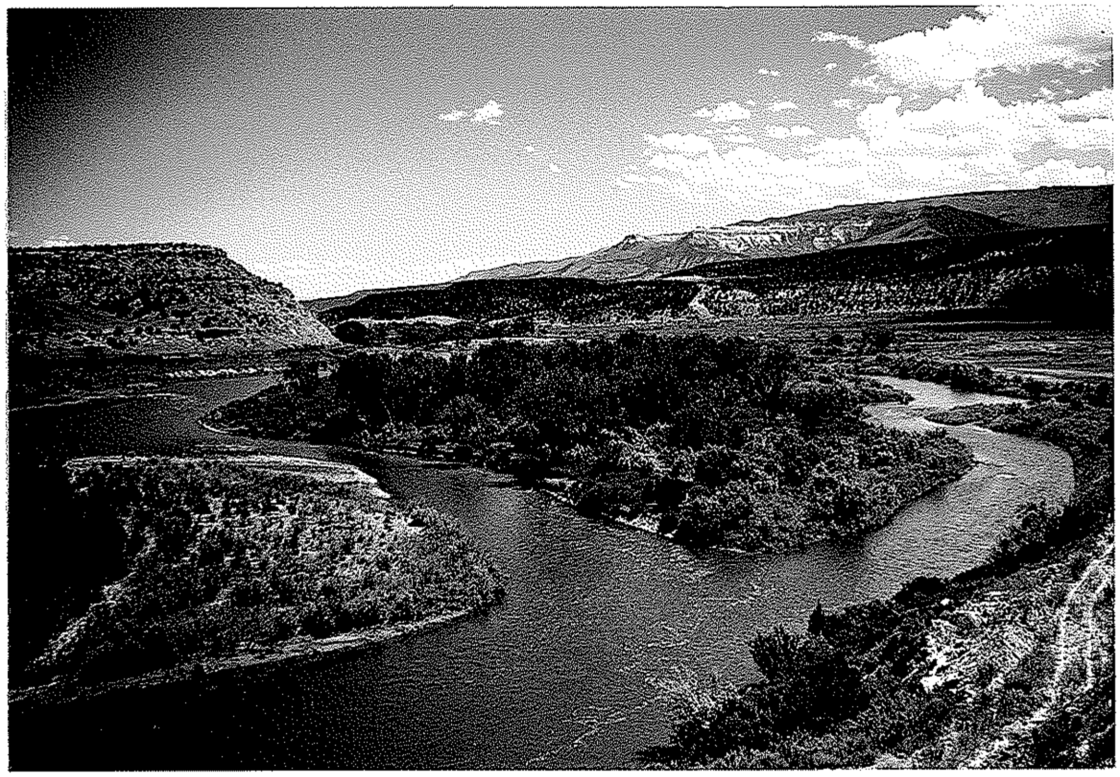
U.S. Fish & Wildlife Service

FLOW REGIMES FOR RESTORATION AND MAINTENANCE OF SUFFICIENT HABITAT TO RECOVER ENDANGERED RAZORBACK SUCKER AND COLORADO PIKEMINNOW IN THE UPPER COLORADO RIVER



Interim Recommendations for the Palisade-to-Rifle Reach

Flow Regimes for Restoration and Maintenance of Sufficient Habitat to Recover Endangered Razorback Sucker and Colorado Pikeminnow in the Upper Colorado River: Interim Recommendations for the Palisade-to-Rifle Reach

Final Report

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TABLE OF CONTENTS

TABLE OF CONTENTS (Continued)

LIST OF TABLES

Appendix Tables

LIST OF FIGURES

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EXECUTIVE SUMMARY

Suitable flow regimes are needed to promote recovery of endangered fishes in the upper Colorado River (USFWS 1987, USFWS 2000), and legal protection of instream flows is required before delisting can occur (USFWS 2001). In addition to improving adult habitat by providing more optimum flows in areas currently occupied by the endangered fish, the Recovery Program seeks to increase the extent of adult habitat by providing passage facilities at diversion structures that have historically prevented access to once occupied reaches. One such reach is the Colorado River upstream of Palisade, Colorado. Assuming future Recovery Program activities are successful in repopulating the area between and above the diversions with Colorado pikeminnow *Ptychocheilus lucius* and razorback sucker *Xyrauchen texanus*, flow regimes suitable for these fish will need to be provided. This report identifies such flows. In doing so, needs of the fish within these reaches are considered as well as those of fish downstream, also affected by such flows.

For summer and winter, recommendations are based largely on the determination of what flow levels maximize the amount of those habitats most used by razorback sucker and preferred by Colorado pikeminnow. Because these fish are essentially absent upstream of the diversions, reach-specific habitat-use and habitat preference information is lacking. Also, habitat mapping of representative reaches at various discharges is required before flow levels that maximize certain habitats can be determined. To date, such mapping within the subject reaches at base flows has been very limited. At this time, the only practical approach for developing summer and winter flow recommendations is to use results from the Grand Valley as a surrogate for more reach-specific information. Therefore, interim recommendations presented here are based on the assumption that habitats preferred in these upstream reaches will be the same as those in the 15-mile reach immediately downstream and that flow levels that maximize these habitats will be similar among reaches. In general, the recommendation for summer and winter are for flows to be between 1,600 and 2,500 cfs.

In determining optimum flows for spring, a primary goal was to assure that high runoff flows provide the sediment transport function necessary for channel maintenance such that important habitat types remain available and fine sediment deposition problems do not develop. Thus, flow recommendations for spring are aimed more at maintaining and enhancing these effects than for maximizing rare fish habitat used during the spring months as was the case for the summer and winter periods. The exception to this is to assure that certain key habitats (i.e., flooded bottomlands) used by razorback suckers during the spring spawning period are provided periodically. The bankfull discharge is a critical level during spring because it is a threshold for important sediment transport processes as well as the level at which over-bank flooding appreciably begins, thereby providing razorback sucker larvae with critical nursery habitat. Reach-specific geomorphic studies indicated that the magnitudes of the bankfull discharges in De Beque Canyon and in the floodplain upstream of De Beque were very similar to the bankfull discharge in the downstream 15-mile reach. It is recommended that this bankfull discharge be reached in all above-average and wet years. Mean monthly flows for all years and peak flows for below-average and dry years follow those previously recommended for the 15-mile reach.

Although the recommendations presented here are a best estimate of flows that will most benefit future populations of the endangered fish, there are constraints to implementing these recommendations. These constraints are due to the demands of the irrigation and power canals that divert large amounts of water from the river during summer and, to a lesser extent, during winter. As long as current operations at these diversions continue, flows required at Cameo must be high enough to supply the canals and satisfy the 15-mile reach needs as well. During the summer this can result in more water in the river than is optimum for the endangered fish upstream of Cameo. Conversely, during the winter, flows in the reach between the diversions can get too low for the fish. These constraints are discussed and the flows that satisfy all needs to the greatest extent possible are described.

INTRODUCTION

The goal for recovery of the endangered fishes of the Colorado River is to achieve naturally self-sustaining populations and to protect the habitat on which they depend (USFWS 1987, USFWS 2000, USFWS 2001). Identification and protection of instream flows for the endangered fish is required before delisting can occur (USFWS 2001) and is one of seven elements of the Recovery Implementation Program Recovery Action Plan (RIPRAP). Section 2.1 of the RIPRAP (USFWS 2000) discusses this element as follows:

"Recovery cannot be accomplished without protecting and managing sufficient habitat to support self-sustaining populations of the endangered fishes. Protecting instream flows is key to protecting the habitat of these fishes. The first step in instream flow protection is to identify the flow regimes needed by the fish. In the Recovery Program, determining flow needs is primarily the responsibility of the Fish and Wildlife Service (in cooperation with other participants). Factors considered in determining flow needs include: flow effects on reproduction and recruitment; flow effects on food supplies and nonnative fishes; and interrelationships between flow and other habitat parameters believed to be important to the fish, such as channel structure, sediment transport, substrate characteristics, vegetative encroachment, and water temperature. Flow recommendations (for all or certain seasons) have been or are being developed for most river reaches targeted for recovery in the upper basin. Flow recommendations often are made in stages, with initial flow recommendations based on the best available scientific information, historic conditions, and extrapolation from similar reaches. Recommendations then are refined following additional field research."

To date, flow regimes needed to assist recovery of Colorado River populations of Colorado pikeminnow (*Ptychocheilus lucius*) and razorback sucker (*Xyrauchen texanus*) have been identified for a 15-mile reach between the Grand Valley diversion dam at Palisade, Colorado and the Gunnison River confluence, hereinafter referred to as the '15-mile reach' (Osmundson et al. 1995). In addition, recommendations for the Gunnison River downstream of Delta, Colorado and the Colorado River downstream of the Gunnison River confluence are currently being developed as part of the Aspinall Unit biological opinion process (McAda 2001).

In addition to improving adult habitat by providing more optimum flows in areas currently occupied by the endangered fish, the Recovery Program seeks to increase the extent of adult habitat by providing passage facilities at diversion structures that have historically prevented access to once occupied reaches. One such reach is the Colorado River upstream of Palisade, Colorado. Three diversion dams occur within a 13-km (8-mile) stretch just upstream of Palisade and have prevented upstream movement of fish for over 80 years (Anderson 1997). Assuming that future Recovery Program activities (construction of fish passage facilities, razorback sucker stocking and bottomland restoration) are successful in repopulating the reaches between and above the diversions with razorback sucker and Colorado pikeminnow, flow regimes suitable for these fish will need to be provided. This report provides initial recommendations for suitable flow regimes during the summer and winter periods based on the best scientific information, historic conditions, and extrapolation from similar reaches, as discussed in the RIPRAP (see above). Refinement of summer and winter recommendations will require additional site-specific field research. However, for the spring period (April-July), site-specific research has already been conducted and the relevant findings are incorporated in this report and no additional studies to further refine spring recommendations are anticipated. Hence, this report identifies flow regimes needed by the fish during spring and provides interim recommendations for summer and winter. In doing so, needs of the fish within these reaches are considered as well as those of fish downstream, also affected by such flows.

Background

The Grand Valley Irrigation Company Diversion Dam (GVICDD), at the top of the 15-mile reach, was constructed in 1883 and supplies water to the Grand Valley Canal (Fig. 1). Only 0.9-1.2 m (3-4 feet) high, it blocked upstream movement of fishes only during periods of low flow. The Bureau of Reclamation (USBR) modified this structure in 1998 to allow passage during all but the very lowest flows (Burdick 1999). A second diversion structure, the Price-Stubb dam, was constructed in 1911 three miles farther upstream; it stands 3 m (10 ft) high and blocks upstream movement of fish at all flow levels. However, water is no longer diverted at this structure. A Colorado pikeminnow implanted with a radio-tag in the 15-mile reach was tracked upstream of GVICDD to the base of the Price-Stubb Dam two summers in a row (Osmundson and Kaeding 1989), and several adult Colorado pikeminnow have been captured in this 5-km (3-mile) reach in recent years (USFWS unpublished data). A third dam, the Grand Valley Project Diversion Dam (GVPDD), is located about 8 km (5 miles) upstream of the Price-Stubb dam. This dam,

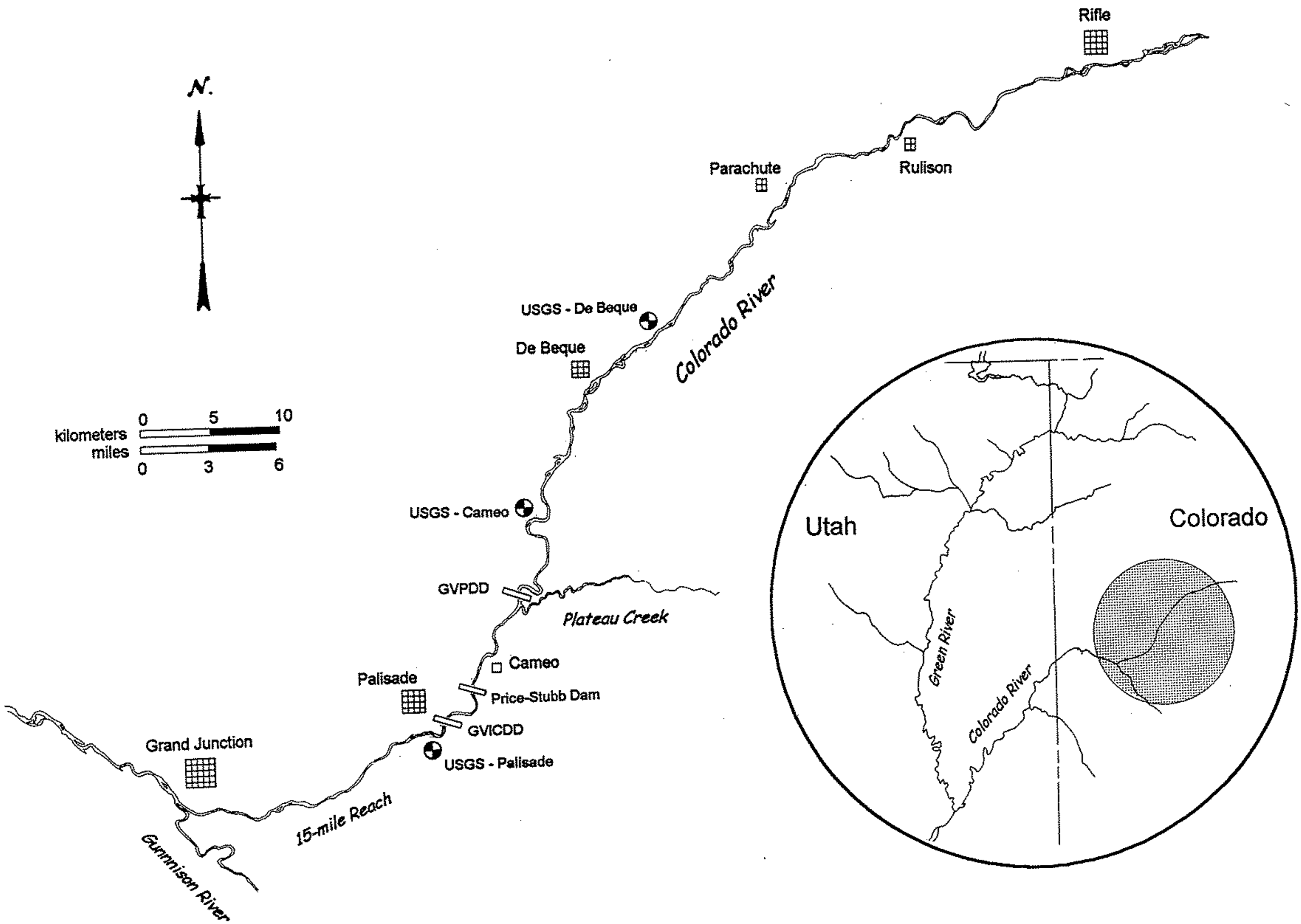

Figure 1. Map of the Colorado River from Grand Junction to Rifle, Colorado. GVICDD: Grand Valley Irrigation Company Diversion Dam; GVPDD: Grand Valley Project Diversion Dam. Crossed circles indicate location of USGS (United States Geological Survey) gauges: at Palisade No. 09106150; at Cameo No. 09095500; at De Beque No. 09093700.

completed in 1916, provides water to the Government Highline Canal and the Orchard Mesa Power Canal. It stands 4.3 m (14 feet) high and is also a barrier to upstream movement of fish at all flow levels. Because of water withdrawal for the Government Highline and Grand Valley canals, flows during the irrigation season vary considerably among the three contiguous reaches: the most upstream reach, GVPDD-to-Rifle, has the most water, the GVICDD-to-GVPDD reach has a moderate amount, and the 15-mile reach (downstream of GVICDD) has the least. Because no water is removed at the Price-Stubb Dam, the 5-km (3-mile) segment downstream and the 8-km (5-mile) segment upstream of this structure experience the same flow regime. Plateau Creek enters the Colorado River just downstream of GVPDD, but during summer provides a relatively small contribution of water, averaging 20-60 cubic feet per second (cfs).

