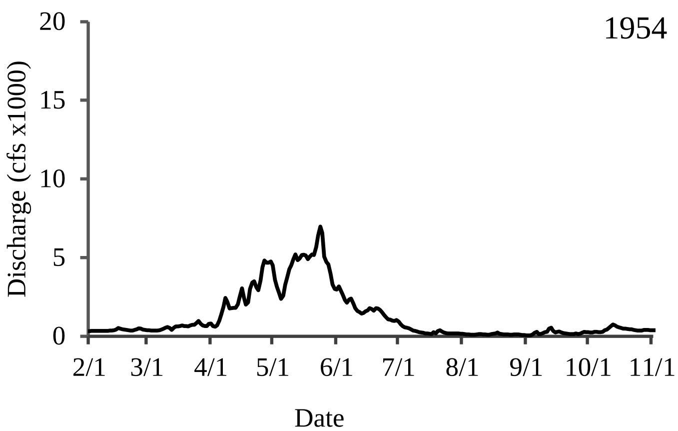
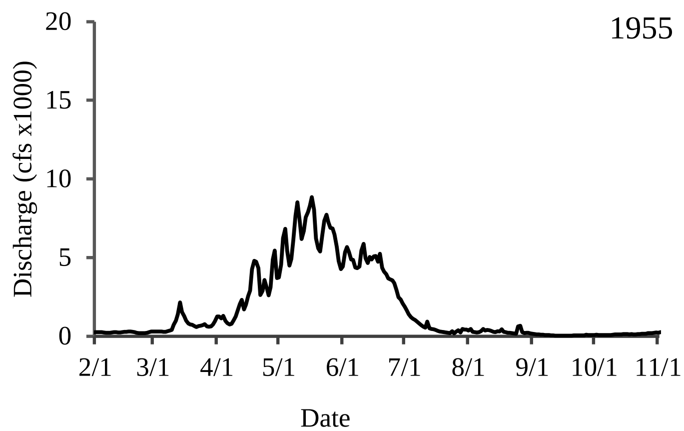
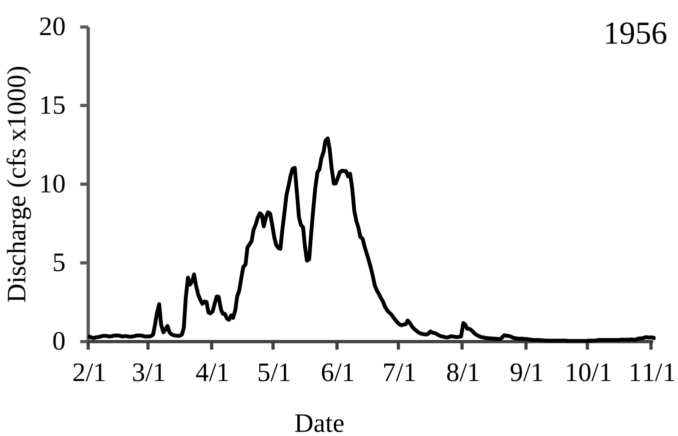
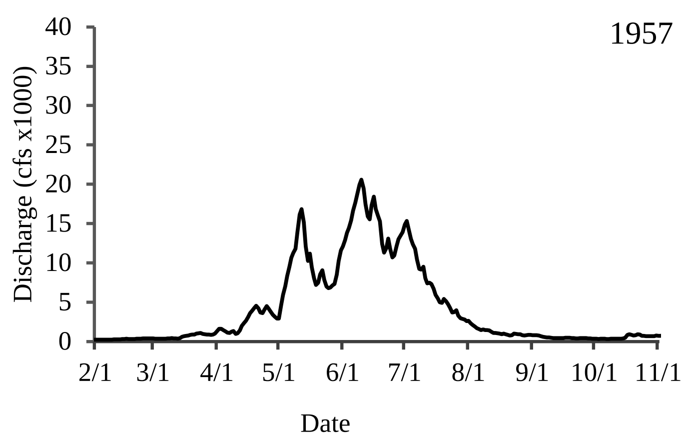
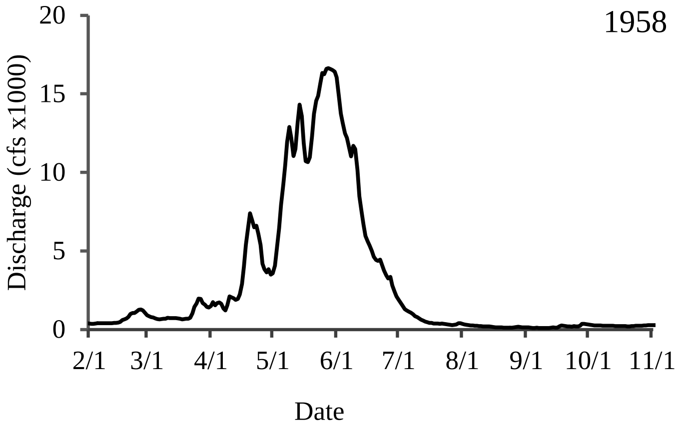
Discharge (cfs x1000)
0
5
10
15
20
2/1
3/1
4/1
5/1
6/1
7/1
8/1
9/1
10/1
11/1
Date


1954
Discharge (cfs x1000)
0
5
10
15
20
2/1
3/1
4/1
5/1
6/1
7/1
8/1
9/1
10/1
11/1
Date


1955
Discharge (cfs x1000)
0
5
10
15
20
2/1
3/1
4/1
5/1
6/1
7/1
8/1
9/1
10/1
11/1
Date


1956
Discharge (cfs x1000)
0
5
10
15
20
2/1
3/1
4/1
5/1
6/1
7/1
8/1
9/1
10/1
11/1
Date


1957
Discharge (cfs x1000)
0
5
10
15
20
25
30
35
40
2/1
3/1
4/1
5/1
6/1
7/1
8/1
9/1
10/1
11/1
Date


1958
Discharge (cfs x1000)
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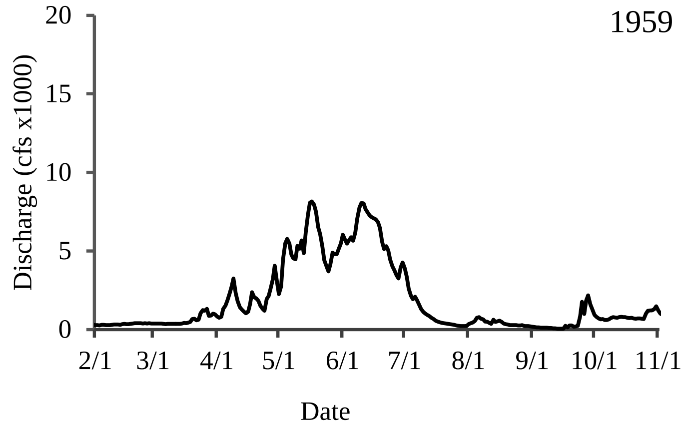
Date


1959
Discharge (cfs x1000)
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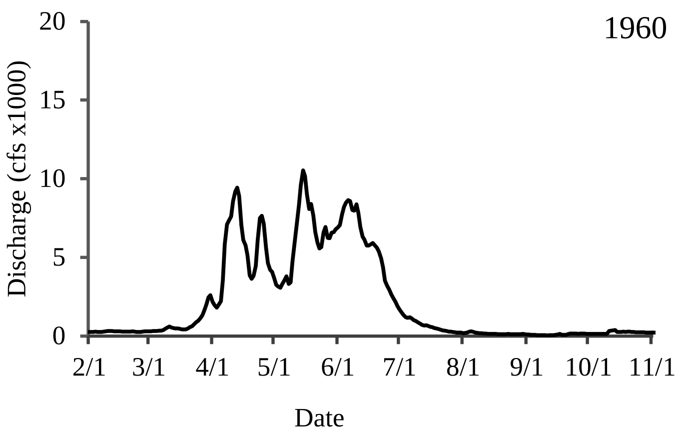
1960
Discharge (cfs x1000)
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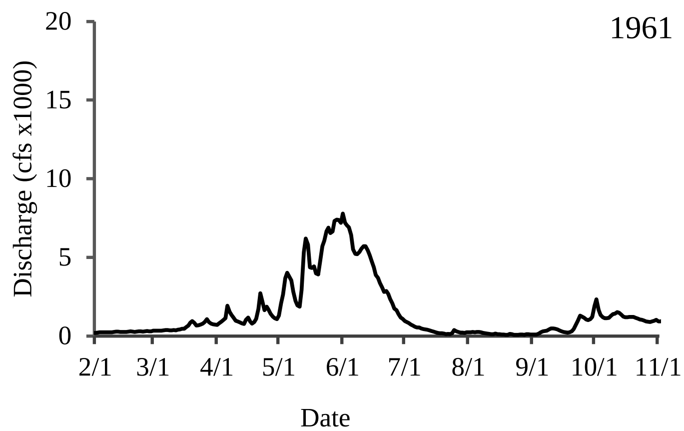
Date


