RELATIONSHIPS BETWEEN FLOW AND RARE FISH HABITAT IN THE '15-MILE REACH' OF THE UPPER COLORADO RIVER

Final Report

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EXECUTIVE SUMMARY

Introduction

This report presents the results of a U.S. Fish and Wildlife Service (FWS) habitat evaluation study for a 15-mile segment of the Colorado River. Utilizing new information provided here as well as that collected by other researchers, recommendations for instream flows provided in earlier FWS documents is updated and refined. The river segment in question, hereafter referred to as the '15-mile reach' is viewed as critical in recovering Colorado River populations of endangered Colorado squawfish (*Ptychocheilus lucius*) and razorback sucker (*Xyrauchen texanus*).

Previous recommendations for flows during summer (July-September) in the 15-mile reach were provided by Kaeding and Osmundson (1989). In that report, flow levels were recommended based on output from the Physical Habitat Simulation System (PHABSIM), a model often employed within the larger Instream Flow Incremental Methodology (IFIM). Summer use of the reach was considered most valuable as habitat for adult Colorado squawfish and the PHABSIM model was used to predict what flow level would maximize the amount of river consisting of microhabitats with a set of depth, velocity and substrate characteristics often selected by adult squawfish.

FWS later provided recommendations for the 15-mile reach for the remainder of the year, i.e., the winter and spring months (Osmundson and Kaeding 1991). In determining flows for the winter months, use of comparatively deep water by both species during winter led FWS to conclude that flow needs would be greater than during summer. Until more data could be collected or analyzed the interim recommendation was for current or historic flow regimes to be maintained.

For the spring months, FWS concluded that the greatest value of high flows, typical of the spring runoff period, was the year-round benefits provided by the scouring and flushing action of the flood waters, i.e., channel maintenance, removal of embedded fine sediments from gravel and cobble substrates, control of vegetation encroachment, entrainment of organic debris from the floodplain into the channel, control of otherwise prolific non-native fish , etc. Of particular importance was a relationship that was noted between reproductive success of Colorado squawfish and peak spring flows within a given range of magnitudes. In addition, FWS linked the spawning and nursery habitat needs of razorback sucker to the ability of the river to flood its banks during the spawning period.

Summer and Winter Flows

Serious shortcomings of the IFIM approach used in developing flow recommendations for the endangered fish in the upper Colorado River led FWS to initiate a new study for determining recovery flows for the non-runoff, summer and winter periods. Rather than modeling microhabitats based on depth, velocity and substrate measurements at a site thought to be representative of the reach, the approach used here was to determine which habitat types (pools, riffles, etc.) were preferred by the fish and then determine at what flow level such preferred types are maximized in area. As with other instream flow methodologies, the underlying assumption is that increases in the amount of preferred or optimum habitat increases carrying capacity and, barring other potentially limiting factors, results in an increase in population size.

Four sub-reaches averaging 0.5 miles in length were selected as study sites within the 15-mile reach. The sites were selected based on results from a previous radiotelemetry study that indicated they were areas of high use by the endangered fish. To determine habitat preference for adult Colorado squawfish, the percent frequency of use of each habitat type by an individual fish within the study sites was compared with the relative availability of each habitat type within the study sites. Difference between frequency of use and availability provides a measure of the degree of preference for a given habitat type. For instance, if a fish is found in pools 90% of the time, but pools make up only 10% of the total water area within a reach of river that the fish occupies, preference for pools is indicated, i.e., the fish is selecting a habitat type in greater proportion than its availability would alone predict if selection of sites was random. Preference rating for pools for the fish in the example would be 0.8 (0.9 minus 0.1). This process is repeated for each fish for which location data were collected within the study sites. Preference rating for pools for each fish is then averaged to arrive at a mean preference rating for pools by squawfish in general. This exercise was repeated for each of eight habitat types that collectively made up the total water area of the study sites.

Habitat frequency of use data were collected by radio tagging a sample of Colorado squawfish and razorback sucker and recording their location once weekly. When a location was made, the habitat type at the site of the fish was recorded as was the mean-column water velocity, depth and substrate type. Habitat availability data was collected by mapping habitat delineations on aerial-video prints of the study sites. A field crew mapped habitat units within the sites from on-the-ground vantage points while video of the sites was taped from a helicopter flown at a constant elevation. Once the habitat units were overlain on the video images and scanned into a computer, areas of individual habitat units could be measured and their percent contribution to the total water area of a study site calculated. This process was repeated at 11 different flow levels ranging from 557 to 11,200 cfs, as measured at the top of the 15-mile reach, to gain an understanding of how relative availability and total water area of eight habitat types change as a function of discharge level.

Eddies, pools and deep backwaters were found to be the habitats preferred by adult squawfish during summer. Interestingly, these are habitat types that are relatively rare, comprising only a small proportion of the total water area. When summer water levels became very low in the reach, fish modified their behavior and were found in the more common slow and fast run habitats, or left the reach entirely by moving downstream below the confluence with the Gunnison River where more water was available. In winter, eddies, pools and backwaters were again found to be the preferred habitat types, with pools preferred most. Of the flow levels typical of summer and winter conditions, both recently and historically, the flow level evaluated here that provided the greatest amount of the preferred habitat was 1,630 cfs. This became the basis for the new summer and winter instream flow recommendation. Other variables that were examined included the suitability of depth at various flow levels and the interspersion or density of habitat types.

In years with above average winter precipitation levels, a flow of 1,630 cfs is recommended for summer. In years of somewhat below average precipitation, when the ideal flow of 1,630 cfs would be difficult to meet, the recommendation could be relaxed to 1,240 cfs. At this flow, the area of preferred habitat would be reduced but the flow would not be so low as to compel the fish to modify their habitat selection or be forced from the reach. In years of drought (20% lowest precipitation years), when even 1,240 cfs would be difficult to meet, flows should not fall below 810 cfs. Hopefully, at this level the fish that remain in the reach can wait out the period until more favorable conditions return with the end of the irrigation season.

In winter, flows in the reach are generally not limiting. In fact, due to storage in upstream reservoirs, flows during recent years have been higher on average than they were historically. The recommendation is for a winter instream flow of 1,630 cfs to be maintained in all years except during periods of drought (lowest 20% of years) when the recommendation could be relaxed to 1,240 cfs.

Spring Flows

The earlier (1991) FWS report that dealt primarily with spring flow needs in the 15-mile reach described how the frequency of years with very high spring flows has greatly decreased since the early part of the century, and how years with low spring flows, once rare, are now commonplace. The magnitude of the annual peak day (average discharge over 24 hrs on the highest day of the year) was used to describe the attenuation of the spring hydrograph over time. To provide some idea of this change, the frequency of years with peaks in excess of a given amount can be compared between a block of years early in the century with a block of years later in the century. Years with peak runoff greater than 23,000 cfs occurred in 73% of the 41 years prior to 1943. Since 1954, years with a peak flow in excess of 23,000 cfs occurred only eight times, or 20% of the 40 years. For low-water years, a peak discharge less than 13,000 cfs never occurred in the 41 years prior to 1943, whereas since 1954, the annual peak flow was less than 13,000 cfs in 45% of the years (18 of 40 years). The year 1943 is used because many upstream water storage and trans-basin diversion projects began coming on line at that time. Though some of this change in the hydrograph may be attributable to changes in weather, the effect of water regulation has no doubt been significant.

Using what is known about the life history of the Colorado squawfish and razorback sucker, FWS went on to discuss how this change in the magnitude of flows during the spring months could negatively affect the ability of these endangered fish to successfully reproduce and survive. Data were provided that demonstrated a relationship between the relative number of squawfish larvae produced in a year and the magnitude of the spring hydrograph: years of low spring runoff generally resulted in lower larval production. An explanation offered for this was that high flows are periodically needed to build cobble bars and flush fine sediment from the gravel/cobble substrates used by squawfish for spawning. Without sufficiently high flows, coarse particles become embedded in a tight matrix of silt and sand; the interstitial voids needed to protect deposited eggs are lost and egg-hatching success is reduced. Data also showed that razorback sucker spawning activity in the upper Colorado River is timed to coincide with the peak runoff period. Captures over the past 20 years indicate that most adults in spawning condition are found in warm, off-channel ponds and inundated floodplain habitats during the period of high water. Historically, these habitat types would have been extensive and available in most years. Today, potential sites are few and flows often do not reach levels high enough to inundate low-lying floodplain features.

FWS also reported on observations made in the 15-mile reach during the drought years of 1988-1990. During this period, backwaters, a low-velocity habitat important to both young and adult fish, were filling in with silt and sand because low spring flows were insufficient to flush fine sediments through the system. Tamarisk, an aggressive, exotic woody plant that stabilizes stream and river banks, colonized sand and cobble bars throughout the 15-mile reach. In the absence of high flushing flows, seedlings were able to develop deep, extensive root systems such that dislodging them once high water again returned would be very difficult. Data also indicated that during these three back-to-back low-water years, non-native minnows capable of preying on or competing with larval endangered fishes greatly increased in numbers.

Based on the rapidity with which these ecological changes occurred, as well as the need for relatively frequent spawning success of the endangered fish, FWS proposed a range of minimum peak flows along with a frequency with which they should occur. In addition to the one day peaks, mean monthly flows capable of producing such peaks as well as serving to maintain the natural shape of the hydrograph were also proposed.

In the study presented in the current report, data were collected that shed additional light on some of the topics discussed earlier. Stream bed monitoring indicated that spring runoff in 1993, with a peak flow of 25,900 cfs, was capable of mobilizing coarse bed materials and thereby winnowing accumulated fines from the channel substrate. This was supportive of the earlier recommendation of a peak flow during wet years to exceed a minimum of 23,500 cfs. Transects that crossed backwaters within the reach were monitored over a four-year period. Changes in fill and scour of fine sediments from one year to the next indicated that a spring discharge with a peak of about 12,900 cfs was capable of flushing accumulated sediments from the bottom of the backwaters thereby restoring their depth. This observation allowed the recommendation for a minimum peak flow during low-water years to be reduced from 14,800 cfs to 12,900 cfs.

As other ongoing studies in the upper Colorado River are completed, additional information will help provide a greater understanding of the relationships between flow and rare fish habitat. Flow recommendations will periodically need to be updated and refined accordingly. For now, we are satisfied that the recommendations provided here are an improvement over those provided earlier and feel strongly that timely implementation of these recommendations will make a significant contribution to the recovery of endangered Colorado River fish.

INTRODUCTION

Background

Populations of Colorado squawfish (*Ptychocheilus lucius*) and razorback sucker (*Xyrauchen texanus*) have diminished since historic times. The range of the Colorado squawfish has been reduced by 80% (Tyus 1990); the razorback sucker, a similar amount. This has compelled the U.S. Fish and Wildlife Service (USFWS) to list each as endangered species. Both species are endemic to the Colorado River basin and were formerly widespread and abundant (Girard 1856, Jordan and Evermann 1896, Miller 1961). Riverine populations are now confined to the upper basin (upstream of Glen Canyon Dam). There, the Colorado, Green and San Juan rivers and associated tributaries comprise the remaining range of these species. Currently, the Green/Yampa river system supports the most viable population of Colorado squawfish and also contains the largest number of adult razorback sucker remaining in the upper basin (Holden and Wick 1982, Lanigan and Tyus 1989). The San Juan system contains the most diminutive population of Colorado squawfish, and no razorback sucker have been found there in recent years (Ryden and Pfeifer 1993). This report focuses on the Colorado River. There, a small remnant population of razorback sucker persisted up through the mid-1980's; since then only a few individuals have been captured (Valdez et al. 1982, Osmundson and Kaeding 1991, Burdick 1992, USFWS unpublished data). Colorado squawfish continue to persist but distribution and abundance have declined to the point that long-term survival is far from assured.

Reduction in range can generally be attributed to dams and diversion structures. Large dams and associated cold-water releases render downstream reaches uninhabitable. Range is also reduced where large or small structures prevent young and adults from returning upstream after they have migrated downstream. In those nonfragmented reaches where habitat for all life phases still exist, it is difficult to quantify the factors that negatively effect remaining populations. Factors that have been implicated include predation or competition from nonnative fishes, mortality from ingestion of spined prey, angler-associated adult mortality, reproductive problems associated with environmental contaminants, low egg-hatching success due to infrequent flushing of spawning substrates, a reduced food base, low availability of quality nursery habitat, and degradation or simplification of adult habitats. Though some or all of these factors may act in concert, the relative importance of each for each species within each river is unknown. Indeed, several of these factors are strongly suspected but have not been demonstrated.

With the exception of angling mortality and problems associated with environmental contaminants, many of the suspected problems listed above have been caused or exacerbated by flow regimes that have been significantly altered during the past 100 years. Even problems associated with nonnative fish can in part be linked to reduced flows that have allowed the colonization and continued proliferation of certain species (Osmundson and Kaeding 1991, Muth and Nesler 1993).

Legal protection of sufficient instream flows to support self-sustaining populations of the endangered fish is one of the primary goals of the Recovery Implementation Program[1] (USFWS 1987, USFWS 1993). Instream flow needs are based upon the habitat requirements of rare fish species at various life stages. Identification of habitat requirements and instream flow needs of the rare fish is perhaps the most important element of the research effort expended by the Recovery Program.

Continued, ongoing research which will refine existing flow recommendations and integrate new information into the process is an explicit element of the Recovery Program (USFWS 1987). In Colorado, the Colorado Water Conservation Board is responsible for appropriating instream flows.

In 1988, the 15-mile reach (RM 171-185) of the upper Colorado River was identified as one of the highest priority areas for instream flow protection. In May 1989, the USFWS provided recommendations for flows needed for rare fish in the 15-mile reach during the summer months (July-September); in April 1991, recommendations for the remainder of the year (October-June) were provided (see Kaeding and Osmundson 1989 and Osmundson and Kaeding 1991).

Approach Used for Summer and Winter Recommendations

The earlier summer recommendations were largely aimed at providing flows that would optimize adult squawfish physical habitat within the reach and to boost water temperatures during July to promote growth of young squawfish within and downstream of the reach. To relate flows to adult squawfish habitat, an analytical model was used; this was the Physical Habitat Simulation System (PHABSIM-2), a technique often employed within the larger Instream Flow Incremental Methodology (IFIM) described by Bovee (1982).

Untested assumptions and other limitations associated with utilizing IFIM[2], along with some site-specific problems (e.g. representativeness) prompted USFWS to initiate an alternative method of tying flows to habitat needs. Results from such a method would either substantiate the PHABSIM-2 output, identify discrepancies, or serve to refine the earlier recommendations. It was hoped that if this new technique showed promise, it could be used throughout the upper basin as a standardized means of developing flow recommendations.

The approach used in this study to determine the best summer and winter flows for the reach was to identify which habitat types were preferred by the fish and then determine the flow level at which the amount or total area of those types is maximized. To determine habitat preference, frequency of use of habitat types by the fish was compared with relative availability of those habitat types. To determine the total area of those preferred habitats at different flow levels as well as relative availability for fish use, habitats were mapped with a combination of on-the-ground mapping and aerial videography. Stage and stream-bed cross sections were also monitored to determine at what flow level insufficient depth might become limiting. Like IFIM, this method attempts to quantify changes in habitat with changes in discharge. Also like IFIM, it assumes that, given the alleviation of other potentially overriding limiting factors, area of preferred habitat is correlated with standing

[1] The Recovery Implementation Program is an interagency consortium of Federal, State and private groups whose mission is to recover four endangered fish (Colorado squawfish, razorback sucker, bonytail and humpback chub) in the Upper Colorado River Basin while providing for future water development to proceed in compliance with the Endangered Species Act.

[2] Problems associated with utilizing IFIM for the endangered Colorado River fish have been summarized by Kaeding and Osmundson (1989), Osmundson and Kaeding (1991) and Stanford (1993).

to support the target species. Habitat capacity is defined as the level above which emigration stocks, i.e., increases in preferred habitat result in a concomitant increase in the capacity of a reach occurs (Mesick 1988: Bartholow et al. 1994). Unlike IFIM, this method actually measures changes in mesohabitat area within several study sites, rather than estimating changes in microhabitats from measurements of depth, velocity and substrate along several transects within one study site. Mesohabitats are defined as a discrete unit of habitat at the pool/riffle scale that has distinct hydrologic and biological characteristics (from Kershner et al. 1992); it is assumed that each mesohabitat type tends to behave similarly in response to discharge fluctuations (Bartholow et al. 1994). The mesohabitat approach used here eliminates the need to assume that depth, velocity and substrate are variables independent of one another and equal in importance in influencing microhabitat selection by the fish, model assumptions for which IFIM has often been criticized (Patten 1979; Orth and Maughn 1982; Mathur et al. 1985).

The mesohabitat mapping approach also allows the measurement of habitat heterogeneity, an environmental variable not addressed by IFIM. Retention of natural habitat interspersion and juxtaposition should be an instream flow consideration (Bartholow et al. 1994), adding an additional quality component to a method otherwise driven by habitat quantity considerations. In conjunction with maximizing preferred habitats, managing for habitat heterogeneity provides a hedge against the uncertainty of not knowing the importance of habitats that the target species does not prefer or use very much (Bovee personal communication). High habitat heterogeneity or diversity assures that these other habitats are interspersed with preferred habitats and are present to fulfill their respective functions. In this study, density of mapped habitat units was used as a measure of interspersion; it was treated as a secondary consideration to the primary objective of maximizing area of preferred habitat.

Approach Used for Spring Recommendations

In determining optimum flows for the spring months, 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, control of non-native fish, etc. Thus, recommendations for spring flow levels were aimed more at maintaining and enhancing these effects than for optimizing rare fish habitat used during the spring months as was the case for the summer and winter periods. The exception to this was to assure that certain key habitats used by razorback sucker during spring were provided. This was because, unlike Colorado squawfish which spawn during summer, razorback suckers spawn in spring; thus, maintaining or enhancing appropriate habitats during this period could be critical to reproduction and survival of razorback young.

For the reasons outlined above, this report does not employ for the spring period the approach used for recommending summer and winter flows, i.e., determining the flows at which preferred mesohabitats are maximized in area. The approach and rationale used in the previous FWS report on spring flows (Osmundson and Kaeding 1991) remains the most valid, and the existing recommendations for spring flows provided in that report are largely maintained here. That report is referenced in this report where appropriate and is included in its entirety as Appendix IX. In the current report, new information collected by FWS as well as that collected by others is used to refine the existing recommendations for spring, focusing primarily on geomorphic issues discussed in the earlier report but for which data were lacking. New studies included monitoring stream bed cross sections through years of low and high flow regimes to provide insights into minimum peak flows required to (1) maintain backwater depth through flushing the bed of accumulated fines (silt) and (2) to cleanse within-channel substrates of accumulated fines via mobilization of coarse bed materials.

Study Objectives

Because these populations are now in danger of extirpation, the management objective is to provide favorable if not optimum conditions that promote species recovery. Maintaining the status quo, which includes conditions that have led to population decline, will not be sufficient (Tyus 1992). This is true for managing nonnative fish, contaminants, and other impacts in addition to altered flow regimes. Therefore 'minimum' flows recommended in this report are something more than that which will enable survival of individual fish: we define minimum flows for endangered fish as those necessary for species recovery, i.e., those that promote increases in population size.

The primary objectives of this study were to:

1) determine how changes in flow result in changes in riverine habitats,
2) determine habitat preferences of the endangered fish,
3) determine at what discharge the quantity and quality of preferred habitats are maximized,
4) present revised flow recommendations based on integration of new and existing data.

Due to the interrelatedness of the topics addressed in this report, layout of an organizational format that clearly addresses each of the above objectives in a sequential manner was problematic. To identify which sections in the report address each of the objectives, we have listed after each heading, where appropriate, the Objective No. from the list above.

Adjacent Reaches and Companion Studies

We conducted this study in both the 15-mile reach and the reach (18-mile) immediately downstream. Here we report only on the results from the 15-mile reach. Results for the 18-mile reach will later be presented under separate cover. For water management purposes, it makes sense to treat these two reaches separately because the flow regimes of each are different. However, from a biological standpoint, it is difficult to study the 15-mile reach in isolation. Many adult fish move in and out of the reach on a seasonal basis, using the adjacent 18-mile reach and other downstream reaches of the Colorado River as well as the lower 2.2 miles of the Gunnison River below the Redlands Diversion Dam. In addition, larvae of spawning adults may drift for long distances downstream of the Grand Valley and it may be many years before these young mature and return to the 15-mile reach. For the reader unfamiliar with these and other important traits of the Colorado squawfish, a brief description of its life history is provided in Appendix I.

As in earlier reports, the 15-mile reach is here regarded primarily as important habitat for adult Colorado squawfish throughout the year and for razorback sucker during spring. Spawning in the reach by both species occurred in the past and may still occur on a limited or infrequent basis (McAda and Kaeding 1991; Osmundson and Kaeding 1989). Management of the reach should include consideration of its value as potential spawning habitat. The focus of this report is on flow effects on adult Colorado squawfish summer and winter habitats in the reach. Flow effects on summer and winter habitats of razorback sucker is not emphasized in this report because all habitat use data outside the spring spawning season were collected from the 18-mile reach.

Although this report primarily focuses on physical habitat for adults of the target species, we recognize that flow also affects other organisms within the river community which in turn have a direct effect on the well-being of the endangered fishes. Flow interaction with food availability dynamics is currently being investigated in a separate study. Other relevant studies not yet complete include research conducted by geomorphologists from the University of Colorado which will determine threshold flows necessary for transport of sediment in the 15-mile reach, a subject addressed later in this report. Also, a study aimed at identifying bottomlands that could be reconnected to the river via a combination of flows and removal of levees is currently being conducted by the USFWS. It and studies by Van Steeter and Pitlick (University of Colorado) will identify the magnitude and frequency of spring flows necessary to sufficiently inundate floodplain sites and thereby provide important razorback sucker spawning and nursery habitat. Results from these and other studies will later need to be integrated with results presented in this report.

METHODS

Study Area

The Grand Valley is the uppermost portion of the range of the Colorado squawfish in the main-stream Colorado River. The upper end is demarcated by the Price Stubb Diversion structure (RM 188.3) that blocks upstream movement of fishes. However, most rare fish use extends only to the Grand Valley Diversion (RM 185.4), a seasonal barrier three miles downstream of the Price Stubb Dam. The Grand Valley consists of two major reaches: one above the mouth of the Gunnison River (15-mile reach) and one below (18-mile reach). These segments contains more adult Colorado squawfish per mile than any other portion of the Colorado River and also contain what may be the only remnant population of riverine razorback sucker (USFWS unpublished data). Because of inflow from the Gunnison River, the 18-mile reach has a greater discharge on any given day than does the 15-mile reach (Fig. 1). Also the two reaches differ in average gradient: river elevation falls 9.0 ft/mile in the 15-mile reach, and 6.7 ft/mile in the 18-mile reach.

Within the 15-mile reach the Colorado River alternates between single-thread and multi-thread channels. Pitlick and Van Steeter (1994) suggest that it is very close to a threshold between braiding and meandering. They describe the riverbed as formed by cobble- and gravel-sized

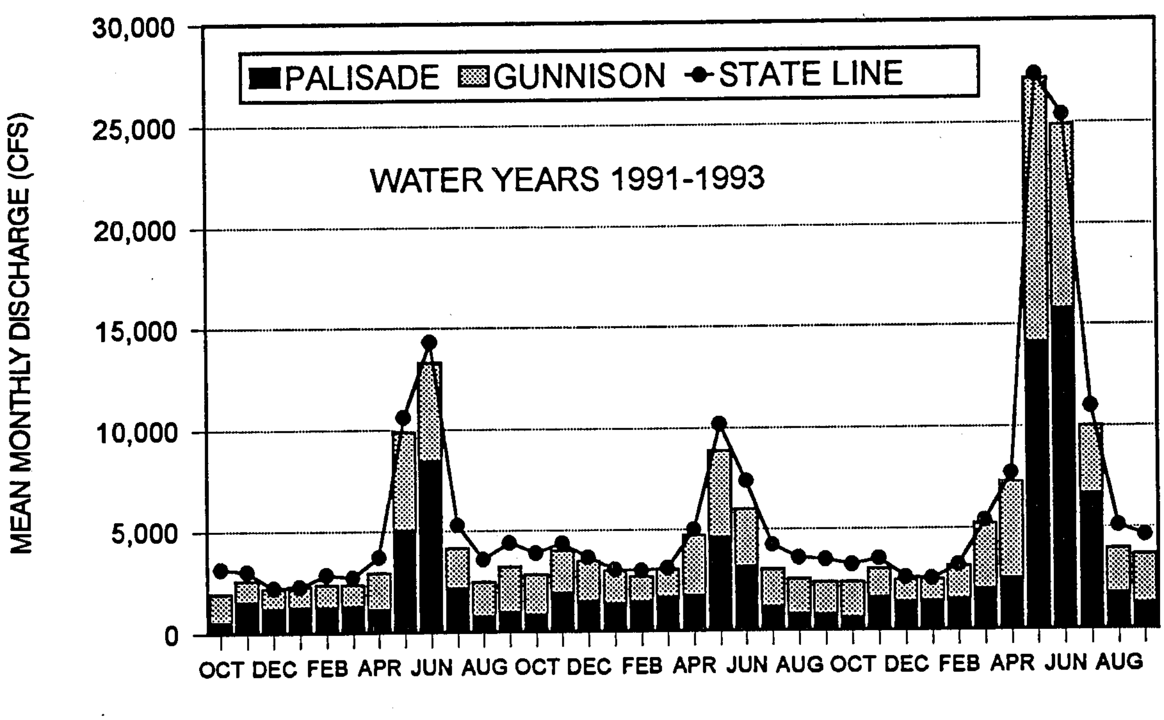


Figure 1. Contribution of flows to the Colorado River from the Colorado and Gunnison rivers, using 1991-1993 as an example. Returned irrigation flows account for the difference between discharge at the State Line gage and the combined Colorado-near-Palisade and the Gunnison-near-Grand Junction gages. Flows at the top of the 18-mile reach would be somewhere between the combined flow and the State Line flow because 15-mile reach return flows would be added but not the 18-mile reach return flows.

sediment while the banks and floodplain are made up mostly of fine sand and silt. In many places, tamarisk, Russian olive and willow line the banks; in addition, banks in many places have been artificially modified by levees and rip-rap. Information on average channel width and depth as well as flows necessary to top the banks within the 15-mile reach is currently being prepared by Van Steeter and Pitlick (University of Colorado).

Flows in the 15-mile reach are greatly reduced during the irrigation season (April-October) when two local irrigation systems withdraw large amounts of water from the river. The Grand Valley Canal diversion is immediately upstream of the 15-mile reach; the Government Highline Canal dam and diversion is located nine miles upstream. Together, they account for a net loss to the 15-mile reach of 1200 to 1600 cfs, depending on the month. These canals have been in operation since before the turn of the century. In addition to this, large dams and transbasin diversions have been built in the headwaters of the Colorado River beginning in the mid-1930's; this has further reduced flows in the 15-mile reach, particularly during the spring runoff period. Changes in the hydrologic regime of the reach since the historic period were described by Osmundson and Kaeding (1991; see Appendix IX).

Fish that share the 15-mile reach with the endangered Colorado squawfish and razorback sucker include four other native species and at least 17 non-native, introduced species (Appendix II; Table I). Flannelmouth sucker (*Catostomus latipinnis*) and bluehead sucker (*Catostomus discobolus*), both native species, are the most common of the large fish in the reach; red shiner (*Cyprinella lutrensis*), fathead minnow (*Pimephales promelas*) and sand shiner (*Notropis stramineus*), all non-native species, are the most abundant of the small fishes there (Osmundson and Kaeding 1989; USFWS unpublished data).

Summer and Winter Flow Needs

Site Selection

Eight study sites were selected (Table 1); four in the 15-mile reach (Fig. 2); four in the 18-mile reach. Known concentration areas for one or both species were selected as study sites. Concentration areas for adults were identified using location data from a previous radiotelemetry study (for sites in both the 15- and 18-mile reaches); for larvae and young-of-year Colorado squawfish (18-mile reach), from previous dip-net and seine surveys (data from Osmundson and Kaeding 1989). We felt that specific areas the endangered fish have selected over other areas are most important and were the ones to focus our studies on. This is in contrast to having selected sites on the basis of how representative they are of the reach as a whole as IFIM attempts to do.