Capture records indicate the De Beque-to-Rifle reach has provided important habitat to razorback suckers up until recent times (Kidd 1977, Valdez et al. 1982, W. Elmblad, Colorado Division of Wildlife [CDOW], unpublished data). Fish biologist George Kidd, conducting fish surveys in the mid-1970s, located several hundred spawning razorback suckers around June 1 in a zero-velocity, 3.2 h (8-acre) pool situated on the north side of the river just upstream of De Beque, Colorado. More than 70 adults were caught in trammel nets in two hours and eggs were collected from the substrate (George Kidd, personal communication). Also, a longtime area fisherman reported that he used to catch 2-4 "humpback suckers" (razorbacks) per day in a slough just downstream of Rulison during 1938-1940 (Simon Wadell, personal communication). More recently, a single adult was captured by CDOW personnel from a riverside pond 9.7 km (6 miles) downstream of Rifle, Colorado in 1991 and a total of 165 different adults were captured from a pond 1.6 km (1 mile) downstream from the town of De Beque during 1992-1993 (W. Elmblad, personal communication). These recent observations prompted the U. S. Fish and Wildlife Service (USFWS) to extend the designation of critical habitat for razorback sucker in the Colorado River upstream as far as the town of Rifle (USFWS 1994).

No observations are on record that would verify recent or historic use by Colorado pikeminnow of the two reaches upstream of the Price-Stubb Dam. Extensive surveys in the mid-1970s (Kidd 1977, G. Kidd, personal communication) and in the early 1980s (Valdez et al. 1982) failed to detect any Colorado pikeminnow in these upstream reaches. More recently, electrofishing surveys in the 1990's by CDOW (Anderson 1997) and USFWS (Wydoski 1994, Osmundson 1999, R. Burdick, unpublished data) also found none. One anecdotal observation from the 1960s appears to have merit; another probably does not. Robert Burdick, a USFWS biologist who has captured many Colorado pikeminnow during his professional career remembers his grandfather and he catching several Colorado pikeminnow in the lower end of Plateau Creek while angling for trout in the mid-1960s. The only other known observation is less reliable. Pressey (1968), a writer for a popular outdoors magazine, provided an account of an angling trip upstream of Glenwood Springs in 1963 during which he caught a fish he could not immediately identify; he later concluded the fish must have been a Colorado pikeminnow:

> "I was shocked to see a nearly black fish of about 15 inches" (380 mm) "that possessed cross-hatched scales of small size." "...The mouth of the fish was more toward the bottom of the head like a sucker, but still possessed the mandible-like action of a trout or bass."

The far upstream location of this observation (well within cold-water, salmonid habitat) and the author's description suggests a misidentification; however, as with other anecdotal information, readers are encouraged to judge for themselves the validity of such accounts.

Analysis of temperature regime suitability for Colorado pikeminnow indicates that individuals of this species are likely to establish year-round home ranges in the Colorado River as far upstream as De Beque, Colorado, if given the opportunity. Also, limited use by Colorado pikeminnow in reaches upstream of De Beque is anticipated (Osmundson 1999) based on observations of Colorado pikeminnow distribution in the Yampa (Nesler 1995) and Gunnison (Burdick 1995) rivers. Critical habitat for Colorado pikeminnow in the Colorado River extends upstream to Rifle, Colorado (USFWS 1994).

General Approach

Because no individuals of either species have been recently found in riverine habitats upstream of the Price-Stubb Dam, no habitat use data are available that might provide insight into which habitats are preferred. At this time, the only practicable approach for developing recommendations for summer and winter flows is to use information collected from the Grand Valley as a surrogate for more reach-specific information. However, one limitation to this approach is that razorback sucker habitat preference was not learned in prior studies in the Grand Valley because few habitat-use data were available from reaches where mesohabitats were later mapped. Habitat preferences of Colorado pikeminnow derived from the 15-mile reach can be used, but, the necessary mapping of meso-habitats (riffles, pools, eddies, etc.) at base flow levels in the Palisade-to-Rifle reach has been very limited. Such mapping is needed to discern at what discharge preferred habitat types are maximized (see approach used by Osmundson et al. [1995] for recommending base flows in the 15-mile reach). In the interim, it is assumed here that flow levels that maximize these habitats in the subject reaches will be similar to those that do so in the 15-mile reach.

The current practicality of implementing summer flow recommendations in these reaches is particularly problematic due to the local diversions of water for irrigation and power production. The senior water rights associated with these diversions will necessarily dictate a minimum amount of water delivered through these two reaches, particularly during the irrigation season. When this amount is added to the amount already recommended for endangered fish habitat in the 15-mile reach, the minimum delivery amount may be more or less than the flow level that most benefits endangered fish within these reaches. Assuming that these senior water rights will continue to be exercised and the amounts diverted remain constant, any lowering or raising of flows in the subject reaches will also be experienced downstream in the 15-mile reach. Thus, senior diversion rights and endangered fish flows in the 15-mile reach place constraints on flexibility of flow management in the reaches upstream of the diversions, particularly during late summer and early fall. This report provides recommendations for summer and winter flows in the Palisade-to-Rifle reaches based on what is considered best for the endangered fish within these reaches and then discusses the current constraints imposed on implementing these recommendations.

In determining optimum spring flows, Osmundson and Kaeding (1991) concluded that the greatest value of high flows, typical of spring, was the year-round benefits provided by the scouring and flushing action of the flood waters (i.e., channel maintenance, removal of fines from coarse substrates, control of encroaching vegetation, entrainment of organic debris into the system and control of non-native fish). Thus, flow recommendations for spring are aimed more at maintaining and enhancing these effects than for optimizing rare fish habitat used during the spring months as was the case for summer and winter. The exception to this is to assure that certain key habitats used by razorback sucker during spring are provided. This is because, unlike Colorado squawfish which spawn during summer, razorback suckers spawn in spring; thus, maintaining or enhancing appropriate habitats during this period is likely to be critical to reproduction and survival of young.

After this introduction, the report begins with a review of habitat use and a description of life history attributes of the two target species. Next is a section summarizing flow effects on important habitats and on critical life history processes. This is followed by a summary of current and historic hydrology of the subject reaches. Finally, objectives of flow management and specific recommendations for flows are provided.

RAZORBACK SUCKER

Information presented here regarding habitat use in the upper Colorado River is from reports by Osmundson and Kaeding (1989) and Osmundson et al. (1995) and is based on results of year-round radiotelemetry of razorback sucker in the Grand Valley during 1986-1988 (Appendix Table I). Habitats preferred by razorback suckers (those habitats used in greater proportion than their availability would predict) were not identified in those studies. Other attributes of the life history of this species as related to its flow needs were recently summarized by McAda (2001) and are reviewed here where appropriate.

Adult Habitat Use

Winter

Other than during the spawning period, individual razorback suckers have very localized home ranges. Though data are limited (3-15 observations per month; 1-4 different fish), the pattern includes an extended winter period that lasts from November through April. During this time, razorback suckers were primarily located in pools (61%) and slow runs (24%) and were occasionally found in low-velocity eddies (11%) associated with pools.

Spring

In April or May razorback suckers begin to move in search of spawning sites. Use of pools dropped off entirely during May while use of slow runs (36%) and backwaters (45%) increased. Flooded gravel pits become available during June and razorback suckers tend to seek out these sites for staging or spawning activities. Gravel pit ponds accounted for 43% of June observations.

Summer

There is no clear distinction between spring and summer periods for razorback sucker. July is a transitional month between the spring spawning period (late April through late June) and the late summer growing season (August through October). As seasonal flows decrease in July, flooded gravel pits become increasingly unavailable while backwaters, formed at the base of de-watered side channels, appear. Radio-telemetered razorbacks were located in such backwaters 36% of the time during July. Their use of pools and slow runs also increased during July. Along with the spring months of May and June, July was the only period that razorback suckers were sometimes found inhabiting shoreline habitat (7-9% of observations). During August-October, pools and slow runs were used almost exclusively, with the two habitats receiving approximately equal usage.

Other Life History Attributes

Reproduction

The timing of razorback sucker spawning appears to be related to a suite of environmental variables that vary substantially among basin locations and among years within locations. Spawning occurs earlier in the lower basin than in the upper basin. In reservoir habitat of Lake Mojave (lower basin), uninfluenced by seasonal flow patterns, most spawning occurs from January to April (Minckley 1983, Langhorst and Marsh 1986, Mueller 1989). In the Green River (upper basin), spawning occurs during mid- to late May in high water years and April to mid-May in low water years (Muth et al. 1998). In the upper Colorado River, capture dates for ripe adults during a 15-year period corresponded to the period when peak snow-melt runoff flows typically occur: of 42 ripe fish, 40 (95%) were captured between May 20 and June 17, and 84% of peak flows in the Grand Valley over an 83-yr period occurred between May 20 and June 23 (Osmundson and Kaeding 1991).

Migrations to spawning areas have been documented in upper basin rivers. In the Grand Valley, 2 adults migrated 11 and 26 km just prior to the estimated spawning period (Osmundson and Kaeding 1989); in the Green River, adults have migrated as far as 190 km (Tyus and Karp 1990). Razorback suckers in spawning condition are generally captured in the Green River system in one of two known mid-channel sites in riffles or shallow runs with a gravel or cobble substrate (Tyus and Karp 1990). In the lower basin, razorback suckers successfully spawn along gravel beaches of large reservoirs (Douglas 1952, Minckley 1983, Bozek et al. 1984, Mueller 1989, Holden et al. 1999). No mid-channel spawning sites have been located in the upper Colorado River. During 1974-1991, 38 of 42 adults in spawning condition captured in the Grand Valley were from flooded gravel pits (summarized by Osmundson and Kaeding 1991). It is unknown whether these fish, when caught, were staging in preparation for mid-channel spawning or whether they spawned in these off-channel habitats. McAda and Wydoski (1980) captured two ripe females and five ripe males in one trammel net in a large gravel-pit pond near Grand Junction and believed these fish were spawning at the time of capture.

Availability of appropriate temperatures plays an important role in reproductive success of fishes. Incubation time and hatching success of fertilized razorback sucker eggs varies with water temperature. After egg deposition and fertilization, embryos incubate in the substrate for varying lengths of time, with the shortest times occurring at the warmest temperatures (Haines 1995). In the Green River, mid-channel spawning results in larval production in water temperatures that average 14°C. Studies by Inslee (1982) and Hamman (1985) indicated that optimum temperatures for reproduction were 20-22°C. Marsh (1985) experimentally controlled temperature to determine effects on hatching success of razorback sucker eggs: of six temperatures, 20°C resulted in highest hatching success, followed by 25°C. There was a significantly lower hatching success at 15°C, and complete egg mortality at 5, 10, and 30°C. Haines (1995) performed similar experiments at temperatures of 12, 16 and 20°C, and found that hatching success increased with increasing temperatures and ranged from 48% (12°C) to 67% (20°C). The availability of water temperatures near 20°C immediately following spawning is therefore an important variable influencing the reproductive success of this species.

Main channel temperatures in the Colorado River during spring runoff, when razorback suckers are generally found in spawning condition, are well below the optimum for egg incubation and hatching success (20°C) averaging 13°C at Cameo (USGS gauge). Osmundson and Kaeding (1991) suggested that razorback suckers in the upper Colorado River may spawn in warm, flooded, off-channel habitats as a means to sidestep the cool waters of the main channel thereby allowing them to extend the limits of their range far upstream. Timing reproduction to coincide with spring runoff allows access to these flooded off-channel habitats. One benefit of off-channel spawning is the assurance that all larvae produced will be placed directly within, productive, rearing habitats (see below). Alternatively, mid-channel spawning of razorback suckers observed in the Green River system is believed to coincide with runoff to ensure that emerging larvae will have access to productive, flooded, off-channel habitats as they drift downstream (Tyus and Karp 1990, Muth et al. 1998).

Survival of young razorback suckers has been documented in two off-channel habitats in recent years: Old Charley Wash, beside the Green River in Utah, and Etter Pond, beside the Colorado River near De Beque, Colorado. Modde (1996) found 28 young-of-the-year (YOY) razorback suckers in Old Charley Wash in 1995 and Elmblad (CDOW, personal communication) captured 165 adults from Etter Pond. A Lincoln-Peterson mark-recapture effort provided an estimate of 575 adults in the pond (95% CI = 320-830). Genetic analyses of the Etter Pond fish indicated that almost all were siblings and otilith aging revealed most were hatched in 1983 or 1984, the year the pond flooded; however, one fish was 20+ years old (F. Pfeifer, USFWS, personal communication). It is unknown whether the younger fish drifted into this newly-excavated pond as larvae during the high spring flows of 1983 or 1984 or whether adults entered and spawned there producing the younger cohort. Similarly, in the wetland of Old Charley Wash, eight adults were found along with the 28 YOY (Modde 1996).

Growth

Rapid early-life growth of fishes promotes survival and decreases generation time (maturity is reached at an earlier age), boosting the potential for population increase (Kaeding and Osmundson 1988). For young razorback sucker, limited data suggests that growth rate is highly variable, and is strongly influenced by environmental conditions. At swim-up, larvae average 9-11 mm (Marsh 1985, Snyder and Muth 1990). At two months old, two YOY captured from a backwater in the Green River were 37-39 mm long (Gutermuth et al. 1994). The 28 YOY found in Old Charley Wash averaged 94 mm in late October of their first year (Modde 1996). The importance of providing young razorback suckers access to warm, off-channel habitats was demonstrated when 430 age-0 razorbacks averaging 55 mm long were stocked into a riverside, gravel-pit pond in June 1987. By mid-November they averaged 306 mm (Osmundson and Kaeding 1989). Near the end of the second growing season (late September 1988), average length (405 mm) had increased by 99 mm. In comparison, similar size-groups (200-400 mm) stocked into riverine habitats grew an average of 37 mm/yr in the San Juan River (Ryden 2000) and 62 mm/yr in the Gunnison River (B. Burdick, unpublished data). At the end of their third growing season, 34 of the pond-reared individuals (averaging 462 mm) were sacrificed and all had developing gonads indicating sexual maturity (65% males; 35% females). Growth slows dramatically after razorback suckers mature, averaging 1.66 mm/yr in the middle Green River (Modde et al. 1996).

COLORADO PIKEMINNOW

Information presented here regarding habitat use in the upper Colorado River (Appendix Table II) is from Osmundson and Kaeding (1989) and on habitat preference from Osmundson et al. (1995) and is based on results of year-round radiotelemetry of Colorado pikeminnow in the Grand Valley during 1986-1989. Other life history attributes, as they relate to the species' flow needs, were recently summarized by McAda (2001) and are reviewed here where appropriate.

Adult Habitat Use

Winter

Between November and February, adult Colorado pikeminnow remain in localized segments of river, primarily low-velocity habitats. Seventy-four percent of pikeminnow locations had mid-column velocities <1.0 ft/sec. Pools and runs accounted for 77-95% of all mesohabitats used during any given winter month; pools comprised 42-62%; runs, 27-41%. All run habitat used was <2.0 ft/sec (slow runs). Eddies and backwaters were the only other habitats used by Colorado pikeminnow in winter. Eddies were used only during January and February and during that time accounted for 5-8% of fish locations; large backwaters were used by some fish all winter accounting for 5-15% of fish locations. Pools, backwaters and eddies were the preferred habitat types during winter in the 15-mile reach (Fig. 2).