1961
Discharge (cfs x1000)
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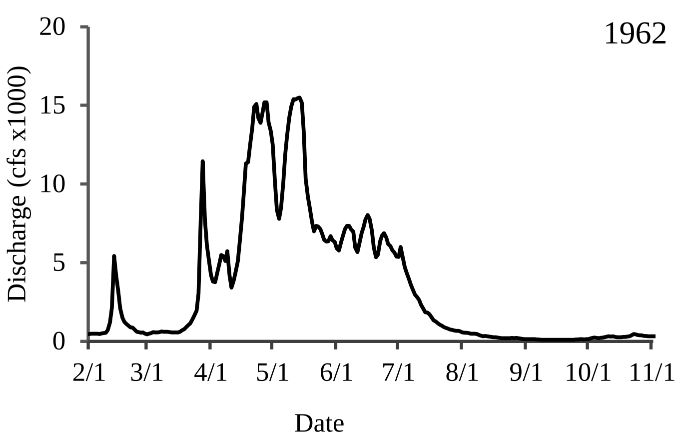
Date


1962
Discharge (cfs x1000)
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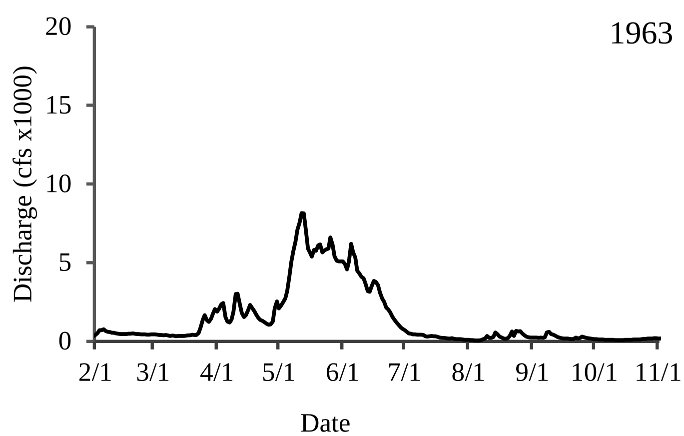
Date


1963
Discharge (cfs x1000)
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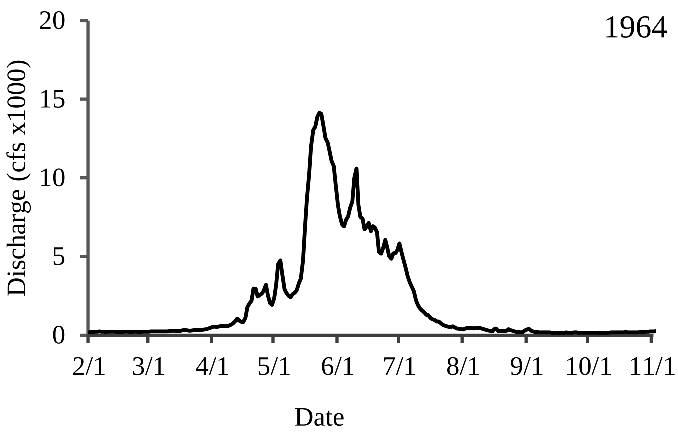
Date


1964
Discharge (cfs x1000)
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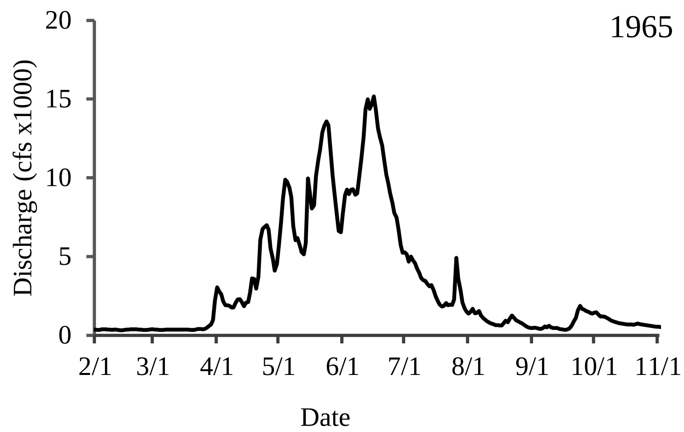
2/1 3/1 4/1 5/1 6/1 7/1 8/1 9/1 10/1 11/1
Date


1965
Discharge (cfs x1000)
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15
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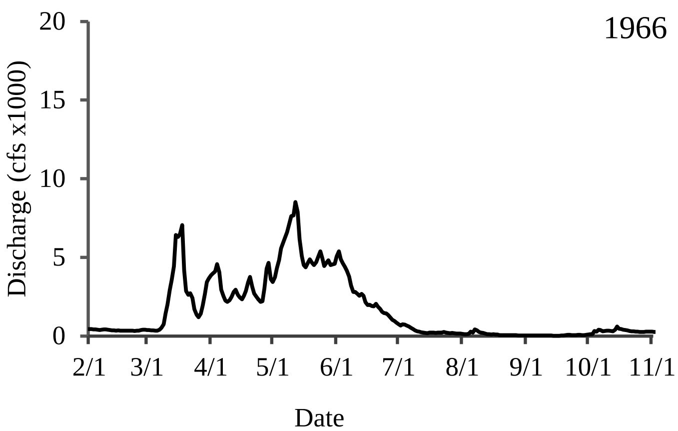
2/1 3/1 4/1 5/1 6/1 7/1 8/1 9/1 10/1 11/1
Date


1966
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15
10
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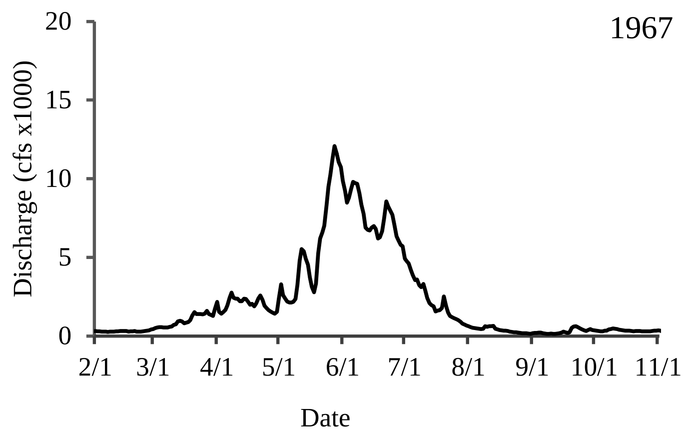
Date