Our focus on preferred habitat types within reaches selected by the fish follows the hierarchial nature of the habitat selection process described by Johnson (1980). First-order selection is the selection of physical or geographical range of a species (Colorado River basin in this case). Within that range, second-order selection determines the home range of an individual or social group (a particular reach within a particular river) . Third-order selection is the usage made of various components within the home range (mesohabitats). Fourth-order selection, not investigated in this study, is the procurement of food items from those available at the third-order selected sites.

Table 1. Location and attributes of study sites.

Site	Location (RM)	Length (mile)	Number of Transects CH	Number of Transects BA	Known Use Spring	Known Use Summer	Known Use Winter
			15-mile Reach				
1	178.0-178.5	0.5	2	0	CS	CS	-
2	175.4-175.9	0.5	1	3	CS	CS	CS
3	175.0-175.3	0.3	1	3	CS,RZ	CS	-
4	174.1-174.8	0.7	2	0	CS,RZ	CS	CS
			18-mile Reach				
5	170.2-170.8	0.6	1	2	CS	CS	CS
6	168.2-168.6	0.4	2	2	CS,RZ	CS,RZ	CS,RZ
7	162.6-162.8	0.2	1	2	-	CS, LV,YOY	-
8	157.8-158.7	0.9	2	2	CS	LV,YOY	-

CS adult Colorado squawfish
RZ adult razorback sucker
LV larval Colorado squawfish
YOY young-of-year Colorado squawfish
CH channel
BA backwater
RM river mile

In the upper Colorado River, unpublished USFWS capture data show that the bulk of the adult Colorado squawfish population occurs in the upper 60 miles of river (between the top of Westwater Canyon and the Grand Valley Diversion dam), while most juveniles occur in the lower 112 miles of river. As juveniles mature, many move to the upper reaches where physical habitat and food supplies are ostensibly more favorable. Within the upper 60 miles of river, the 15-mile reach produced 43% of the fish captured in a systematic netting and electrofishing survey conducted during 1991-1994, though the reach constituted only 23% of the area length.

Within the 15-mile reach, study sites that we selected were 0.3-0.7 miles in length, averaging 0.5 mile, and together (2.0 mi) comprised 14.1% of the reach (14.2 mi). In contrast, 66.8% of all squawfish radiotelemetry locations (1986-1988) in the 15-mile reach (n=377) occurred within the four study sites, and 76.5% of all 15-mile reach, razorback sucker locations (n=17) occurred there.

Thus, from past and concurrent studies, we have identified the hierarchial habitat selection process of adult squawfish within the Colorado River. Adults first concentrate in the upper portion of the

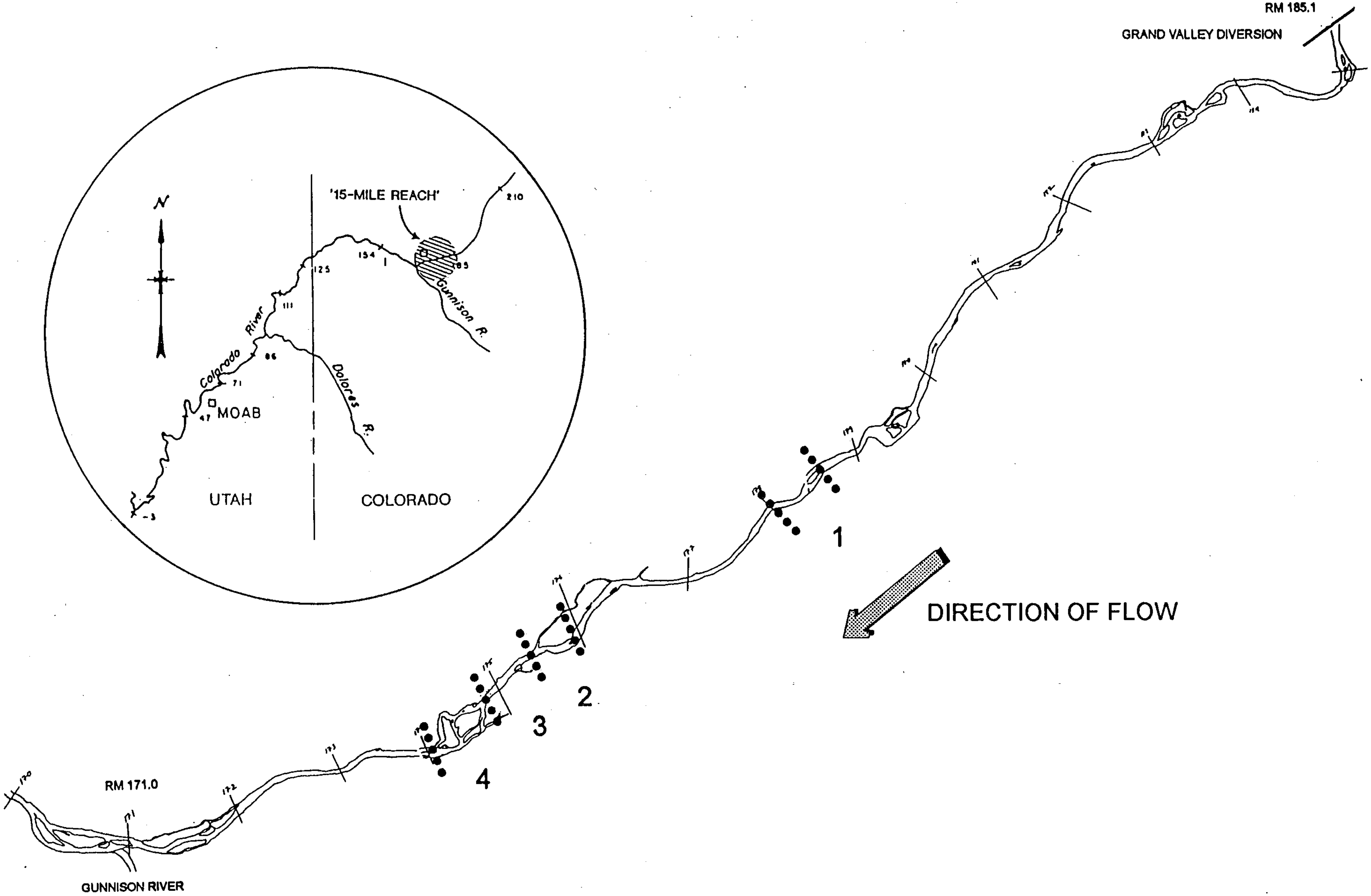


Figure 2. Location of the four study sites within the 15-mile reach. Inset map shows the location of the 15-mile reach in relation to the entire range of the endangered fish in the upper Colorado River.

available range within the river. Second, within the upper portion, they further concentrate in the Grand Valley including the 15-mile reach. Within the 15-mile reach, there are specific subreaches that are further selected. In the study reported here, we utilize these subreaches as study sites and within these identify the preferred mesohabitat types.

Data Collection

Aerial Video and Habitat Mapping

On-the-ground mapping was used to quantify habitat area at various flows. Carter et al. (1985) used this method to determine habitat changes with changes in flow in a stretch of the Colorado River in the Debeque-to-Rifle area. In our study, prints from aerial video were used for base maps for the habitat mapping rather than aerial photography. Aerial video was used because of the large savings in cost of acquisition and processing (acquisition cost was approximately 65% that of aerial photography). Bliesner and Lamarra (1995) are currently using this same videography-habitat mapping technique on the San Juan River. Bureau of Reclamation (BR) acquired the aerial video for our study and later quantified mapped habitat areas. A continuous image of the river was recorded on eleven dates using a video camera attached to the front of a helicopter. Dates were selected to provide a range of different discharge levels. At the time of each flight, USFWS was responsible for mapping habitat within the sites; to do so, numerous vantage points along shore and on the water were used. Color prints of video taken during the previous flight were used as base maps on which to draw habitat boundaries.

Consistency in mapping technique was a crucial element in use of this methodology. Roper and Scarnecchia (1995) found that variation among individual mappers in classifying stream habitat types was related to at least three factors: (1) the level of definition required in classification (e.g., pools in general versus specific types of pools), (2) the level and uniformity of observer training, and (3) the stream channel characteristics. In general, they found that consistency among mappers was poor without extensive and uniform training, and that repeatability was reduced when elaborate habitat classification schemes (many types) were used despite the training provided.

To maintain consistent technique in our study, and thereby reduce one potential source of error, one person (the lead author) was responsible for all habitat mapping during the study. This person also identified habitats at radio-tagged fish locations in the same area during the earlier Osmundson and Kaeding (1989) habitat use study. River area was broken into eight generic mesohabitat types: pools, eddies, riffles, rapids, slow runs, fast runs, backwaters and flooded gravel pits (see Appendix III, Table II for habitat type criteria). Aside from breaking runs into fast (>2 ft/sec) and slow (<2 ft/sec) types and dropping shorelines as a separate type, habitat classification followed that of the previous habitat use study (see Osmundson and Kaeding 1989).

Mapping took two days to accomplish per discharge level; thus, the video imagery was acquired while either the 15- or 18-mile reach was being mapped. Sites in the other reach were mapped the day prior to or following the day of the video flight.

In the laboratory, habitat delineations were transferred from the field maps to hard-copy mosaics of the video images taken at the time of mapping. Some adjustment to the positioning of site boundaries was done at this time for those habitats that could be clearly discerned on the images (backwaters and gravel pits and in some cases riffles and rapids). No adjustment of boundaries were made on maps when the video and mapping occurred on different days. The finalized habitat mosaics were sent to the Remote Sensing Geographic Information Group at BR. These mosaics were scanned into a PC and the habitat delineations were digitized and areas calculated using Map and Image Processing System (MIPS) software (Microimages Co.). These area measurements were then sent back to USFWS in tabular form for graphing and interpretation.

Water Depth and Stream-bed Monitoring

In addition to habitat quantity (area), factors affecting habitat quality also had to be considered. Depth and velocity are important variables that affect site selection by fish (Bovee 1982). Water velocity was taken into account in the definition of each habitat type (Appendix Table II), though depth was not. Thus, if a given habitat type was preferred, we assumed that favorable velocities typical of that type were in part responsible for the fishes selection of sites of that type. Because velocity is taken into account in defining the habitat types, favorable velocities are automatically provided when flow levels create or enlarge preferred habitat types. Depth, on the other hand, was not taken into account in some of the definitions and thus an otherwise preferred habitat could be rendered unfavorable if depth at the site dropped below some unknown suitability threshold. Thus, the situation could arise where at a given discharge level adequate or even maximum area of preferred habitat (as viewed from the air) is provided but is of little benefit to the fish because of insufficient depths. We therefore needed some measure of how habitat depth varied with change in discharge.

To measure the effect of discharge level on depth, permanent transects were set across various river features and stage height (water surface elevation) was monitored there at the time of each mapping exercise. In November of each year bed elevation was measured along the transects so that depth at the various flow levels could be derived from the stage height readings. One or two channel transects were established within each study site and 2-3 transects established across a backwater if one was present within the site. A total of six channel cross-sections and six backwater cross-sections (two backwaters) were monitored during 1990-1991. In fall of 1992, an additional transect was established at the mouth of each of the two backwaters; these were also monitored again in fall of 1993.

Reinforcing rod headpins were used as reference elevations. Transect ends were marked with reinforcing rod and orange flagging. All measurements were taken using a surveyor's level and 25-foot, recessed-faced, level rod. Cross-sections were measured by reading the elevation off the bed at every 10-ft interval or at every significant ground break, whichever was least. Intervals across the channel were determined using a marked kevlar cable stretched between two fence posts. A fiberglass, 1/10th-foot-graduated tape was used across backwaters, islands and shores. Transects extended across channels between high points on shore that we estimated to be above the 10-year floodplain; across backwaters, from a high point on shore to the transect high point on the island. Some channel cross-sections encompassed the entire width of the 10-year floodplain (including active and dormant side channels) while others did not.

River Discharge

Mean-daily stream flow was obtained from U.S. Geological Survey (USGS) gages for the dates when habitat was mapped and when stage elevations and bed cross-sections were measured. For sites in the 15-mile reach, two methods were employed: after September 1990, readings from a new gage set up near the top of the reach (Station No. 09106150) were used; prior to that, estimates of stream flow were calculated based on a formula that combines the readings of the upstream Cameo and Plateau Creek gages and then subtracts stream flow diverted between those gages and the top of the reach (see Osmundson and Kaeding 1991). Together with personnel from USGS (Dan Collins, Sub-District Chief, Western Slope Sub-District) we plotted stream flow based on the gage readings against stage elevation at three main channel (single channel) transects in the 15-mile reach. This was done on logarithmic graph paper. A french curve was then used to correct inconsistencies in gage readings or gage and diversion-based, calculated stream flows. This also helped smooth out any differences between reported mean daily flows and the flows during that part of the day specific to when the mapping was being done.

Discharge varies among sites within the reach. Due to groundwater seepage and numerous irrigation return canals, flow increases progressively downstream. During the irrigation season, flow at the bottom of the reach can be 150-400 cfs (averaging 200 cfs) higher than at the top (Roush 1994). Due to time constraints while mapping, actual flow at the study sites could not be measured. We used the flow at the top of the reach, either measured or calculated, as a consistent surrogate for flow at the sites. Thus, to produce reported conditions at the sites or to recommend flows for the reach it is assumed that discharge at the top of the reach is supplemented with the current level of inflows unaccounted for here.

Analysis

Habitat Mapping Corrections

Inconsistent scale of the aerial video prints resulted in erroneous habitat-area calculations during the original MIPS analysis. Problems were detected when it was noted that total water area (TWA) did not always decrease with declining flows; in many instances TWA increased when it should have decreased. Accurate scale is critical for this type of study because small differences in scale will necessarily result in measured differences in habitat area among dates that will erroneously be attributed to changes in flow. When the 1990 and 1991 data were combined and arrayed by discharge level, from high to low, TWA would increase at many 1990 data points even though the flow level was lower than for the preceding 1991 data point. As it turned out, there were several differences in how BR had both acquired and analyzed the data between years. During the 1990 videotaping, the helicopter was flown at a constant elevation as measured by a barometric altimeter and the scale was calibrated to the lengths of nearby bridges. In 1991, the helicopter was equipped with a radar altimeter and the scale was calibrated to flying height. Correction factors were calculated for the 1990 data to bring it more into line with the technique used in 1991. Although this helped to some extent, problems still persisted. To reduce scale problems further we developed habitat area correction factors for each flight date at each study site. We did this by plotting TWA versus discharge and fit a regression line to that relationship. The predicted TWA for a given discharge was divided by the measured TWA at that discharge to provide the correction factor; all habitat areas for that study site and discharge level were then multiplied by this correction factor. For the 15-mile reach, the relationships were somewhat curvilinear and were best described by natural log transformations (a quadratic polynomial was used to best describe the relationship for Site 4).

In cases where the video was filmed one day before or after the day that the habitat was mapped (four of the 11 flights for the 15-mile reach), changes in flow level from one day to the next resulted in another source of error. To correct for this, mean discharge on the day of the video flight was used in the discharge versus TWA regressions rather than the discharge on the day of mapping; this was because TWA was calculated from the video prints rather than from the field maps. The TWA for the discharge on the day of mapping was then predicted from the relationship and correction factors for habitat areas were derived by dividing this predicted TWA (for the day of mapping) by the measured TWA (for the day of video) as before. Regression values and correction factors as well as unadjusted and adjusted data are provided in Appendix V (tables V-VI).

Seasonal Partitioning of the Year

For management purposes, it is useful to group months into seasons so that a given flow recommendation can be implemented for a block of months rather than on a month-by-month basis. In addition, analyses involving a limited number of fish observations is greatly enhanced if observations made during different months can be pooled to increase sample size. To block months into seasons, the habitat use patterns of each species were analyzed to identify changes in behavior that would mark the beginning or end of seasons. Seasons were defined for each species by examining the radiotelemetry data collected throughout the Grand Valley and identifying blocks of months within which habitat utilization was similar.

Though this report focuses primarily on adult Colorado squawfish flow needs in the 15-mile reach during summer and winter, the needs of squawfish in the 18-mile reach immediately downstream as well as the summer and winter flow needs of razorback sucker there will need to be addressed in a future report. Thus, consistency in seasonal partitioning between the two reaches is required because flows in the reaches will later need to be coordinated.

Previous studies by Osmundson and Kaeding (1989) indicated that Colorado squawfish and razorback sucker exhibit somewhat different annual behavior patterns in habitat use which results in a somewhat different seasonal partitioning of months. These patterns were re-examined for this study. If instream flows are to be managed on a seasonal basis in one river for two species, the year must be partitioned in such a way that combines the season specific needs of both species. To do this we averaged the monthly Colorado squawfish and razorback sucker percent use of each habitat type (Appendix tables III and IV) and looked for major breaks in the averaged habitat use pattern.

Determining Preference For Habitat Type

To determine habitat frequency of use, we first partitioned the 1986-88 radiotelemetry data such that only those fish locations made within the current study sites were included in the analysis. Habitat data from the four sites were pooled into one composite; according to Gauch (1982), averaging out differences among samples by forming a composite tends to raise the level of abstraction, emphasizing broader features of the data (Kinsolving and Bain 1993). Pertinent location data included river mile, date, and habitat type. Habitat use data were further partitioned by season and percent use of each type was calculated for each fish. A seasonal frequency of use value was calculated for each habitat type by averaging the percent values across all fish. This follows the 'aggregate percent method' recommended by Swanson et al. (1974) that greatly reduces biases associated with unequal number of locations among sampled fish.

From the videography mapping data, overall habitat availability was also calculated. This was done for each fish individually and then averaged across fish. Percent total area of each habitat type, within study sites comprising the home range of a fish, was averaged over a range of seasonal flows that were similar to those that occurred when the fish location data were collected. This average percent abundance or availability of each type was then averaged across all pertinent fish. River-wide habitat use data (Appendix tables III and IV) indicated that none of the habitat types are completely avoided. Thus, we assumed that all habitat types present within a study site at a given flow were available for the fish to use, and we assumed that relative abundance (percent total water area) of a given habitat type is a measure of the relative availability of that type. Based on the stable channel configuration between and during the two studies, radiotelemetry and mapping, we also assumed that habitat availability when the fish use data were collected was the same as when the habitat mapping data were collected (see Appendix IV for a discussion of this).

To determine if adult squawfish prefer particular types of habitat, we compared usage with availability (Williams and Marshall 1938, Hess and Rainwater 1939, Jacobs 1974, Swanson et al. 1974, Chesson 1978, Gilmer et al. 1975, Johnson 1980, Osmundson 1990). The degree of preference, or lack thereof, for a particular habitat type is estimated by the average difference between the percent that that type contributes to the total water area available to an individual fish and the percent frequency of use of that type by the individual fish. If there is no preference, fish should be located in the various habitat types in the same frequency as the occurrence or availability of those types. For example, if 20% of the total water area is comprised of pool habitat, one would expect 20% of the fish locations to be in pools if habitat selection was random, i.e., no preference. If the fish exhibit a preference for certain habitat types, i.e., more use than availability would predict, we assume that those types are important in fulfilling some biological need. Maximizing the quantity and quality of such habitats is viewed as benefiting the fish and is therefore a goal of flow management.

To determine preference, we compared habitat usage with habitat availability for each fish that had one or more locations within the four study sites. Locations falling outside the study sites were not used. Percent availability of each habitat type within a given fishes range (one or more study sites) was subtracted from the percent use of that type by that fish. Differences were then averaged across all fish. The mean difference was then used as a measure of the degree of preference for that habitat type. Those types with positive values (>0) were considered to be preferred; the higher the value, the more preferred. Negative values were interpreted simply as a lack of preference for a type rather than an active avoidance of it (see Johnson 1980).

<u>Determining Flow Levels That Maximize Preferred Habitat</u>

As flow level varies, the area of each habitat type also changes. The goal was to identify those flows that provide the maximum amount of the preferred habitat. For each flow level, all mapped areas of a given habitat type were summed for each site and then totaled for all four sites. This provided the total area of each habitat type provided at each of 11 flow levels.

To select a level that provided the most of a preferred habitat we looked only at the range of flows that were less than or equal to the historic range for the particular season of interest. In doing so, we assumed the species or population was adapted to virgin conditions but that historic conditions were also apparently adequate. The decline of these fish populations coincided with major water withdrawals from the system during the mid part of the century. Average historic summer flows in the 15-mile reach are based on the 1902-1942 period of record (closure of the first dam, Green Mountain, was in fall 1942). Virgin flows were higher because diversions for the Grand Valley were put on line prior to the historic period (the historic period starts when gages were built and records were first kept). These first local diversions largely impacted the summer flows in the 15-mile reach. However, anecdotal reports indicate that Colorado squawfish and razorback suckers remained abundant in the Grand Valley throughout the early part of the century (Quarterone 1993). Additional water depletions did not begin occurring until the second development period (1942-1953) when dams and transbasin diversions were built in the headwaters. Thus, since the fish were apparently still doing well under historic (though altered) conditions, we looked for an optimum flow among those that were equal to or less than the mean monthly flows of the historic period.

To optimize adult habitat, our primary goal was to determine what flow level maximized the amount of the preferred habitat types. We assumed that non-preferred types were already under-utilized, and maximizing the area of those would do little to directly benefit the fish. We do, however, recognize that some habitats provide important indirect benefits that may be ignored by this methodology (areas of high food production, etc.).

When more than one habitat type is preferred, additional weight must be given to those types more preferred than others. We therefore used the mean difference between habitat use and availability, our measure of preference, as a weighting factor. For each preferred habitat type, we summed the areas from each site to form a pooled composite of the four sites. The total absolute area within the four sites was then multiplied by the preference weighting factor. These weighted areas were then summed. That flow level at which the highest summed value occurred was considered best.

Spring Flow Needs

New information collected during this study is used to supplement the existing FWS spring flow recommendations provided by Osmundson and Kaeding (1991). In the earlier report, relationships between spring flows and certain geomorphic issues were discussed; these were based on casual observations made within the 15-mile reach over time but for which actual data were lacking. In the current study, stream bed cross sections monitored for the summer and winter habitat depth studies, described earlier, were also used to provide insights into sediment transport issues involving spring runoff. Specifically, we were interested in determining the minimum peak flows required to (1) maintain backwater depth through flushing the bed of accumulated fines (silt) and (2) cleanse within-channel substrates of accumulated fines via mobilization of coarse bed materials.

Again, there were one or two transects established across either main or secondary channels within each study site and 2-3 transects established across a backwater if one was present within the site. A total of six channel cross-sections and six backwater cross-sections (two backwaters) were monitored each fall during 1990-1993. In fall of 1992, an additional transect was established at the mouth of each of the two backwaters; these were monitored again in fall of 1993 along with the other transects.

Stream bed elevation was monitored along each backwater transect to determine degree of annual scour or fill. We assumed that scour occurs only during the high flows of spring and deposition occurs throughout the year: coarse and fine sediments are moved and redeposited in spring whereas fines can settle out at any time. Identification of spring flows that are sufficient or insufficient in magnitude was based on whether there was a net gain or net loss in depth, i.e., when scour exceeds deposition, spring flows were considered sufficiently high to maintain backwater depth. Scour and fill data for channel transects were useful in identifying spring flow levels capable or not capable of mobilizing coarse bed materials.

FISH HABITAT USE

General

Selection of mesohabitats by adult Colorado squawfish and razorback sucker changes seasonally. Osmundson and Kaeding (1989) documented year-round frequency of use of eight habitat types in the Grand Valley during 1986-1988 by identifying the position of individual fish once weekly using radiotelemetry (Appendix tables III and IV). The authors later reported (Osmundson and Kaeding 1991) three major seasons in which habitat selection by Colorado squawfish was distinctly different: winter (November-February), spring (April-June) and summer (July-September). October and March were reported as transitional periods during which the fish shift in and out of their winter behavioral mode (Fig. 3). Depth of sites selected by squawfish also varied with time of year (Fig. 4). Habitat seasonality of razorback sucker was similar to Colorado squawfish though some differences were noted. To manage the river to provide favorable habitat, flows must also change in a seasonal manner that corresponds to the fishes' season-specific, habitat needs. Here we reexamine the seasonality of habitat use and suggest a somewhat different partitioning of the year for purposes of flow management. The following provides a review of habitat seasonality as determined during 1986-1988 and includes data from both the 15- and 18-mile reaches (see Osmundson and Kaeding 1989 for methodology). Monthly frequency of use for each habitat type was calculated by dividing the sum of all locations per month by the number of locations in that type.

Adult Colorado squawfish

Winter

Between November and February, adult squawfish remain in localized segments of river, primarily low velocity habitats. Seventy-four percent of squawfish 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 that squawfish were located in during winter. Eddies accounted for 5-8% of fish locations during January and February only, while large, chute-channel backwaters were used by some fish all winter accounting for 5-15% of fish locations.

Spring

During spring, when water velocities are high and main-channel temperatures still relatively low, squawfish often seek out warm, off-channel, low- to zero-velocity sites. Backwaters and flooded gravel pits together comprised 45% of squawfish location sites 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 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% in April to 27% in May to 13% in June; during the same period, fast runs increased in use from 0-3% to 19%.

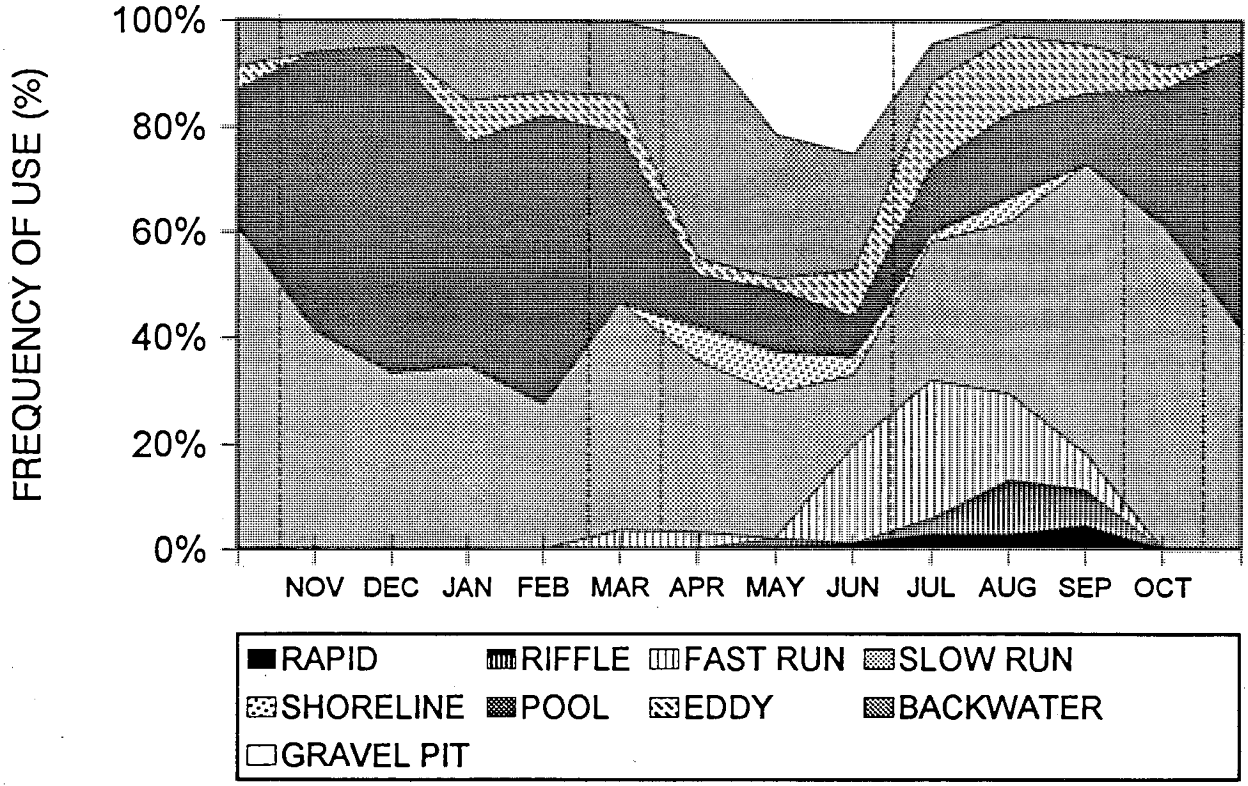


Figure 3. Frequency of use of nine habitat types by Colorado squawfish in the upper Colorado River. Data were collected in the Grand Valley during 1986-1989. Sample size varies by month; refer to Appendix Table III.