Spring

During spring, when water velocities are high and main-channel temperatures still relatively low, Colorado pikeminnow often seek out warm, off-channel, low- to zero-velocity sites. Backwaters and flooded gravel pits together comprised 45% of pikeminnow locations during April; 49% during May; 47% during June. Some use was also made of eddies (2-9%) and shorelines (3-8%). Use of riffles and rapids was negligible (1-2% during

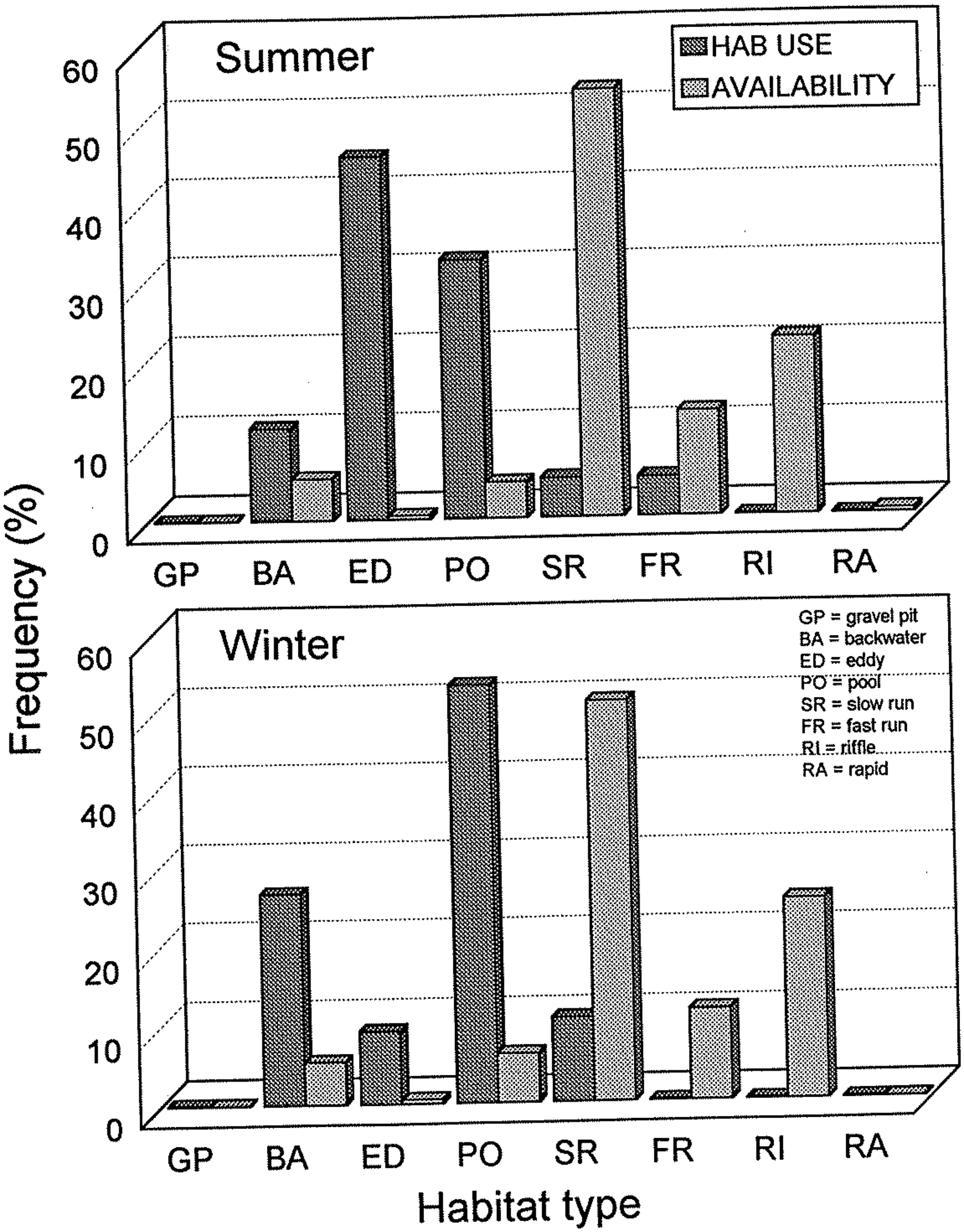

Figure 2. Habitat frequency of use by adult Colorado pikeminnow in the 15-mile reach during summer (1,378-2,368 cfs) and winter (1,654-3,452 cfs) and habitat availability there during summer (1,240-2,870 cfs) and winter (1,630-2,870 cfs). Mean frequency of use is averaged across fish (summer: n = 5 fish and 26 fish locations; winter: n = 4 fish and 67 locations). Data from Osmundson et al. (1995).

May or June only). Selection of runs changed toward the end of spring when use of higher velocity sites increased: slow runs declined in use from 32% (April) to 27% (May) to 13% (June); during the same period, fast runs increased in use from 0-3% to 19%.

Summer

During summer, flows decline in magnitude from relatively high levels in July to the yearly low in September and water temperatures are at an annual high during July and August. Use of fast runs peaked in July at 26% and then tapered off to 7% in September. Conversely, use of slow runs increased during this period: after reaching an annual low in late spring (13%) use steadily increased through summer (26-55%) and peaked during the transitional month of October (61%). Together the two run types accounted for 49-52% of habitats selected during summer. Backwaters were little used during this time (3-7%) and flooded gravel pits were largely unavailable. Shorelines and rapids each accounted for only 0-4% use. Annual use of riffles was highest during the summer months but use was relatively low compared to other habitat types (3-10%). Colorado pikeminnow use of eddies also reached a yearly high during summer (9-16%). Pools were also used (13-16%), but as in spring, summer use of pools was low compared to the remainder of the year. Eddies, pools and backwaters were the preferred habitat types of adult pikeminnow in the 15-mile reach during summers with moderate base flows (Fig. 2). During summers of low flow, slow runs and fast runs were preferred.

Transitional periods

Flows and temperatures are low during October and March and changes in fish habitat use indicated these were transitional months that marked the beginning and end of winter. Water temperature during October is somewhat higher than during March. Pools and slow runs were primarily selected during these months: pool use accounted for 32% in March and 26% in October; slow runs, 43% in March and 61% in October. Large backwaters were used 14% of the time in March and 9% in October. Other habitat types were used little or not at all: eddies were used 4-7%; fast runs 0-4%; riffles, rapids, shorelines were not used and flooded gravel pits were unavailable.

Other Life History Attributes

Distribution

Populations of Colorado pikeminnow require an extensive length of river so that an array of habitat types are provided to meet the changing needs of different life stages. Larvae hatched in cobble-gravel substrates of high-gradient reaches drift 100-200 km downstream to low-gradient reaches where backwaters formed in silt-sand bars provide ideal nursery habitat (Haynes et al. 1984, Tyus and Haines 1991). Insectivory is largely replaced by piscivory during the first year (Vanicek and Kramer 1969, Muth and Snyder 1995). As Colorado pikeminnow mature (7-8 yr), the need for larger forage fish is not met in lower reaches of the Colorado River mainstem where native, large-bodied, prey fish are scarce. Consequently, condition (weight as a function of length) declines prompting many Colorado pikeminnow to disperse to upper reaches and tributaries where native suckers and chubs are more abundant (Osmundson et al. 1998). This progressive dispersal pattern results in relatively segregated life stages and adult densities are surprisingly clumped near the upstream margins of their range. This pattern is generally repeated in the Green River system: there, most YOY and subadults are located in middle to lower reaches of the Green River whereas in the upper reaches, as well as the major tributaries, most fish are adults (McAda et al. 1997). Based on these patterns, it is likely that reaches in the Colorado River upstream of the diversion dams, the subject of this report, were historically used primarily by adults, as is currently the case in the Grand Valley.

Reproduction

Colorado pikeminnow undergo extensive spawning migrations in the Green River system (Tyus 1991, Irving and Modde 2000) and relatively short ones in the Colorado River (McAda and Kaeding 1991). Spawning occurs as spring flows are decreasing and water temperatures are increasing (Haynes et al. 1984, Nesler et al. 1988, Tyus 1991, McAda and Kaeding 1991, Bestgen et al. 1998, Anderson 1999, Trammell and Chart 1999a). In general, spawning occurs earlier during low runoff years and later in high runoff years (McAda and Kaeding 1991, Tyus and Haines 1991, Bestgen et al. 1998), presumably because extended runoff during high water years delays warming of the river. In the Colorado River during 1992-1996, spawning began at flows ranging from 8,000-37,000 cfs 1-4 weeks after runoff had peaked for the year and shortly after river temperatures reached 17-18°C (Trammel and Chart 1999a, Anderson 1999). River temperatures were 20-22°C by the time spawning ended (McAda 2001). Although some spawning may occur at cooler temperatures (see Bestgen et al. 1998), most spawning in the Colorado, Green, and Yampa rivers occurs at water temperatures between 18-22°C (McAda and Kaeding 1991, Tyus 1991, Bestgen et al. 1998, Anderson 1999, Trammell and Chart 1999a).

Spawning occurs over gravel-cobble substrates in riffles or runs adjacent to pools or low-velocity habitats where adults may stage or rest between spawning efforts (Tyus and McAda 1984). Two canyon-bound reaches in the Green and Yampa rivers are used for spawning by most adults that reside in the Green River system (Tyus 1991, Irving and Modde 2000). In the Colorado River, adults spawn in smaller groups and in more locations (McAda and Kaeding 1991). Over the years, five suspected spawning sites have been located in the Colorado River. All have been in alluvial reaches. Aggregations of adults have been documented at one site in the Grand Valley in three different years (USFWS, unpublished data). At this site, spawning appeared to occur at the base of a chute channel that bisected a cobble-based island. Cobble spilling into the main channel from this side channel was very loose with deep interstitial spaces (Bliesner and Lamarra 1995). Other adults were found in eddies and calm zones between the thalweg and island shoreline, ostensibly staging or resting (USFWS, unpublished data).

Colorado pikeminnow are broadcast spawners with adhesive eggs (Hamman 1981), and it is hypothesized that eggs settle into the interstitial voids of cobble substrates. Northern pikeminnow *P. oregonensis* spawn over similar substrate and eggs have been found 15 cm below the substrate surface (Beamesderfer and Congleton 1982). Colorado pikeminnow eggs incubate for 4-7 days depending on water temperature (Hamman 1981, Marsh 1985, Bestgen and Williams 1994) and larvae remain in the gravel for an additional 6-7 days after hatching (Bestgen et al. 1998). Emerging larvae are entrained in the current and many drift long distances downstream before being deposited in backwaters of low-gradient reaches (Tyus and Haines 1991, Trammell and Chart 1999a).

It is unknown whether spawning historically occurred in the Palisade-to-Rifle reaches prior to the construction of the diversion dams. De Beque Canyon, upstream of the most upstream diversion dam, has numerous cobble-bar islands and side channels that may contain suitable sites for Colorado pikeminnow spawning (Anderson 1997). However, duration of temperatures in excess of 18 and 20°C, is short in years of high, extended runoff and timing of such temperatures is delayed compared to more downstream reaches (Osmundson 2000). Until Colorado pikeminnow can be reestablished in this area, and the degree to which they use this reach for spawning can be assessed, its potential as spawning habitat should be assumed. However, the suitability of potential spawning sites in alluvial reaches upstream of De Beque Canyon, also identified by Anderson (1997), is expected to progressively decline with decreasing upstream temperatures (see Osmundson et al. 1998).

Reproductive success of Colorado pikeminnow is strongly influenced by the flow regime. Results from larval drift studies in the Colorado River during 1992-1996 indicated that highest larval production (drift densities) occurred in years with moderate (1996) to high (1995) spring flows, and lowest larval production occurred in years with low (1992 and 1994) spring flows (Anderson 1999, Trammell and Chart 1999a). However, high larval production alone does not necessarily result in high numbers of YOY in fall. McAda and Ryel (1999), using 15 years of fall YOY data and USGS flow records (1982-1996), found that antecedent flows were just as important in predicting YOY density in fall as were flows that occurred in the year of reproduction. Highest densities of YOY occurred in years that had high peak flows (>50,000 cfs at the state line USGS gauge) in the previous year and moderately high flows (30,000-40,000 cfs) in the year when the young fish were produced.

Although high numbers of larvae are produced in years of very high runoff, such years are also characterized by high flows extending into August, which appear to have a negative effect on YOY numbers in fall. Larvae in such years are produced late and backwaters are fewer in number. McAda and Ryel (1999) suggested that larvae are carried downstream out of the nursery area at such times and are perhaps lost to nonnative fish predation in Lake Powell. However, although exceptionally high water in wet years result in low fall YOY numbers, it is important in setting conditions for successful reproduction in the following year, so long as the following year has moderately high spring flows followed by low stable base flows. The cause-effect explanation offered by McAda and Ryel (1999) is as follows: high, bed-mobilizing flows are needed to create and maintain ideal substrate conditions for egg deposition and incubation and the effect of this sorting and cleaning of the gravel-cobble substrate is carried over into the following year when moderately high flows are then adequate to remove any additional fine sediment deposited between runoff events; moderate flows also allow for earlier spawning, a longer first-year growing season, and more backwater habitats for the small fish to settle in. In conclusion, for high YOY numbers, two conditions need to be met: high larval production in summer followed by high larval survival and retention in the nursery area until fall. This combination occurs when a particular set of hydrological conditions are provided.

Diet, growth, body condition and carrying capacity

Once Colorado pikeminnow are over a year old they switch from a diet consisting of invertebrates to one consisting almost entirely of fish (Vanicek and Kramer 1969, Muth and Snyder 1995). Backwaters are good nursery habitats because they are warm, lack current, and contain relatively abundant supplies of zooplankton, macroinvertebrates, and small-bodied fish (Graboswski and Hiebert 1989). Even after Colorado pikeminnow move to main-channel habitats, small-bodied fish, primarily non-native minnows, provide a substantial part of their diet until pikeminnow reach a length of at least 550 mm. Larger individuals are thought to require larger forage items (Osmundson et al. 1998), as is the case with other warm-water piscivores such as northern pike *Esox lucius* and muskellunge *E. masquinongy* (Scott and Crossman 1973, Gillen et al. 1981, Diana 1987). Information from limited stomach content data suggests that relatively large, soft-rayed, fusiform-shaped fish are eaten, including various species of sucker. Consumed suckers were as long as 47% of the Colorado pikeminnow's length (summarized by Osmundson et al. 1998).

Theoretically, positioning of Colorado pikeminnow within the river, at both macro- and micro- scales, is driven primarily by growth maximization, and growth is largely dependent on the interaction between temperature and food availability (Weatherley 1972). Achieving maximum growth enhances the ability of the individual to survive and reproduce. When food availability is low, growth slows and body condition declines. To the extent possible, Colorado pikeminnow may prevent this by selecting foraging sites with high rates of energy return (food) for energy expended (foraging activity). Good conditions for growth include suitable temperatures in combination with relatively high availability of forage fish. The benefits of high forage density may be enhanced by a combination of physical habitats and river features that facilitate efficient foraging, thereby promoting fish growth and allowing more Colorado pikeminnow to occupy a given reach of river (i.e., forage availability as opposed to forage abundance). Supportive evidence for this includes: (1) the dispersal of adults in the Colorado River to reaches upstream of Westwater Canyon where native forage is most abundant (Osmundson et al. 1998), (2) the relatively high density of adult Colorado pikeminnow in the 18-mile reach (downstream from the Gunnison River confluence) where total area of specialized habitats (non-run habitats) is highest (Osmundson et al. 2001), (3) the preference for river segments that contain a complex of habitat types, as opposed to simple, single-thread, run-dominated segments (Osmundson and Kaeding 1991), and (4) the preference for certain habitat types, such as pools, eddies, etc. (previously discussed). Because habitat and food are so tightly interrelated, it is difficult to separate selection for food from selection for habitats that allow efficient foraging (Magnuson et al. 1979). Nevertheless, to promote growth of individual Colorado pikeminnow and maximize carrying capacity of the river, abundant forage and a diversity of habitats are important.