1967
Discharge (cfs x1000)
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15
10
5
0
2/1 3/1 4/1 5/1 6/1 7/1 8/1 9/1 10/1 11/1
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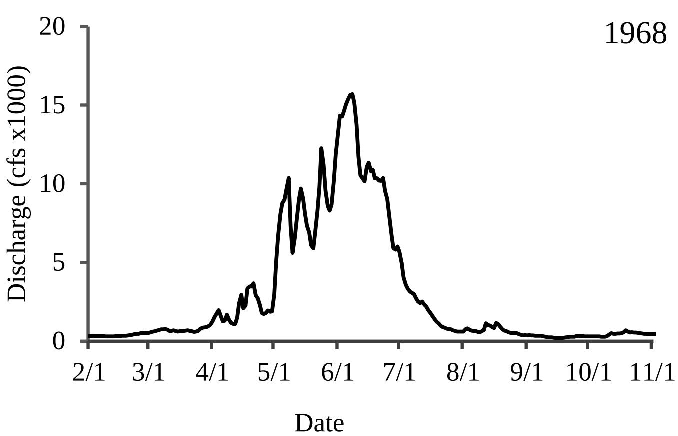
1968
Discharge (cfs x1000)
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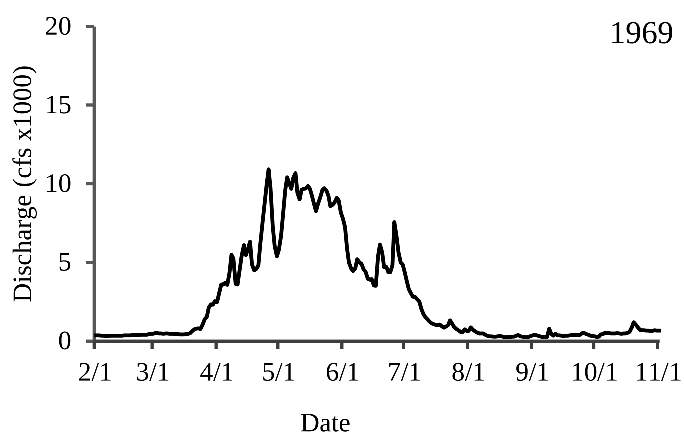
15
10
5
0
2/1 3/1 4/1 5/1 6/1 7/1 8/1 9/1 10/1 11/1
Date


1969
Discharge (cfs x1000)
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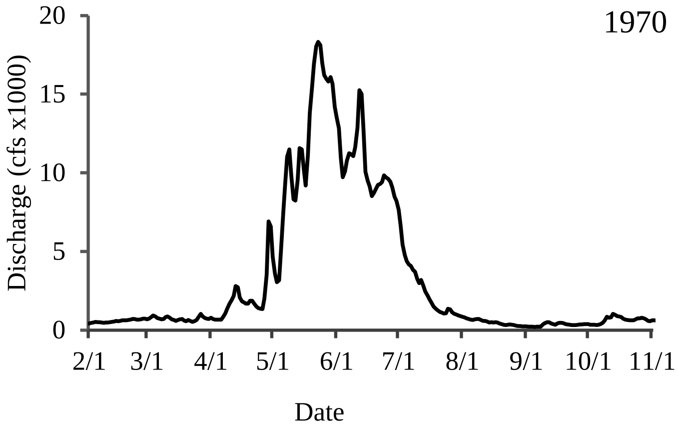
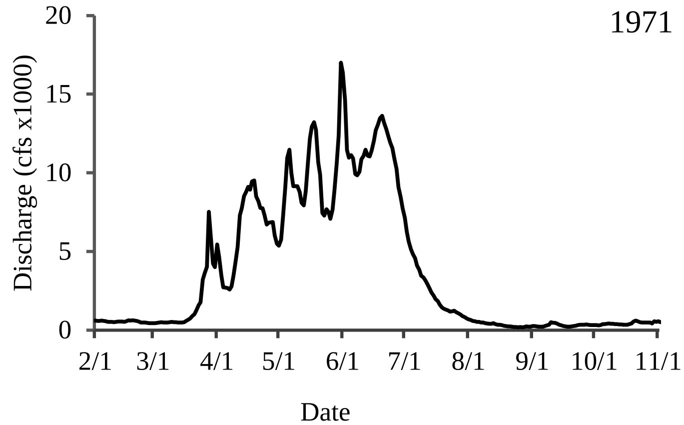
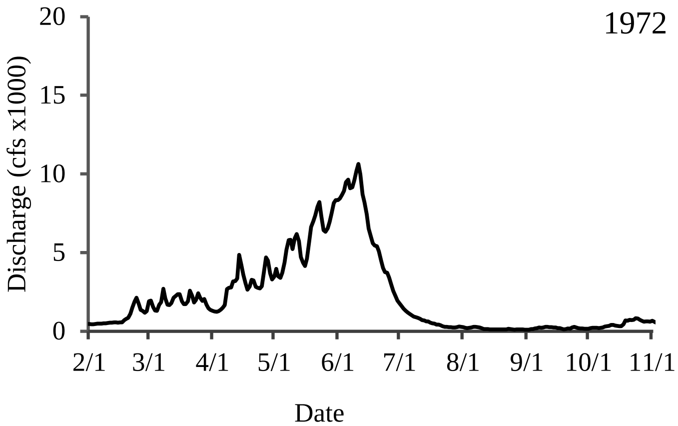
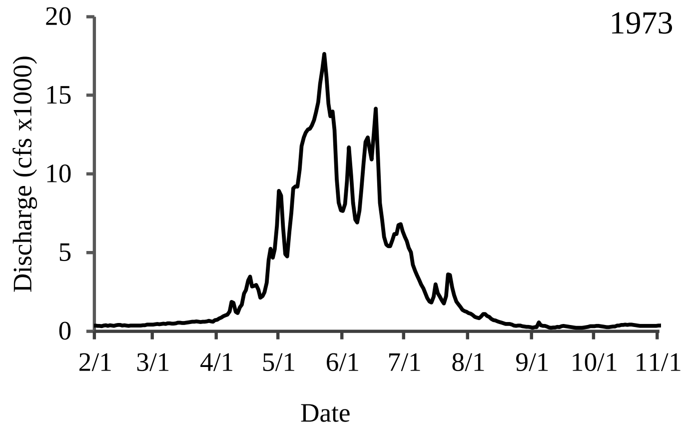
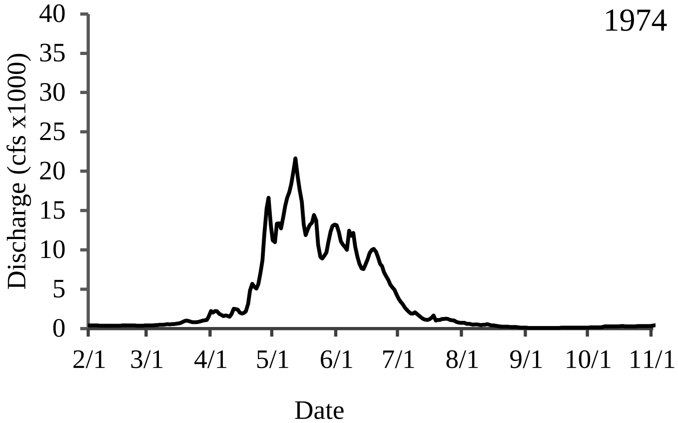
15
10
5
0
2/1 3/1 4/1 5/1 6/1 7/1 8/1 9/1 10/1 11/1
Date