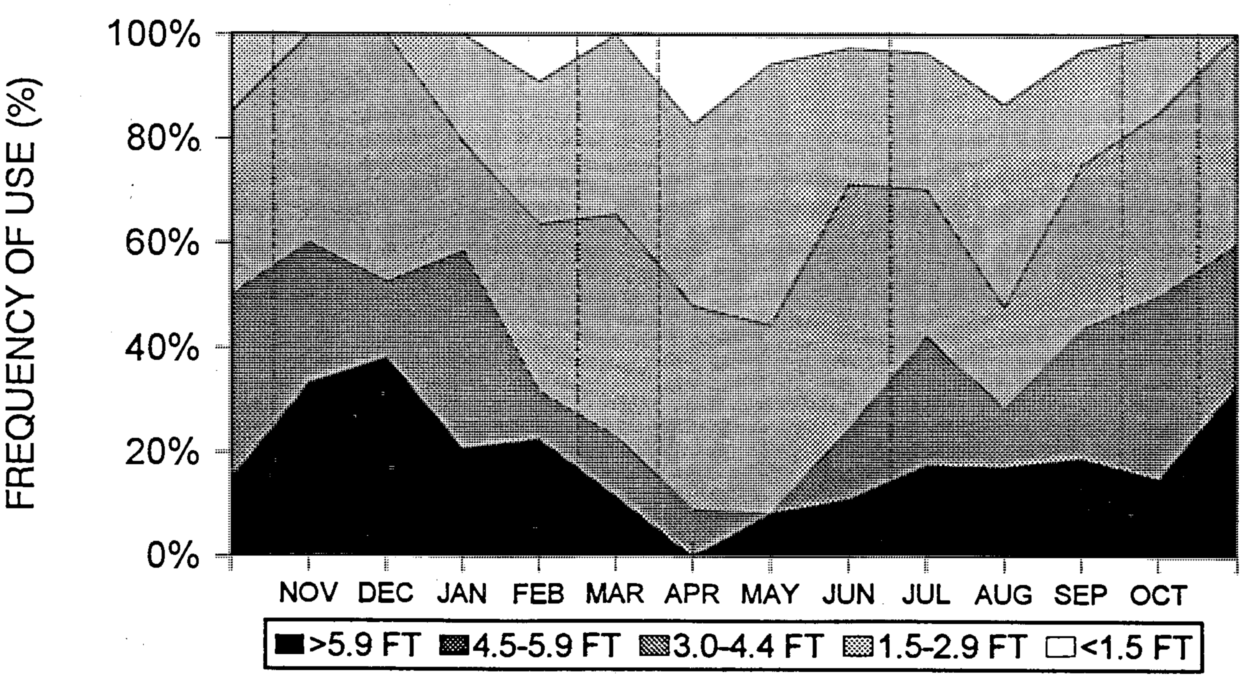


Figure 4. Frequency of depths (five ranges) at locations of Colorado squawfish in the upper Colorado River. Data were collected in the Grand Valley during 1986-1989.

Summer

During summer, flows decline in magnitude from relatively high levels in July to the yearly low in September; 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%). Squawfish use of eddies also reached a yearly high during summer (9-16%). Pools were used to a significant degree (13-16%); however, like spring use, summer use of pools was low compared to the remainder of the year.

March and October

Flows and temperatures are low during the transitional months, with temperature somewhat higher during October than during March. Pools and slow runs are 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 selected; flooded gravel pits were unavailable.

Adult Razorback Sucker

Winter

Seasonal habitat use patterns are somewhat different for razorback sucker than for Colorado squawfish (Figs. 5 and 6; Appendix Table IV). Other than during the spawning period, individual razorback suckers appear to have very localized home ranges. Though razorback suckers were caught and radio tracked within the 15-mile reach during spring, all radiotelemetry information during the remainder of the year came from the 18-mile reach. Whether some razorback suckers use the 15-mile reach throughout the year is not known. Though data are limited (3-15 observations per month; 1-4 different fish), the pattern appears to include an extended winter period that lasts from November through April. During this time, razorback sucker are primarily located in pools (61%) and slow runs (24%); they are also occasionally found inhabiting low-velocity eddies (11%) associated with pools.

Spring

In April or May razorback sucker begin to move in search of spawning sites. Use of pools appears to drop off entirely during May while slow run (36%) and backwater habitat (45%) use increases. Flooded gravel pits become available during June and razorback sucker tend to seek these sites out for either staging or spawning activities. Gravel pits account for 43% of the June observations;

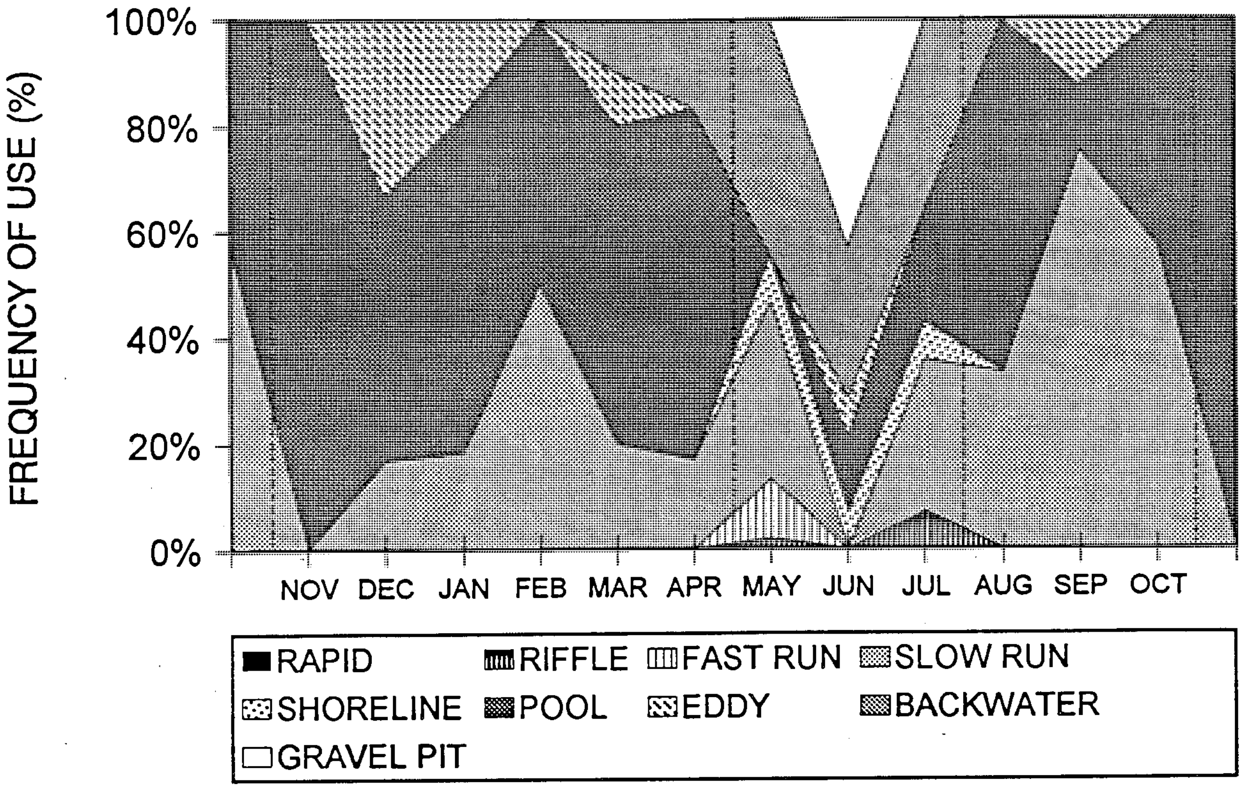


Figure 5. Frequency of use of nine habitat types by razorback sucker in the upper Colorado River. Data were collected in the Grand Valley during 1986-1988. Sample size varies by month; refer to Appendix Table IV.

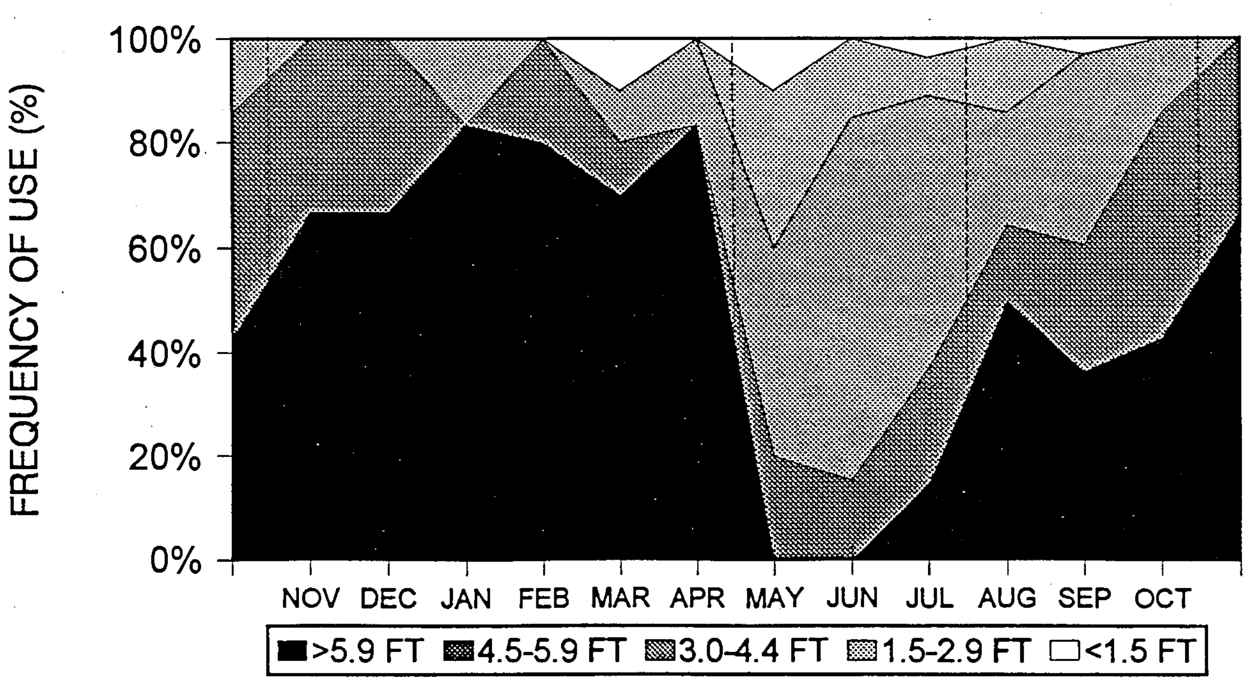


Figure 6. Frequency of depths (five ranges) at locations of Razorback sucker in the upper Colorado River. Data were collected in the Grand Valley during 1986-1988.

backwaters and gravel pits combined account for 72%. Use of runs drops off entirely during June. The spring period ends when adults return to their home range area.

Summer

There appears to be no clear distinction between a spring and summer period for razorback suckers. July might be viewed as a transitional month between the spring spawning period (late April through late June) and summer (August through October) use of the non-spawning home range. In July, chute-channel backwaters continue to be used (36%) but gravel pits are no longer available. Use of pools and slow runs begins to increase again in July. July, along with the spring months of May and June is the only period that razorback sucker are sometimes found inhabiting shoreline habitat (7-9%). During the August-October period, habitat usage is fairly evenly divided between pools and slow runs which together are used almost exclusively.

Seasonal Partitioning of the Year

Though coexisting under the same conditions, the different behavioral patterns of razorback sucker and Colorado squawfish result in a year that is partitioned somewhat differently. However, because we can only recommend one flow regime for the river, a third seasonal partitioning was made that was a composite of the ones made for each species. Summer and winter flow needs of razorback sucker in the 15-mile reach could not be addressed in this report because of a lack of 15-mile reach summer and winter habitat use data, i.e., radio-tagged razorback suckers spent their summers and winters in the adjacent 18-mile reach. However, to keep things consistent, we used patterns of habitat use of both species to partition seasons in a way that can be used for both reaches.

Transitional periods were either lumped or split but the core months of each season stayed basically the same (Fig. 7). A distinct winter period emerged in which averaged pool use was greater than 40% for all months and use of slow runs was 20-40%. Winter included November, December, January, February and March. A 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 habitats used 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 for the fish to be quite active. July appears to be more of a transition month. Although habitat use for Colorado squawfish 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%).

Besides lumping March in with the winter months, the biggest departure in seasonal partitioning from the earlier flow recommendations is including October in the summer period and splitting out July from the summer and including it as part of spring. Including July as one of the spring months also makes sense from a hydrologic standpoint; flow levels are still quite high, considerably above base flow. Thus, we end up with a spring period which includes the runoff months and two base-flow periods, summer and winter.

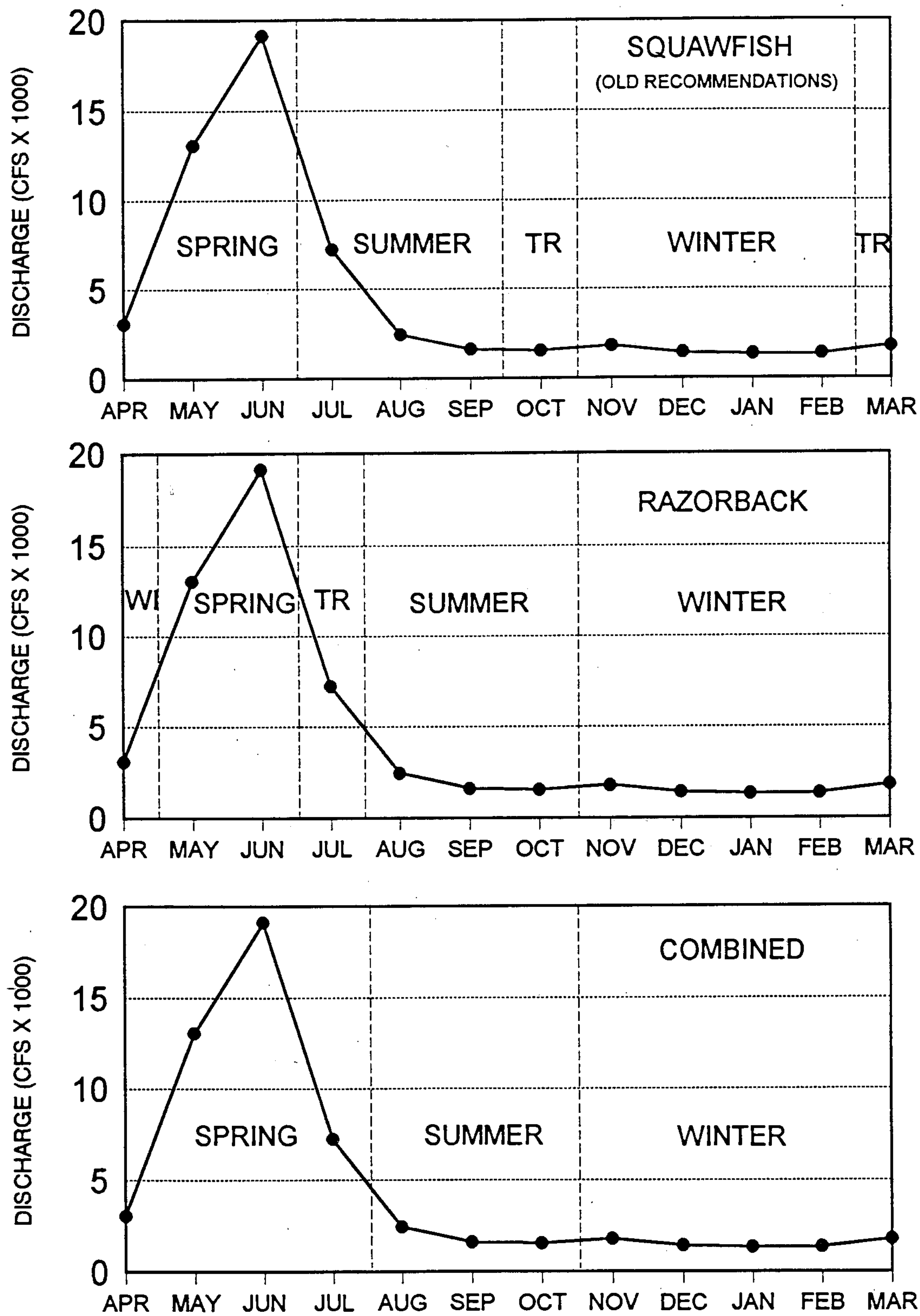


Figure 7. Seasonal partitioning of the year based on the habitat use behavior of Colorado squawfish (top), razorback sucker (center), and a combination of the two (bottom). Seasons in this report follow those in the bottom graph. Hydrograph shown is example only. TR = transition periods.

HABITAT AREA AS A FUNCTION OF DISCHARGE
(Objective No. 1)

Change in Area of Mesohabitats

General

We mapped habitats in the study sites at 11 different discharge levels: five during 1990; six during 1991 (Figs. 8 and 9). Discharge ranged from a low of 557 cfs to a high of 11,200 cfs, as measured at the top of the 15-mile reach. With some minor exceptions, increases or decreases in the area of a particular habitat type from one flow level to the next occurred in a reasonably predictable manner. Examples of maps of one study site at two different flows is provided (Fig. 10).

Flooded Gravel Pits

The one flooded pond made up a total of 15% of Site No. 3 and 2.5% of the four sites combined during discharge levels greater than 9,000 cfs. At lower flows, its percent contribution was less. At flows of 2,870 cfs or less, the pond was isolated from the river (Fig. 11). Unlike backwaters, gravel pits continue to enlarge with increased flow. At very high flows, over-bank flooding would create additional low-velocity, inundated, floodplain habitat types. Such high flows did not occur during the mapping years of 1990-1991. A few gravel pits, such as the one in Site No. 3, communicate with the river at relatively low spring flow levels. Most along the river are separated by high dikes. Because over-bank flooding occurs much more infrequently than was the case during historic flow conditions, these few connected gravel pits may function as an ecological surrogate for once common inundated, floodplain habitats.

Backwaters

Total area of backwater habitat peaked when discharge was 7,620 cfs and decreased at higher discharge levels (Fig. 11). Most backwaters in the 15-mile reach are created in side channels that cease to flow during low water. The upper end goes dry and is cut off from the main channel; at the lower end, water from the main channel backs up into the mouth forming a zero-velocity habitat. These backwaters continue to increase in size with flow until the river tops over the bar at the upper end of the channel and the side channel begins to flow again. As flows increase, some backwaters are lost to this process while others are still becoming larger. At the same time, still others may be just beginning to form as less-frequently, flooded channels or other low-lying features become inundated. At the eleven flow levels we studied, more backwater area was lost than created at flows greater than 7,620 cfs. Backwater area also decreased as flows were reduced below 7,620 cfs. As flows dropped below 1,530 cfs, additional side channels dried up at the upper end forming backwaters at the lower end. This created a spike of increased backwater area at 1,240 cfs. At flows less than this, backwater area again decreased as the main channel lost its ability to keep the mouths of chute channels inundated.

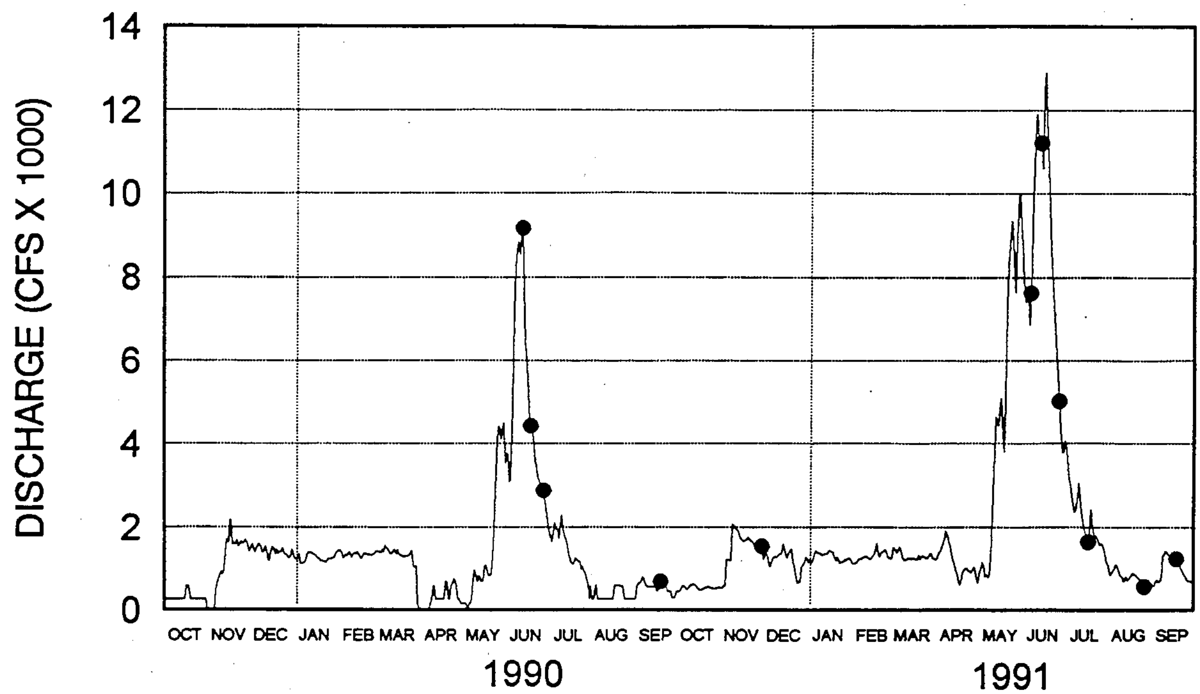


Figure 8. Discharge at the top of the 15-mile reach during 1990-1991, including the days when habitat mapping was conducted.

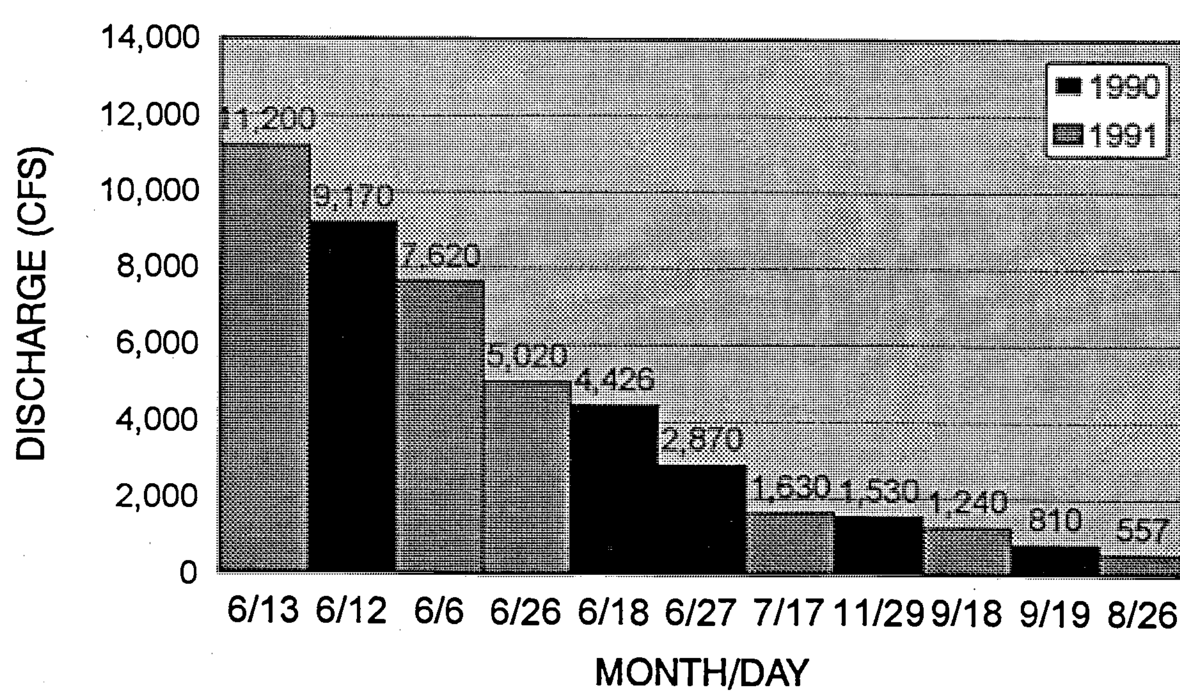


Figure 9. Flow level (cfs) on the day of habitat mapping in the four 15-mile reach study sites.

Figure 10. Maps of Site No. 4 at two different discharge levels showing level of mesohabitat delineation. Discharge levels were 11,200 cfs (left map) and 1,240 cfs (right map).

Eddies

Eddies form primarily at the mouths of backwaters, and to a lesser extent in embayments along shorelines. Total area of eddy habitat was therefore maximized at the same discharge level as were backwaters, at about 7,620 cfs. Eddy area decreased with declining flow until flows reached 2,870 cfs. Below this level, eddy area increased with flow modestly and was relatively stable (1,416-1,615 m^2) between flows of 1530 and 810 cfs. When discharge declined to 557 cfs, eddy area was cut to half (802 m^2) that at 810 cfs.

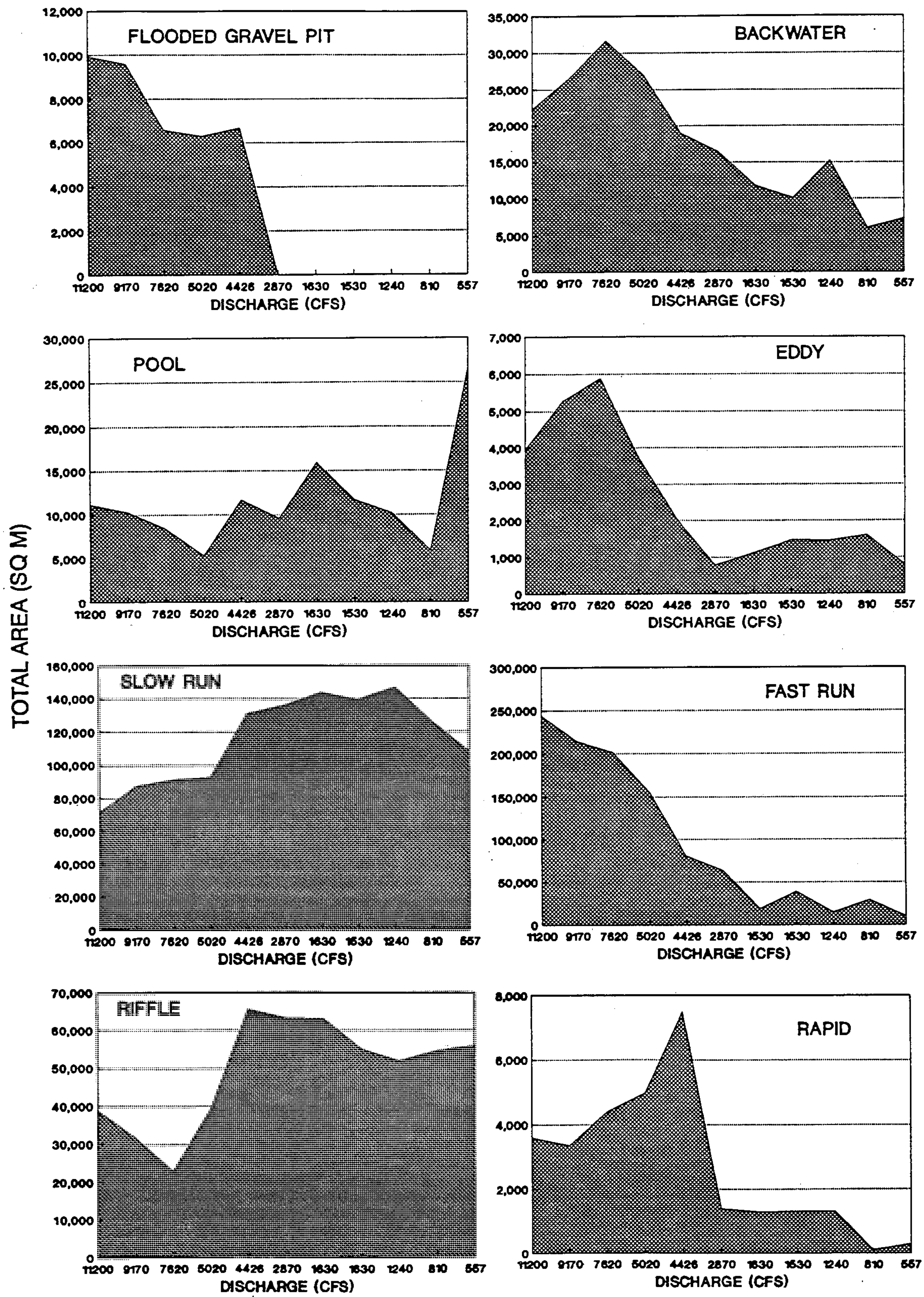


Figure 11. Variation in total area (m^2) of each of eight habitat types in the four 15-mile reach study sites. Total area (m^2) of each of eight habitat types in the four 15-mile reach study sites was summed.