SEASONAL PARTITIONING OF THE YEAR

To provide favorable habitat for the endangered fish, flows must change in a seasonal manner corresponding to season-specific habitat needs. Osmundson et al. (1995) blocked months into seasons by analyzing habitat-use patterns of each species and identifying changes in behavior that marked the beginning or end of seasons. Though coexisting under the same conditions, the different behavioral patterns of razorback sucker and Colorado pikeminnow result in a year that is partitioned somewhat differently (Fig. 3). However, because only one flow regime can be recommended for the river, a third seasonal

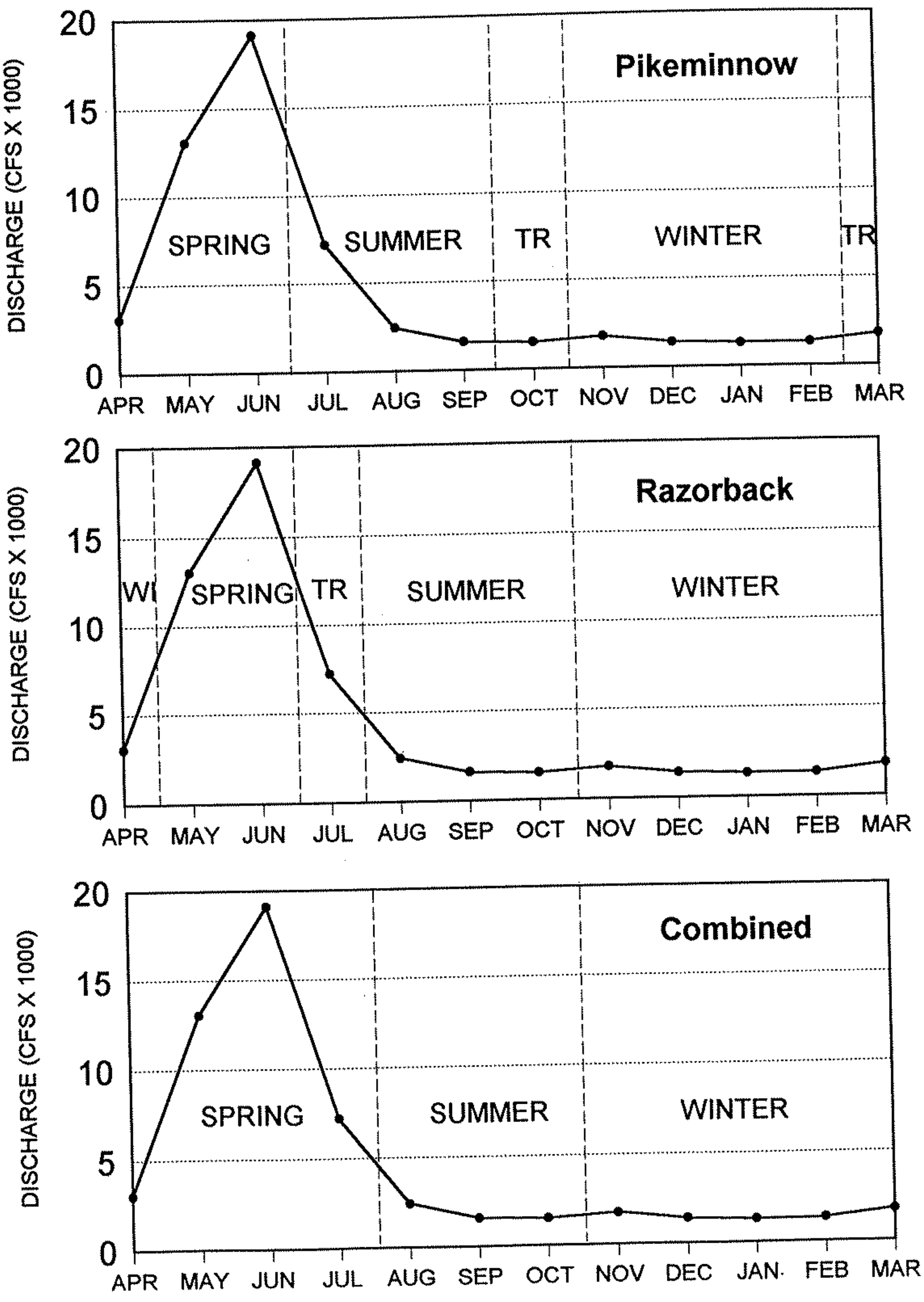

Figure 3. Seasonal partitioning of the year based on the habitat-use behavior of Colorado pikeminnow (top), razorback sucker (center), and a combination of the two (bottom). Seasons in this report follow those in the bottom graph. Hydrograph shown is example only. TR = transition periods. Figure from Osmundson et al. (1995).

partitioning was made that was a composite of the ones made for each species. Transitional periods were either lumped or split but the core months of each season stayed basically the same.

A distinct winter period emerged in which averaged pool use for both species was greater than 40% for all months and use of slow runs was 20-40%. Winter included November, December, January, February and March. The core spring season included April, May and June when use of pools averaged 30-40% and backwater use was 20-40%. Summer included August, September and October. In October, the diversity of habitat use declines and pool use increases for both species. However, slow run use is still high and pool use is not nearly as high as during winter. Also, main channel temperatures are still high enough in October for the fish to still be quite active. July appears to be more of a transition month. Although habitat use for Colorado pikeminnow is fairly constant during July, August and September, habitat use by razorback sucker in July is more similar to that during May and June, particularly the continued high use of backwaters (36%). July was included as one of the spring months not only because of the habitat-use pattern of razorback suckers, but also because flow levels are still quite high from snowmelt runoff during this time, having not yet returned to base flow levels. This results in a spring period which includes the runoff months (April-July) and two base-flow periods, summer and winter.

FLOW EFFECTS

Habitat Heterogeneity and the Creation and Maintenance of Mesohabitats

Fish habitat in rivers is largely controlled by the interacting factors of channel width, depth, slope, substrate size and the surrounding topography (Lamarra 1999). Channel-forming flows are high flows capable of eroding banks, moving large substrate particles, shifting cobble and gravel bars, and scouring vegetation (Pitlick et al. 1999). When such flows occur in unconfined reaches, where the river is free to move laterally, side channels are formed. Deposits of cobble and gravel can also create islands resulting in multi-thread channels or complex river reaches. Often associated with multi-channel sites are riffles at the upstream end and sometimes pools at either the downstream end or to one side of the riffle. Backwaters are formed at the downstream end of some side channels when inflow at the upstream end ceases or is reduced as runoff flows subside. Eddies form at the interface of the backwater mouth and the main channel. Thus, lateral movement of the channel during high flow events is the process responsible for channel complexity and the creation of preferred mesohabitats (Pitlick et al. 1999).

Adult Colorado pikeminnow in the Grand Valley prefer segments of river that contain a diversity of habitat types. Partitioning the river into 0.65-km segments from Loma to Palisade, Osmundson and Kaeding (1991) categorized segments as either simple (single-thread) or complex (multi-thread or containing backwaters), and found that the river consisted of about equal proportions of the two segment types. During radiotelemetry studies, adults were located in complex segments 85% of the time during spring; 71%, during summer; 62%, during winter. These complex segments are preferred presumably because they contain more of the preferred mesohabitats (pools, eddies and backwaters) than do simple segments (primarily consisting of fast and slow runs) and because a variety of habitat types juxtaposed to one another allows more efficient exploitation of resources, i.e., feeding and resting habitats are close together (Osmundson and Kaeding 1991).

Osmundson et al. (1995) selected four complex sub-reaches within the 15-mile reach for habitat mapping during 1990-1991. The reaches selected were those heavily used by adult Colorado pikeminnow. At a moderate base flow (1,630 cfs), backwaters comprised 5% of the total water surface area of the four sub-reaches; pools comprised 6%; eddies, 0.4%; riffles, 25%; slow runs, 56%; fast runs, 7%; rapids, 0.5%. Thus, even in complex reaches, a small percentage of the total wetted channel area is comprised of non-run habitats; the preference by adult Colorado pikeminnow for such sites underscores the importance of creating and maintaining such features.

When flow is reduced and sediment input remains the same, fine-sediment deposition occurs in low velocity sites such as side channels, backwaters and the river margin. Osmundson et al. (1995) and Van Steeter (1996) documented the deposition of fine sediment at the mouths of backwaters in the Grand Valley. The deposited sediment was not displaced during several consecutive years of low flow and backwater mouths progressively filled until fish access was blocked. When vegetation encroaches into the channel during periods of low flow, deposited sediments become stabilized. It then becomes increasingly difficult to scour sediments from these habitats (Pitlick and Van Steeter 1998). Over time, this process leads to a loss of channel complexity and a concomitant loss of the preferred habitats associated with complex sites. Comparing historic with recent aerial photographs of the river, Van Steeter and Pitlick (1998) calculated that 25% of the historic side channel and backwater area in the Grand Valley was lost from this channelization process during the preceding 50 years. Similar analyses by Pitlick and Cress (2000) indicate a 31% loss of side channel and backwater area in the 45-km De Beque-to-Rifle reach.

After the channel is shaped by the high flows of spring, the quantity (total area) of preferred mesohabitats is affected by river stage. In the 15-mile reach, weighted area of mesohabitats preferred by adult Colorado pikeminnow in summer (eddies, pools and backwaters) was 29% higher at a discharge of 1,630 cfs than it was at 1,240 cfs, and 42% higher than at 2,870 cfs (Osmundson et al. 1995).

In 1983, a year of very high spring flows, Carter et al. (1985) mapped Colorado River habitats near Parachute, Colorado at flows ranging from 1,710 to 28,300 cfs (measured at the USGS gage near De Beque). Their 3.2-km (2-mile) study area, judged to be representative of the De Beque-to-Rifle reach, was mapped once in March and then weekly from 18 June to 3 September (12 mapping dates). Wetted area was broken into 12 categories, or mesohabitats. Results revealed that at flows less than 10,000 cfs total area of both pools and backwaters was highest at 1,710 cfs, the lowest flow studied (Fig. 4 and 5). Eddies, however, did not appear until mapping occurred at the next higher discharge, 3,840 cfs. To determine which of these two flow levels provided the greatest area of preferred habitat for adult Colorado pikeminnow, I multiplied the preference rating for each of the three preferred habitat types (derived from Osmundson et al. 1995) by the total area of the corresponding habitat type and summed the values to provide weighted area of preferred habitat at each flow level (see Osmundson et al. 1995 for methods). At 1,710 cfs, the

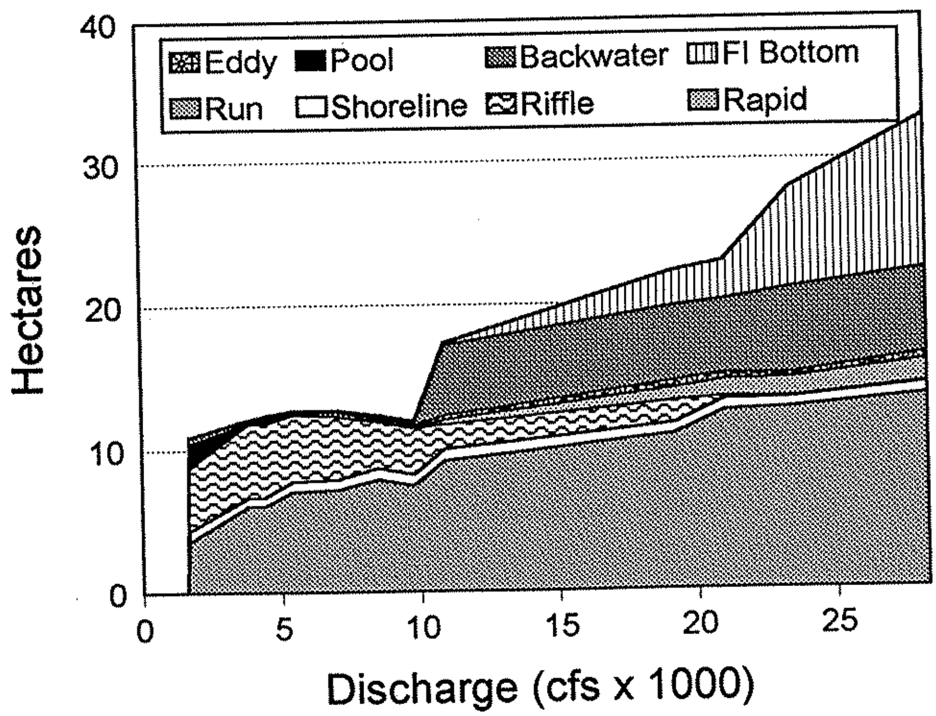

Figure 4. Cumulative area of eight major mesohabitat types at 12 discharge levels in a 3.2-km-long study area near Parachute, Colorado, 1983. Data from Ecosystem Research Institute (1983) and Carter et al. (1985).

weighted total area of both summer and winter preferred habitat was more than 10 times that provided at 3,840 cfs.

Creation and Maintenance of Nursery Habitat Backwaters

The primary Colorado pikeminnow nursery area in the Colorado River is the 103-km (64-mile) reach downstream of Moab, Utah (McAda et al. 1994). Backwaters there are formed by a different process than backwaters in the upper river. Most backwaters in the upper river result from water backing into the downstream ends of side channels that have gone dry on the upstream end. In contrast, most backwaters in the lower river result from water backing into depressions in sand bars. Backwater depressions are created by scour channels and migrating sand waves (Rakowski and Schmidt 1997). Scour channels are formed by the erosion/deposition cycle of small channels behind large alternating sand bars.