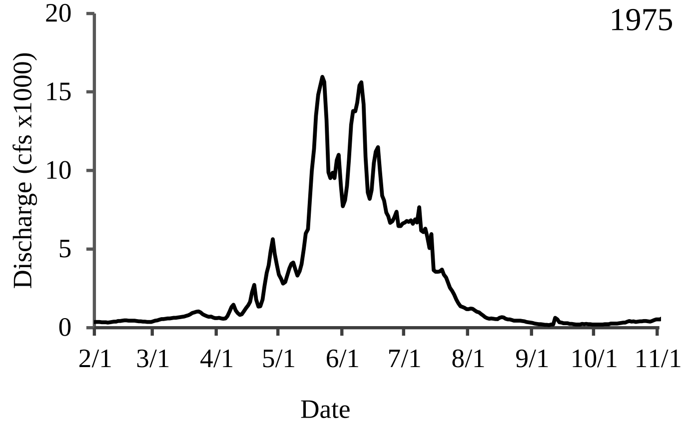

1970
Discharge (cfs x1000)
0
5
10
15
20
2/1
3/1
4/1
5/1
6/1
7/1
8/1
9/1
10/1
11/1
Date

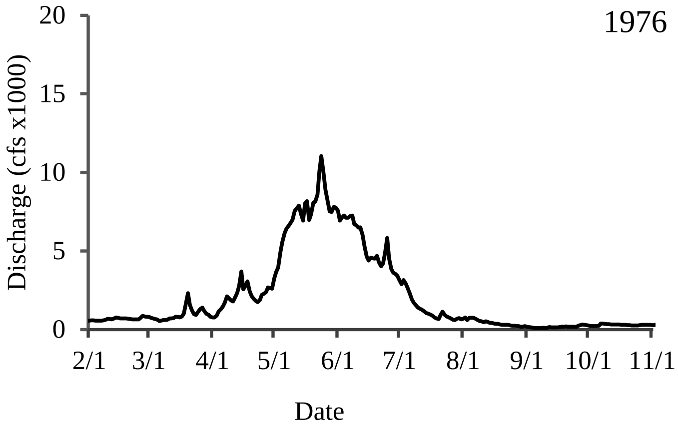

1971
Discharge (cfs x1000)
0
5
10
15
20
2/1
3/1
4/1
5/1
6/1
7/1
8/1
9/1
10/1
11/1
Date


1972
Discharge (cfs x1000)
0
5
10
15
20
2/1
3/1
4/1
5/1
6/1
7/1
8/1
9/1
10/1
11/1
Date


1973
Discharge (cfs x1000)
0
5
10
15
20
2/1
3/1
4/1
5/1
6/1
7/1
8/1
9/1
10/1
11/1
Date


1974
Discharge (cfs x1000)
0
5
10
15
20
25
30
35
40
2/1
3/1
4/1
5/1
6/1
7/1
8/1
9/1
10/1
11/1
Date


1975
Discharge (cfs x1000)
0
5
10
15
20
2/1
3/1
4/1
5/1
6/1
7/1
8/1
9/1
10/1
11/1
Date


1976
Discharge (cfs x1000)
0
5
10
15
20
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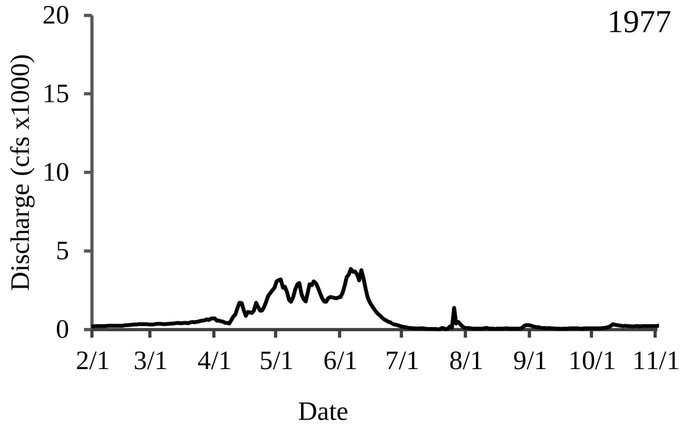
3/1
4/1
5/1
6/1
7/1
8/1
9/1
10/1
11/1
Date


1977
Discharge (cfs x1000)
0
5
10
15
20
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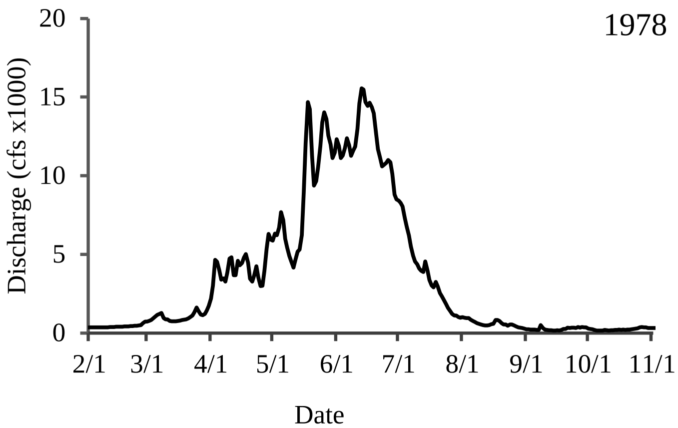
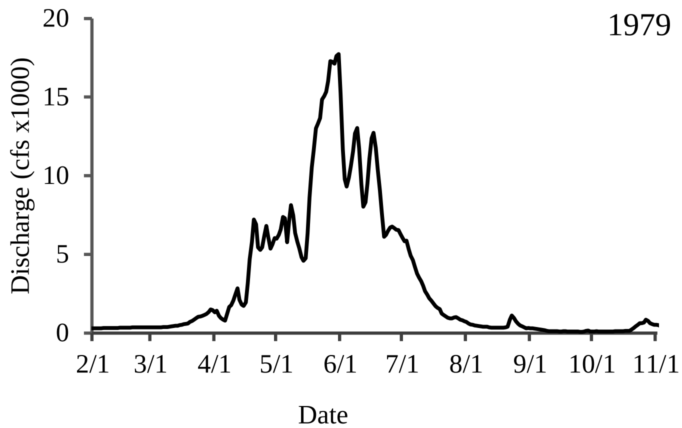
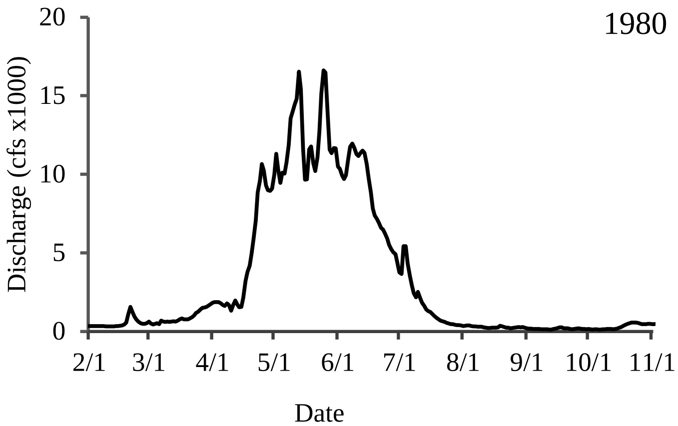
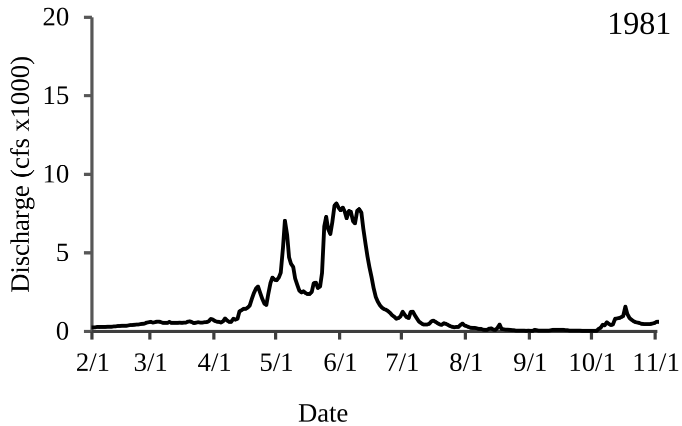
3/1
4/1
5/1
6/1
7/1
8/1
9/1
10/1
11/1
Date


1978
Discharge (cfs x1000)
0
5
10
15
20
2/1
3/1
4/1
5/1
6/1
7/1
8/1
9/1
10/1
11/1
Date


1979
Discharge (cfs x1000)
0
5
10
15
20
2/1
3/1
4/1
5/1
6/1
7/1
8/1
9/1
10/1
11/1
Date


1980
Discharge (cfs x1000)
0
5
10
15
20
2/1
3/1
4/1
5/1
6/1
7/1
8/1
9/1
10/1
11/1
Date


1981
Discharge (cfs x1000)
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10
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20
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3/1
4/1
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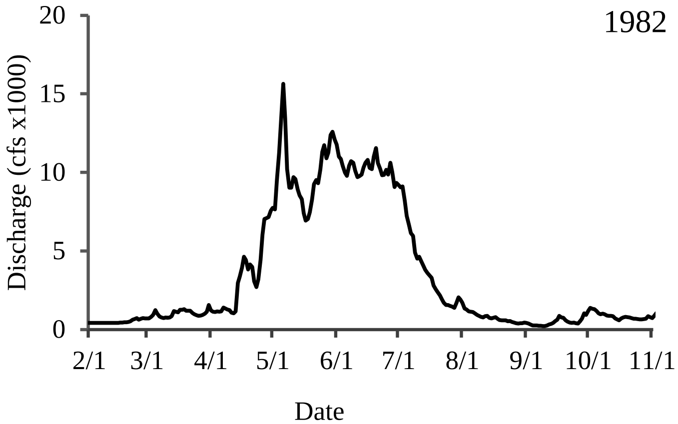
8/1
9/1
10/1
11/1
Date