Pools

As flows declined from 11,200 to 5,020 cfs, pool area decreased by half to a low of 5,300 m^2. As discharge continued to decline, pool area increased; at 1,630 cfs, total pool area was three times what it was at 5,020 cfs. However, at still lower flows, pools again decreased in area and were back to about 5,900 m^2 at 810 cfs. At very low flows (557 cfs), velocities are significantly reduced and many portions of slow runs were transformed into pools; by definition, pools are any within-channel habitats with a mean-column velocity $\leq$ 0.35 ft/sec. As a result, pool area dramatically increased at very low discharge.

Slow Runs

Slow runs were the dominant habitat type at discharges of 4,400 cfs or less. As flows continue to decline, slow run area gradually increases to a high at 1,240 cfs. At still lower flows, some slow runs are transformed into riffles or pools and total slow run area decreases. However, at even the lowest flows, slow runs make up over 50% of the total water area.

Fast Runs

With rising flows, fast runs increase in area in a consistent manner. The higher the water, the greater the area of fast runs. Above 4,400 cfs, fast runs become the dominant habitat type (46-60% of TWA). At flow levels of 1,630 cfs or less, fast runs make up 5-20% of the TWA.

Riffles

Change in the quantity of riffle habitat occurs in just the opposite sequence as that of backwaters and eddies. Riffle area was lowest at 7,620 cfs and then almost tripled as flows declined to 4,426 cfs. As flows further declined by 87%, from 4,426 to 557 cfs, total riffle area never decreased by more than 21%. As a percent of total habitat, riffles consistently comprised 20-27% of the total water area at flows of 4,426 cfs or less. Thus, riffles remain relatively constant and fairly abundant at all moderate to low flows.

Rapids

Rapids occurred at all flow levels in Site No. 1 only. In the other three sites, rapids occurred only when discharge exceeded 4,426 or 5,020 cfs. Total rapid area peaked at 7,900 m^2 when discharge was 4,426 cfs, and decreased at higher flows presumably as they were transformed by deeper water into fast runs. At the lowest flows, rapids disappeared almost entirely.

Change in Habitat Composition

During the higher discharge levels (5,020-11,200 cfs), fast runs were the dominant habitat type, comprising 46-60% of the total water surface area (Fig. 12). At flows less than 5,020 cfs, fast run area tapered off and slow runs (40-60%) became the dominant type. At all discharge levels less than 2,870 cfs, riffle habitat was the next most abundant type (21-27%) after slow runs. The other five habitat types that we mapped were much less abundant and made up a relatively small part of

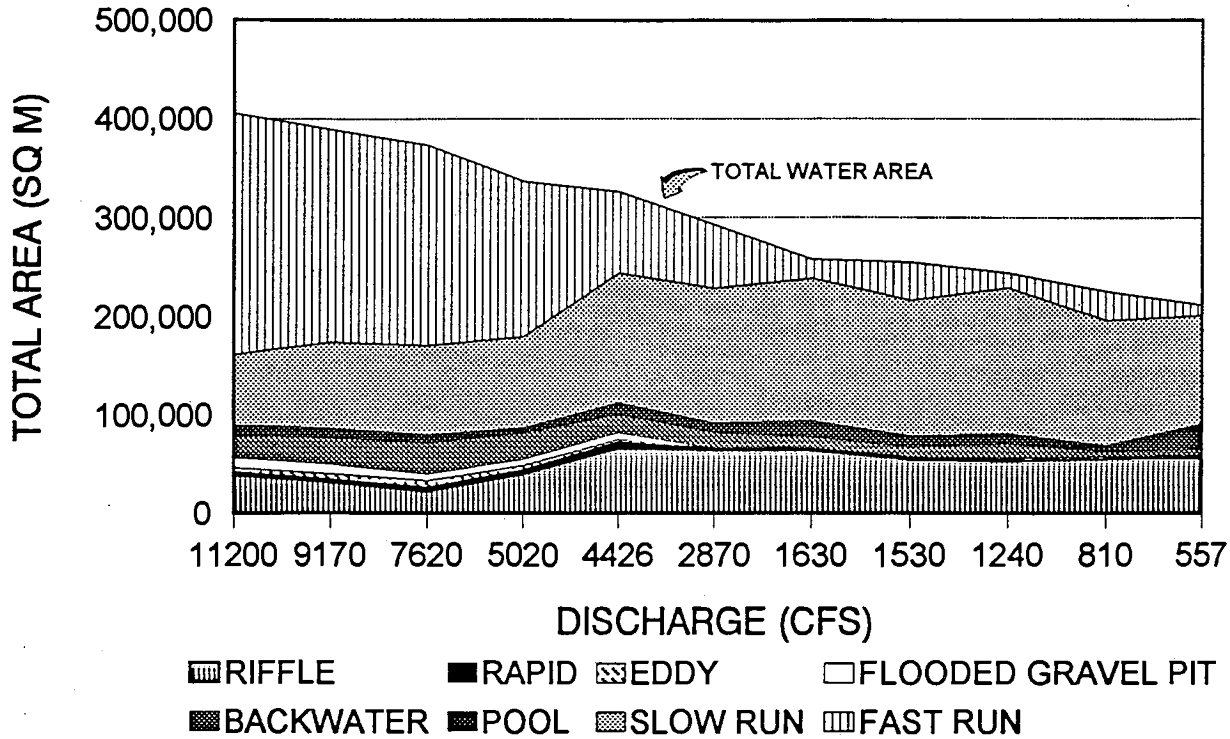


Figure 12. Variation in total water area and habitat composition with discharge level. Total area (m^2) of each of eight habitat types in the four 15-mile reach study sites was summed.

the total water surface area. Backwaters, eddies, pools and rapids collectively comprised only 6-14% of the total surface area. Only one gravel pit pond was present and it was flooded and accessible only during high water.

SUMMER AND WINTER FLOW NEEDS

Habitat Area

Summer Habitat Use and Availability

Squawfish use of habitats during summer differed between periods of moderate-flow and low-flow conditions (Fig. 13). When mesohabitat use data were partitioned into two categories, those locations made during summer flow levels of 1,378-2,368 cfs and those made during flows of 268-931 cfs, different patterns of habitat use emerged. During times of moderate flow levels, the fish used a greater variety of habitats. Backwaters, eddies and pools collectively accounted for a mean use of 90%, while mean run use was only 10%. In contrast, during low water conditions, no fish were found in backwaters, eddies, or pools; mean use of slow and fast runs, on the other hand, was 97%.

Relative availability of habitats did not differ significantly between periods of moderate-flow and low-flow conditions (Fig. 14). Percent total area for each habitat type was averaged across those flows that most closely corresponded to those that occurred at the time when fish-use data were collected. For the moderate-flow period, maps made at 1,240, 1,530, 1,630 and 2,870 cfs were used to calculate mean percent area; for the low-flow period, 557- and 810-cfs-maps were used. Though absolute area decreases with declining flows, relative area or percent composition evidently changes little. At both moderate and low summer flow levels, slow runs accounted for 54% of the total water area. Riffles made up 22% of the total water area during moderate flows, and 25% at low flows. The greatest change in percent composition was for fast runs and pools. Fast runs made up 13% of the TWA at moderate flows and 9% at low flows. As flows dropped, pools increased from 4.5% to 7.5% of TWA.

Thus, the change in habitat use between a moderate- and low-flow period without a corresponding change in relative habitat availability indicates that other factors also play a role in whether a particular habitat type will be selected. Though backwaters, eddies and pools are still present, and therefore available during low-flow conditions, their lack of use suggests that attributes of these habitats, either physical or biological, have changed and are no longer found desirable by the fish. Conversely, runs and slow runs are readily available at moderate flow levels and yet are little used then. Our habitat mapping only provides information on habitat quantity, not quality. Two physical attributes that would affect habitat quality were examined; these were habitat depth and habitat diversity (discussed later).

Summer Habitat Preference *(Objective No. 2)*

Backwaters, eddies and pools were preferred habitats during moderate summer flow levels in the 15-mile reach (Fig. 15). The mean preference rating for eddies was highest followed by pools and backwaters. Slow and fast were also used but were not preferred. No use of rapids was observed and gravel pits were unavailable during summer (Fig. 11).

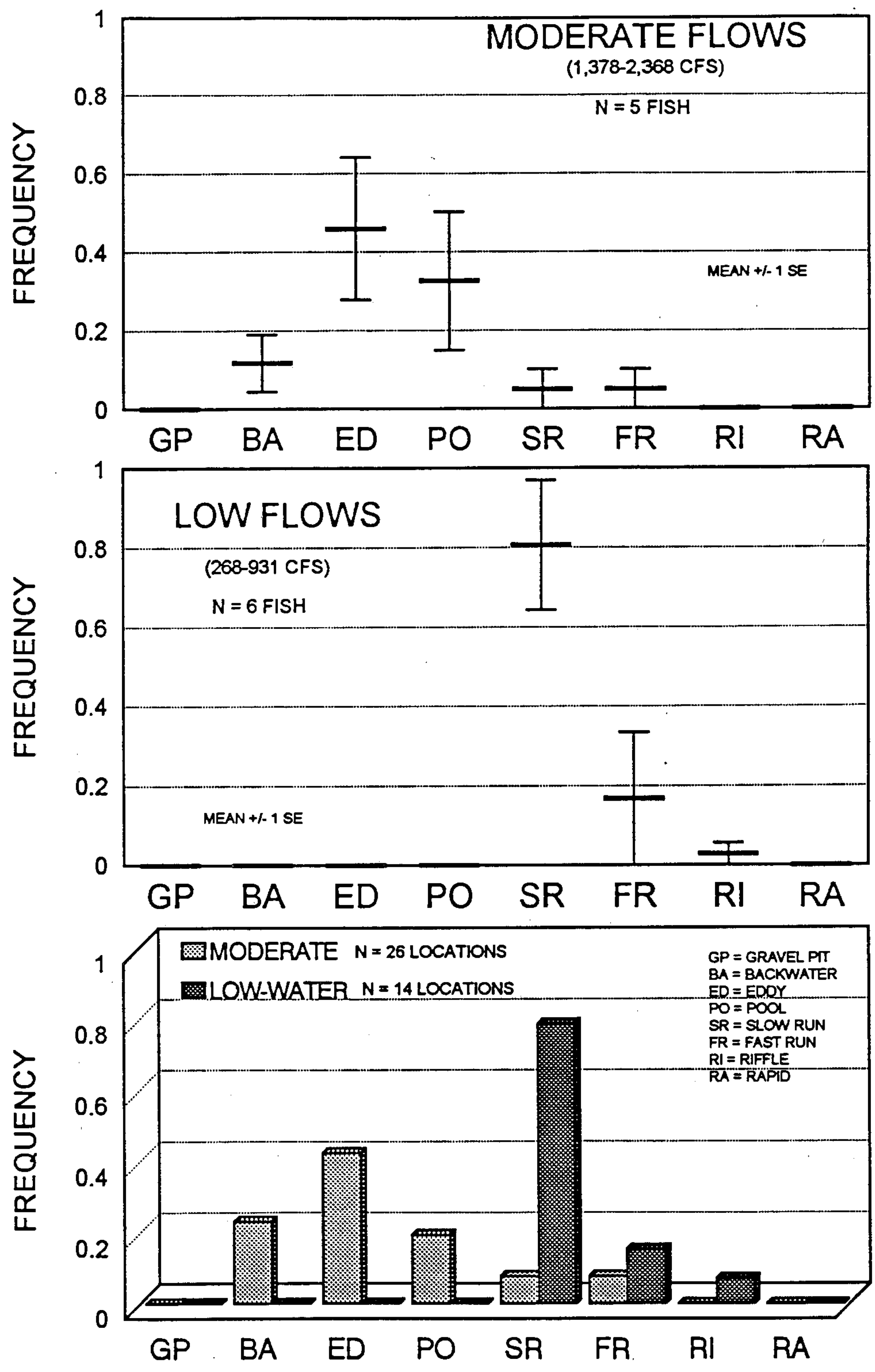


Figure 13. Frequency of use of habitat types by adult Colorado squawfish in the 15-mile reach study sites during summer periods of moderate flow and low flow levels. Top two graphs represent the mean frequency of use averaged across fish. Bottom graph represents the percent locations in each habitat type of the total locations made in each period, irrespective of the number of locations per fish.

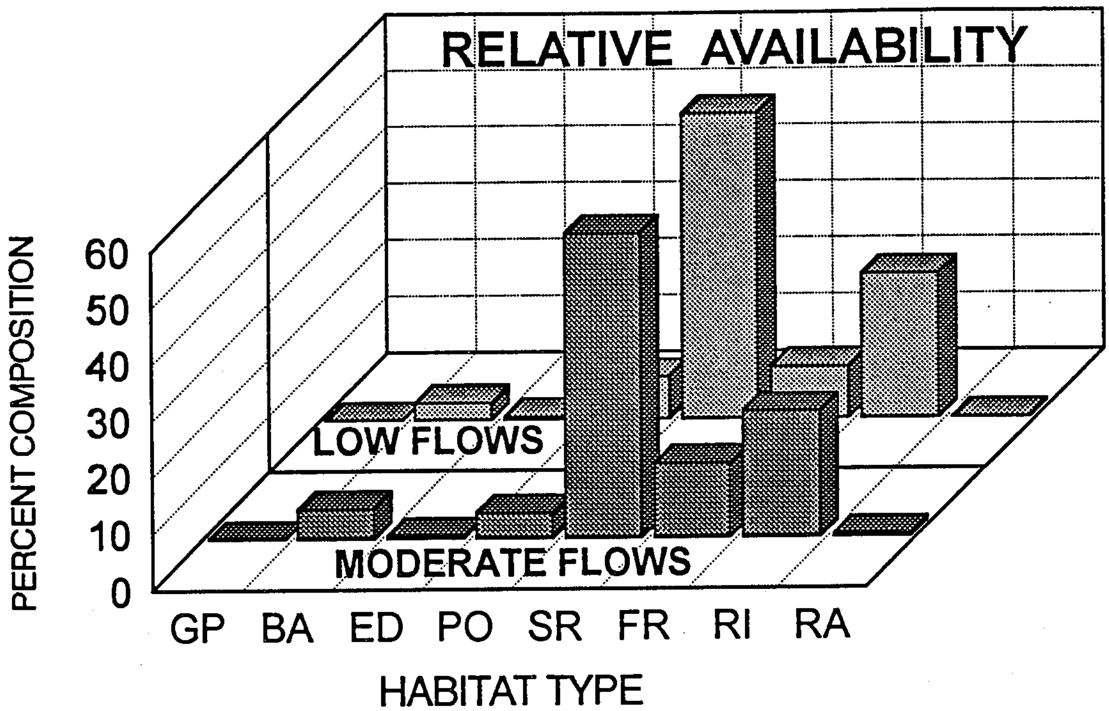


Figure 14. Habitat composition (percent total area) of the four 15-mile reach study sites during periods of moderate summer flow levels and low flow levels.

During low flow periods, no use of backwaters, eddies or pools was observed. Slow runs and fast runs, not preferred at moderate flow levels, were preferred when water was low (Fig. 15).

Lowered suitability of backwaters, eddies and pools may force fish into suboptimal habitats (slow and fast runs) that they otherwise would not select. Change in use of habitats may result from changes in quality of physical habitat features such as depth, dissolved oxygen, etc., or changes in biotic interactions. Displacement of squawfish from backwaters during low flow conditions is likely in response to reduced depth and cover. Displacement from eddies and pools, generally deeper than backwaters, is more difficult to explain. Movement into runs from eddies and pools may be precipitated by movement of other fish: they may be following their displaced food fishes, or avoiding those fish with which they negatively interact.

It is likely that during times of very low flow, much of the reach becomes unsuitable to squawfish as well as to other fishes. In the Grand Valley, the Colorado River has few instream boulders or undercut banks and little overhanging vegetation that typically provide cover for fish in many western streams and rivers. Here, depth, turbidity and perhaps agitation of the surface in some areas are the only sources of cover. Native fish have made the most of this limited cover by developing cryptic coloration and countershading as a mechanism to minimize detection by predators. Our observations indicate that large portions of the 15-mile reach are shallow at low water and when the water becomes clear, there is little cover for squawfish or the fish they feed upon. Fish normally distribute themselves so that competition for food in any one locality is reduced. A loss of cover from low flows may lead to displacement from established home feeding ranges. If such conditions are temporary, fish are apt to become stressed when they are concentrated in limited areas of suitable cover; if the conditions are more permanent, a loss of carrying

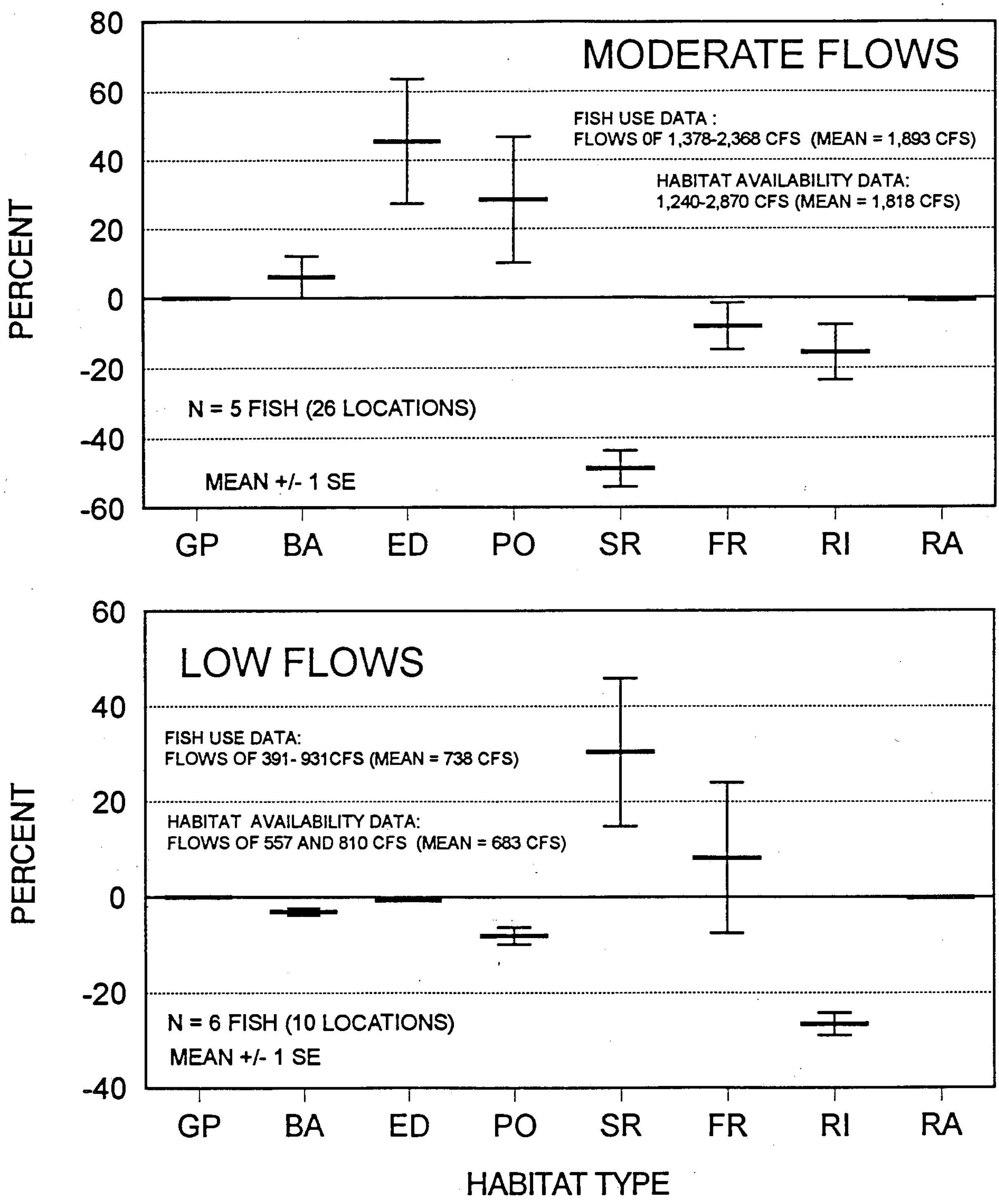


Figure 15. Summer habitat preference by adult Colorado squawfish using one or more of the four 15-mile reach study sites. Preference is measured by the mean difference between percent habitat use and percent habitat availability. Difference for a given habitat type is calculated for each fish and then averaged across all fish. Preferred habitats are those with mean differences greater than zero. Data and calculations are in Appendix tables IX-XIV.

capacity for the reach can be expected. Aggressive, introduced carp and channel catfish may become concentrated in low-velocity eddies and pools; this might explain displacement of squawfish into runs.

In the 15-mile reach, squawfish have two options in dealing with low summer flow conditions. One method is to 'hole up' in portions of slow runs that remain relatively deep due to springtime scouring of the bed and the presence of a downstream control structure such as a submerged cobble bar. At such times the fish are concentrated in these sites and are not free to utilize the resources of the entire river. The strategy is to wait out the low-water period until higher flows return. The second strategy is for the fish to travel downstream and wait out the low-flow period in reaches below the confluence with the Gunnison River where more water is available.

Though our sample is small, we have some evidence to indicate that adult squawfish may indeed leave the 15-mile reach when water becomes low. During 1986 we maintained contact with three squawfish from May through December. All three spent the year within the reach (one briefly left during the spawning season and returned in July). Mean monthly flows during August, September and October in 1986 were 2,040, 1,868 and 2,223 cfs, respectively. During 1987, mean flows were somewhat lower: 1,214 cfs in August, 812 cfs in September and 733 cfs in October. We maintained contact with 5 squawfish during 1987. Three remained in the reach year-round (one left and returned in July), one left and returned by October 9 prior to the end of the irrigation season, and one left and returned on November 9 shortly after the irrigation season ended and more water was returned to the reach. Mean flows were lowest in 1988: 588 cfs in August, 542 cfs in September and 178 in October. Contact was maintained with two squawfish; both left the reach after the spawning period was over and did not return that year. One left in late September or early October; the other left in late July or early August. Such displacements from the home range are no doubt stressful for fish and strongly suggest a seasonal reduction in carrying capacity for the reach - this in a river where quality adult habitat is already much reduced in miles.

During our 1986-1988 radiotelemetry study, squawfish experienced a range of summer flow levels. The months of August, September and October of 1986 and August of 1987 had moderate-flows comparable to historic (1902-1942) summer flow levels (see Osmundson and Kaeding 1991). September and October of 1987 and 1988 and August of 1988 had flows slightly lower than the mean flows of recent (1954-1989) summer months. All summer flows today are approximately 1,600 cfs lower than they would be under virgin conditions because of water diverted immediately upstream by local irrigation companies. These withdrawals predate the historic period. Thus, without alterations, a summer day with a flow of 500 cfs, for example, would be more than 2,100 cfs under normal conditions.

Tyus (1992) warned against determining instream flow needs of fish based on fish habitat use data collected under altered, suboptimal and perhaps unsuitable habitat conditions. Resulting recommendations will likely provide a minimum amount of water needed for fish survival rather than a more favorable amount needed to promote population recovery. Data from the 1986-1988 study indicated that during low-water conditions some squawfish left the 15-mile reach and those that stayed displayed a distinct change in habitat selection. We interpret such behavioral changes as reflective of suboptimal conditions. Our view is that squawfish habitat use data collected from the 15-mile reach during abnormally low-water conditions may demonstrate the ability of the species to modify its habitat use patterns to enable it to temporarily cope with adverse conditions, but it is not reflective of the needs or preferences of the species under optimum conditions more likely to allow the population to thrive. Thus, our recommendations are based on the habitat-selection behavior of adult squawfish observed during the higher, somewhat more normal flow conditions.

Ranking Flow Levels by Weighted Area of Preferred Summer Habitats *(Objective No. 3)*

Among the moderate discharge levels (1,240, 1,530, 1,630 and 2,870 cfs) a flow of 1,630 cfs provided both the highest total area and the highest total weighted area of the habitat types preferred at those flow levels (Fig. 16). Total weighted area at 1,630 cfs was 26% higher than at the discharge level with next highest TWA value (1,530 cfs). The highest weighted area occurred at a discharge of 557 cfs. However, because these habitats are not preferred when the water is that low, weighted area of backwaters, eddies and pools is irrelevant at the lower flow levels. Based on this analysis, 1,630 cfs is the best flow level during summer.

For slow and fast runs, preferred at low flow levels, total area and total weighted area increases with increasing discharge. However, as before, weighted area at moderate discharge levels is irrelevant because slow and fast runs are preferred only at the lower flow levels. Of the discharge levels studied here, 810 cfs provided a 20% increase in weighted area over that at 557 cfs (Fig. 16). We recommend a minimum of 810 cfs during drought years.

Winter Habitat Use and Availability

For winter, no comparison could be made between habitat use during low-flow and moderate-flow conditions. All winter, habitat-use data were collected during moderate-flow levels because in winter no water is withdrawn for irrigation, and upstream dams often release additional water to increase reservoir storage capacity in anticipation of spring runoff. When habitat-use data were collected (November-March 1986-1988), flows in the 15-mile reach were 1,654-3,452 cfs (Appendix Table IX).

Adult Colorado squawfish used fewer habitat types during winter than during summer (Fig. 17). In the study sites where fish were located during winter, no rapids or gravel-pit ponds were available. Also, unlike summer, fast runs and riffles were not used in winter. Colder water temperatures resulting in lower metabolic rates during winter may account for avoidance of high velocity sites. During winter, Colorado squawfish were located largely in pools (53%) and backwaters (27%).

Again, to determine availability, percent total area of each habitat type was averaged across those flows that most closely approximated those that occurred at the time when habitat use data were collected. Maps made at 1,630 and 2,870 cfs were used to calculate mean percent area. Again, slow runs (51%) and riffles (23%) accounted for about 74% of all water surface area at this flow range.

Winter Habitat Preference *(Objective No. 2)*

As in summer, backwaters, eddies and pools were the preferred types of habitat in winter (Fig. 18). Unlike summer, however, pools rather than eddies were the most preferred type. The preference rating (mean difference between use and availability) for pools was twice that for backwaters and five times higher than that for eddies. Slow runs were also used but were not preferred.