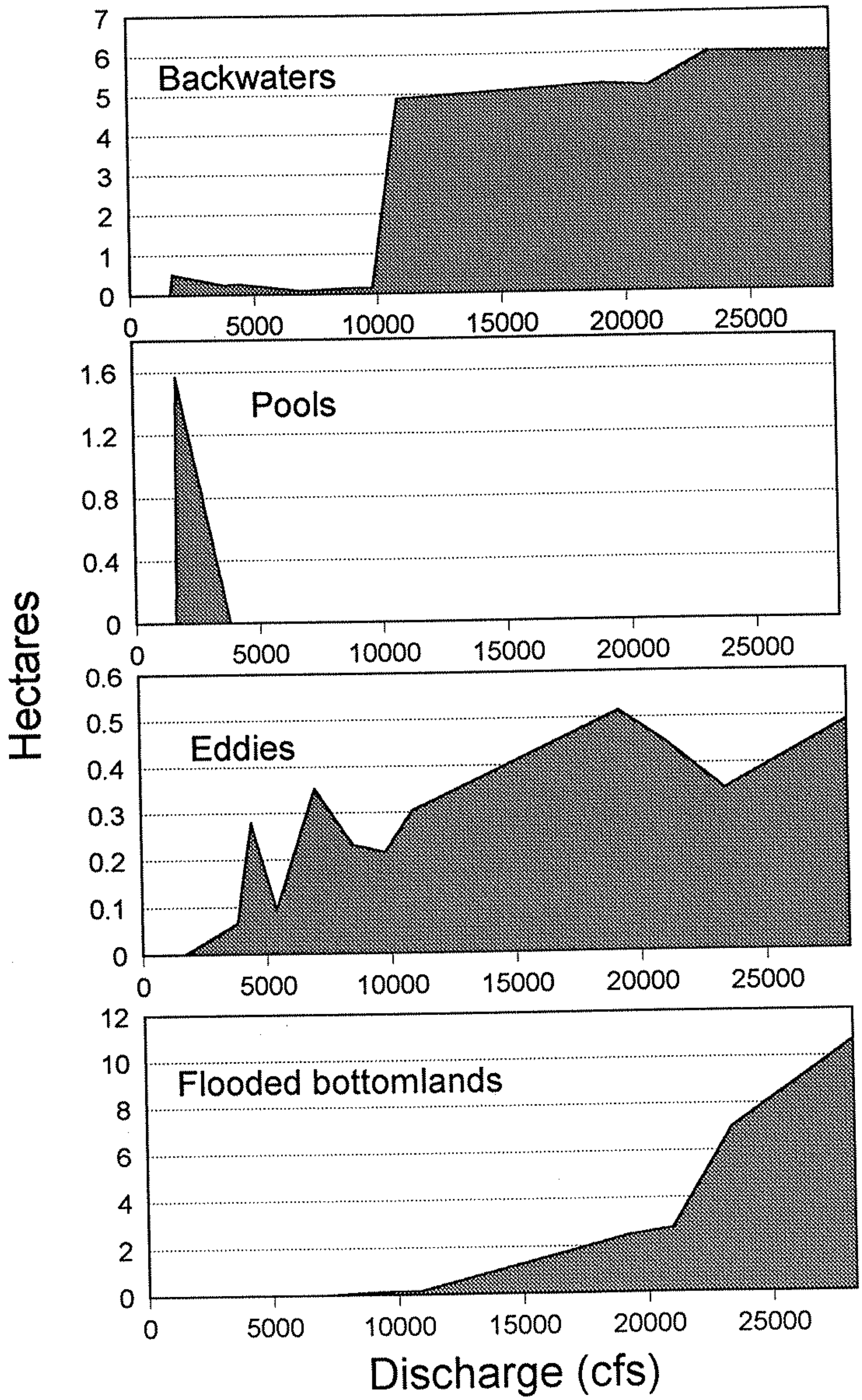

Figure 5. Cumulative area of four preferred mesohabitat types at 12 discharge levels in a 3.2-km-long study area near Parachute, Colorado, 1983. Data from Ecosystem Research Institute (1983) and Carter et al. (1985).

Trammel and Chart (1999b) concluded that scour-channel backwaters comprised the majority of backwater area and are preferred by YOY Colorado pikeminnow. The authors suggested this preference may be due to the greater depth and persistence of this backwater type compared to the more numerous, smaller backwaters created by migrating sand waves. High flows do not increase backwater number or area in the year they occur, but they are critical for the continued persistence of backwaters of sufficient size and quality. Periodic large floods are necessary to rebuild bar topography and channel relief. Moderate peaks in years following large floods rearrange the deposits which later become mid-channel bars at base flow (Rakowski and Schmidt 1997). Because bar topography changes annually, there is no single discharge that maximizes backwater number or area during base flows; the base flow that maximizes backwater availability in fall depends on antecedent flows. However, McAda (2001) reported that backwater number and area in the lower Colorado River declines when base flows exceed 4,000 cfs.

It is difficult to arrive at specific base flows in the Palisade-to-Rifle reach that will provide optimum flows for nursery habitat downstream near Moab. Clearly, very high spring flows are periodically needed to rebuild eroded sand bars in the lower river and high base flows should be avoided so that flows near Moab do not exceed 4,000 cfs.

Flooded Bottomlands for Razorback Sucker

Spring flows high enough to inundate bottomlands adjacent to the river channel are periodically needed to benefit razorback sucker reproduction and survival of young (Wydoski and Wick 1998). Larval razorback suckers initially feed on diatoms, rotifers, algae, and detritus (Bestgen 1990, Papoulias and Minckley 1992); soon afterward, they select larger zooplankton, primarily cladocerans and copepods (Marsh and Langhorst 1988). To survive the critical first phase of life (the transition from endogenous to exogenous nutrition), razorback sucker larvae require 30-60 food organisms per day (Papoulias and Minckley 1992). Such zooplankton densities were found in floodplain habitats of the Green River, rarely found in backwaters, and never found in the main channel of upper basin rivers (Cooper and Severn 1994a, 1994b, 1994c, 1994d, Grabowski and

Hiebert 1989, Mabey and Shiozawa 1993), underscoring the importance of larval access to floodplain habitats.

To appreciably flood bottomlands along the upper Colorado River, flows must exceed the bankfull level. Pitlick and Cress (2000) estimate the median bankfull discharge in De Beque Canyon (upstream of the upper diversion structure) is approximately 20,500 cfs (based on field measurements of bankfull characteristics of eight evenly spaced cross-sections). In the alluvial reach upstream (De Beque-to-Rifle), where adjacent bottomlands are present, the estimated median bankfull discharge is 22,000 cfs (based on 24 cross sections).

In the Carter et al. (1985) mapping study, those habitats that exhibited predictable and regular changes with flow were generally associated with physical features of the river that were inundated when the river flowed beyond its normal channel banks (backwaters, flooded woodlands and rubble flats) or were manifestations of river hydraulics at various stages (rapids, runs and eddies increased with discharge; riffles decreased). Total area of backwaters declined when flows increased from 1,710 to 9,000 cfs, but then increased 50-fold at discharges over 10,000 cfs. Some flooded bottomlands were present at discharges of 10,000-21,000 cfs, but were nonexistent at flows less than 10,000 cfs. As discharge increased above 21,000 cfs, total area of flooded bottomlands began to increase exponentially, indicating a threshold for significant over-bank flooding somewhere between 21,000 and 23,400 cfs. This inflection point corresponds with the median bankfull discharge of 22,000 cfs calculated by Pitlick and Cress (2000) for the entire De Beque-to-Rifle reach.

Successful year classes of razorback sucker largely depend on larvae being placed in habitats containing adequate densities of forage; such densities are largely restricted to flooded bottomlands. The necessary duration of flooding may depend on the time required for larvae to feed during their critical first phase of life. The timing, density, size, and duration of zooplankton availability must 'match' the timing of the swim-up stage of fish larvae. Razorback sucker larvae must find food of the right size and density within 8-19 days of swim-up or they will exceed the point of irreversible starvation (Wydoski and Wick 1998). After inundation, some time is required for larvae to drift into or hatch within the newly created habitat, and for zooplankton blooms to occur (see Cooper and Severn 1994b). A minimum duration of inundation that assures time for these two processes to occur as well as provide time for larvae to feed and grow may be 3-4 weeks.

Within-channel Productivity

Assuming that reproduction and survival of young can be enhanced for Colorado River populations of razorback sucker and Colorado pikeminnow, carrying capacity of their environment will become the next factor that limits population size. Providing the maximum amount of preferred mesohabitats partially addresses this constraint. In addition to limitations imposed by physical habitat are the limitations of food availability. Habitats containing abundant food will support more fish than those that do not. To provide more food for the endangered fish, primary and secondary productivity should be maximized. Algae and detritus form the base of the riverine food web, directly supporting invertebrates and some fish. Adult razorback suckers feed on benthic and drifting invertebrates, algae, and detritus (Bestgen 1990), as do sympatric bluehead suckers *Catostomus discobolus* and flannelmouth suckers *C. latipinnis* (Osmundson 1999). Periphyton and terrestrial inputs of organic debris are the source of detritus. Most terrestrial organic debris enters the river during spring when high flows flood the banks and entrain shoreline and bottomland accumulations of branches and leaf litter. For periphyton production, clean rock surfaces for attachment sites are required as well as sufficient water clarity to allow light penetration to the river bed. Invertebrates feed on algae attached to rock surfaces and on detritus both in the drift and in the interstitial spaces among coarse substrate particles. In addition to food, invertebrates, like fish, require certain physical habitats: these include rock surfaces for attachment sites and interstitial spaces for shelter (Waters 1995). Fish that subsist on algae, detritus and invertebrates in turn provide forage for the piscivorous Colorado pikeminnow (Osmundson et al. 1998, Osmundson 1999).

To promote within-channel productivity, high spring flows are needed to clean gravel-cobble substrates (Osmundson et al. 2001). In the absence of flows of sufficient magnitude fine sediment (silt and sand) accumulates in the river bed filling the spaces required by many invertebrate species (Osmundson and Scheer 1998, Osmundson et al. 2001). If the tops of rocks become covered with fine sediment, algal production may also decline. To flush fine sediment from the bed, flows must be high enough to dislodge and move the larger particles. Gravel river beds are typically composed of surface and subsurface layers. The surface layer, sometimes called a pavement or mobile armour, is coarser than the subsurface material. Milhous (1973) found that mobile armour plays an important role in the deposition and retention of fine sediment. At low flows, the immobile surface layer acts as a sink for suspended sediment, which deposits at the interface between the pavement bottom and the subsurface top. This zone acts as a silt reservoir: at high discharge the pavement is set in motion; the bed then becomes a source of suspended sediment as fines are winnowed out. Milhous (1973), O'Brien (1987) and Wilcock et al. (1996) have emphasized the necessity of surface layer mobilization for removing fines below the surface layer. Pitlick and Van Steeter (1998) found that the minimum flow necessary to produce widespread movement of the bed in the 15-mile reach, and the two reaches immediately downstream of the Gunnison River inflow (18-mile and Ruby-Horsethief Canyon), corresponded with the bankfull flow. As discussed above, the bankfull flow in De Beque Canyon is approximately 20,500 cfs and in the De Beque-to-Rifle reach, approximately 22,000 cfs. In the 15-mile reach, the bankfull flow is approximately 21,500 cfs (Pitlick and Cress 2000).

Thus, bankfull flows not only provide razorback sucker larvae and adults with critically important off-channel habitats and entrain organic debris from bottomlands into the main channel, they also serve to mobilize within-channel substrates, flushing fines from the bed and optimizing living space for macroinvertebrates. Ideally, these high spring flows should then be followed by base flows with low turbidity to promote algal production.

Colorado Pikeminnow Spawning Cues

Cues that trigger Colorado pikeminnow to undergo spawning migrations and to initiate spawning appear to be largely controlled by river flows and temperature. Adults begin migrating to spawning areas as peak runoff declines and water temperature increases

(Tyus 1991, McAda and Kaeding 1991). Back calculating hatching dates from total length of larvae, McAda and Kaeding (1991) found that timing of spawning during 1982-1985 varied among years but generally occurred when water temperatures were 18-22 C and river flow was 15-30% of the maximum discharge for the year. More recently, larval drift studies from 1992-1996 revealed that spawning began as early as June 5 (1994) and as late as July 11 (1995); spawning began 1-4 weeks after runoff peaked and shortly after main-channel temperatures reached 17-18 C (Trammel and Chart 1999a, Anderson 1999). In general, spawning occurred earlier during years of low runoff and later in years of high runoff. This phenomenon has also been observed in the Green River sub-basin (Tyus and Haines 1991, Bestgen et al. 1998). During years of high runoff, flows stay high for an extended period and temperatures do not rise sufficiently until flows subside, pushing the spawning period later into the summer.

Spring flows are thus important in triggering adult physiology and behavior associated with reproduction. Rising water levels in spring along with increasing photo-period no doubt triggers the resumption of vitellogenesis following a winter dormancy of developing eggs (Tyus 1990). Warm water found in flooded backwaters, tributary mouths and bottomlands during April, May and June may hasten the gamete maturation process (Valdez and Wick 1983). Declining water levels following the spring peak may cue fish to seek spawning sites. After fish reach spawning sites and begin to congregate in staging pools, some time may elapse while fish await final physiological changes to take place (final egg maturation, ovulation, etc.) and for the requisite mix of environmental factors to occur. What these environmental factors are is unclear, but probably include some range of suitable depths and velocities over a substrate that has been sufficiently cleaned of fine sediment. Females likely provide cues to males that ovulated oocytes are ready to be oviposited and fertilized. How long individual fish participate in spawning is unknown, but larval-drift data indicate that overall spawning activity may last 5-8 weeks, with spawning at downstream sites beginning 1 day to 3 weeks earlier than at upstream sites (Trammel and Chart 1999a). If runoff is extended too long and temperatures remain low, it has been suggested that a decreasing photoperiod (after June 22) may prompt fish to spawn even though optimum temperatures have not been attained (C. McAda, personal communication)

The process of gamete development, migration, staging, egg ripening and spawning occurs over an extended period and each phase is timed to roughly coincide with predictable phases in the runoff cycle. The duration of these runoff phases may therefore be as important as the magnitude of runoff. Maintaining a semblance of the historical duration of the runoff period may therefore be necessary for this species to successfully complete its annual reproductive cycle.

HYDROLOGY

The flow regime of the Colorado River has been significantly altered as a result of water development. Understanding the effects of water development on endangered fish and their habitats requires an evaluation of the manner in which this alteration has occurred. Previous attempts to do this have relied on comparisons between mean monthly flows (and mean annual peak flows) of a 'pre-development' block of years with those of a 'post-development' block of years (Osmundson and Kaeding 1991, Pitlick et al. 1999). However, accurate quantification of effects from regulation on discharge is difficult because of: (1) changes in climate between periods and (2) inadequate samples (years) that truly represent pre- or post-development periods. Consequently, results can vary greatly depending on the years selected for comparison. Fortunately, for the Palisade-to-Rifle reach, these potential sources of bias can be avoided by using a data set developed by the Natural Resources Conservation Service (NRCS). The NRCS investigators estimated, to the extent possible, what the monthly inflow at the USGS gauge near Cameo would have been in the absence of regulation. They did this by examining monthly storage and diversion records for each year during 1958-1997 (ungauged diversions could not be accounted for). For this report, the unregulated monthly yield values (acre feet) provided by NRCS were converted to mean monthly discharges (cfs); these were then compared with actual discharges recorded at the USGS gauge. Hence, the same block of years was used in comparing regulated with unregulated flows.

Additional calculations were required to determine the effect of regulation on annual peak flows at the Cameo gauge. Linear regression was used to calculate the relationship between total yield during the April-July period and the magnitude of average discharge on the peak runoff day (Fig. 6). This relationship was derived by using a block of years that occurred prior to the development of most regulation in the upper Colorado River basin (i.e., preceding construction of Green Mountain Reservoir; Liebermann et al. 1989) and for which monthly yield and peak discharge records were available (1902-1942). The unregulated annual peak discharges at Cameo and the unregulated annual total yield for the April-July period at Cameo as calculated by NRCS for the 1958-1997 period were then predicted using this relationship.

To facilitate comparisons between average monthly discharges of regulated and unregulated flows at Cameo, the 1958-1997 block of years was first divided into four precipitation categories based on the total annual (Jan-Dec) unregulated yield at Cameo.

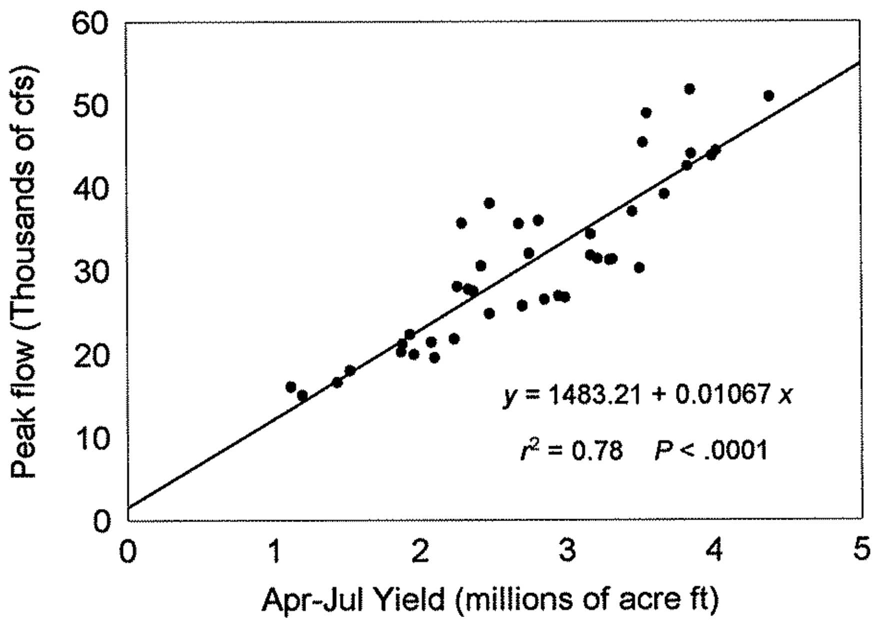

Figure 6. Relationship between total yield at Cameo during the April-July runoff period and the average discharge of the peak day. Data are from the 1902-1942 period of record; 1934-1942 data are from USGS gage at Cameo; 1902-1933 data are from USGS gage at Palisade with estimates of Government Highline Canal diversion depletions added back. Monthly yields (acre feet) were calculated from average monthly discharge (mean cfs x days in month x 1.9835).