1982
Discharge (cfs x1000)
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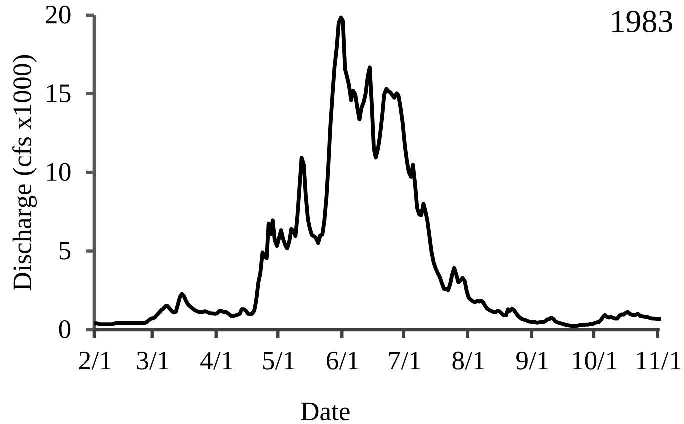
2/1 3/1 4/1 5/1 6/1 7/1 8/1 9/1 10/1 11/1
Date


1983
Discharge (cfs x1000)
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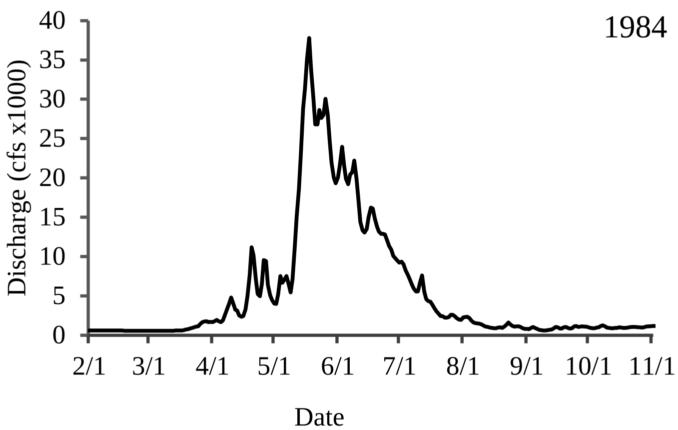
0
2/1 3/1 4/1 5/1 6/1 7/1 8/1 9/1 10/1 11/1
Date


1984
Discharge (cfs x1000)
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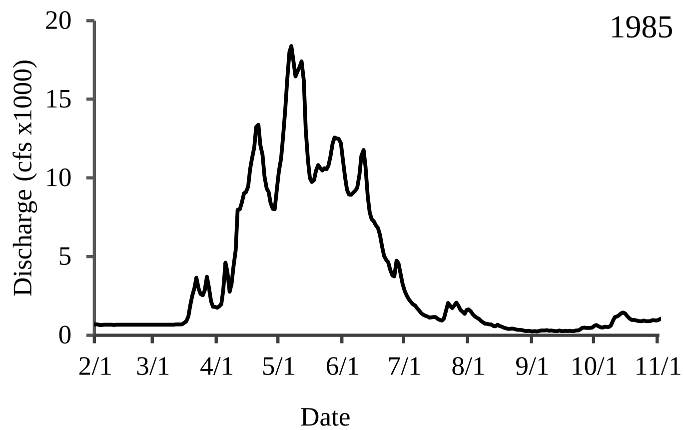
Date


1985
Discharge (cfs x1000)
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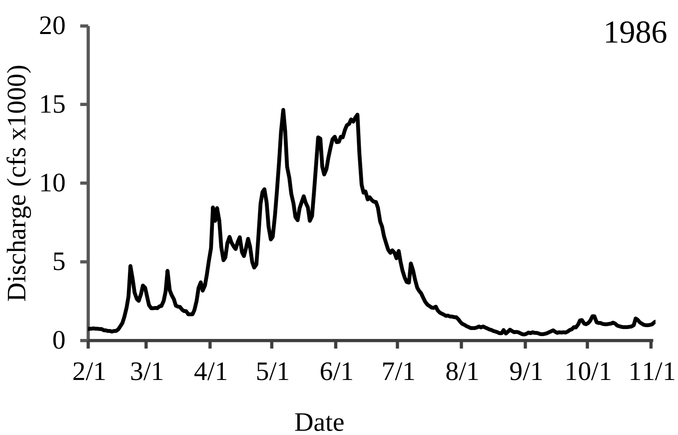
1986
Discharge (cfs x1000)
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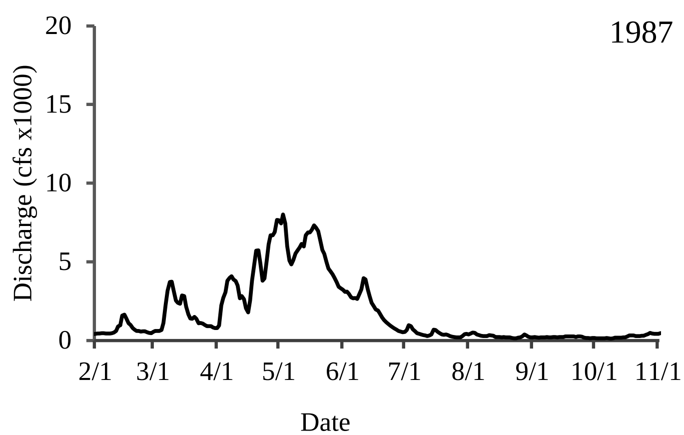
1987
Discharge (cfs x1000)
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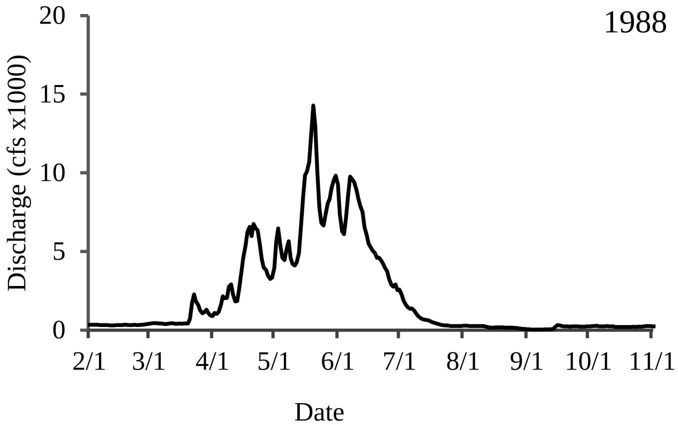
1988
Discharge (cfs x1000)
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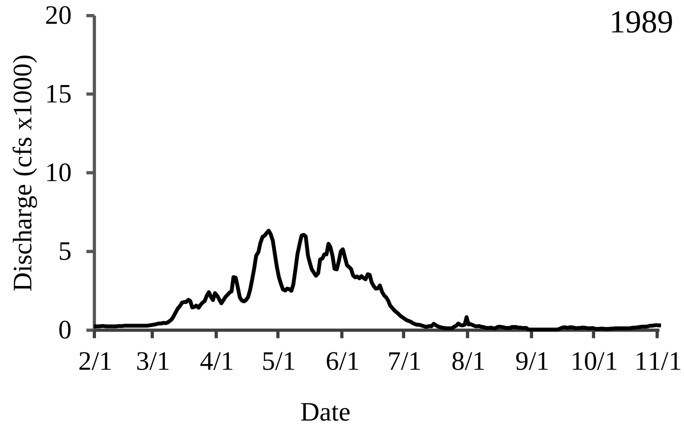
Date