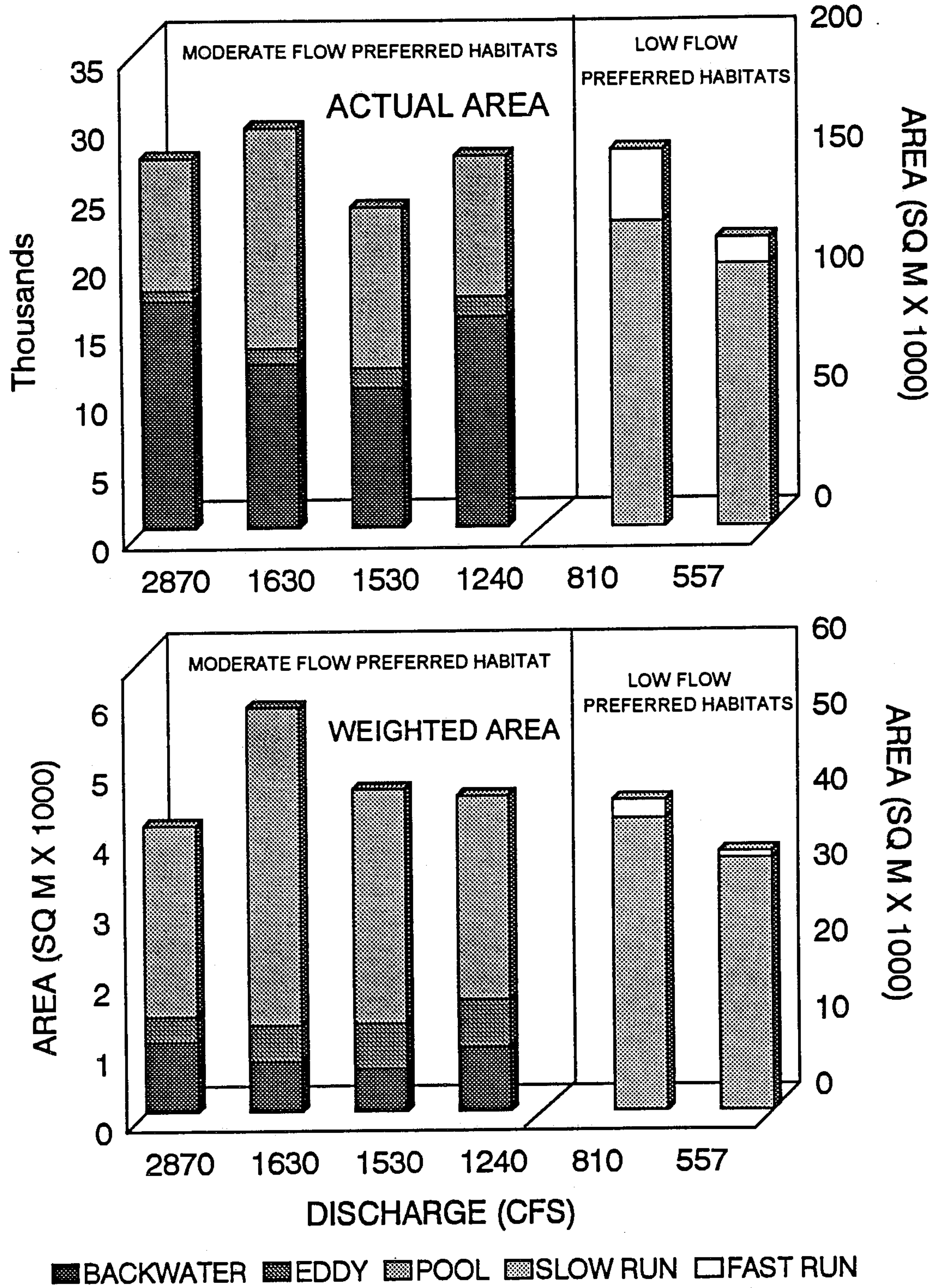


Figure 16. Total area (top graph) and total weighted area (bottom graph) of preferred habitats. Total area of each preferred habitat type at each flow level was multiplied by the preference score for that type; the preference score was the mean difference between use and availability. Weighted area is less than total area because the preference score multiplier is generally <1.0. Total weighted area is therefore a relative value for making comparisons among flow levels; it takes into account the total area of each preferred habitat type and the degree of preference for that type. See Appendix Table XIV for calculations.

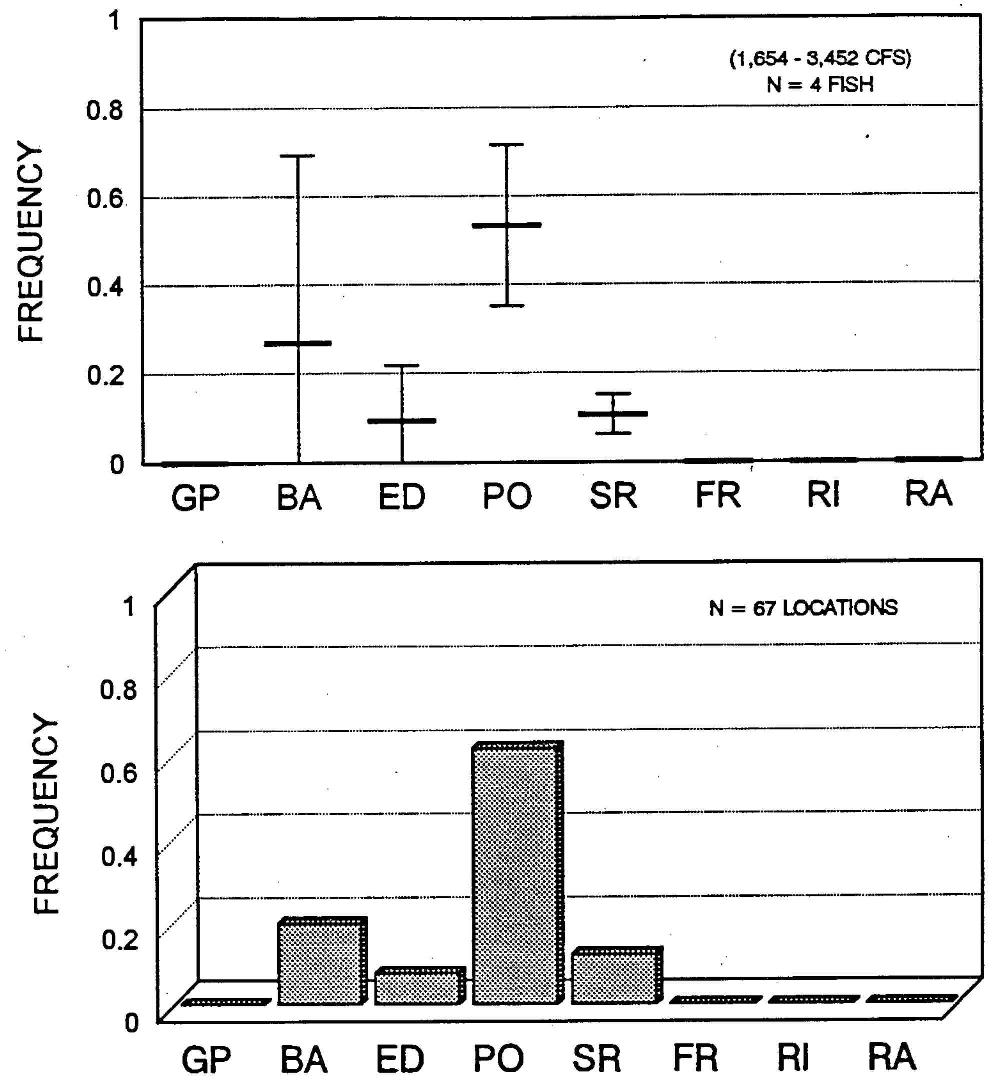


Figure 17. Habitat frequency of use by adult Colorado squawfish during winter. Top graph: percent use averaged across fish; bottom graph: total number of locations in each habitat type divided by the total number of locations.

Ranking Flow Levels by Weighted Area of Preferred Winter Habitats *(Objective No. 3)*

During the winter months, we only identified which habitats were preferred at moderate-flow levels. During summer, we saw that habitat usage changed as flows became low. We do not know whether this is also the case during winter. In fact, because the range of mean monthly flows when winter habitat use data were collected was 1,654-3,452 cfs, the only discharge levels studied during the mapping effort that roughly corresponded to this were 1,630 and 2,870 cfs. Of these, 1,630 cfs provided the highest weighted area of preferred habitats (Fig. 19); weighted area was 25% higher than at 2,870 cfs. When we included lower discharge levels in our comparison, 1,630 cfs remained the discharge with the highest weighted area until we reached the lowest discharge at which habitats were mapped: 557 cfs. At this level, absolute pool area goes up as slow runs lose velocity.

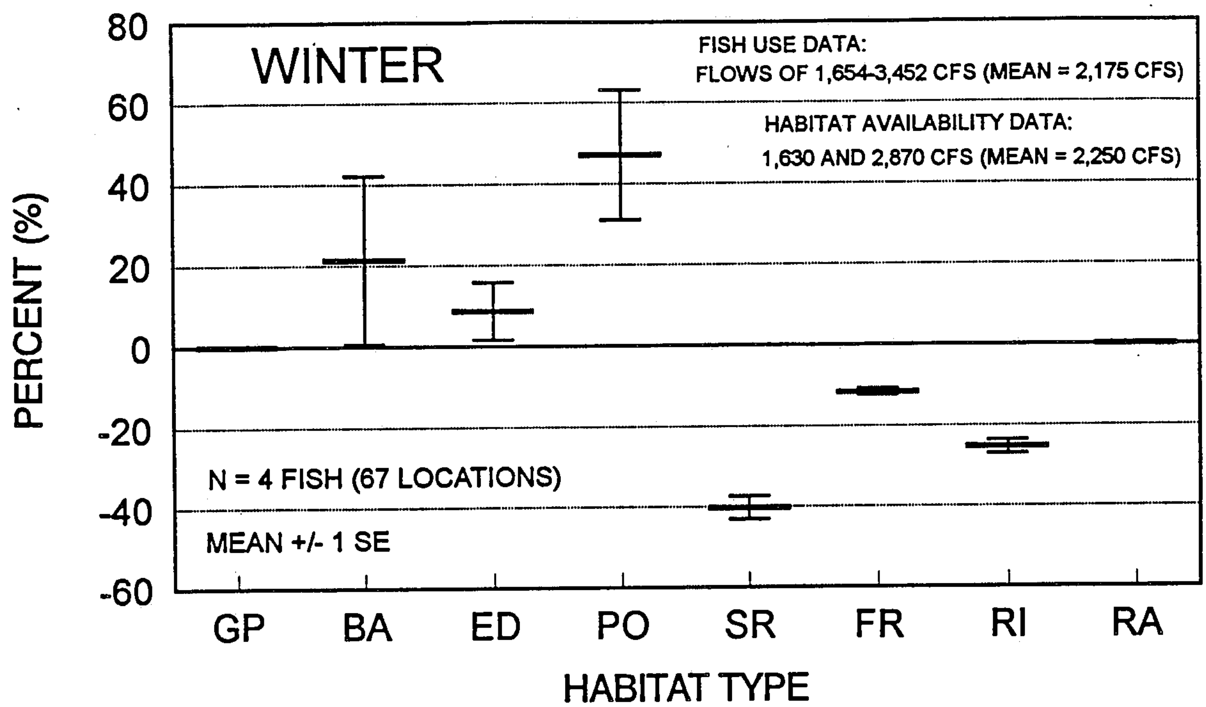


Figure 18. Winter habitat preference of adult Colorado squawfish using one or more of the four 15-mile reach study sites. See Fig. 11 for explanation.

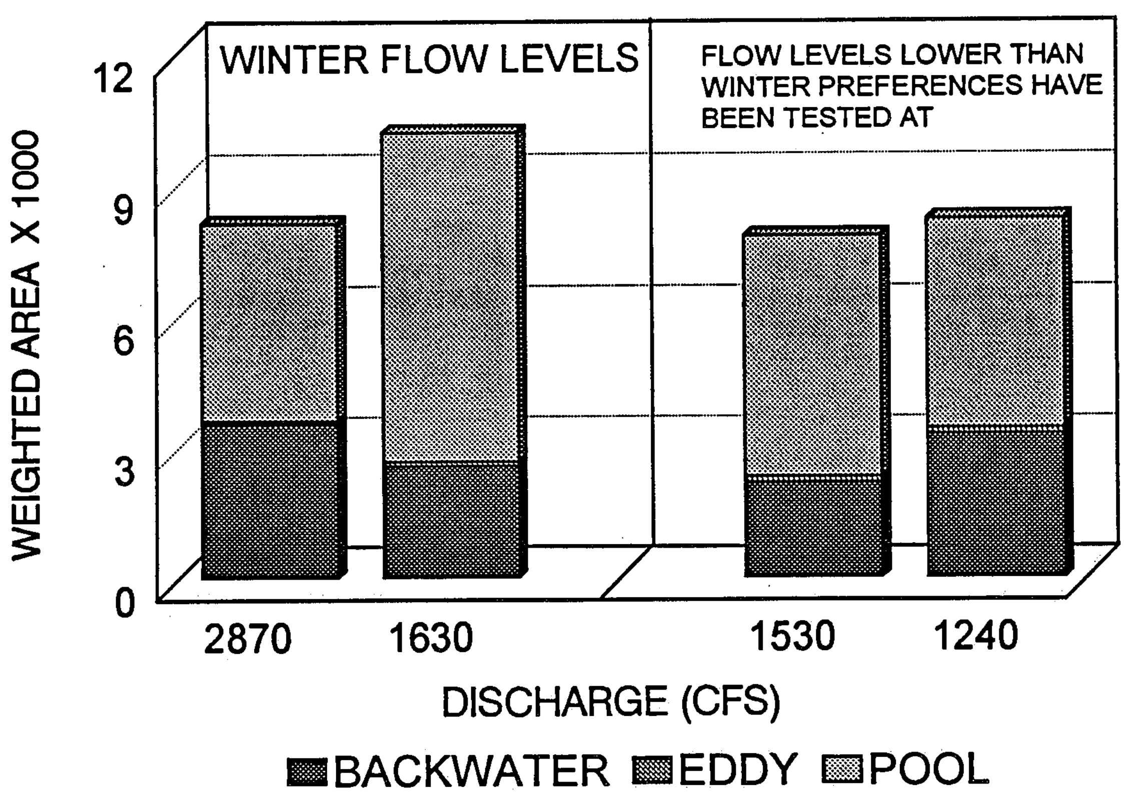


Figure 19. Total weighted area of preferred habitats during winter. See Fig. 16 for explanation.

Because pools are highly preferred during winter, weighted area also goes up. However, because we do not know if backwaters, eddies and pools will still be preferred at flows less than 1,654 cfs during winter, we cannot recommend a winter flow of 557 cfs based on weighted area of pools, backwaters and eddies. Thus we recommend 1,630 cfs as the best discharge level for maximizing the area of preferred habitats during winter.

Mean winter flows (November-March) during the historic period (1902-1942) range from 1,322 (January) to 1,789 cfs (November) and averaged 1,531 cfs for all months (see Osmundson and Kaeding 1991). Recent (1954-1989), mean, winter flows range from 1,765 (January) to 2,161 cfs (November) and average 1,920 cfs. Thus, our recommended winter flow of 1,630 cfs would be 100 cfs higher than average historic winter flows and 290 cfs less than recent winter averages.

Habitat Depth

Minimum Flows for Providing Suitable Depth

Habitat quality needs to be considered along with maximizing habitat area. Two measurable variables that affect quality are habitat depth and habitat diversity. Depth, considered in this section, is an important component of cover. As discussed earlier, depth and turbidity are probably the primary sources of cover for fishes in this portion of the Colorado River, though during winter, ice provides a third cover component (Osmundson and Kaeding 1989).

Backwaters, eddies and pools are the preferred habitat types of adult squawfish during summer and winter. During winter, pools replace eddies as the most preferred type. Depth at fish locations within these habitat types varied somewhat between summer and winter (Fig. 20; Table 2). Though depths at fish locations in eddies did not differ significantly between seasons, depths in backwaters and pools selected by the fish did differ between summer and winter. Fish used deeper backwater sites in summer than in winter and used deeper pools in winter than in summer.

Our objective was to use the stage/depth information obtained from the 12 transects to see if depth of preferred habitats was suitable or not during the flow levels recommended from the mapping output. We felt that for each habitat type, the average depth used by the fish, or rather the range of variance about the mean (plus or minus one standard error), provided a reasonable estimate of optimum or at least suitable depth. Preferred depth, a better indicator of optimum depth, could not be determined because measuring preference requires a comparison between use and availability. We had too little depth data to determine availability. Using the depth-use data, backwaters, for example, would have a range of suitable depths during summer of 3.4-4.5 ft; during winter, 2.6-3.1 ft (see Table 2). Presumably, water more shallow than that generally used by the fish provides insufficient cover. Water deeper than average should provide additional cover and therefore is not considered detrimental. Low use of deep water likely reflects its low availability.

Ideally, using the above example, we would like to know at what flow level the average and maximum depth of most backwaters in the 15-mile reach is at least 3.4 ft during summer and 2.6 ft during winter. This was the rationale behind monitoring stage at our transect sites. Stage, along with the bed cross-section data, allowed us to measure maximum and average depth at various flows (Table 3). However, there were not enough transects to allow us to make more general conclusions about relationships between stage and depth of habitats in general. For example, to

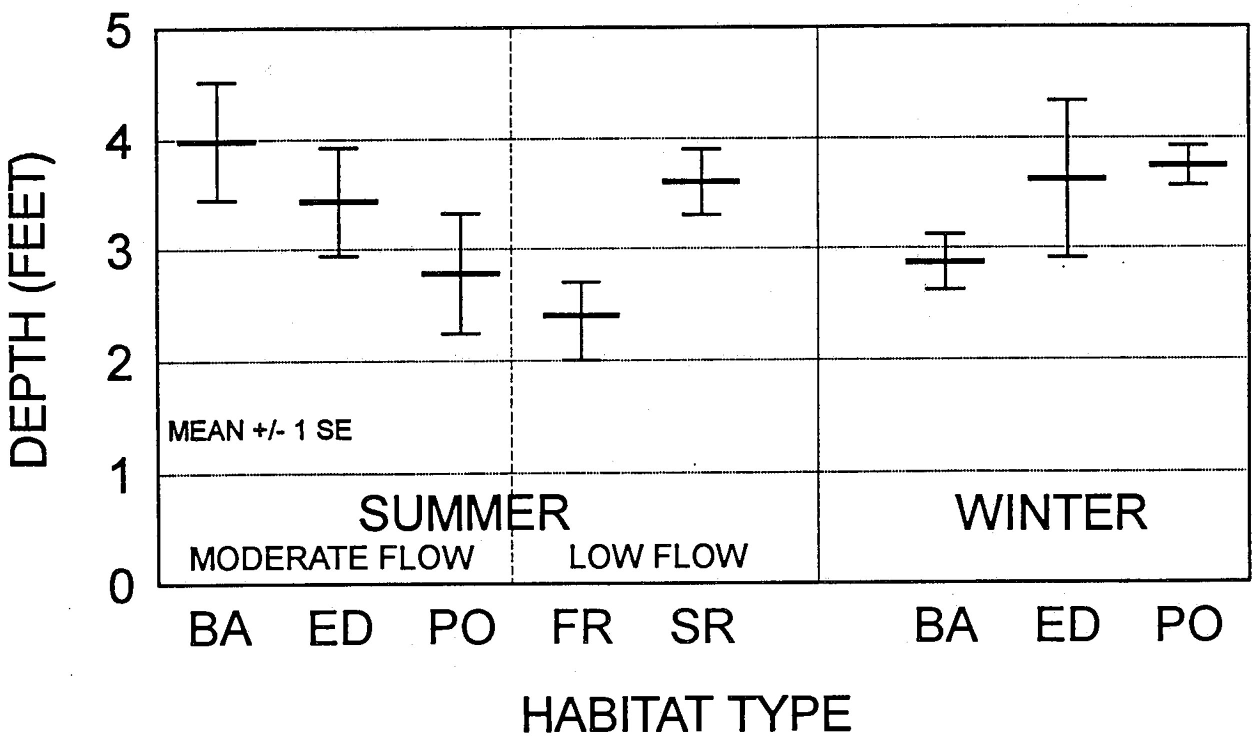


Figure 20. Mean depth at squawfish locations in the 15-mile reach, 1986-1988. Error bars are plus or minus one standard error.

Table 2. Depths at Colorado squawfish locations within preferred habitats in the 15-mile reach, 1986-1988.

Habitat	Season	Mean	SE	+/- SE	Range	Median	Location N	Fish N
BA	Summer	4.0	0.54	3.4-4.5	2.5-5.5	4.1	6	2
ED	Summer	3.4	0.49	2.9-3.9	1.1-7.0	2.9	12	4
PO	Summer	2.8	0.54	2.2-3.3	0.9-4.3	3.1	6	5
BA	Winter	2.9	0.25	2.6-3.1	1.7-3.7	2.9	10	2
ED	Winter	3.6	0.71	2.9-4.3	1.5-5.1	3.9	5	2
PO	Winter	3.7	0.18	3.6-3.9	1.4-8.0	3.8	48	5
FR	Lo-Summer	2.4	0.35	2.0-2.7	1.8-3.0	2.3	3	2
SR	Lo-Summer	3.6	0.27	3.3-3.9	1.4-7.6	3.3	26	7

determine at what stage or flow level the average depth of most eddies is suitable, one would need to monitor at least two transects across each of several eddies either randomly selected or thought to be representative of most eddies in the reach. Time and manpower constraints, i.e., level of funding, precluded this sort of large-scale effort. As it was, we monitored 26 transects within the Grand Valley, 13 of which were in the 15-mile reach. Of the 15-mile reach transects, four crossed primary or secondary channels within multi-channel sites, and three crossed the main channel at single-channel sites (Fig. 21 and Table 3). These sampled either riffle or run habitats. The remaining six transects sampled what later turned out to be preferred habitats: one crossed a pool, one crossed an eddy, and four crossed two portions of two backwaters. Note: At the time the transects were established (1990), we did not yet have the benefit of the data needed to determine which habitat types were preferred. The following contains a description of depths at the various transects, arranged by habitat type. Figures of each cross section with stage level superimposed is provided in Appendix No. VII.

Eddy Transect (Appendix Fig. V)
Transect No.5 bisected a large eddy located just outside the mouth of a large backwater within Site No.2. Maximum depth ranged from 7.3 to 12.8 ft depending on flow level; average depth ranged from 4.4 to 7.2 ft. Even at the lowest flows studied (557 cfs), suitable depth for summer (2.9-3.9 ft) and winter use (2.9-4.3 ft) was exceeded.

Pool Transect (Appendix Fig. VIII)
The south end of transect No. 10 bisected a pool located just outside a large backwater within site No. 3. Contours of the pool changed between fall of 1990 and fall of 1991. Moderately high spring flows in 1991 scoured bed sediments resulting in greater depth. Average depth during 1990 was less than suitable for summer use (2.2-3.3 ft) at flows less than 1,240 cfs (Table 4). Maximum depth exceeded 2.2 ft at all flows. For winter use, average depth was less than the suitable range (3.6-3.9 ft) at flows of 5,020 cfs or less. Maximum depth of the pool met or exceeded the suitability criteria at all flows higher than 810 cfs. Because the pool was deeper in 1991, suitable summer depths were met or exceeded at all flows: average pool depth was 2.3 ft at the lowest flow (557 cfs). For winter, average depths in 1991 were suitable at flows greater than 2,870 cfs. This illustrates an important point regarding maintenance of habitat quality: for some habitats, depth is a function not only of stage, or degree of inundation, but also the history of bed sedimentation or degree of scouring (discussed later under Spring Flows).

Backwater Transects (Appendix Figs. V and VII)
Transects No. 3 and 4 bisected a large backwater in site No. 2 (Appendix Fig. V). One (No.3) was placed towards the upstream end and the other (No.4) at about midway (Fig. 21). This backwater had a fairly uniform depth throughout its length. Average depths at the transects were never suitable for summer use (3.4-4.5 ft). Maximum depth was suitable for summer use at flows greater than 5,020 cfs at the upper site and greater than 4,426 at the midway site. Average depth was suitable for winter use at flows of 9,170 cfs or greater at the upper site and 7,620 cfs at the midway site. Maximum depth was optimum or greater for winter use (2.6-3.1 ft) at flows greater than 2,870 cfs at both upper and midway sites. In summary, most of this backwater was less than suitable in terms of depth at all flow levels typical of summer or winter conditions. Twelve squawfish locations made within this backwater during summer of 1986 and winter of 1986-1987 indicate that backwater depth was greater at that time: depth at fish locations ranged from 1.7 to 5.5 ft. One location, made one third the way up the backwater was 4.7 ft deep in August 1986

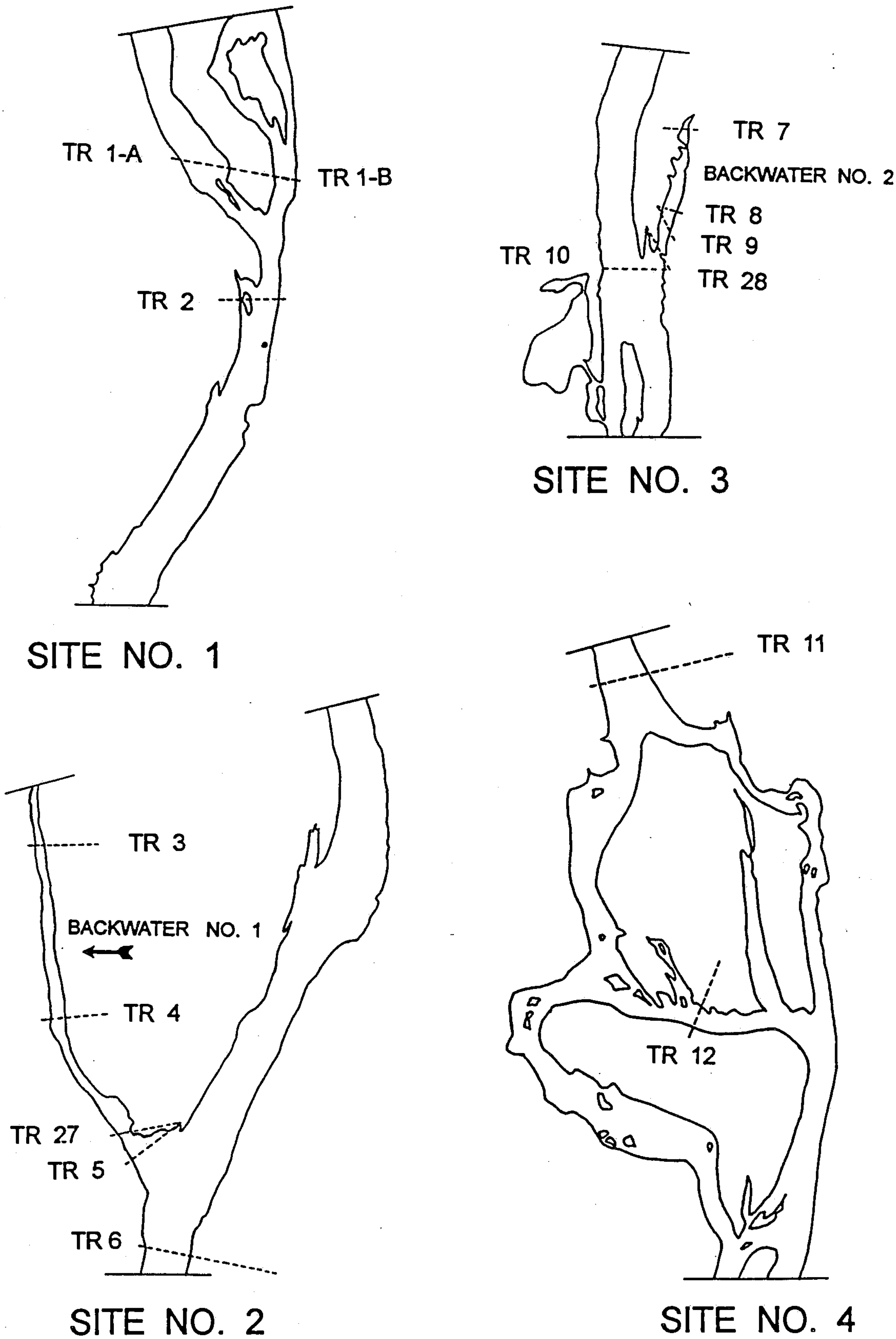


Figure 21. Placement of transects within the four 15-mile reach study sites.

Table 3. Maximum and average depth of 12 stream bed cross sections at different flow levels, organized by habitat or channel type. Data are identical to that in Appendix Table XV where depths are organized by cross-section number.