The categories were dry (20% of years; 81-100% exceedance); below-average (30% of years; 51-80% exceedance); above-average (25% of years; 26-50 % exceedance) and wet (25% of years; 0-25% exceedance). This partitioning of years was selected to maintain consistency with categories used in the current recommendations for flows in the downstream 15-mile reach (see Osmundson et al. 1995).

Mean monthly flows have generally increased at Cameo during the base-flow months and decreased during runoff months (Tables 1 and 2; Fig. 7). Regulation has increased winter base flows (November-March) by 6-23%, depending on the month and the precipitation category (in general, the wetter the year, the greater the increase). Summer base flows of September-October have also increased from regulation but the increases are generally not as high (0-16%) as during the winter months and there is no clear pattern that follows precipitation categories. The exception to this is during September of dry years when flows average 31% higher than they would be without regulation. Presumably, this is due to upstream water storage that is released to meet the senior rights of downstream Grand Valley irrigators. Summer base flows of August have increased 8% during dry years and decreased 7-10% during below-average, above-average and wet years. Runoff flows during April have declined 13% during dry years while remaining relatively unchanged (-4 to +4%) during other years. The most significant changes to the hydrograph occur during the runoff months of May-July with mean flows having declined by 17-41%. The greatest declines during the spring period consistently occur during the month of June. For both May and June, the drier the year, the more that regulation decreased flow (as a percent of unregulated flow). Hence, the greatest percent declines occur in June of dry years.

The magnitude of the annual peak flow, generally occurring during late May or early June, has also significantly declined as a result of regulation (Fig. 8). The largest mean percent decrease (41%) is for the dry category, but mean declines are also great for other precipitation categories, ranging from 27% to 36% (Table 2). Based on comparisons of peak flow, the early part of the century was evidently wetter than the later part of the century: the median peak flow of the 1902-1942 period was 30,500 cfs, whereas the median of the estimated unregulated peak flows of the 1958-1997 period was 26,000 cfs, representing a decline of 15% that can be attributed to changes in climate. However, the

Table 1. Mean monthly discharge (cfs) in the upper Colorado River at Cameo under unregulated (predicted) and regulated (actual) scenarios for four types of water year (dry, below average, above average, wet), based on 1958-1997 records.

	Dry		Below average		Above average		Wet	
	Unreg	Reg	Unreg	Reg	Unreg	Reg	Unreg	Reg
JAN	1,323	1,550	1,353	1,600	1,506	1,767	1,592	1,893
FEB	1,301	1,504	1,425	1,624	1,462	1,772	1,680	1,956
MAR	1,512	1,641	1,610	1,805	1,675	2,032	1,953	2,317
APR	2,706	2,355	2,784	2,633	3,316	3,351	4,240	4,290
MAY	7,099	4,695	9,168	7,008	11,718	9,183	15,349	12,722
JUN	8,600	5,005	14,308	9,764	18,341	13,022	23,988	18,449
JUL	3,163	2,461	4,574	3,500	8,937	6,792	12,415	10,401
AUG	1,958	2,064	2,536	2,318	3,096	2,798	4,986	4,439
SEP	1,496	1,937	2,039	2,137	2,065	2,334	3,052	3,015
OCT	1,724	1,813	1,987	2,098	2,033	2,327	2,814	2,930
NOV	1,521	1,621	1,786	1,907	1,901	2,181	2,327	2,649
DEC	1,285	1,384	1,492	1,684	1,610	1,894	1,897	2,316
Peak	15,367	9,115	21,321	15,592	28,750	18,560	37,583	27,470

Table 2. Mean percent difference between unregulated (predicted) and regulated (actual) average monthly flows in the upper Colorado River at Cameo for four types of water year (dry, below average, above average, wet), based on 1958-1997 records. Positive numbers indicate increases in flow due to regulation; negative numbers indicate decreases due to regulation.

Month	Dry	Below average	Above average	Wet
JAN	16.8	17.9	17.1	18.2
FEB	15.7	13.3	21.5	15.9
MAR	8.1	11.2	20.5	19.6
APR	-12.9	-4.3	1.0	4.0
MAY	-33.6	-23.7	-21.5	-17.3
JUN	-41.2	-31.7	-29.1	-23.5
JUL	-18.5	-22.4	-23.1	-17.0
AUG	8.3	-7.4	-8.3	-10.1
SEP	31.4	8.3	15.4	0.2
OCT	7.8	9.6	16.2	6.8
NOV	6.4	7.0	15.8	14.6
DEC	7.8	12.9	17.6	22.8
Peak day	-40.5	-27.3	-35.8	-27.4

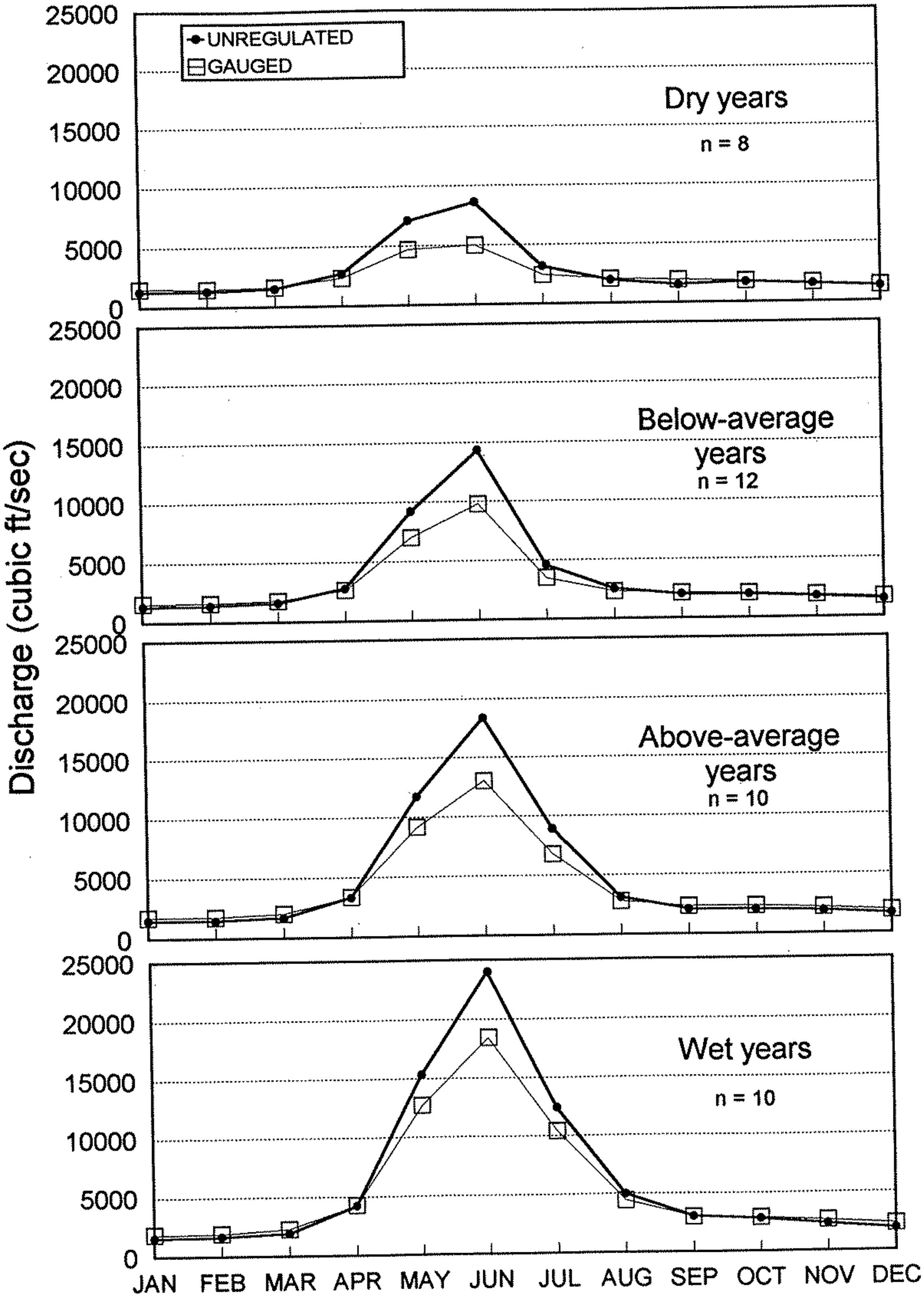

Figure 7. Unregulated (predicted) and regulated (actual) mean monthly flows at the USGS gauge near Cameo averaged over several years within each of four precipitation categories during 1958-1997.

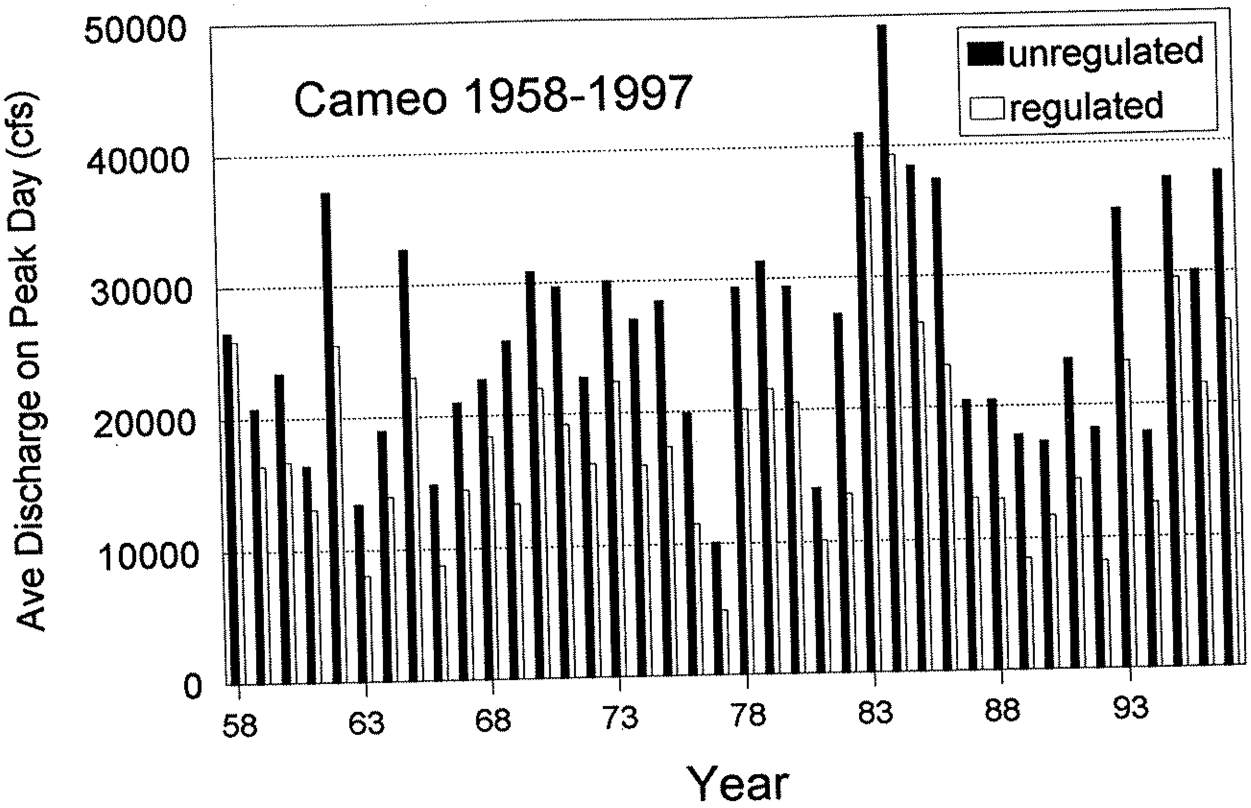

Figure 8. Unregulated (predicted) and regulated (actual) annual peak discharge (mean flow of the highest day of the year) at the USGS gauge near Cameo during 1958-1997.

effect of regulation on peak flows has been considerably greater than the effect of climate: the median of actual gauged peak flows for the 1958-1997 period is 16,550 cfs, representing a decline of 36% from the 26,000 cfs median of predicted peak flows of the same period if the river had been unregulated. The combined effect of climate change and regulation has resulted in a 46% decrease in the median peak discharge at Cameo from the first to the last half of the 20th century.

The median bankfull discharge is the point at which significant mobilization of the bed has begun at half of the sites (Pitlick and Cress 2000), and is a level at which the rate of bottomland inundation begins to accelerate (Carter et al. 1985). This discharge is estimated to be 22,000 cfs for the De Beque-to-Rifle reach, 20,500 cfs in De Beque Canyon, and 21,500 cfs in the 15-mile reach (Pitlick and Cress 2000). Thus, when the bankfull discharge in the De Beque-to-Rifle reach is met, it is also met in De Beque Canyon. If not for the diversions, it would also be met in the 15-mile reach. To keep low-velocity areas (backwaters, side channels) free of fine sediment accumulation and substrates clean so as to promote successful spawning of fishes and maximum production of invertebrates, it is important that these flushing events occur frequently. In addition, razorback suckers need bottomlands to flood periodically so that strong year classes can be produced.

The regulated and predicted unregulated discharges at Cameo are useful in describing the reduction in bankfull discharge frequency as a result of regulation. This frequency was calculated for the four precipitation categories (Table 3). During dry years, bankfull discharge is not met with or without regulation. Also, during wet years, this threshold is always met with or without regulation. It is during the below-average and above-average years that changes in frequency have occurred; these changes have been substantial: in below-average years, the frequency of bankfull discharges has dropped from 42% to 8% (a decline of 80%); during above-average years, the frequency has dropped from 100% to 10% (a decline of 90%). For all precipitation categories, the bankfull frequency has dropped from 63% of the years to 30% (a decline of 52%).

The length of time between bankfull events is perhaps more biologically relevant than frequency of occurrence. The average interval separating events provides a measurement of how long vegetation has the opportunity to become established, coarse substrate to become embedded with fines, and backwaters to fill with sediment. The mean length of time between events cannot be broken down by precipitation category because it is calculated using a series of consecutive years. A comparison of predicted unregulated peak flows with actual peak flows for the 1958-1997 period indicates that regulation lengthened the mean interval between bankfull events from an estimated 1.6 years to 3.6 years (a 125 % increase). With regulation, the maximum number of consecutive years that occurred without a bankfull discharge was 10 years; without regulation, this maximum interval would have been only 5 years (Table 3).

Table 3. Frequency of occurrence (percent of years) and mean interval between (years) bankfull events (annual discharge reaching or exceeding 22,000 cfs in the De Beque-to-Rifle reach). Frequencies are by precipitation category. Results are based on 1958-1997 period of record. Range of bankfull intervals in parentheses.