1989
Discharge (cfs x1000)
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2/1 3/1 4/1 5/1 6/1 7/1 8/1 9/1 10/1 11/1
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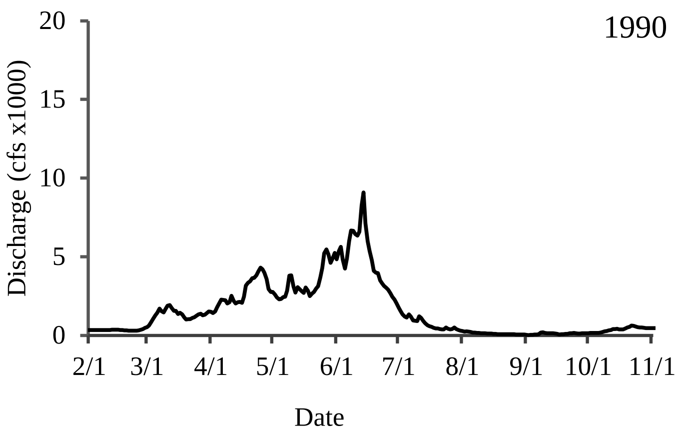
1990
Discharge (cfs x1000)
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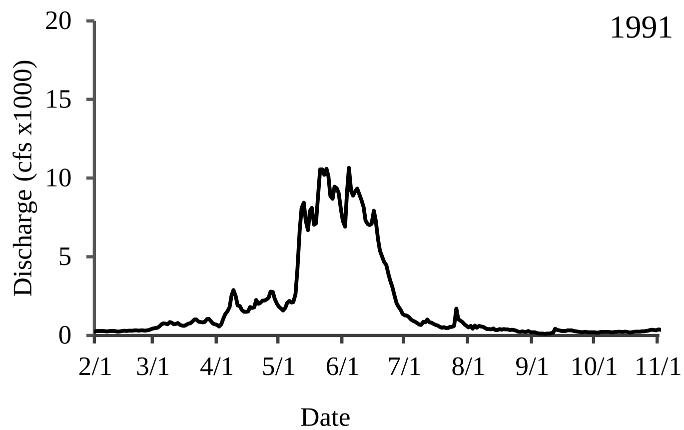
2/1 3/1 4/1 5/1 6/1 7/1 8/1 9/1 10/1 11/1
Date


1991
Discharge (cfs x1000)
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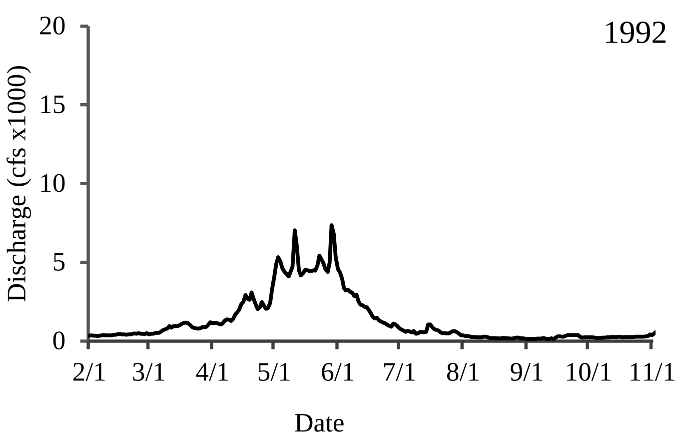
2/1 3/1 4/1 5/1 6/1 7/1 8/1 9/1 10/1 11/1
Date


1992
Discharge (cfs x1000)
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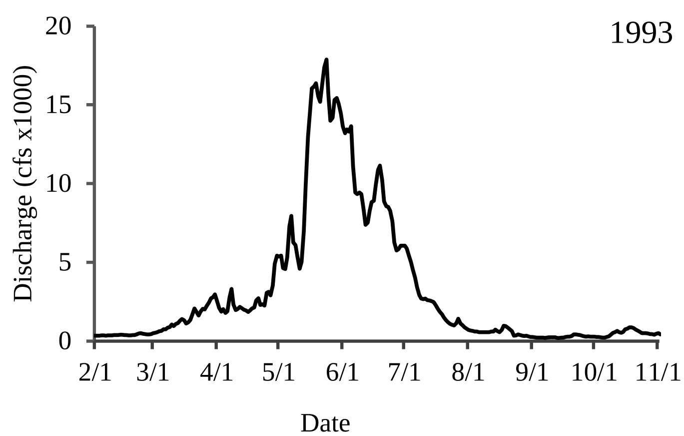
20
2/1 3/1 4/1 5/1 6/1 7/1 8/1 9/1 10/1 11/1
Date


1993
Discharge (cfs x1000)
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15
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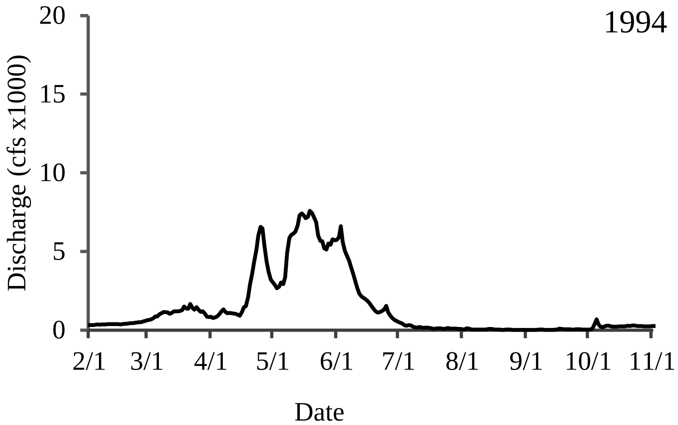
Date


1994
Discharge (cfs x1000)
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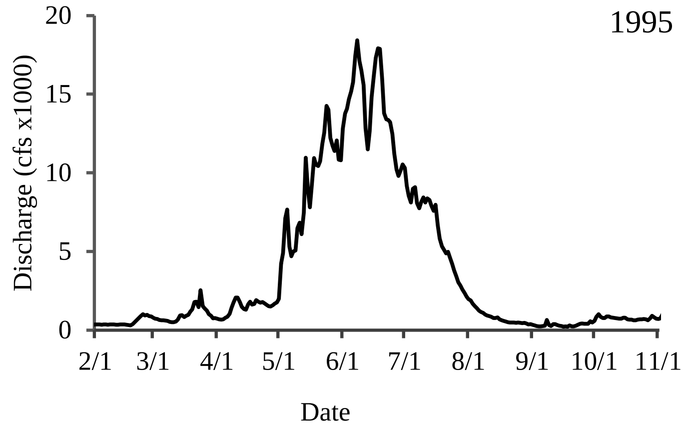
15
20
2/1 3/1 4/1 5/1 6/1 7/1 8/1 9/1 10/1 11/1
Date


1995
Discharge (cfs x1000)
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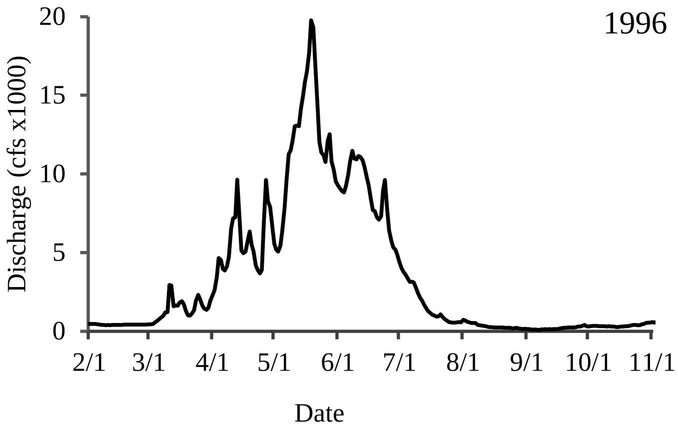
10
15
20
2/1 3/1 4/1 5/1 6/1 7/1 8/1 9/1 10/1 11/1
Date


1996
Discharge (cfs x1000)
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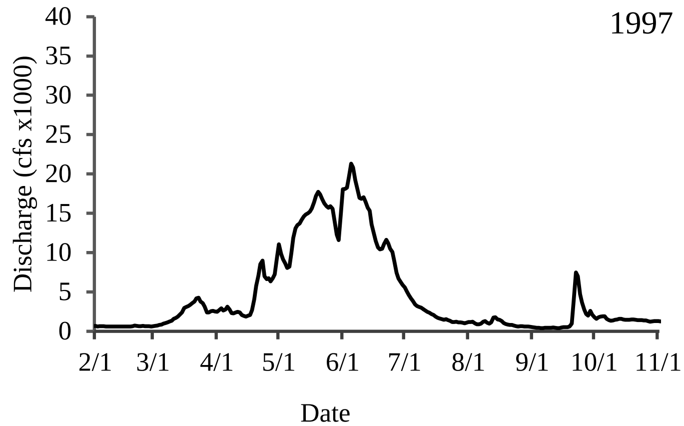
10
15
20
2/1 3/1 4/1 5/1 6/1 7/1 8/1 9/1 10/1 11/1
Date