15-MILE REACH TRANSECTS - MAXIMUM DEPTHS (FT)

FLOW	BACKWATER NO. 1		BACKWATER NO. 2			EDDY	POOL	
(CFS)	UPPER	MIDWAY	UPPER	MID-90	MID-91	NO. 1	NO.1-90	NO.1-91
11200	5.64	5.64	6.38	5.58	8.10	12.78	8.34	8.83
9250	5.06	5.11	5.73	5.17	7.69	12.22	7.90	8.39
9170	5.03	5.09	5.70	5.14	7.66	12.19	7.89	8.38
7620	4.55	4.53	5.16	4.72	7.24	11.75	7.52	8.01
5020	3.32	3.61	4.02	3.61	6.38	10.74	6.42	7.14
4426	3.03	3.20	3.73	3.31	6.09	10.38	6.09	6.86
2870	2.12	2.35	2.97	2.55	5.29	9.49	5.32	6.08
1630	1.58	1.67	2.48	2.03	4.55	8.80	4.62	5.35
1530	1.52	1.57	2.37	1.96	4.48	8.73	4.55	5.27
1240	1.30	1.27	2.23	1.61	4.24	8.46	4.25	4.98
900	0.83	0.73	2.08	1.05	3.89	7.86	3.81	4.61
810	0.73	0.51	2.04	0.87	3.73	7.61	3.61	4.49
557	0.71	0.37	1.51	0.01	3.19	7.32	2.89	4.07

FLOW (CFS)	SIDE CHANNELS					MAIN-SINGLE CHANNELS		
	NO. 1	NO.2	NO.3	NO.4 - 90	NO.4 - 91	NO. 1	NO. 2	NO. 3
11200	6.05	7.63	9.25	6.80	8.00	10.21	9.79	9.91
9250	5.32	7.04	8.73	6.34	7.54	9.67	9.35	9.62
9170	5.28	6.98	8.68	6.31	7.51	9.63	9.31	9.60
7620	4.69	6.35	8.25	5.86	7.06	9.06	8.79	9.30
5020	3.88	4.96	7.34	4.73	5.93	7.72	7.57	8.41
4426	3.66	4.61	7.08	4.40	5.60	7.23	7.2	8.13
2870	3.17	3.74	6.35	3.58	4.78	6.19	6.28	7.55
1630	2.85	3.02	5.88	2.92	4.05	5.32	5.52	7.01
1530	2.82	2.94	5.82	2.85	3.99	5.24	5.42	6.99
1240	2.71	2.74	5.64	2.79	3.82	5.04	5.11	6.76
900	2.51	2.41	5.34	2.48	3.55	4.73	4.69	6.47
810	2.37	2.37	5.19	2.35	3.47	4.46	4.56	6.34
557	2.22	2.22	5.07	2.05	3.08	3.99	4.23	5.99

AVERAGE DEPTHS (FT)

FLOW	BACKWATER NO. 1		BACKWATER NO. 2			EDDY	POOL	
(CFS)	UPPER	MIDWAY	UPPER	MID-90	MID-91	NO. 1	NO.1-90	NO.1-91
11200	3.22	2.99	3.55	3.74	5.24	7.17	5.15	5.70
9250	2.64	2.58	4.02	3.33	4.83	6.93	4.71	5.26
9170	2.61	2.67	3.99	3.30	4.80	6.90	4.70	5.25
7620	2.30	2.64	3.45	3.14	5.02	6.64	4.33	4.88
5020	1.48	1.99	2.99	2.63	4.16	6.48	3.57	4.01
4426	1.31	1.84	2.70	2.33	3.87	6.12	3.24	3.73
2870	0.93	1.19	1.94	1.82	3.07	5.57	2.47	3.32
1630	1.56	1.16	1.86	1.30	3.33	5.56	2.74	3.19
1530	1.50	1.06	1.75	1.39	3.26	5.49	2.67	3.11
1240	0.87	0.89	1.61	1.21	3.02	5.22	2.37	3.25
900	0.81	0.35	1.46	0.65	2.67	4.97	1.93	2.88
810	0.71	0.24	1.42	0.57	2.51	4.72	1.73	2.76
557	0.69	0.17	1.31	0.01	1.97	4.43	1.77	2.34

FLOW (CFS)	SIDE CHANNELS					MAIN-SINGLE CHANNELS		
	NO. 1	NO.2	NO.3	NO.4 - 90	NO.4 - 91	NO. 1	NO. 2	NO. 3
11200	4.66	5.74	6.56	3.34	3.39	6.20	3.73	4.30
9250	4.09	5.15	6.04	2.88	3.00	5.93	3.37	4.20
9170	4.04	5.09	5.99	2.85	2.97	5.89	3.33	4.18
7620	3.46	4.46	5.56	2.59	2.89	5.32	3.51	3.88
5020	2.76	3.07	4.65	2.32	2.90	4.19	3.85	5.53
4426	2.54	2.95	4.39	2.59	3.12	3.70	3.64	5.25
2870	2.05	2.32	3.66	1.99	2.30	2.79	3.18	4.89
1630	1.80	1.96	3.37	1.33	1.89	2.07	2.88	4.56
1530	1.77	2.10	3.31	1.26	1.95	1.94	2.78	4.54
1240	1.66	1.90	3.13	1.20	1.89	1.74	2.62	4.31
900	1.46	1.57	2.83	1.00	2.50	1.43	2.20	4.02
810	1.32	1.44	2.68	0.87	2.42	1.23	2.07	3.89
557	1.17	1.38	2.56	0.95	2.29	1.46	1.87	3.72

when flows were approximately 2,300 cfs. Flows during 1990 and 1991 would need to have been greater than 8,000 cfs to create a comparable depth. We suspect that sedimentation of this backwater and the lack of adequate flushing flows during the low-flow years of 1988-1990 was responsible for reducing depth and thereby degrading the quality of this backwater.

Backwater No.2, within site No.3, was sampled with transects Nos. 7, 8 and 9. Transect No.9 was later dropped from the analysis because it was laid out diagonally across the backwater instead of perpendicular to the long axis. Transect No.7 bisected the top end of the backwater and No.8 bisected it about midway up its length. Considerable bed change occurred at the midway site between 1990 and 1991. Scouring of bed sediments during the spring of 1991 left the backwater about three feet deeper. We graphed stage at various flows separately for the 1990 and 1991 cross-sectional profiles (Appendix Fig. VII). To achieve suitable summer depth at the deepest point, the midway transect in 1990 would require flows in excess of 4,426 cfs. For winter use (2.9-4.3 ft), flows in excess of 2,870 cfs were required at the midway transect. In 1991, flows of only 810 cfs were adequate to provide a suitable summer depth at the deepest point on the midway transect. For winter use, flows as low as 557 cfs were adequate in 1991 to provide a maximum depth that was suitable. Again, adequate depth at this backwater was as much a function of previous flushing spring flows as it was of stage.

Run Transects (Appendix Figs. III, IV, VI, VIII and IX)
Fast and slow runs were preferred habitats only during summer when flows were 391-931 cfs. Suitable depth for fast runs during low-water, summer periods was 2.0-2.7 ft, but this was based on a very small sample (n=3 locations). For slow runs, suitable depth was 3.3-3.9 ft (n=26 locations) during low-water, summer periods (Table 2).

Transects Nos. 1-B and 12 (side channel Nos. 2 and 4) and transects Nos. 2 and 6 (main channel Nos. 1 and 2; Table 3) bisected channel segments that contained fast runs when flows were low (810 and 557 cfs). Maximum depth along these transects during low flows exceeded our estimate of suitable depth for fast runs. Average transect depth was less than suitable during low flows in most cases but averages often included other habitat types adjacent to the fast runs and thus may not be a valid measure for comparison. Average depth for transect No. 12 (side channel No. 4) did fall within the range of suitability but only in 1991 after spring flows that year had scoured and deepened the bed (Table 3).

Transects Nos. 1-A and 10-N (side channel Nos. 1 and 3) and transect No. 11 (main channel No. 3) bisected channels consisting primarily of slow runs at low flows. Maximum depth was less than the suitable at flows of 810 and 557 cfs at transect No. 1-A but was more than suitable at transect Nos. 10-N and 11. Average depth was insufficient at the two side channel sites (TR Nos. 1-A and 10-N) but was within the range of suitability at the one main channel site (TR No. 11).

Summary
We were able to develop some insight into the relationship between stage and habitat depth by monitoring 13 different transects in the 15-mile reach. However, it is difficult to draw definitive conclusions about minimum flows needed to provide adequate depth due to our low number of transects across some key habitat types and the dynamic nature of substrata. From our observations over the years, both through radiotelemetry contacts and catch rates, the two backwaters we sampled with transects are probably the most important, i.e., heavily used, backwaters in the 15-

mile reach if not the upper Colorado River. Thus, if not representative of backwaters as a whole, they are representative of backwaters with features attractive to adult squawfish. The four secondary and three main-single, channel segments sampled with transects were not necessarily areas of high squawfish use; some were known to have been used, others were not. How representative our transect sites were of fast and slow runs throughout the reach is unknown. At the time of study design and selection of transect sites, it was not known that eddies and pools were the most preferred habitats types; in retrospect, it is clear that these important types were under sampled. Thus, we draw what conclusions we can regarding flows needed to maintain adequate depth within the various habitat types, recognizing the limitations of our sample.

The one eddy we sampled maintained depth that exceeded summer and winter suitability criteria at all flows studied (Table 4). For the pool, the deepest point was sufficient for summer use at all flows, but average depth was suitable only at flows of 1,240 cfs or greater. For winter use, the deepest point was suitable at flows of 810-900 cfs but flows had to be greater than 5,020 cfs to provide an average depth that was adequate. Scouring of the bed in 1991, however, resulted in maximum depths in the pool that later met or exceeded the suitability criteria at all flows studied.

Of the two backwaters studied, backwater No.1 had less than suitable depth at all flow levels typical of summer or winter conditions and higher spring flows in 1991 failed to improve conditions there. Backwater No.2, on the other hand, did benefit from the 1991 spring flows: in 1990, both maximum and average depths were less than adequate at both upper and midway sites during all flows typical of summer or winter conditions. But in 1991, average depth at the midway transect was very close to being suitable for summer use at flows of 1,630 cfs, and maximum depth there met the criteria at flows of 810 cfs. For winter use, maximum depth in 1991 at the midway transect in backwater No. 2 met or exceeded the suitability minimum at all flows studied, and average depth did so at flows of 900 cfs.

During low summer flows when runs are preferred, maximum depth was suitable at all flows for fast runs at two secondary and two main-single channel sites. Average depth was greatly improved at one secondary-channel site after the bed was scoured in spring of 1991. For slow runs, maximum depth during the lower flows was less than adequate at one secondary channel transect but was more than adequate at a different one. At a main-single, channel transect that bisected a slow run, maximum depth was also suitable at the lower flows.

Depth in Relation to The Summer-Winter Flow Recommendations

In a previous section, we found that flows of 1,630 cfs provided the best combination of habitats (total weighted area) preferred during summer (backwaters, pools and eddies). We therefore recommended a flow of 1,630 cfs for the top of the 15-mile reach during summer (August-October). During years of below average precipitation when it would be difficult to meet this recommendation, 1,240 cfs would still provide sufficient flows such that Colorado squawfish would continue using their normally preferred habitats. During drought years fish would be forced to modify their behavior but 810 cfs would result in significantly more total weighted area of slow and fast runs than would 557 cfs. During winter, habitat preferences change somewhat and flows in the reach are higher on average than during summer. However, flows of 1,630 cfs were also found to provide the greatest total weighted area of preferred winter habitat.

Our goal in monitoring depth at various locations across different habitat types was to find if depth was limiting or unsuitable at the recommended flow levels. For instance, if a flow of 1,630 cfs was recommended on the basis of providing near maximum area of preferred habitat, would depth of key habitats also be sufficient at that flow?

For moderate-to-high flow summers, the recommended 1,630 cfs provided more than adequate depth (maximum and average) at the pool and the eddy transects (Table 5). However, suitable depth was not provided by 1,630 cfs at transects in the two backwaters. At backwater No.1, increasing the flow to 2,870 cfs would provide greater depth but depth at both transects would still fall far short of being suitable. This was also the case for backwater No.2. However, at the midway transect there, maximum depth sufficiently deep at flows less than 1,630 cfs once the bed elevation dropped in 1991, and average depth was nearly optimum (3.3 vs 3.4 ft) at 1,630 cfs.

For low-flow summers, the recommended 810 cfs resulted in more than adequate depths at the deepest point along four fast-run transects and two of three slow-run transects.

For winter use, maximum depths along the pool and eddy transects were suitable at 1,630 cfs. Average depth along the eddy transect at 1,630 cfs was also more than adequate though not so at the pool transect. Neither average nor maximum depths were suitable at 1,630 cfs for transects at backwater No.1. At backwater No.2, however, maximum depth at the upper transect was nearly deep enough (2.48 vs 2.60 ft.) at a flow of 1,630 cfs, and at the midway transect, maximum and average depth was sufficient, but again, only after the scouring flows of 1991.

From the limited depth data that we acquired, it appears that depth of preferred habitats would not be improved significantly by adjusting the recommended flows upward within ranges typical of summer or winter conditions. Though the average depth along the transects often did not meet the minimum criteria for suitability, the maximum depth did. Average depth would be best because a greater volume of water could be exploited by one or more fish. However, with at least the maximum depth being optimum, we can assume an adult squawfish is capable of occupying some portion of a given habitat.

The eddy and pool that we monitored maintained suitable depth at the recommended flows as did most of the fast and slow runs. Depth of both backwaters was unsuitable in 1990 and flows needed to provide suitable depth would be much greater than flows typical of summer or winter. However, depth of backwater No.2 was made suitable by spring flushing flows in 1991. The spring flows required to do this at backwater No.1 are evidently higher. Backwater No.1 was formerly used by squawfish in summer of 1986 and winter of 1986-1987 presumably when the bed was lower and the water deeper following the high flows of 1983-1986. After our stage monitoring ended, the bed at Backwater No.1 was again lowered by the spring flows of 1993 (discussed later under Spring Flows).

The summer and winter flow recommendations, designed to provide the maximum area of preferred adult squawfish habitat, should also be adequate to provide these habitats with suitable depth. Examination of stage and depth at bed cross-sections indicated that the recommended summer flow of 1,630 cfs would provide such depths in most cases. Backwaters are the most sensitive to changes in stage and most prone to sedimentation during years of low flow. To maintain adequate depth of backwaters in the 15-mile reach, not only should the recommended

Table 4. Minimum flow levels (in cfs) known to have provided suitable depths for a given habitat type within a given season. Less than (<) signs indicate that these depths were met with flows less than the lowest monitored (557 cfs). Greater than (>) signs indicate that the flow listed did not provide suitable depth but suitable depth was provided at some flow between the listed flow and the next highest flow monitored. Flows in parentheses are minimum flows needed after bed sediments were flushed in 1991.

		Summer		Winter	
Habitat	Transect	Max Depth	Ave Depth	Max Depth	Ave Depth
ED	5	<557	<557	<557	<557
PO	10-S	<557	>900 (<557)	≥810 (<557)	>5,020 (>2,870)
BA-1-U	3	>5,020	>11,200	>2,870	≥9,170
BA-1-M	4	>4,426	>11,200	>2,870	≥7,620
BA-2-U	7	>2,870	≥7,620	>1,630	>2,870
BA-2-M	8	>4,426 (>557)	>9,250 (1,630)	>2,870 (<557)	≥5,020 (≥900)
FR-1	1-B	<557	>1,240		
FR-2	12	<557	≥2,870 (557)		
FR-3	2	<557	>1,530		
FR-4	6	<557	>557		
SR-1	1-A	>2,870	>5,020		
SR-2	10-N	<557	≥1,530		
SR-3	11	<557	<557		

Table 5. Transects where suitable depth was provided by the recommended flow.

Habitat	Transect	Max Depth	Ave Depth	Max Depth	Ave Depth
	Summer: Moderate-to-High Flow Year (1,630 cfs)			Winter: (1,630 cfs)	
ED	5	Yes	Yes	Yes	Yes
PO	10-S	Yes	Yes	Yes	No
BA-1-U	3	No	No	No	No
BA-1-M	4	No	No	No	No
BA-2-U	7	No	No	No	No
BA-2-M	8	No (Yes)	No (Yes)	No (Yes)	No (Yes)
	Summer: Low-Flow Year (810 cfs)				
FR-1	1-B	Yes	No		
FR-2	12	Yes	No (Yes)		
FR-3	2	Yes	No		
FR-4	6	Yes	Yes		
SR-1	1-A	No	No		
SR-2	10-N	Yes	No		
SR-3	11	Yes	Yes		

summer and winter flows be met, but spring flows with sufficient flushing capability need to be provided with routine frequency.

Habitat Heterogeneity

A component of habitat quality often overlooked in many instream flow models is habitat diversity. Osmundson and Kaeding (1991) found that adult Colorado squawfish in the Grand Valley prefer river segments with a complex morphometry over those that are simple, i.e., squawfish were located in complex river segments more often than availability of those sites would predict if selection was random. Osmundson and Kaeding (1991) hypothesized that selection for complex channel areas (containing one or more islands, large backwaters, or side channels) was due to greater habitat diversity within these areas. A suite of mesohabitats in close proximity to one another allow fish to efficiently exploit a range of habitat types when fulfilling daily requirements (foraging, resting, avoiding predation, etc.). Energy that would otherwise be expended for excess travel among habitat types can instead be conserved for growth or reproduction. Osmundson and Kaeding (1991) stressed the need for high spring flows to create and maintain channel complexity so as to preserve habitat diversity.

Here we explore the role of stage in influencing habitat diversity. We make the same assumption that clusters of various habitats are beneficial to squawfish, but rather than compare complex with simple channel segments, or investigate how spring flows affect channel complexity, we take the analysis in a different direction to see how habitat diversity within a complex channel area changes as a function of flow level or stage during base flow conditions. Thus, assuming channel configuration stays relatively constant during that portion of the year following spring runoff, is there a range of flows during summer and winter at which habitat diversity is maximized?

Numerous indices have been devised to measure species diversity within ecological communities (see Odum 1971). We explored the use of these indices as a means to measure habitat diversity, replacing types of species with types of habitats. Diversity indices are generally of three types: 1) those that measure species richness, i.e., number of different species; 2) those that measure species evenness, i.e., number of individuals of each species; and 3) those that take both richness and evenness into account.

The widely used Shannon-Weaver index of overall diversity (Shannon and Weaver 1963) falls under the third type listed above. We attempted to use this index but found that: 1) habitat richness, or number of different habitat types, did not vary within our study sites from one flow level to the next (excepting the addition of the gravel pit pond at site 3 at flows of 4,426 cfs or higher); and 2) maximizing habitat evenness, i.e., the flow at which proportions of each habitat type are most nearly equal (either in terms of area or number of mapped polygons) was somewhat contrary to our objective of maximizing the area of preferred habitat types. Diversity, using the Shannon-Weaver index, was highest at 4,426 cfs.

Density turned out to be the measure best describing how an individual fish might exploit neighboring habitat types with minimal energy expenditure. Density can be measured as either the number of mapped polygons (discrete habitat units) per unit area of water or as polygons per unit length of river. For polygons per hectare of water, we summed the total number of polygons across the four study reaches and divided by the total water area of the four reaches to arrive at a density estimate for each flow level. As before, the four study sites were treated as one composite reach. For habitat units per mile of river, we summed the total number of polygons and divided by the summed miles of river in the four study sites.

For habitat units per hectare, there was an inverse relationship: as flow increased, habitat density declined (Fig. 22). When density and discharge were graphed, the overall trend was apparent but an anomaly existed: the trend was inconsistent at the lower discharge levels. Density declined sharply between flows of 557 and 810 cfs, and increased again at 1,240 cfs before declining again. In an attempt to understand this inconsistency, we partitioned the data by year of mapping. What emerged were two lines that were relatively consistent (Fig. 22). The difference between the two lines was that flows at the lower end of the spectrum resulted in higher densities in 1991 than in 1990. One possible explanation for this is that the experience of the individual performing the on-the-ground mapping increased as the project progressed and slightly more detailed maps were produced toward the later part of the study.

Regardless of the cause, there appears to be a consistent pattern in which density decreases only slightly between lower and mid-range flows and declines more at higher flows. In 1990, density dropped sharply between flows of 1,530 and 2,870 cfs; in 1991, between flows of 1,240 and 1,630 cfs. Thus, habitat density was highest at 557 cfs, and 98% of maximum at 1,240 cfs. Habitat units per hectare at 1,630 cfs, the recommended summer and winter flow, was 76% of that at 557 cfs.

The highest total number of discrete habitats, and therefore the highest number per mile, occurred at 1,240 cfs. Number per mile did not vary as much with discharge as number per hectare (Fig. 22). At the recommended flow of 1,630 cfs, habitats per mile was 82% that at 1,240 cfs.

Final Considerations for Summer and Winter Flow Recommendations

(Objective No. 4)

In developing the final summer and winter flow recommendations, our primary consideration was to maximize the area of preferred habitat while minimizing potential depth limitations. Analysis of effects of discharge on habitat area resulted in 1,630 cfs as the best flow level for both seasons. A secondary consideration was to retain a reasonably high degree of interspersion of individual habitat units. Interspersion (density), was highest at 557 cfs (per unit area) and 1,240 cfs (per linear mile of river).

We conclude that 1,630 cfs remains the best flow of those studied for the following reasons: 1) a flow of 2,870 cfs would provide less preferred habitat and a lower density of habitats than at 1,630 cfs; 3) a flow less than 1,630 cfs would provide less preferred habitat area while depth could become limiting in more locations; 4) though interspersion was not maximized at 1,630 cfs, it remained reasonably high; (5) for winter, flows less than 1,630 cfs are outside the range of flows within which winter preference could be tested and the next highest flow studied, 2,870 cfs, is considerably higher than the mean flow of either the recent or historic winter periods; and (6) when summing weighted area of preferred habitat, backwaters made up a large contribution (24-41%) to total area, yet stage and bed profile monitoring indicated that adequate depth in backwaters is far from assured; a large proportion of backwaters may often be unsuitable due to insufficient depth.

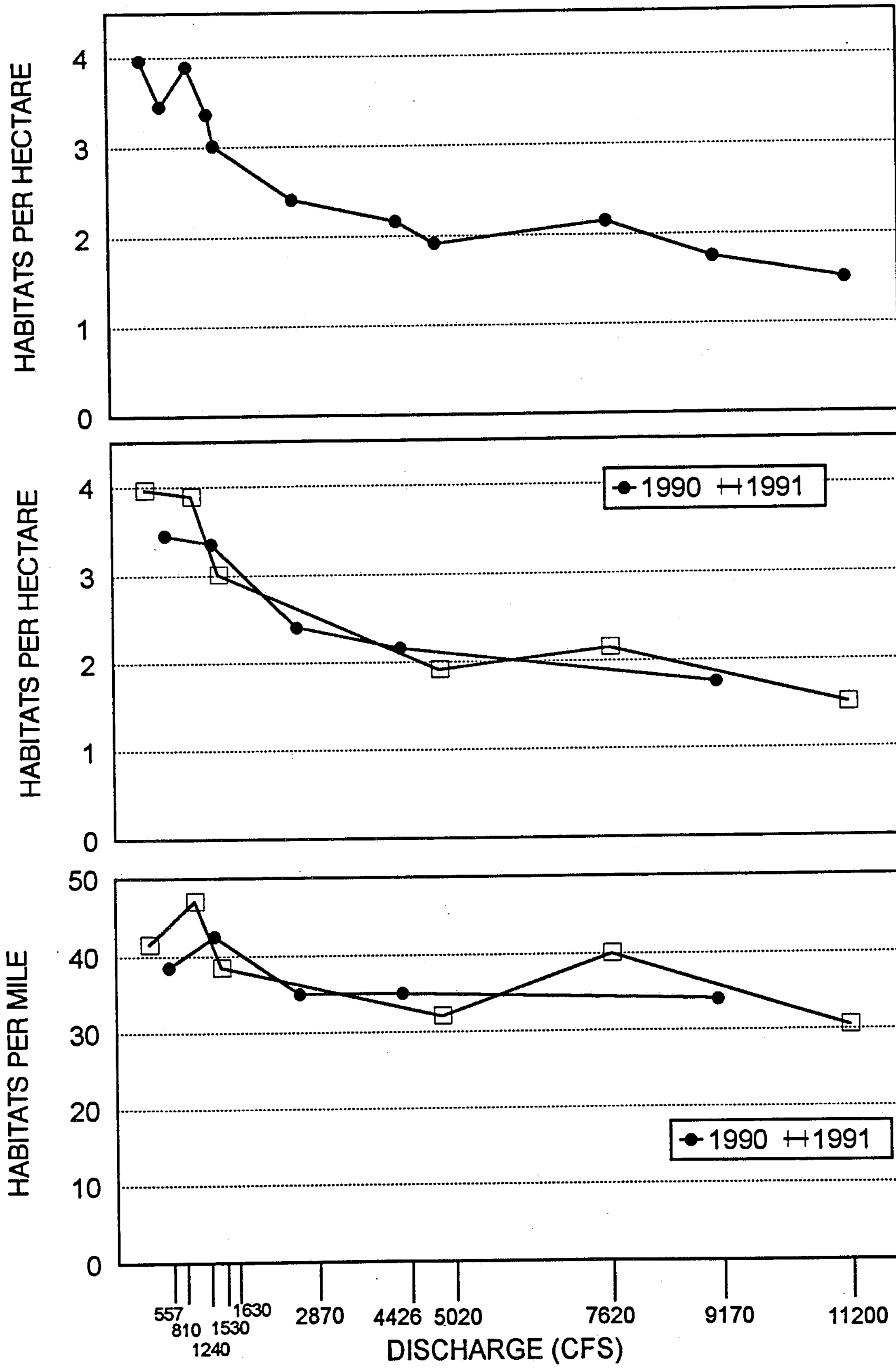


Figure 22. Density of habitats in the study reaches at various discharge levels. Upper two graphs show habitat units per area; lower graph, habitat units per mile. Line in upper graph includes both 1990 and 1991 data; lower two graphs separate data by year (see text).

Thus the flow that relies least on backwaters for maximizing total area of preferred habitat, is the flow most likely to result in the highest amount of preferred habitat that is actually usable. At 1,630 cfs, backwaters made up the smallest proportion (24%) of total weighted preferred habitat (at 1530 cfs it was 26%; at 1,240 cfs, 38%; at 2,870 cfs, 41%).

Thus, our recommendation for summer is to maintain flows of 1,630 cfs during years of above average (50%) precipitation and for flows to not fall below 1,240 cfs during years of low precipitation when the recommendation of 1,630 cfs would be difficult to meet. During drought years (the lowest 20%), fish could probably be maintained at 810 cfs. For winter, flows of 1,630 cfs are recommended for most years (80%), and 1,240 cfs should be a minimum flow during years of drought. These recommended flows are for the top of the 15-mile reach, measured at the USGS gauging station, and assume that current irrigation return flows continue to provide additional water at various downstream points within the reach.

SPRING FLOW NEEDS

Background

Recommendations for flows in the 15-mile reach during spring were previously provided by Osmundson and Kaeding (1991). They documented the extent to which spring flows have been reduced since the 1940's, largely as a result of upstream water storage and transbasin diversions. Effects of reduced flow on populations of Colorado squawfish and razorback sucker were described. The authors developed their conclusions using a combination of empirical data, observations, and current biological and geomorphological theory.

Recommendations for spring flows in the 15-mile reach were designed to fulfill two purposes: 1) improve habitat conditions within the 15-mile reach ; and 2) together with flows from the Gunnison River, improve conditions downstream of the reach. Benefits described by Osmundson and Kaeding (1991) that result from higher spring flows included: 1) maintenance of channel complexity and habitat heterogeneity; 2) improvement of Colorado squawfish reproductive success; 3) inundation of bottomlands for razorback sucker spawning and nursery habitat; and 4) control of certain prolific, non-native fish species.

Relationships between flow and reproductive success of Colorado squawfish and relationships between flow and control of non-native fish species were based on locally-collected, empirical data. The need to inundate low-lying lands adjacent to the river during the razorback sucker spawning season was based on biological data regarding attributes of razorback sucker life history. Importance of channel complexity was based on squawfish habitat selection data that was collected locally. The effect of flow on channel maintenance in the 15- and 18-mile reaches was based on observations of vegetation encroachment and deposition of fine sediments there over a six-year period coupled with causal explanations in the literature by geomorphologists studying similar trends in other river systems.