	Total	Dry	Below Ave	Above Ave	Wet
			Frequency		
Unregulated	62.5	0.0	41.7	100.0	100.0
Regulated	30.0	0.0	8.3	10.0	100.0
			Mean Interval		
Unregulated	1.6	(1-5)			
Regulated	3.6	(1-10)			

FLOW OBJECTIVES AND RECOMMENDATIONS

Objectives

Flow-related objectives for the Palisade-to-Rifle reach can be formulated for each season using the life history attributes and seasonal habitat-use patterns of razorback sucker and Colorado pikeminnow summarized earlier. These objectives are primarily aimed at maintaining or improving habitat important to recovery of the two populations. Consideration of habitat needs in reaches downstream of Palisade are also considered.

Many of the objectives listed below involve providing seasonally preferred or important (high use) mesohabitats for different life stages of the two species. Flows function in two ways to create and maintain these habitat types. First, high flows during spring runoff are required to shape the channel by eroding banks, scouring the bed, transporting sediment and depositing sediment. In this manner features of the channel are created that allow mesohabitats to form. Secondly, this shaped channel is filled with water to varying degrees and the river stage determines the mesohabitat type that occurs at a given site. Changes that result from these two processes occur at different temporal scales. The channel features created by sediment-moving flows often persist for several or many years whereas changes in stage occur daily and will vary dramatically among seasons within years and within seasons among years. As river stage declines in some side channels, a fast run may become a slow run, the slow run may in turn become a pool, and if stage declines far enough, a pool may become a backwater. Thus, to provide the important mesohabitats identified above, channel-forming flows and stage-forming flows must occur with sufficient magnitude. In the case of stage-forming flows, the proper magnitude may occur only within a relatively narrow range. The sediment-moving function of the channel-forming flow may be accomplished in a short period of time (days). However, so fish can use a particular mesohabitat over an extended period of time, flows that keep the river at the necessary stage may be required for a much longer duration (months). Objectives outlined below are summarized in Table 4.

Razorback sucker

Summer.--Razorback suckers primarily use pools and slow runs during the August-October period. Maximizing availability of these habitats is an objective for the summer months. Another objective is to ensure that within-channel habitats are productive so that growth rates are rapid and individuals maintain good body condition.

Winter.--Pools, slow runs and low-velocity eddies are important mesohabitats for razorback suckers during winter. Ensuring availability of these mesohabitat types is a primary winter objective.

Spring.--Backwaters, slow runs and flooded off-channel sites are important to razorback suckers during spring. This is the most critical season for this species because spawning occurs during this time. The current population is near extirpation because recruitment has been unable to keep up with mortality. To assure that the population becomes self-sustaining, once it is augmented with hatchery-reared individuals, management strategies will need to focus on providing conditions that promote successful reproduction and survival of young. Warm, zero-velocity, off-channel habitats such as ponds and flooded bottomlands are important components of the reproductive strategy of this species, especially near the upstream limits of its range. Adults stage in these areas prior to spawning and may in fact spawn within these habitats if given the opportunity and the proper conditions. In the subject reach, primarily between De Beque and Rifle, short-lived (terrace) bottomlands predominate, but some persistent (depression) bottomlands are also present. If mid-channel spawning occurs, off-channel habitats can serve as important rearing areas for larvae drifting downstream. The productive nature of these sites allows adults to increase body condition and fuel gamete production prior to spawning and increases survival rates of young by boosting growth rates. Maximizing area and availability of these flooded off-channel habitats helps provide a variety of sites from which razorback suckers can select those most suited to their needs. This is a primary objective for the spring months.

Colorado pikeminnow

Summer.--Eddies, pools and backwaters are preferred mesohabitats of adult Colorado pikeminnow during summer. Preference for a habitat type suggests such sites have particular importance (frequency of use is much higher than would be expected based on its relative availability). Providing maximum amounts of these preferred habitat types is a primary objective for reaches occupied by adults. In the Palisade-to-Rifle reach, seasonal foraging is expected to extend upstream farther than the winter range. The upstream extent of potential summer foraging is uncertain at the present time; however, from a temperature standpoint, Una (rk 348), can serve as an interim approximation because it is estimated to have similar annual thermal units (36 ATU) as the Yampa River at Craig, Colorado where summer observations of pikeminnow have been reported (Miller and Rees 1997; H. Tyus, personal communication). Another objective is to provide conditions that maximize production of potential forage fish such as native suckers and chubs. Late summer is also a critical time for larvae and YOY; during this period backwaters need to be available in downstream nursery areas. Maximizing potential nursery habitat is a primary objective for the August-October period.

Winter.--Pools, backwaters and eddies are preferred mesohabitats of adult Colorado pikeminnow during winter. Slow runs are also used extensively by adult pikeminnow during winter, but not in greater proportion than the availability of such habitats would predict. It is estimated that winter home ranges of pikeminnow will extend upstream almost as far as De Beque, Colorado (Osmundson 1999). Maximizing area and availability of preferred habitats in this sub-reach is a primary objective for the winter months.

Spring.--During April, May and June, pikeminnow concentrate in off-channel habitats including backwaters, flooded ponds and inundated tributary mouths. These areas are used to a much greater degree than their availability would predict. Such habitats are characterized by low velocities and significantly warmer temperatures than nearby within-channel habitats. They serve as refuges from the rigors of within-channel, high-velocity, spring-runoff flows. By using these warm habitats, adults can increase their annual thermal units for growth and thereby extend their range farther upstream than might otherwise be possible if only within-channel habitats were available. Additionally, warmer temperatures may play a role in the gamete maturation process prior to the spawning season. Ensuring availability of such habitats is a primary objective for April-June. During late June and all of July, availability of within-channel spawning habitats becomes critically important. Promoting conditions that create spawning bars and assure that characteristics of those bars during the spawning season result in maximum reproductive success of Colorado pikeminnow is a primary objective for the spring period.

Recommendations

The lack of site-specific habitat preference data and limited base-flow mapping data from the two reaches upstream of Palisade make development of summer and winter flow recommendations difficult at this time. Until such data are collected, the assessment presented here is based on the assumption that habitats preferred in these upstream reaches will be the same as those in the 15-mile reach immediately downstream. Additionally, flow levels that maximize these preferred habitats are also assumed similar among reaches.

Table 4. Objectives by season, species, life-stage and targeted reach (following colon).

	Summer
1a)	Provide pools and slow runs for adult razorback suckers: alluvial reaches in the Grand Valley would have highest priority during the irrigation season; for the Palisade-to-Rifle reach, provide these habitats to the extent possible without reducing availability in the Grand Valley.
1b)	Provide maximum periphyton, zooplankton and macroinvertebrate productivity in within-channel substrates for adult razorback suckers: Palisade-to-Rifle and downstream.
1c)	Provide backwaters for YOY razorback suckers: Palisade-to-Rifle and downstream
1d)	Provide eddies, pools and backwaters for adult Colorado pikeminnow: The Grand Valley would have highest priority during the irrigation season; for the Palisade-to-Una reach, provide these habitats to the extent possible without reducing availability in the Grand Valley.
1e)	Provide maximum forage fish densities in within-channel habitats for adult Colorado pikeminnow: the Grand Valley would have highest priority during the irrigation season; for the Palisade-to-Una reach, provide maximum forage to the extent possible without reducing availability in the Grand Valley.
1f)	Provide backwater habitat for larval and YOY Colorado pikeminnow: downstream reaches.
	Winter
2a)	Provide pools, eddies and slow runs for adult razorback sucker: Palisade-to-Rifle and downstream.
2b)	Provide pools, eddies, and backwaters for adult Colorado pikeminnow: Palisade-to-De Beque and downstream.
	Spring
3a)	Provide warm, zero-velocity, off-channel habitats (backwaters and flooded bottomlands) for adult razorback sucker: Palisade-Rifle and downstream.
3b)	Provide warm, zero-velocity off-channel habitats for larval and YOY razorback sucker: Palisade-to-Rifle and downstream.
3c)	Provide warm, zero-velocity, off-channel habitats for adult Colorado pikeminnow: Palisade-to-De Beque and downstream.
3d)	Provide within-channel spawning habitat for Colorado pikeminnow in July: Palisade-to-De Beque and downstream.

This later assumption may be more applicable to the alluvial portions of the Palisade-to-Rifle reach, where fish communities are very similar to the 15-mile reach, than to the 16-km (10-mile) sub-reach within De Beque Canyon where lower densities of native fish occur (see Anderson 1997 and Osmundson 1999), i.e., differences in hydrology-habitat relationships within a canyon setting might provide one explanation for the observed differences in fish numbers. Aside from this exception, the working assumptions applied here are reasonable enough that a preliminary assessment of summer flow needs can be provided. Until appropriate studies can be planned and carried out that reduce these current uncertainties, this assessment can serve as an interim recommendation for summer and winter flow regimes. However, for spring flows, geomorphology and habitat-mapping studies were site-specific and additional field studies are unlikely. Thus, until changes are warranted through an adaptive management approach, the spring flow recommendations presented here should be considered final.

Summer (August-October)

At 1,630 cfs, weighted area of habitat preferred by adult Colorado pikeminnow in the 15-mile reach was 26% and 29% greater than at the lower flow levels of 1,530 cfs and 1,240 cfs, respectively. However, it is unknown whether weighted area would have been greater at flows somewhat higher than 1,630 cfs: no additional habitat mapping was conducted until flows reached 2,870 cfs. Weighted area at 1,630 cfs was 42% higher than at 2,870 cfs. Similarly, during the Carter et al. (1985) study, no habitat mapping was conducted between the flow levels of 1,710 and 3,840 cfs, and weighted area of preferred habitat was 93% less at 3,840 cfs than at 1,710 cfs. Thus, the optimum flow for producing habitats preferred by adult Colorado pikeminnow is not known but lies somewhere between 1,630 and 2,870 cfs. Unregulated inflow at Cameo during summer (Aug-Oct) averaged 1,500-2,000 cfs (depending on the month) during dry years, 2,000-2,500 cfs during below-average years, 2,000-3,100 cfs during above-average years, and 2,800-5,000 cfs during wet years (Table 1).

Although an argument can be made that restoring natural flow levels, as well as the natural month-to-month and year-to-year variation inherent in a natural flow regime, is the most conservative approach for restoration of an ecosystem that is not fully understood, it is the view of this author that restoring the critical functions of the natural flow regime should be the focus of management efforts whenever possible. In many cases, this may be accomplished without a return to a completely 'natural' regime or require amounts of water that would have occurred under natural conditions. Also, to date, there has been little evidence that extremely low or extremely high summer flows, whether artificial or natural, are beneficial to either Colorado pikeminnow or razorback sucker. It is more likely that in aggregate such flows are detrimental to native fishes: very low flows hamper fish movements, stress fish when they are crowded into restricted pools, desicate riffle and shoreline invertebrate communities, and may favor reproduction and survival of non-native fishes adapted to lentic or low-velocity environments. Although very low flows boost water temperatures and thereby enhance larval and juvenile Colorado pikeminnow growth rate, this effect does not offset the lower numbers of larvae produced in such years (McAda and Ryel 1999). High summer flows reduce preferred mesohabitats, leading to a reduction in carrying capacity for adult endangered fishes; such flows reduce first-year growth rate of Colorado pikeminnow and evidently play a role in low survival or retention of Colorado pikeminnow larvae in downstream nursery reaches (McAda and Ryel 1999). Thus, management efforts should be aimed to reduce the occurrence of these extreme high and low base-flow conditions. Based on the habitat mapping results from the 15-mile (Osmundson et al. 1995) and De Beque-to-Rulison reaches (Carter et al. 1985), and the NRCS unregulated flow estimates for Cameo, summer base-flow conditions most suited to adult Colorado pikeminnow and perhaps razorback sucker probably fall within the range of about 1,600-2,500 cfs. August typically has somewhat higher flows than either September or October; however, survival and retention of Colorado pikeminnow larvae may be enhanced by the early stabilization of base flows (McAda and Ryel 1999). It is therefore recommended that base flows upstream of Palisade be between 1,600 and 2,500 cfs during August-October (Table 5). The exception to this would be in months of dry years when something less than the optimum amount would have occurred some of the time under unregulated conditions. Thus, the recommendation for months of dry years would be to use the <u>average</u> unregulated monthly inflow of such years (Table 1) as the target flow. This will allow flows to drop below the optimum amount and simulate 'natural' low flows; however, using the average for months of this hydrological category will allow avoidance of extremely low flows during years of unusually low snowpack.

Although the above recommendation is a best estimate of flows that will most benefit the target species during summer in the two reaches upstream of Palisade, there are constraints to implementing this recommendation that need to be discussed. These constraints are due to the irrigation diversions at GVICDD and GVPDD. As long as current operations at these diversions continue, flows required at Cameo must be high enough to supply the canals and satisfy the 15-mile reach recommendations downstream. The Grand Valley Canal generally diverts 640 cfs; the Government Highline Canal, 1,620 cfs. The Orchard Mesa Power Canal returns part of the amount diverted for the Government-Highline Canal (generally 570 cfs) back to the river at the top of the 15-mile reach. During summer, Plateau Creek adds approximately 20-60 cfs to the river between the two diversions. Recommendations call for a minimum of 810 cfs at the top of the 15-mile reach during dry years, 1,240 cfs during below-average years, and 1,630 cfs during above-average and wet years (Osmundson et al. 1995). Assuming an average net depletion of 1,690 cfs is required to supply local irrigation needs during summer, and assuming a Plateau Creek contribution of 40 cfs, flows at the Cameo gauge (just upstream of the top diversion) need to be 2,460 cfs during dry years, 2,890 cfs during below-average years, and 3,280 cfs during above-average and wet years (Table 6). These numbers are as much as 780 cfs higher (above-average and wet years) than recommended for providing optimum fish habitat upstream of GVPDD and as much as 1,000 cfs higher than average unregulated inflows at Cameo (September of dry years). Very high summer flows at Cameo not only reduce important adult habitat upstream but also make it more difficult for flows downstream of Moab, Utah to remain below 4,000 cfs, the discharge above which nursery habitat for YOY Colorado pikeminnow is reduced.

Between GVICDD and GVPDD, discharges decrease by 1,620 cfs (the amount diverted at GVPDD), and would therefore result in flows of 880 cfs during dry years, 1,310 cfs during below-average years, and 1,700 cfs during above-average and wet years, amounts similar to those currently recommended for the 15-mile reach. The diversion needs at Cameo, as outlined above, could be adjusted down for periods when smaller amounts are diverted for the Government Highline Canal (less than peak demand) and by the future amount reduced by the U. S. Bureau of Reclamation's Grand Valley Water Management Project.

The relative importance of the 15-mile reach (Osmundson 2000) makes implementing FWS flow recommendations there the highest priority at this point in time. As long as local diverters continue current operations, average summer flows upstream of Cameo will remain somewhat higher than optimum during below-average, above-average and wet years. When summer discharge at Cameo exceeds 3,280 cfs, excess water should be considered detrimental to endangered fish habitat and it is recommended that it be stored upstream to the extent possible.

Winter (November-March)

Winter flow objectives are to provide the maximum amount of habitat preferred by adult Colorado pikeminnow and razorback sucker. Average unregulated inflow at Cameo during November-March is about 1,300-2,300 cfs, depending on the month and the wetness of the year. Again, it is recommended that flows be held at levels estimated to maximize preferred winter habitats, i.e., 1,600 to 2,500 cfs. However, it is difficult to recommend minimum flow levels higher than what would have occurred naturally. Thus, in months of years with unregulated flows averaging less than 1,600 cfs, the average unregulated flow for that precipitation category becomes the recommended minimum flow (Table 5). However, flows higher than this and still within the 1,600-2,500 optimum range are preferred.