1997
Discharge (cfs x1000)
0
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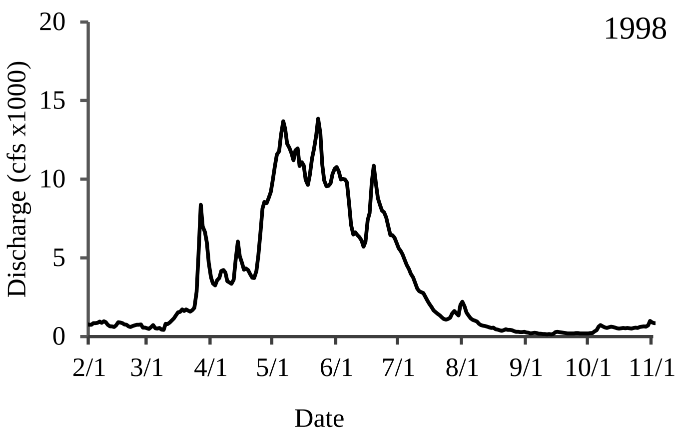
10
15
20
25
30
35
40
2/1 3/1 4/1 5/1 6/1 7/1 8/1 9/1 10/1 11/1
Date


1998
Discharge (cfs x1000)
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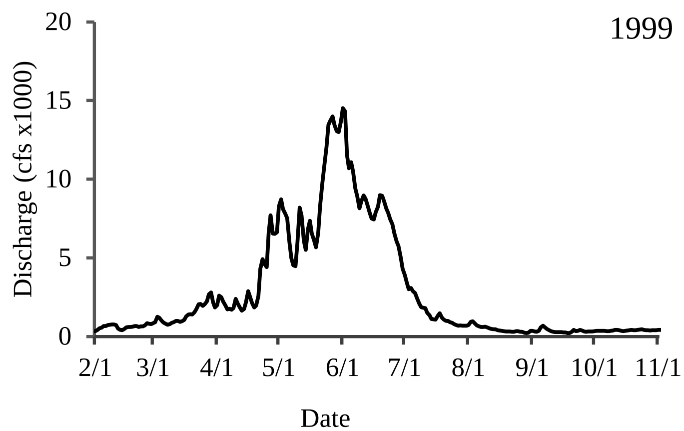
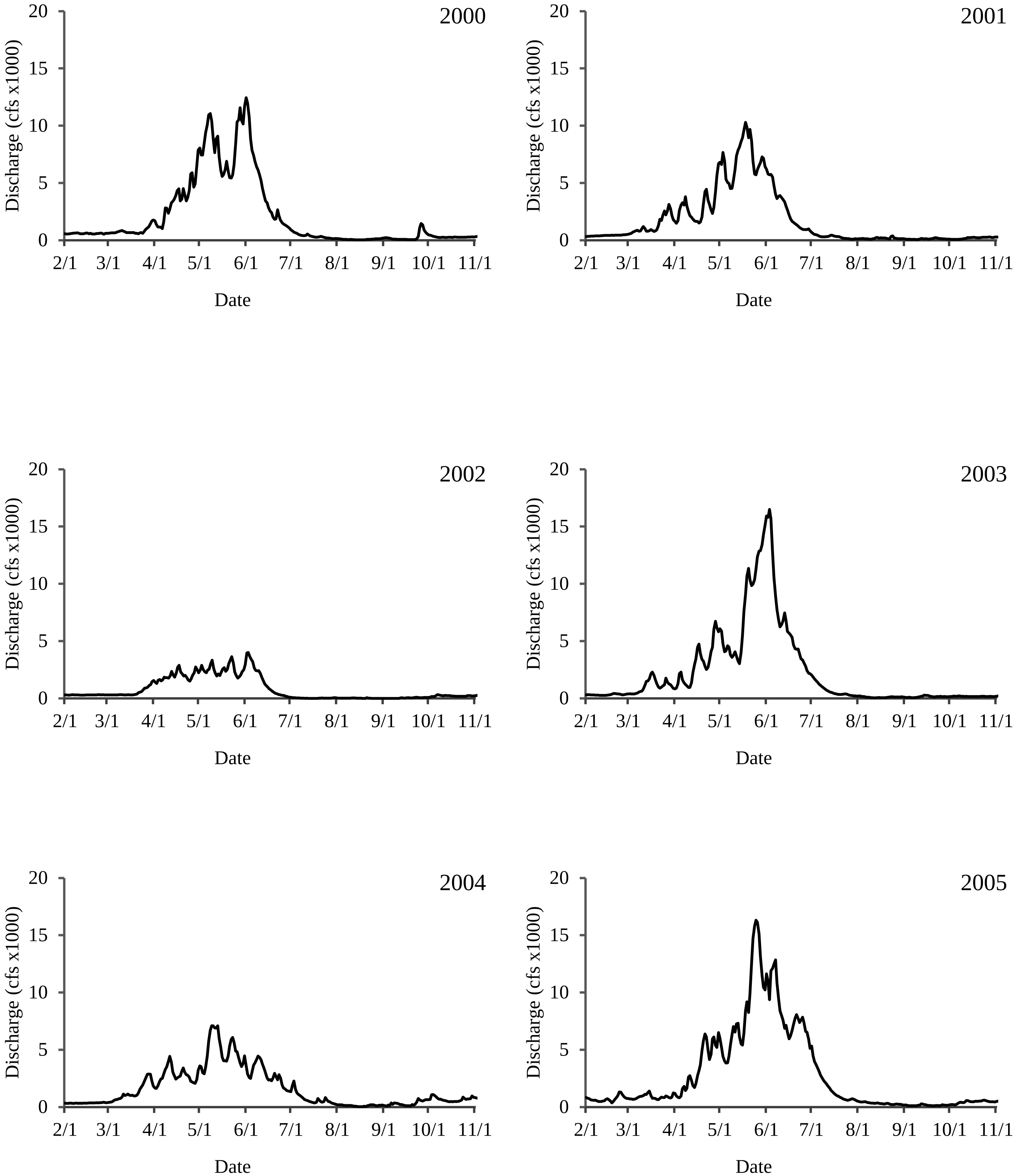
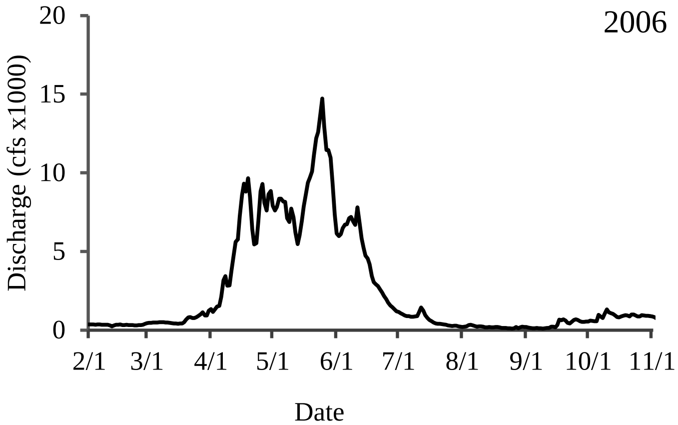
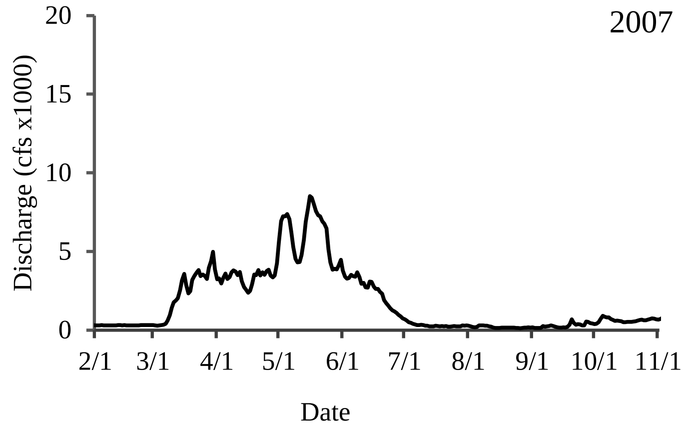
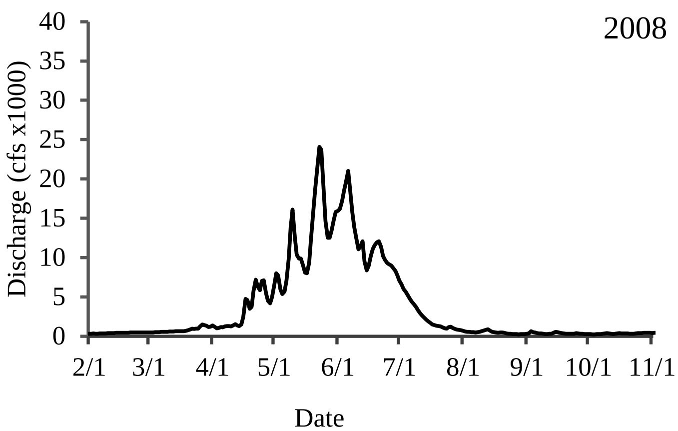
5
10
15
20
2/1 3/1 4/1 5/1 6/1 7/1 8/1 9/1 10/1 11/1
Date