Osmundson and Kaeding (1991) recognized the potential for habitat loss due to sedimentation of low-velocity sites and channel simplification but had no data to document its occurrence; in addition, they had no data on the magnitude or duration of flushing flows necessary to prevent it. As described earlier, the stream-bed, cross-section monitoring conducted for the present study revealed year-to-year changes in habitat depth due to scouring and filling of fine sediments, particularly in backwaters. In this section, we present the results of four years (1990-1993) of stream bed monitoring in the 15-mile reach and relate year-to-year changes to spring discharge.

In addition to our study, researchers from the University of Colorado Geography Department initiated a study in 1993 to evaluate the history of channel change in the Grand Valley and determine threshold flows required for sediment transport. Highlights of a progress report on that work (Van Steeter and Pitlick 1994) and its implications for spring flow recommendations are also provided.

Stream Bed Monitoring

We monitored 12 stream-bed cross sections in the 15-mile reach once yearly (October-November) during 1990-1993. Two additional transects were added in fall of 1992 and monitored again in 1993. Year-to-year stream bed changes are described for each transect in Appendix VIII.

Stream Bed Movement in Relation to Flows

Flows periodically produce bed load movement that has significant effects on substrate and channel configuration. Sediment deposition on the stream bed is a function of velocity and amount of sediment in suspension. As a result, the quality of fish and invertebrate habitats are often in a state of flux. In the 15-mile reach, cobble is the primary bed material in areas of fast moving water. But, the river transports enormous quantities of fine sediments, particularly silt. In low-velocity sites, fines are deposited. Such low-velocity habitats include pools, backwaters and eddies. As flows increase in spring, water in habitats that are of low-velocity during most of the year may become quite swift. At some point current becomes sufficient to scour fines from the bottom. These are transported downstream where they are deposited in sites that are of low velocity during high water, such as shorelines or the tops of islands.

For a given low-velocity site to maintain constant depth and width from one year to the next, there must be a balance between the amount of fines that are scoured in spring and the amount that is deposited during the course of the year. In a given year, the balance is often tipped either in favor of more scour than fill or more fill than scour resulting in a net gain or loss of sediment from the bed. At a particular site, gain or loss will depend on the magnitude and duration of the flushing flows and the amount of sediment being carried by the river. If more deposition than scour occurs for several years, depth of a backwater, for instance, may be reduced to the point where that habitat becomes unsuitable to large fish, or if a silt bar forms across the backwater mouth, access to the backwater may become blocked.

Fine sediment, if unconsolidated, may be scoured from the bottoms of backwaters, pools and eddies relatively easily. However, submerged or emergent bars are quickly colonized by vegetation. If a root system becomes sufficiently established, it takes a much higher flow to erode or scour the silt than if the bar was unvegetated. To keep backwaters open, flows of a sufficient magnitude must be provided frequently enough to remove accumulated sediments before too much backwater depth is lost and before vegetation on bars becomes too deeply rooted.

During the year, fine sediment also settles into the interstitial voids among cobble out in the channel. To invertebrates, voids are particularly important as shelter and as collectors of detritus (Rabeni and Minshall 1977). Production of many stream insects in riffles depends on the presence of silt-free interstitial spaces (Ward 1976). If unconsolidated, cobble and gravel can be periodically moved and flushed of fines relatively easily at moderately high flow levels. However, if not routinely flushed or moved, cobble can, over time become tightly embedded in silt and sand to the point that only the top half of the rocks are exposed to the water. This leaves little space or cover for invertebrates or fish eggs that depend on the sheltered microhabitats provided by interstitial voids. Once tightly embedded, it takes a much higher flow level to mobilize the bed and winnow out fine sediments (Bob Milhous personal communication).

Using the sites that we monitored as a sample, we wanted to see how the spring flows of each year affected the bed. 1991 was a low-to-moderate flow year (peak day averaged 12,900 cfs), 1992 was a low flow year (peak day averaged 7,560 cfs), and 1993 was a high flow year (peak day averaged 25,900 cfs). We categorized the transect sites into the following categories: eddy, pool, backwater, isolated backwater pool, and channel.

Eddy

The bed of the one eddy we monitored was more scoured than filled in 1991; in 1992, it was more filled than scoured; in 1993, it was scoured in one area and filled in another.

Pool

The bed of the one pool we monitored was scoured in 1991, accumulated fill in 1992, and was greatly scoured in 1993.

Backwater

The two backwaters we sampled reacted differently to the flows of 1991 and 1992: one was relatively unchanged at both transects during both years (slight fill in 1991 at TR 4), while the other was clearly scoured in 1991 and significantly filled in 1992. In 1993, bottom sediments were significantly scoured at both transects within both backwaters. In addition, the bars that had become established in the mouths of each backwater were both removed. Figs. 23 and 24 illustrate the dynamics of fill and scour at backwater No.2 (Site 3).

Isolated Backwater Pool

One site located at the far upper end of one backwater was converted to an isolated pool (at low flow) early in the study. It accumulated some fill in 1991, experienced minor scour and fill in 1992, and was primarily filled in 1993.

Channel

We monitored seven different channel beds. In 1991, one was scoured, one was both scoured and filled (the thalweg was scoured; the shallow pool received fill), and the five others were unchanged. In 1992, one had sediment removed from the side of the channel, one received fill on top of a riffle, one had both scour and fill (fill in the thalweg; scour from the pool), and four others remained unchanged. In 1993, two channels had large amounts of coarse materials removed from the bed, two received significant deposits of material, two were both scoured in some areas and filled in others, and none remained unchanged.

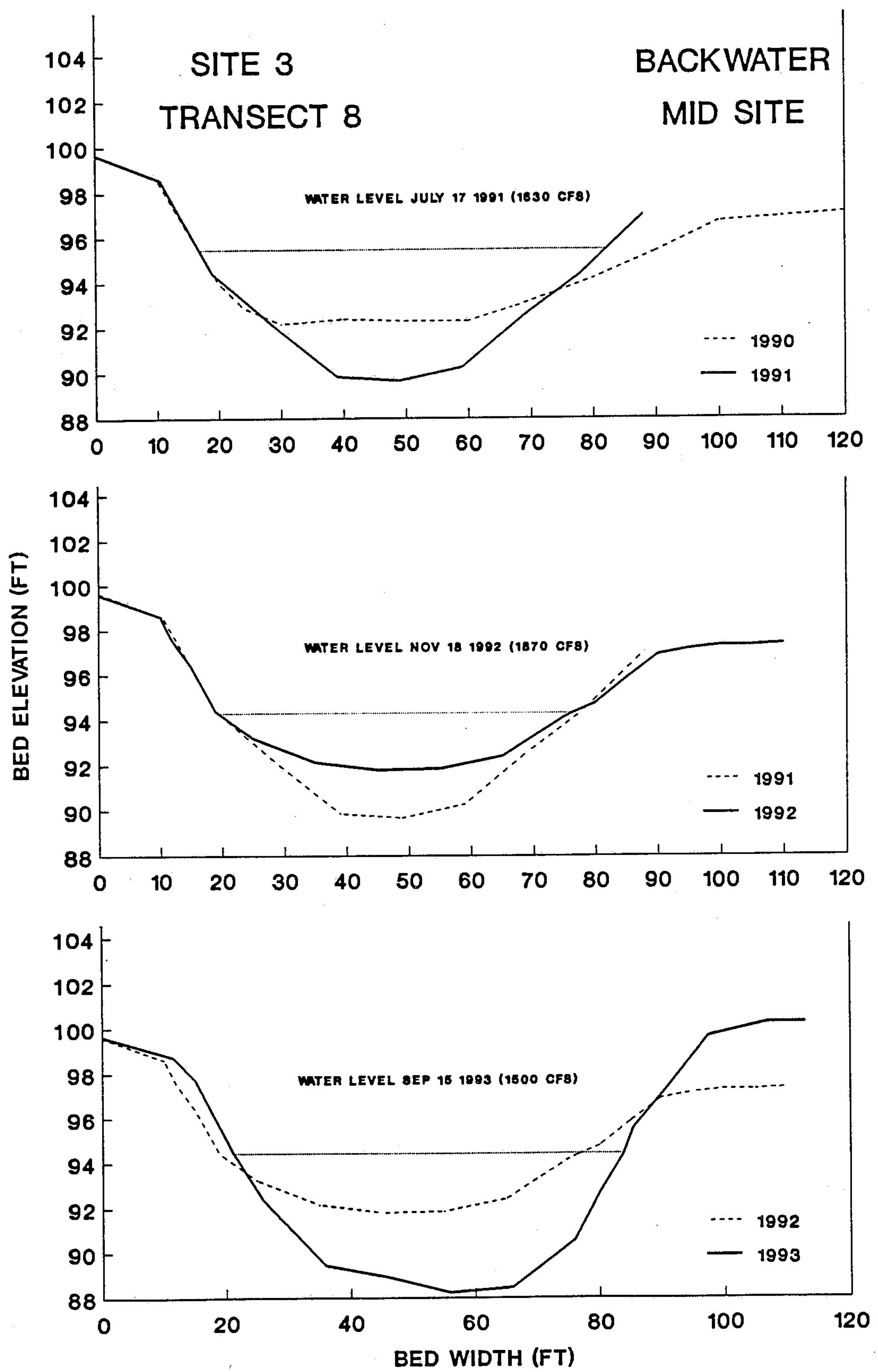


Figure 23. Change in bed elevation across a backwater in Site 3 over a three-year period. Transect No. 8 was located midway up the length of the backwater. Measurements were taken each fall, 1990-1993. Descriptions of year-to-year scour and fill at this site are provided in Appendix VIII.

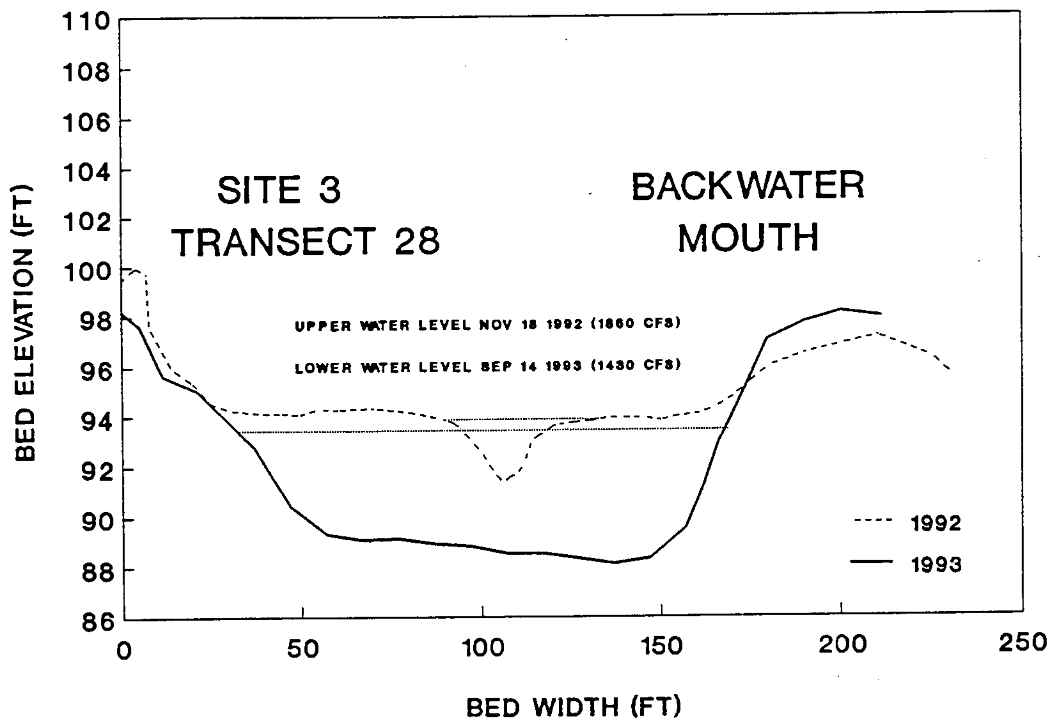


Figure 24. Change in bed elevation across the mouth of a backwater in Site 3. Measurements taken in fall of 1992 and 1993. Descriptions of year-to-year scour and fill at this site are provided in Appendix VIII.

In 1991, scouring of fine sediment was greater than deposition in the pool, the eddy and one of the two backwaters. However, in 1992, more deposition than removal occurred in these low-velocity habitats. In 1993, both erosion and deposition occurred in the eddy, but the pool and all sites within both backwaters were deeply flushed of sediments. Thus, it appears that a peak flow of 7,560 cfs is insufficient to prevent net accumulation of sediment in several key low-velocity habitats that were monitored. A peak flow of 12,900 cfs appeared sufficient to deepen several of the key sites. Clearly, a peak flow of 25,900 cfs had a restorative effect on all low-velocity habitats that were monitored.

In the more high-velocity channel sites, where cobble was the primary substrate type, little bed disturbance was observed in either 1991 or 1992. The trough, or thalweg, of one site (TR 12) was clearly deepened in 1991, but we believe this was due to the cobble there being unconsolidated alluvium deposited on the bed from the steep bank above it where loose cobble continues to slough into the channel. Only in 1993, with a peak flow of 25,900 cfs, was the bed disturbed sufficiently to cause widespread mobilization of cobble and gravel.

As mentioned before, several variables interact to determine degree of scour or fill in a given year at a given site: magnitude and duration of the high flow, the amount and timing of sediment transported into the system that year, and prior history of scour and fill events, i.e., degree of consolidation of bed materials, extent of vegetation encroachment, etc. The magnitude of the peak flow, therefore, is not the only determining factor. Timing of sediment input from contributing watersheds is largely beyond control. However, if high flow events could occur with proper frequency and very low-flow spring discharges prevented, fine sediment storage in the river can be reduced, and also, vegetation encroachment can be held in check. The history or sequence of flow events is important: though 1987 and 1991 had very similar annual peak flows (12,953 and 12,900 cfs), the amount of fine sediment present and the extent of vegetation encroachment was much less during 1987 (Osmundson personal observation). This was because 1987 followed four years of extremely high flows (Appendix Fig. I) that left the reach remarkably free of fine sediment; 1991, on the other hand, followed three years of very low spring flows during which time a large amount of fine sediments accumulated in the reach.

Other Geomorphology Studies

Van Steeter and Pitlick (1994) reported on preliminary results from a study they are currently conducting in the Grand Valley portion of the Colorado River, including the 15-mile reach. A Geographic Information System (GIS) was used to analyze pairs of aerial photograph sets shot at similar discharges. With these they compared attributes of channel morphology between early and later dates. Also, they used hydraulic modeling to determine threshold flows needed to mobilize the channel bed at one site in the 18-mile reach (downstream of the 15-mile reach).

Photo sets from 1937 and 1986 were compared as were those from 1954 and 1968. They reported that between 1954 and 1968 total water surface area of side channels and backwaters in the Grand Valley decreased by 27% and between 1937 and 1986 it had decreased by 18%. Van Steeter and Pitlick provided tables in their report that show the amount of area present on each date for each river mile. They also provided graphs that show by river mile the amount of gain or loss of area from the earlier date to the later date. We partitioned their data to examine change in the 15-mile reach alone and found that 49% of side channels and backwater area was lost between 1954 and 1968, and 33% was lost between 1936 and 1986. How much of this change in morphology is attributable to attenuation of flows and how much is due to bank stabilization by landowners has not yet been determined. Clearly, a significant amount of channel complexity and habitat has been lost since the early part of the century.

At one site in the 18-mile reach, Van Steeter and Pitlick (1994) made a series of field measurements needed to provide the data for hydraulic modeling and estimation of coarse sediment (cobble and gravel) transport under a range of flow conditions. They reported a threshold for initial motion of coarse bed material occurs at a discharge of about 21,180 cfs at this site. Significant motion of materials, or general movement of the bed, occurs at a discharge of 40,600 cfs. Such large-scale movement of the bed is necessary for periodic bar-building, chute-cutting, and general reconfiguring of the channel so as to maintain complexity of habitats. In 1994, a congregation of spawning squawfish was found in the 18-mile reach at a newly formed bar at the base of a side channel that did not exist prior to the high spring flows of 1993 (USFWS unpublished data). The cobble at this site was exceedingly loose with interstitial voids extending down to depths as much as three cobble diameters (Bliesner and Lamarra 1995). In the Grand Valley, such clean sites, obviously attractive to spawning squawfish, may only be available in years following recent movement and cleansing of bed materials. In other years, squawfish may be compelled to spawn in areas with less than optimum substrate conditions. This might explain, in part, year-to-year variation in reproductive success rates reported for the Colorado River (see Haynes et al. 1984, Osmundson and Kaeding 1989, McAda and Kaeding 1989, Osmundson and Kaeding 1991, McAda et al. 1994).

Revisiting the earlier July Recommendations

Preliminary recommendations for the 15-mile reach defined the summer period as July, August and September. Kaeding and Osmundson (1989) based their summer flow recommendations on a combination of PHABSIM output, aimed at maximizing optimal, adult-squawfish microhabitat, and a temperature model aimed at artificially boosting July water temperatures to promote growth and survival of larval and young-of-the-year squawfish.

The July flow recommendation of Kaeding and Osmundson (1989) was novel in that it proposed an enormous reduction in flow during this month to encourage earlier spawning of squawfish. The rationale was to increase the length of the first growing season. The mean July flow at the top of the 15-mile reach during the historic period (1902-1937) was 7,212 cfs; during the recent period (1954-1989), July flows have averaged 4,341 cfs, a decline of 40% (Osmundson and Kaeding 1991). Kaeding and Osmundson (1989) recommended July flows of 700-1200 cfs. Implementation of such a recommendation would result in a 83-90% reduction from historic levels and a 72-84% reduction from recent levels.

The magnitude of July flows have always provided a transition from the highs of spring to the base flow of late summer and winter. When the earlier summer flow recommendations were made, recommendations for spring flows had not yet been developed. Recommendations for spring and winter were later provided under separate cover. When now viewed in the context of the entire water year, we can see that the earlier summer flow recommendations would result in the elimination of the transitional period from the spring highs to base flow. Assuming full regulation of the river and implementation of the recommendations, spring flows during June, the month of highest annual flow, would drop precipitously to a base flow in July. One wonders how such an abrupt decline in flow would effect squawfish spawning, which typically occurs in July, as well as other aspects of the river ecosystem. Stranding of benthic invertebrates and disruption of riverine food webs could have a negative impact on the native fish community (Stanford 1994).

Implementing a flow regime that eliminates the transitional, gradual ramping down of the hydrograph is risky in that we have no knowledge of what negative effects it may have on aquatic organisms long adapted to a more naturally shaped hydrograph. Therefore the case for low flows during July must be a strong one to justify taking this risk.

Now that several years have passed and additional data have been collected it is appropriate to take an adaptive management approach to this question and now reevaluate the July recommendation. Kaeding and Osmundson (1989) presented a convincing argument with supportive data that higher temperatures and a longer growing season would result in greater first-year growth of Colorado squawfish. The relationship between degree days and total length of age-O squawfish in the fall makes sense and is borne out by empirical data presented in their report as well as additional data subsequently collected (USFWS unpublished data). Kaeding and Osmundson took this observed relationship and hypothesized that greater growth would result in increased first-year survival. They based the July flow recommendation on this hypothesis.

Although the growth-vs-survival hypothesis is logical and intuitively appealing, it has not been borne out by subsequent studies. Kaeding and Osmundson (1988) described two ways in which first year survival would be enhanced by higher temperatures and advancing the date at which spawning occurs :

1) Higher summer temperatures result in young squawfish growing faster; leaving them vulnerable to predation (when small) for a shorter period of time.
2) Extending the first-year growing season by advancing the spawning date increases the length of time young-of-the-year squawfish may grow before the onset of winter. Studies of other fish have indicated that over-winter mortality is related to fish size, i.e., if the fish is too small going into winter its energy stores will be insufficient to sustain itself until spring.

A case can be made for reducing exposure to predation by enhancing growth rate. Lower flows in the summer would promote higher temperatures leading to higher feeding rates and probably growth rates. The problem, however, is that if feeding rates are increased for squawfish they likely are also increased for other warm-water, predacious fish that may prey on squawfish. The same can be said for extension of the growing season by advancing the spawning date. Although young may grow more in a given year, they may be exposed to more intense and prolonged predation pressures during that time.

The primary objective of extending the first-year growing season was for the young to enter their first winter at a larger size. Kaeding and Osmundson (1988) recommended, "Investigations should be conducted to determine the relation between size of age-0 squawfish and over-winter survival. If an important relation occurs, it would provide useful objectives for possible growth-enhancement efforts." Since the time of their recommendation, two such studies have been completed. The first was a laboratory study by Thompson et al. (1991) in which they held age-O squawfish of various lengths in aquaria with simulated winter temperatures. One group was fed while another was starved. All large fish (44 mm long), whether fed or starved, survived the 210-d winter period. Survival of small (30 mm long) and medium (36 mm long) sized fish was determined by whether they were allowed to feed or not. For small fish, mortality by day 210 was 97% for those starved while only 5% for those allowed to feed. For medium sized fish, mortality was 93% for those starved and only 2% for those fed.

Thus, the need for squawfish to reach a certain size by late fall in order to make it through the winter is only important if squawfish do not feed during winter but rather rely entirely on fat reserves accumulated prior to winter. However, Thompson et al. (1991) found that under laboratory conditions age-0 squawfish do indeed feed at temperatures of 3-5 C. In addition, Osmundson and Kaeding (1989b) found zooplankton and chironomid larvae in the stomachs of 60% of the fingerling squawfish (n = 22) sampled from a pond in mid-December when water temperature was 3 C. Thus, evidence indicates that squawfish, though ceasing to grow during winter, do not cease to feed. Therefore, size going into winter is probably not a critical factor in their ability to survive.

A field study conducted by Valdez and Cowdell (1994) on the lower Colorado River (RM 0-50) compared catch rates of age-O fish in fall with those in early spring of the following year. This was an attempt to measure the significance of over-winter mortality. Although Valdez and Cowdel acknowledged that downstream transport of age-O fish and use of different habitats may account for some of the difference in catch rates between fall and spring, they felt that a large portion of the measured decrease in catch rates was due to over-winter mortality. If this is indeed the case, then their data provide an excellent opportunity to look for a relationship between length in fall and over-winter survival. Mean length of age-O squawfish when collected in fall ranged from 32 mm to 44 mm total length (Table 6). Using mean total length in fall as the independent variable and percent survival as the dependent variable, least square regression resulted in $r^2 = .02$. Two of the years had higher catch rates in the spring than in the preceding fall. When these are excluded from the analysis, r^2 increased to .04. In either case, length going into winter appears to have no relationship to over-winter survival.

One other piece of evidence concerning this question is the recent identification of a strong year class hatched in 1985 or 1986 in the Colorado River and now entering the adult population (McAda et al. 1994, USFWS unpublished). Both 1985 and 1986 were years in which squawfish spawning occurred late in the summer and mean length of young-of-the-year in fall was quite small: 28 and 26 mm TL, respectively (McAda in prep). The fact that this is the largest cohort produced in the Colorado River during the past 10 years despite the small size of the fish when entering their first winter further brings into question the importance of the length of the first growing season.

Considering the results of the studies conducted since Kaeding and Osmundson's preliminary flow recommendations were made, the case for extending the first-year growing season to maximize length of age-O squawfish going into winter appears to be weak. Results from both lab and field studies, though perhaps not definitive, do not support the earlier hypothesis. The risk in implementing such a drastically reduced July flow regime based on this hypothesis cannot be justified at this time. We therefore reject the earlier recommendation for ramping down spring flows to a base of 700-1200 cfs by July. July flows should instead be such that a naturally shaped hydrograph is retained. Flows during July should gradually decline to provide a transition period between the spring high in June and base flow beginning in August.

Table 6. Catch rates of young-of-the-year Colorado squawfish from the lower Colorado River (RM 0-50) during fall and spring, 1987-1994. Data from Valdez and Cowdell (1994).

Winter	Fall CPE	Spring CPE	Spring/Fall	Fall Mean TL
1987-88	1.24	0.45	0.363	44
1988-89	2.64	4.92	1.864	42
1989-90	2.07	0.42	0.203	40
1990-91	2.86	0.63	0.220	44
1991-92	2.30	1.44	0.626	44
1992-93	0.84	0.92	1.095	34
1993-94	2.97	0.53	0.177	32

Colorado squawfish spawning often occurs between early and late July in the upper Colorado River. Although there may be some optimum flow level in July that would facilitate spawning success, researchers have yet to determine precisely what that is. Likely it varies temporally and according to site specific characteristics. Harvey et al. (1993) concluded that recessional flows of 400-5,000 cfs were required to dissect, erode and thereby cleanse squawfish spawning bars in the Yampa River, a smaller river than the Colorado in the 15-mile reach. Until there is a more precise understanding of the relationship between July flows and squawfish spawning success, the most prudent recommendation is to provide sufficient flows in July that allow the shape of the natural hydrograph to be maintained. In this report we include July as one of the spring months.

Recommendations for Spring Flows *(Objective No. 4)*

Osmundson and Kaeding (1991) calculated the flow required to come down the 15-mile reach that, combined with Gunnison River flows, would provide various flow levels at the State Line USGS gage. In developing 15-mile reach recommendations, they targeted certain flow levels needed at the State Line and then worked backward to arrive at appropriate flows in the 15-mile reach. To develop recommendations for the 15-mile reach specifically, regardless of downstream needs, we reexamined the earlier recommendations in light of the new information.

Osmundson and Kaeding (1991) recommended a spring peak flow of >40,000 cfs at the State Line gage to occur at a frequency of one in four years to 1) inundate bottomlands for razorback sucker reproduction, 2) flush otherwise protected habitats of undesirable non-native fish, and 3) maintain complex habitats for adult Colorado squawfish and backwaters for young. Preliminary results from Van Steeter and Pitlick (1994) indicate that 40,600 cfs is the threshold flow needed for general motion of the bed, capable of winnowing out fine sediment. Osmundson and Kaeding (1991) calculated that 40,000 cfs would equate to a flow of 23,500 cfs from the 15-mile reach, and recommended that peak flows in the 15-mile reach should exceed 23,500 cfs at a rate of one in four years. We now know with data presented here that a peak flow of 25,900 cfs was capable of producing widespread movement of the bed in the 15-mile reach and suspect that the recommended peak of 23,500 would also have been capable of this. Results from hydraulic modeling in the 15-mile reach, not yet completed by Van Steeter and Pitlick, will be needed to confirm this.

Osmundson and Kaeding (1991) also recommended a minimum peak flow of 22,000 cfs at the state line, and a range of peak flows between this minimum and 30,000 cfs should occur with a frequency of no more than two in four years. We now know from Van Steeter and Pitlick's hydraulic modeling that flows less than 21,180 cfs (measured at the State Line gage) are below the threshold for limited motion of the bed to begin (at their 18-mile reach site). Thus, in our view, 22,000 cfs was a good estimate of a minimum flow for the 18-mile reach. Osmundson and Kaeding (1991) calculated that this would require about 14,800 cfs from the 15-mile reach. Again, looking at the needs of the 15-mile reach in isolation, we presently do not know the threshold flow needed for initial motion of coarse bed materials, but we do know, based on our studies, that a peak flow of 12,900 cfs in 1991 was successful at flushing fine sediment from many low-velocity sites. With or without limited disturbance of coarse materials on an annual basis, it is important that sediment from low-velocity sites, particularly backwaters, be flushed each year. We can therefore recommend adjusting the minimum peak flow in the 15-mile reach down from 14,800 cfs to 12,900 cfs. Until other information comes forward, the rest of the earlier recommendations for peak flows should be maintained; justification for these is elaborated on in the earlier report (Appendix IX).