Due to the lack of irrigation during winter, constraints in meeting the recommendations are largely absent for the reach upstream of GVPDD. Recommendations for the 15-mile reach during winter are for flows to be held at 1,630 cfs during all years except dry years, when flows could be reduced to 1,240 cfs. The Government-Highline Canal diverts 800 cfs all winter for the Orchard Mesa Power facility; this water is returned to the top of the 15-mile reach. The GVICDD only diverts water during winter for about one week (about 400 cfs), and therefore, to simplify matters, is not considered here. Because of the lack of irrigation, the discharge at Cameo during winter is very similar to the discharge at the top of the 15-mile reach (once the power diversion is added back). Thus, the discharge in the GVPDD-to-Rifle reach can be essentially the same as that for the 15-mile reach. Assuming a 55-cfs average inflow from Plateau Creek, a discharge of 1,600 cfs at Cameo would result in a 1,655 cfs discharge at the top of the 15-mile reach during most years. During dry years, 1,200 cfs at Cameo would result in 1,255 cfs in the 15-mile reach. Thus, discharges in both reaches would approximate the current 1,630 cfs recommendation for the15-mile reach during most years and the 1,240 cfs minimum during dry years.

Unfortunately, implementation of the flow regime described above would leave the 14-km (8.6-mile) reach immediately downstream of GVPDD (the GVICDD-to-GVPDD reach) with low flows: about 855 cfs (1600-800+55 cfs) during most years and 455 cfs (1,200-800+55) during dry years. Assuming continued operation of the diversions, this largely canyon-bound short reach should receive lowest priority in implementing desired flows. Nevertheless, because a discharge of 455 cfs would appreciably reduce slow and fast run habitat (assuming a similar discharge/habitat relationship as in the 15-mile reach), a discharge of 810 cfs (the minimum flow recommended for the 15-mile reach during dry summers) is proposed here as a winter minimum for the GVICDD-to-GVPDD reach. To achieve this, a minimum flow of 1,555 cfs will be required at Cameo during the winter months of dry years (1,555-800+55 = 810). With this inflow at Cameo, the 15-mile reach would automatically receive 1,610 cfs during low-water years, rather than the minimum of 1,240 cfs that was recommended earlier for that reach before upstream needs were considered. Because discharge in excess of 2,500 cfs at Cameo is expected to result in an appreciable reduction of preferred winter habitat for Colorado pikeminnow, any such excess water should be stored upstream to the extent possible.

Spring (April-July)

The median bankfull discharge in the GVPDD-to-Rifle reach (20,500 cfs in De Beque Canyon and 22,000 cfs upstream of the canyon) is similar to that for the 15-mile reach (21,500 cfs). Thus, peak flow targets are similar among areas (bankfull discharge in the GVICDD-to-GVPDD reach has not been determined). High peak flows will cleanse the bed of fine sediment, scour encroaching vegetation, entrain terrestrial organic debris, and maintain dynamic channel characteristics thereby providing a variety of habitat types required by the endangered fish. These high flows will also act to rebuild eroded sand bars in the Colorado pikeminnow nursery area downstream of Moab, Utah. In addition to exceeding the bankfull discharge it is important that the natural shape of the hydrograph be retained so as to provide the behavioral cues associated with spawning and to provide larval, YOY and adult razorback sucker and adult Colorado pikeminnow sufficient time to utilize the productive, warm, off-channel habitats provided during spring runoff.

It is recommended that peak flows that meet or exceed the median bankfull discharge should occur with a mean recurrence interval of 2.0 years. As for the 15-mile reach, this can be accomplished if the median bankfull discharge is reached or exceeded in all above-average and wet years (0-50% exceedance). The duration required to transport sediment through the reach once this threshold is achieved is unknown and would vary depending on how much the threshold is exceeded, i.e., the higher the discharge, the shorter the duration required. For above-average precipitation years, an initial recommendation is for the bankfull discharge to be exceeded for three days. An adaptive management approach will allow this recommendation to be adjusted if and when additional studies determine the durations required (at various discharges) for sediment moving out of the reach to balance the amount moving in.

For wet years, the primary objective is to provide conditions that promote a strong razorback sucker year class. To do so, sufficient area of flooded bottomland habitat needs to be provided such that an array of site types are available, thereby assuring there are those with the requisite characteristics present. In addition, these areas need to be large and well dispersed throughout the reach so that drifting larvae and adults have ready access to them. The Carter et al. (1985) mapping study indicates there is some limited flooding of bottomland habitat at discharges of 10,000-21,000 cfs. However, increases in area of such habitat begin to accelerate in an almost exponential fashion at flows higher than this, presumably after the median bankfull level of 22,000 cfs is exceeded. Thus, much more area of such habitat can be provided with relatively small increment increases of flow above the bankfull level (Fig. 3). Carter's mapping results indicated that area of flooded bottomlands increased by 157% when discharge increased from 21,000 cfs to 23,400 cfs, an increase in flow of only 11.4%. Although higher discharge resulted in even greater area, the 23,400 cfs serves as a useful target. Therefore, the recommendation is that flows in the De Beque-to-Rifle reach should exceed 23,400 cfs at a rate of one in four years. Flows should be maintained above this level for a minimum of three weeks to give razorback sucker larvae adequate time to feed and grow in flooded bottomlands before being compelled to migrate to the main channel. In addition to providing for razorback sucker staging, spawning and rearing habitat, these elevated wet-year flows will allow within-channel substrate mobilization to occur at more sites than the 50% rate attained when the median bankfull level is achieved as during above-average years.

For below-average and dry years, the rationale used in recommending peak flows in the 15-mile reach (see Osmundson et al. 1995) is assumed to be applicable to reaches upstream of GVICDD and GVPDD as well (minimum peaks of 12,900 cfs are needed in dry years to keep backwaters from losing depth to fine sediment deposition; and moderately high peaks are needed in other years to prevent tamarisk seedlings from becoming too well established, keeping non-native minnow numbers in check, and providing some level of bed mobilization). For peaks in the 12,900-22,000 cfs range at Cameo, the mean as well as the median during 1908-1999 has been about 17,400 cfs; thus, this number can serve as a recommended target for peak flows in below- average years. Thus, peak flow recommendations for the Palisade-to-Rifle reach are very similar to those previously made for the 15-mile reach, and therefore the monthly averages during April-July needed to produce these peaks will therefore be similar as well. Hence, recommendations for mean flows during the spring months in the Palisade-to-Rifle reach are the same as those recommended for the 15-mile reach, minus the average monthly amounts contributed by Plateau Creek for each precipitation category. One deviation from the earlier recommendations is that the mean amount recommended for July of dry years be raised; this is so that June flows can decline more smoothly into August flows. Table 5 contains recommendations for mean monthly flows at the Cameo gauge; recommendations for peak flows are as follows:

1) ≥ 23,4 00 cfs (5 in 20 years)
2) 22,000 cfs (5 in 20 years)
3) 17,400 cfs (6 in 20 years)
4) 12,900 cfs (4 in 20 years)

As with summer flows, current diversion operations complicate implementation of the spring recommendations. Although the median bankfull discharge upstream of De Beque Canyon is 22,000 cfs, the target at Cameo will need to be 1,250 cfs higher (23,250 cfs) if the 21,750 cfs target peak flow (above-average years) in the 15-mile reach is met and the canals filled (assumes a combined average net diversion depletion of 1,500 cfs after Plateau Creek is factored in). Similarly, for the wettest years, the minimum peak flow currently recommended for the 15-mile reach is 23,500 cfs, so a minimum peak flow at Cameo of 25,000 cfs would therefore be required to satisfy both fish and local irrigation needs. These additions are also needed for below-average and dry years. However, unlike during summer, additional water in spring should not have a detrimental effect on the endangered fish. Thus, under current constraints, peak flow recommendations at Cameo would be:

1) $\geq$ 25,000 cfs (5 in 20 years)
2) 23,250 cfs (5 in 20 years)
3) 18,200 cfs (6 in 20 years)
4) 14,400 cfs (4 in 20 years)

Table 6 lists the mean monthly flows at Cameo required to provide or exceed recommended flows in the GVPDD-to-Rifle reach, provide recommended flows in the 15-mile reach, and provide minimum flows in the GVICDD-to-GVPDD reach while allowing current diversion depletions at local canals.

UNCERTAINTIES

These flow recommendations are based on the best information available at this time. As our understanding of the life history of these fish and the relationship between flow and habitat becomes more complete, the recommendations provided here will likely need to be adjusted accordingly. For this particular stretch of river there are specific uncertainties that need to be acknowledged here. Uncertainty is inherent in the following assumptions made in this report:

1) The mesohabitats preferred or extensively used by the endangered fish in this reach will be the same as those in the 15-mile reach immediately downstream.
2) Total surface area of key mesohabitats is maximized at the same flow levels in this reach as it is in the 15-mile reach immediately downstream.

Table 5. Recommendations for mean monthly flows (cubic ft/sec) in the upper Colorado River as measured at the USGS gauge near Cameo. April-July values are the same as those recommended for the 15-mile reach immediately downstream (see Osmundson et al. 1995), minus the average monthly amounts contributed by Plateau Creek for each precipitation category. Summer and winter recommendations are given as ranges in months when unregulated inflows at Cameo exceeded the recommended minimum of 1,600 cfs. In months with average unregulated Cameo inflow less than the recommended minimum of 1,600 cfs, the average unregulated inflow became the recommendation (values are rounded to the nearest 100 cfs). 'Rate' is defined as the percent of years that the recommended flows should be provided based on winter snowpack levels. For example, in the wettest 25% of years, flows in June should average at least 14,300 cfs; stated another way, this recommendation should be met in five of every 20 years. During low-water years, June flows should average no less than 6,750 cfs, and such a minimum should occur at a rate of no more than 4 in 20 years (20%). 'Exceedance' (Exc.) is defined as the percentage of years having higher precipitation than those in the specified category (Cat.): for instance, 'dry' years have an 81-100% exceedance value because precipitation in 81-100% of all years exceeded the amount in individual 'dry' years. AA = above average; BA = below average.

Cat.	Rate	Exc.	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
Wet	25%	0-25%	1,600	1,600	1,600	2,910	9,730	14,300	6,770	----------1,600-2,500----------------------				
AA	25%	26-50%	1,500	1,400	1,600	2,260	9,100	14,130	5,380	----------1,600-2,500---------				1,600
BA	30%	51-80%	1,300	1,400	1,600	2,080	7,210	11,120	3,090	----------1,600-2,500---------				1,500
Dry	20%	81-100%	1,300	1,300	1,500	1,700	7,040	6,750	1,950	1,600	1,500	1,600	1,500	1,300

Table 6. Mean monthly flows at the USGS gauge near Cameo required to provide or exceed recommended flows in the GVDD-to-Rifle reach, provide recommended flows in the 15-mile reach and provide minimum flows in the GVICDD-to-GVDD reach while allowing local diversion canals to continue current operations. Flows for spring months were calculated by adding back net diversion amounts to the recommended 15-mile reach mean-monthly discharges (see Osmundson et al. 1995): 1,150 cfs for April; 1,450 cfs for May; 1,500 cfs for June; 1,500 for July.

Cat.	Rate	Exc.	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
Wet	25%	0-25%	1,600	1,600	1,600	4,360	12,170	17,160	8,560	3,280	3,280	3,280	1,600	1,600
AA	25%	26-50%	1,600	1,600	1,600	3,590	10,530	15,750	6,870	3,280	3,280	3,280	1,600	1,600
BA	30%	51-80%	1,600	1,600	1,600	3,410	9,160	12,850	4,650	2,890	2,890	2,890	1,600	1,600
Dry	20%	81-100%	1,555	1,555	1,555	3,010	8,710	8,350	2,980	2,460	2,460	2,460	1,555	1,555

3) The year and sub-reach in which habitat mapping was conducted by Carter et al. (1985) was representative of the reach as a whole.
4) Suitable mainstem and/or bottomland habitat for razorback sucker reproduction and rearing will be available in this reach if appropriate flows are provided.
5) Suitable conditions for Colorado pikeminnow spawning occur in De Beque Canyon.

In addition, the best available information was used to make estimates of several biological and geomorphological parameters. These estimates cannot be validated or refined without additional empirical data collected from these specific reaches or extrapolated from appropriate studies conducted on similar reaches. These parameters include:

1) the upstream extent of the reach that will be used by Colorado pikeminnow during winter and during summer,
2) the duration of bottomland inundation required to assure an adequate level of razorback sucker larval survival, and
3) the duration of median bankfull discharge required to move sediment out of the reach so as to balance the amount moving in.

These questions and current uncertainties will require extensive research to resolve. One of the more tractable issues of those listed above involves assumption 2: are important base-flow mesohabitats maximized at the same flow levels in this reach as they are in the 15-mile reach? Answering this question could go a long way towards resolving one of the most important uncertainties associated with these recommendations. If refining the interim summer and winter flow recommendations for this reach is considered a high priority by the Recovery Program, initiating a habitat-mapping study at various base-flow levels is recommended.

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APPENDIX

Appendix Table I. Seasonal frequency of use of mesohabitats by radio-tagged adult Colorado pikeminnow in the Grand Valley, 1986-1989. Reproduced from Osmundson et al. 1995.

	Month											
	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
GP	0	0	0	3.2	21.6	25.3	4.3	0	0	0	0	0
BA	15.4	13.6	14.3	41.9	27.4	22.0	7.2	2.9	4.5	8.7	5.9	4.8
ED	7.7	4.5	7.1	3.2	2.0	8.8	15.9	14.7	9.1	4.3	0	0
PO	42.3	54.5	32.1	9.7	11.8	7.7	13.0	16.2	13.6	26.1	52.9	61.9
SH	0	0	0	6.4	7.8	3.3	1.4	4.4	0	0	0	0
SR	34.6	27.3	42.9	32.3	27.4	13.2	26.1	32.4	54.5	60.9	41.2	33.3
FR	0	0	3.6	3.2	0	18.7	26.1	16.2	6.8	0	0	0
RI	0	0	0	0	2.0	0	2.9	10.3	6.8	0	0	0
RA	0	0	0	0	0	1.1	2.9	2.9	4.5	0	0	0
N	26	22	28	31	51	91	69	68	44	23	17	21
n	6	6	6	12	13	21	15	14	13	11	9	8

GP = gravel pit
BA = backwater
ED = eddy
PO = pool
SH = shoreline
SR = slow run
FR = fast run
RI = riffle
RA = rapid
N = number of fish locations
n = number of individual Colorado pikeminnow

Appendix Table II. Seasonal frequency of use of mesohabitats by radio-tagged adult razorback sucker in the Grand Valley, 1986-1989. Reproduced from Osmundson et al. 1995.

	Month											
	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
GP	0	0	0	0	0	42.9	0	0	0	0	0	0
BA	0	0	10.0	16.7	45.4	28.6	35.7	0	0	0	0	0
ED	18.2	0	10.0	0	0	7.1	0	0	12.5	0	0	33.3
PO	63.6	50.0	60.0	66.6	0	14.3	21.4	66.7	12.5	42.9	100	50.0
SH	0	0	0	0	9.1	7.1	7.1	0	0	0	0	0
SR	18.2	50.0	20.0	16.7	34.1	0	28.6	33.3	75.0	57.1	0	16.7
FR	0	0	0	0	11.4	0	0	0	0	0	0	0
RI	0	0	0	0	0	0	7.1	0	0	0	0	0
RA	0	0	0	0	0	0	0	0	0	0	0	0
N	11	10	10	6	11	14	14	15	8	7	3	6
n	2	2	2	2	2	4	2	2	2	1	1	2

GP = gravel pit
BA = backwater
ED = eddy
PO = pool
SH = shoreline
SR = slow run
FR = fast run
RI = riffle
RA = rapid
N = number of fish locations
n = number of individual razorback suckers

Cover Photo
The Colorado River near rm 211.5; looking upstream, east of De Beque, Colorado, 1999.
Photo by John Pitlick ©

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