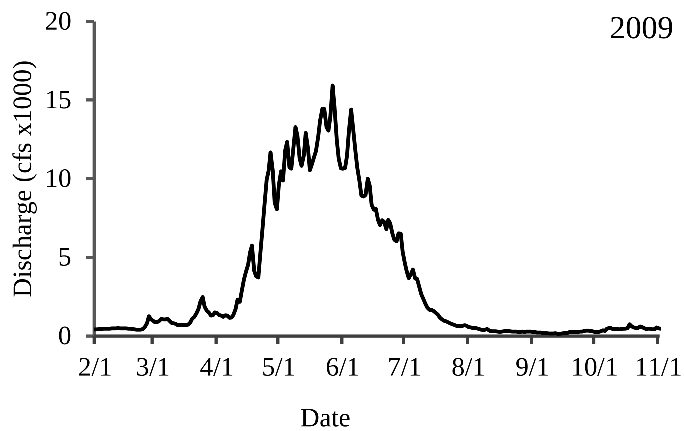

1999
Discharge (cfs x1000)
0
5
10
15
20
2/1 3/1 4/1 5/1 6/1 7/1 8/1 9/1 10/1 11/1
Date

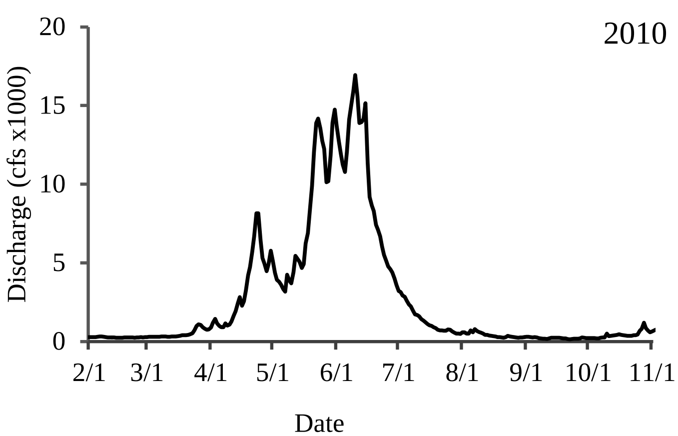

2000
2001
2002
2003
2004
2005
Discharge (cfs x1000)
0
5
10
15
20
2/1
3/1
4/1
5/1
6/1
7/1
8/1
9/1
10/1
11/1
Date

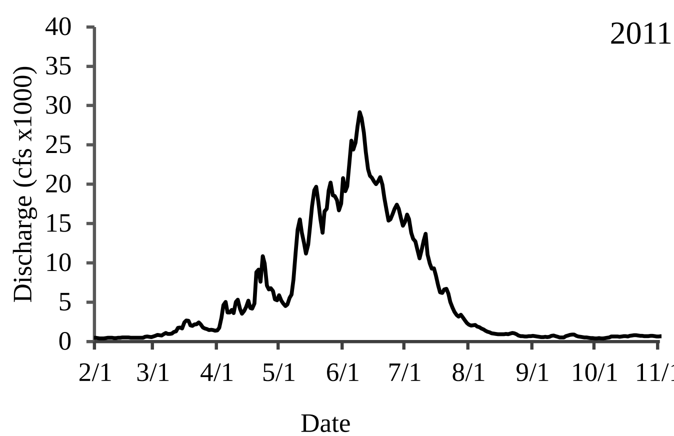

2006
Discharge (cfs x1000)
20
15
10
5
0
2/1 3/1 4/1 5/1 6/1 7/1 8/1 9/1 10/1 11/1
Date

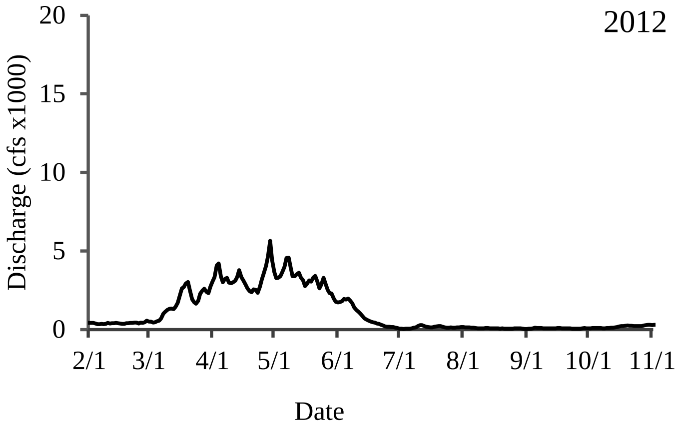

2007
Discharge (cfs x1000)
20
15
10
5
0
2/1 3/1 4/1 5/1 6/1 7/1 8/1 9/1 10/1 11/1
Date

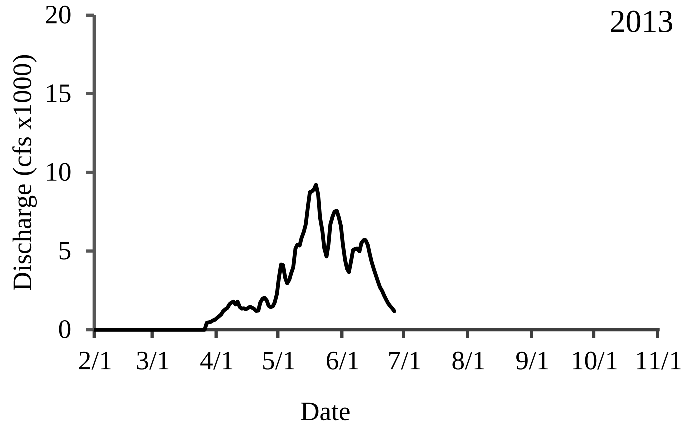

2008
Discharge (cfs x1000)
40
35
30
25
20
15
10
5
0
2/1 3/1 4/1 5/1 6/1 7/1 8/1 9/1 10/1 11/1
Date


2009
Discharge (cfs x1000)
20
15
10
5
0
2/1 3/1 4/1 5/1 6/1 7/1 8/1 9/1 10/1 11/1
Date


2010
Discharge (cfs x1000)
20
15
10
5
0
2/1 3/1 4/1 5/1 6/1 7/1 8/1 9/1 10/1 11/1
Date


2011
Discharge (cfs x1000)
40
35
30
25
20
15
10
5
0
2/1 3/1 4/1 5/1 6/1 7/1 8/1 9/1 10/1 11/1
Date


2012
Discharge (cfs x1000)
20
15
10
5
0
2/1 3/1 4/1 5/1 6/1 7/1 8/1 9/1 10/1 11/1
Date


2013
Discharge (cfs x1000)
20
15
10
5
0
2/1 3/1 4/1 5/1 6/1 7/1 8/1 9/1 10/1 11/1
Date

The Department of the Interior protects and manages the nation's natural resources and cultural heritage; provides scientific and other information about those resources; and honors its special responsibilities to American Indians, Alaska Natives, and affiliated Island Communities.

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National Park Service
U.S. Department of the Interior

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