The following are our recommendations for peak flows in the 15-mile reach:

1) >23,500 cfs in at least five of every 20 years (highest 25% water years)
2) 20,500-23,500 cfs for those above average years with peaks <23,000 cfs (25%)
3) 12,900-20,500 cfs to occur with a frequency of no more than 10 of 20 years (50%), - for these below average years, the minimum peak of 12,900 cfs should occur in no more than 4 of every 20 years, i.e., the lowest 20% of water years

For convenience, these ranges can be simplified to single numbers by taking the mid-point between the low and high end of each range, or by taking the mean of all the peaks within a range that have occurred during the period of record. At the low and high ends of the recommendations there is not a range but rather a minimum high (23,500 cfs) and a minimum low peak (12,900 cfs). Note that '>23,500 cfs' is an open-ended recommendation, i.e., 23,500 cfs is a minimum, and peaks well in excess of this are also considered beneficial. Because the minimum peak (12,900 cfs) is just that, the minimum, it can be used as the single target flow. Thus, we recommend the following target peak flows:

1) ≥23,500 cfs (5 in 20 years)
2) 21,750 cfs (5 in 20 years)
3) 16,700 cfs (6 in 20 years)
4) 12,900 cfs (4 in 20 years)

The frequency recommended for each magnitude of peak flow is based on how rapidly ecological change occurs in the river in the absence of sufficient flows, and is designed to assure that strong year classes of the endangered fish are produced relatively frequently. The highest recommended flows are needed to cleanse within-channel substrate regularly, to maintain the dynamic nature of channel configuration, and to make inundated floodplain habitat available for razorback sucker spawning and nursery needs such that year classes may be successfully produced in at least one in four years. Years when peak flows were between 20,500-23,500 cfs in the 15-mile reach have in the past resulted in strong year classes of Colorado squawfish; successful reproduction of squawfish should occur at least once every four years to assure continued maintenance of the population. The remaining 50% of the years need to be sufficiently high to prevent tamarisk seedlings from becoming too well established and to keep numbers of non-native fish in check. These benefits will probably not be realized during the 20% driest years, but a minimum peak of 12,900 cfs then will guarantee that depth of important low-velocity habitats will be maintained in all years.

Recommendations for flows have, until now, been provided as monthly averages, and have been interpreted as one discharge level for an entire month. Although this is reasonable for base flow conditions when flows are relatively constant for several months at a time, it is not practical during the spring runoff period when flow levels undergo rapid change. During spring, flows rise in April and May, generally reach a peak in late May or early-to-mid June, and then decline rapidly through July to a base flow sometime in August. Earlier recommendations intended that a mean discharge for a given spring month was just that, a mean or average, and was not meant to be interpreted or implemented as a constant, uniform flow for the entire month. It was assumed that natural weather patterns would determine how snow melt occurs and thus the amount of water delivered on individual days would increase or decrease throughout a given month and would always vary among years. So long as a block of water was reserved and made available for this purpose (total acre feet for a given month can be calculated from the recommended mean discharge), it was intended that naturally occurring weather patterns would determine the spread of water over the course of the month.

However, since the earlier recommendations were made it has become apparent that there are some technical and institutional constraints in implementing the spring recommendations on a mean monthly basis as outlined above (Randy Seaholm, Colorado Water Conservation Board). For best results, recommendations should be made for the shortest time step possible. Ideally, a different recommendation would be provided for each day of the spring runoff period. This would reduce ambiguity, make implementation of the recommendations more straight forward, and provide a smoother ascent and descent of the hydrograph. However, this approach remains impractical. Currently, the annual shape of the hydrograph is not predictable for the reasons given above concerning variation in annual snow-melt conditions. To provide a specified amount of water on a specified day would require complete regulation of the river. Thus, in providing recommendations, tradeoffs must be made between ease of implementation associated with a rigid, short time step and the need to accommodate natural variation in annual snow-melt patterns which a broader time step would allow.

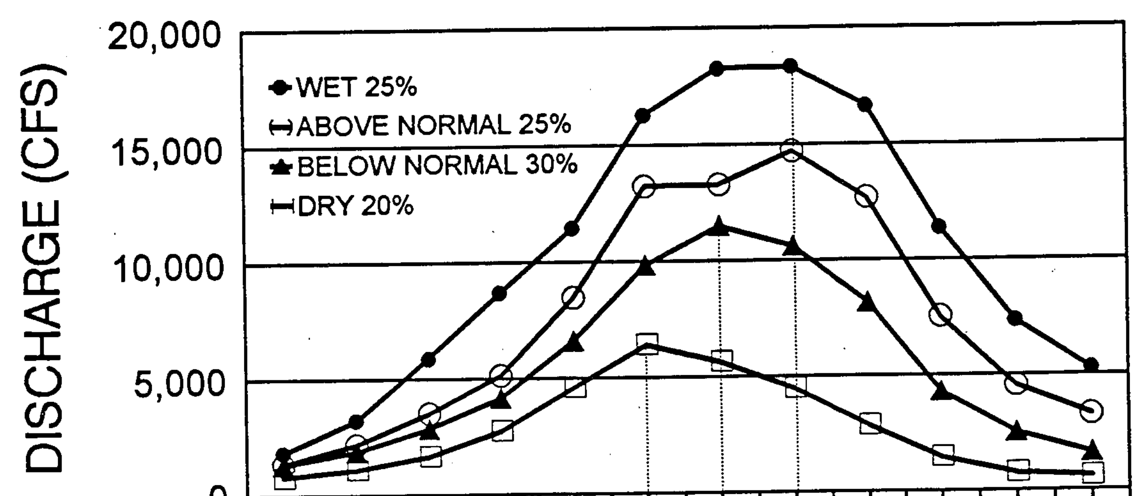
By April 1 of each year there should be enough snowpack data available for water managers to determine whether it will be a high, medium, or low runoff year. Once such a judgement is made, the set of spring recommendations applicable to that type of water year can begin to be implemented. A reevaluation might be made on April 15 or May 1 in years with a wet spring. Over the period of record, there are patterns that emerge that can help predict the general shape of the hydrograph and narrow the period in which the peak day can be expected, once the amount of snowpack is known. For instance, peak flow often occurs in late May during dry years and in mid-June during wet years. Using this information, we felt that each spring month could be broken into three time steps (10 days each for April and June; 10.3 days each for May and July) and that there would be a reasonably good likelihood of the peak day falling within the 10-day period in which the most water was recommended. The methodology that we employed for arriving at the flow recommendations for the 10-day time periods is described below.

We first determined the average shape of the hydrograph for years with similar levels of precipitation. This shape would then be used as a guide for apportioning spring runoff water among 12 time steps (3 10-d periods x 4 months) so that the recommendations would duplicate the expected runoff pattern as close as possible. The first step in this process was to determine the flows in the 15-mile reach during each 10-day time step over an extended period of years. The gage and period of record used was the USGS gage at Cameo for the years 1934-1990. This was the closest upstream gage to the 15-mile reach that had continuous daily records available for an extended period. Mean monthly data for the 15-mile reach for 1897-1989 have been previously pieced together by Osmundson and Kaeding (1991), but much of that data were available only as monthly averages, and not daily averages. For the present exercise, daily averages were required so that averages for the 10-day time steps could be determined. Once the 10-day, Cameo averages were calculated for each year, mean monthly Plateau Creek additions, Government Highline and Grand

Valley canal withdrawals, and Orchard Mesa Power return flows were factored in to arrive at 10-day averages for the top of the 15-mile reach for each year.

The second task was to divide the 1934-1990 period of record into categories according to precipitation level. The actual flows at Cameo are not the best indicator of annual precipitation levels because the percent of water stored upstream, which affects flows at Cameo, is not consistent from year to year (the amount stored is often dictated more by current reservoir levels than by current snow pack levels). To rank years according to winter precipitation, we used a data set provided by the Water Resources Division of the Bureau of Reclamation that gives calculated, mean-monthly, virgin flows at Cameo, i.e., flow levels that would have occurred in the absence of diversions and reservoir storage. We summed the monthly volumes of water for the months of April, May, June and July and then ranked the years from wettest to driest, accordingly. The 50% above-average years were subdivided into wet and very wet groups (25 and 25% of total years), and the 50% below-average years into dry (30%) and very dry (20%) groups.

The third step was to place, by year, the 15-mile-reach, 10-day averages into one of the four precipitation-level groups. For each group of years, we calculated the mean volume of water for each 10-day period and the mean total amount for the April-July period. The percent that each of these 10-day-period averages contributed to the average total amount was then determined. For instance, for the 15 wettest years (25% of 57 years) we divided the mean volume of water delivered in the first 10-day period of April, 35,923 acre ft (or an average discharge of 1,811 cfs; see Fig. 25), by the mean volume of total water delivered during the April 1- July 31 period



	APR 1	APR 2	APR 3	MAY 1	MAY 2	MAY 3	JUN 1	JUN 2	JUN 3	JUL 1	JUL 2	JUL 3
WET 25%	1,811	3,217	5,879	8,694	11,463	16,276	18,266	18,332	16,647	11,391	7,345	5,279
ABOVE NORMAL 25%	1,327	2,162	3,489	5,131	8,447	13,227	13,302	14,727	12,695	7,516	4,542	3,284
BELOW NORMAL 30%	1,320	1,866	2,843	4,153	6,578	9,833	11,504	10,615	8,147	4,295	2,509	1,612
DRY 20%	777	1,088	1,649	2,741	4,573	6,407	5,647	4,458	2,835	1,446	755	595

Figure 25. Average hydrographs for the 15-mile reach for four precipitation-level categories. Data are from the 1934-1990 period of record. Percent amount in each 10-day period is used to calculate flow recommendations based on target peak flows (see text). Values shown are the average discharges of each 10-day period for the group of years falling within the respective precipitation category. Dotted lines indicate in which 10-day period the peak day is most likely to occur.

(2,511,366 acre ft). Thus, for a year of relatively high winter precipitation, we can expect an average of 1.43% of the total water arriving at the top of the 15-mile reach, during the April-July runoff period, to come during the first 10 days of April. These percents were calculated for each of the twelve 10-day periods for each of the four precipitation categories. Together, these percents provided the shapes of the average hydrographs for wet years, dry years, etc. (Fig. 25).

We next determined the overall amount of spring runoff that occurs in years that have produced the target peak flows in the 15-mile reach and then apportioned the total among the twelve time steps using the calculated percents for each as described above. Using the 1902-1993 period of record for the 15-mile reach (Osmundson and Kaeding 1991), groups were compiled of years in which the peak flow was within the target peak flow range. There were four such groups for the four ranges of target peak flows (Table 7). The mean monthly flows were then converted from rates (cfs) to total monthly volume (acre ft); the April, May, June and July volumes were then summed for each year. For each of the peak flow groups, the mean total volume was calculated. We considered this the average volume needed to provide a natural spring hydrograph capable of producing the target peak flow and lesser, elevated flows of a natural duration. This mean total volume was then apportioned to each of the twelve 10-day time steps by multiplying by the percents calculated for each time step. Continuing on with the previous example, a hydrograph with a target peak flow of about 23,500 cfs would require an average volume of water during April-July of 2,216,293 acre ft. (Table 7); multiplying this value by 0.0143 (1.43%) gives the portion of this total needed in the first 10-day period of April (31,693 acre ft.). This can then be converted to a rate if so desired, i.e., an average discharge of 1,598 cfs for the first 10-day time step. This procedure was repeated for each time step. Recommendations for all time steps for each of the other three target peak flow levels were similarly calculated (Fig. 26). However, to avoid the interpretation that a constant discharge for each 10-day time step is desired, the recommendations for the spring time steps are best reported as volumes (acre ft). Otherwise, the average discharge in cfs is likely to be implemented as a minimum flow above which no protection is afforded. Recommended volumes assure creation and protection of the targeted peak flow, which is necessarily higher than the mean of the highest 10-day time step. Thus, while recommendations for summer and winter which are intended to be constant, or instantaneous, may be reported as a rate, spring recommendations, which are intended to vary daily, are reported here as volumes provided over extended periods of time.

Table 7. Peak flow and mean monthly flow at the top of the 15-mile reach during years in which peak flows approximated the recommended peak flows.

YEARS WITH PEAK FLOWS OF 22,300-24,200 CFS

YEAR	PEAK	APR CFS	APR ACRE FT	MAY CFS	MAY ACRE FT	JUN CFS	JUN ACRE FT	JUL CFS	JUL ACRE FT	SUM ACRE FT
1986	22,742	6,234	370,954	12,468	766,639	16,660	991,353	7,036	432,633	2,561,579
1973	23,900	1,089	64,801	9,141	562,066	13,711	815,873	7,787	478,811	1,921,551
1970	22,640	1,599	95,148	13,274	816,198	13,004	773,803	4,393	270,119	1,955,269
1962	24,090	7,946	472,827	13,708	842,884	13,998	832,951	7,409	455,568	2,604,230
1953	22,356	1,286	122,104	4,685	790,988	13,850	970,824	3,141	640,280	1,381,877
1947	24,138	2,052	154,832	12,864	749,545	16,315	1,149,637	10,413	511,338	2,524,196
1911	24,200	2,602	76,523	12,190	288,074	19,320	824,144	8,316	193,135	2,565,352
MEAN	23,438									2,216,293
SE	309									178,460

YEARS WITH PEAK FLOWS OF 20,500-23,000 CFS

YEAR	PEAK	APRIL CFS	APRIL ACRE FT	MAY CFS	MAY ACRE FT	JUNE CFS	JUNE ACRE FT	JULY CFS	JULY ACRE FT	SUM ACRE FT
1986	22,742	6,234	370,954	12,468	766,639	16,660	991,353	7,036	432,633	2,561,579
1979	20,690	2,000	119,010	9,039	555,795	14,313	851,695	6,989	429,743	1,956,243
1970	22,640	1,599	95,148	13,274	816,198	13,004	773,803	4,393	270,119	1,955,269
1965	21,380	1,786	106,276	6,796	417,876	14,575	867,285	8,468	520,685	1,912,122
1953	22,356	1,286	76,523	4,685	288,074	13,850	624,144	3,303	203,097	1,391,838
1951	21,040	1,469	87,413	7,680	472,232	13,174	783,919	6,164	379,015	1,722,579
1919	20,850	4,350	258,847	12,850	790,127	9,083	540,484	3,423	210,475	1,799,933
MEAN	21,671									1,899,937
SE	334									133,075

YEARS WITH PEAK FLOWS OF 12,900-20,500 CFS

YEAR	PEAK	APRIL CFS	APRIL ACRE FT	MAY CFS	MAY ACRE FT	JUNE CFS	JUNE ACRE FT	JULY CFS	JULY ACRE FT	SUM ACRE FT
1991	12,900	1,148	68,312	5,059	311,070	8,488	505,078	2,168	133,307	1,017,768
1987	12,953	3,039	180,836	7,847	482,500	6,668	396,779	1,768	108,712	1,168,827
1980	19,740	2,297	136,883	9,623	591,704	14,119	840,151	3,883	238,760	1,807,298
1978	18,242	1,933	115,023	5,950	365,857	13,075	778,028	4,273	262,740	1,521,648
1975	16,195	1,616	96,160	5,435	334,190	11,645	692,936	7,707	473,892	1,597,178
1974	14,495	2,203	131,090	10,492	645,137	9,664	575,056	3,126	192,213	1,543,496
1972	14,520	1,935	115,142	5,144	316,297	9,786	582,316	2,009	123,530	1,137,285
1971	17,007	4,113	244,744	7,535	463,316	13,846	823,906	5,810	357,248	1,889,214
1968	17,100	1,207	71,823	4,276	262,925	11,635	692,341	2,657	163,375	1,190,463
1964	13,390	778	46,295	5,690	349,870	6,483	385,771	2,080	127,896	909,831
1960	14,592	3,246	193,153	6,109	375,633	9,941	591,539	1,967	120,948	1,281,274
1959	14,232	982	58,434	5,319	327,057	10,104	601,239	1,912	117,568	1,104,296
1956	18,583	2,101	125,020	10,145	623,801	9,326	554,944	1,287	79,136	1,382,900
1945	16,592	971	57,779	9,343	574,487	12,585	746,870	6,610	406,439	1,787,576
1944	18,410	974	57,958	8,912	547,986	14,483	861,811	4,641	285,368	1,753,122
1943	20,406	3,146	187,203	7,328	450,588	14,475	861,335	4,798	295,022	1,794,147
1940	14,320	1,420	84,497	12,860	790,742	7,512	447,002	1,146	70,466	1,392,707
1939	18,189	2,610	155,308	12,860	790,742	9,662	574,937	1,605	98,689	1,619,677
1937	19,360	1,600	95,208	11,520	708,348	8,647	514,540	3,495	214,902	1,532,998
1934	13,538	2,277	135,493	8,983	552,351	2,829	168,340	0	0	856,184
1931	14,600	1,121	66,705	5,033	309,472	8,593	511,326	1,529	94,016	981,519
1925	18,050	4,429	263,548	10,480	644,399	12,230	727,746	5,396	331,792	1,967,485
1915	19,900	2,998	178,396	7,072	434,847	15,220	905,666	6,881	423,102	1,942,011
1913	20,250	4,802	285,743	12,740	783,363	12,550	746,788	4,676	287,520	2,103,414
1908	19,700	3,448	205,173	6,173	379,569	13,970	831,285	5,423	333,452	1,749,479
1902	17,450	1,248	74,262	11,640	715,726	8,046	478,777	1,949	119,841	1,388,607
MEAN	16,720									1,477,708
SE	489									69,913

YEARS WITH PEAK FLOWS OF 11,900-13,500 CFS

YEAR	PEAK	APRIL CFS	APRIL ACRE FT	MAY CFS	MAY ACRE FT	JUNE CFS	JUNE ACRE FT	JULY CFS	JULY ACRE FT	SUM ACRE FT
1991	12,900	1,148	68,312	5,059	311,070	8,488	505,078	2,168	133,307	1,017,768
1987	12,953	3,039	180,836	7,847	482,500	6,668	396,779	1,768	108,712	1,168,827
1969	11,876	3,280	195,176	8,107	498,487	7,396	440,099	4,289	263,724	1,397,487
1967	12,530	1,237	73,608	4,075	250,566	7,779	462,889	3,188	196,025	983,088
1964	13,390	778	46,295	5,690	349,870	6,483	385,771	2,080	127,896	909,831
1934	13,538	2,277	135,493	8,983	552,351	2,829	168,340	0	0	856,184
MEAN	12,865									1,055,531
SE	247									81,120

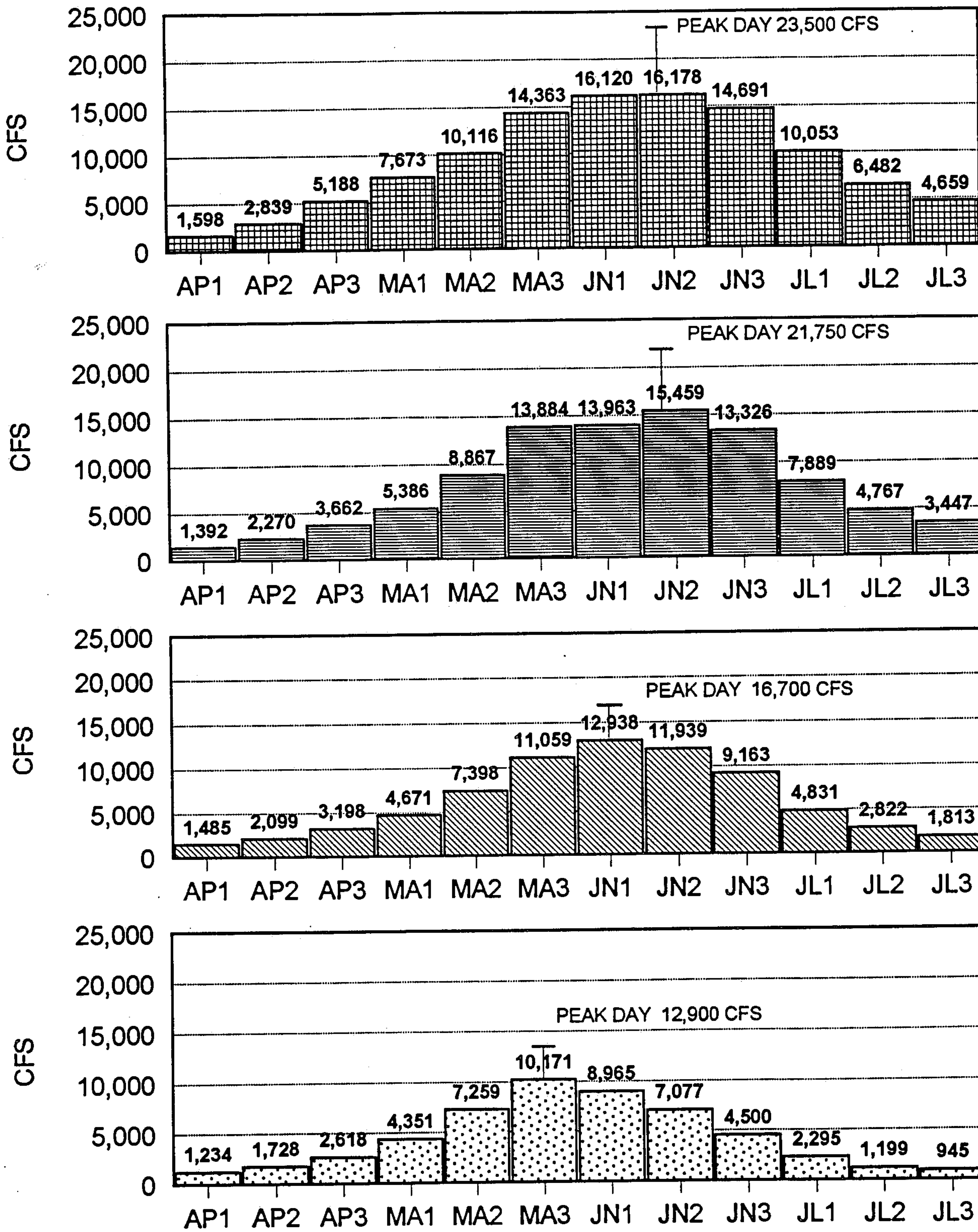


Figure 26. Average discharge for each 10-day period in hydrographs recommended for the spring months of April, May, June and July in the 15-mile reach. April and June are subdivided into three 10-day periods; May and July are subdivided into three 10.3-day periods (see text for explanation of calculations). Recommended magnitudes of annual peak days (average of 24-hr period on highest day of the year) are also shown.

SUMMARY OF YEAR-ROUND RECOMMENDATIONS

Year-round recommendations provided in this report are summarized in Table 8 on a mean monthly discharge basis. Spring (April-July) recommendations are further subdivided into 10-day increments and are reported in volumes of water needed for each of twelve 10-day time periods (Table 9). Variation in precipitation levels from year to year is taken into account and recommendations are provided for years of high, above-average, below-average, and low snow fall. With the exception of winter, recommendations are for flows considerably lower than historic levels but somewhat higher than recent levels (Fig. 27).

We utilized methodologies that relied on data specific to the 15-mile reach. This included data on adult Colorado squawfish habitat preferences, stage vs. habitat quantity and quality relationships, and discharge thresholds for sediment transport. Methodologies used here for developing the summer and winter recommendations take habitat needs and preferences into account in a more direct way than did the earlier recommendations. Earlier July recommendations were based on a hypothesis that a significant reduction in July flows would result in greater over-winter survival via an extended first-year growing season. Results from subsequent studies failed to bear this relationship out. Factors that went into developing the earlier spring recommendations are still considered valid and were retained as the basis for recommendations in this report. Here we provide information regarding flow needs for habitat maintenance and cleansing of coarse substrate that was lacking in the previous report.

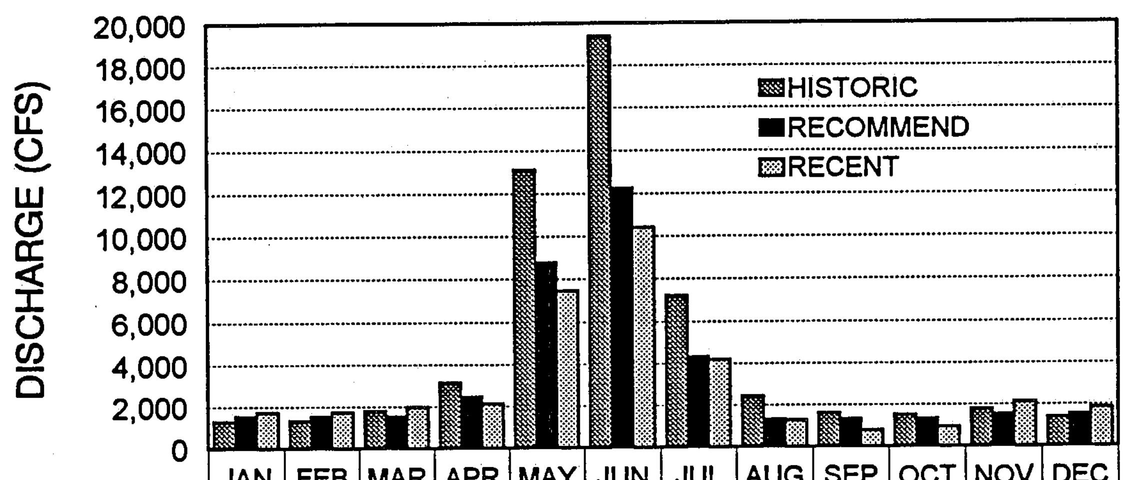
This report represents another evolutionary step in the development of flow recommendations for the 15-mile reach. We have refined the recommendations through a combination of replacing some methodologies with new ones, filling in information gaps with the collection of new data and incorporating results from studies conducted by other researchers. As additional studies are completed, our knowledge of the relationship between discharge and fish habitat will continue to evolve and recommendations will no doubt continue to be refined. For now, we are satisfied that the recommendations provided here are an improvement over those provided earlier and feel strongly that timely implementation of these recommendations will make a significant contribution to the recovery of endangered Colorado River fish.

Table 8. Recommended mean monthly flows for the top of the 15-mile reach in cubic ft/sec. Rate is 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 15,660 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 6,850 cfs, and such a minimum should occur at a rate of no more than 4 in 20 years (20%).

Rate	Exceedance	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
25%	25%	1,630	1,630	1,630	3,210	10,720	15,660	7,060	1,630	1,630	1,630	1,630	1,630
25%	50%	1,630	1,630	1,630	2,440	9,380	14,250	5,370	1,630	1,630	1,630	1,630	1,630
30%	80%	1,630	1,630	1,630	2,260	7,710	11,350	3,150	1,240	1,240	1,240	1,630	1,630
20%	100%	1,240	1,240	1,240	1,860	7,260	6,850	1,480	810	810	810	1,240	1,240

Table 9. Volumes of water (in hundreds of acre ft) needed per 10-day period to produce hydrographs recommended for the 15-mile reach during the spring runoff period (April, May, June and July). AP-1 represents the first 10 days in April; AP-2, the second 10 days, etc.

Rate	Exceedance	AP-1	AP-2	AP-3	MA-1	MA-2	MA-3	JN-1	JN-2	JN-3	JL-1	JL-2	JL-3
25%	25%	317	563	1,029	1,573	2,073	2,944	3,197	3,209	2,914	2,060	1,328	955
25%	50%	276	450	726	1,104	1,817	2,846	2,770	3,066	2,643	1,617	977	707
30%	80%	295	416	634	957	1,516	2,267	2,566	2,368	1,818	990	578	372
20%	100%	245	343	519	892	1,488	2,085	1,778	1,404	893	470	246	194



	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
HISTORIC	1,322	1,346	1,786	3,145	13,091	19,379	7,212	2,446	1,609	1,522	1,789	1,414
RECOMMEND	1,552	1,552	1,552	2,463	8,790	12,253	4,349	1,349	1,349	1,349	1,552	1,552
RECENT	1,726	1,750	1,975	2,142	7,452	10,404	4,197	1,279	775	932	2,122	1,846

Figure 27. Recommended flows for the 15-mile reach in comparison with historic (1902-1942) and recent (1954-1993) periods. Mean monthly flows are the average for each period; for the recommended period, the recommended frequency is taken into account in calculating the long-term monthly averages.

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APPENDIX I

Life History of Colorado Squawfish in the Upper Colorado River

Colorado squawfish are piscivorous cyprinids adapted to life in the warm-water river reaches of the Colorado River Basin. Their ecological function has been that of top predator within the riverine fish community. Most are <650 mm long, though a few old individuals may exceed one meter (39 inches) in length. They are the largest of the native fish and are capable of consuming relatively large prey.

As high spring flows taper off in early summer, adult squawfish migrate to discrete spawning sites where clusters of squawfish congregate, or stage. There they wait for the onset of a suite of favorable environmental conditions before initiating the spawning act. McAda and Kaeding (1991) suggest that in the upper Colorado River spawning areas are widely distributed and that seasonal movements by squawfish to these areas are relatively short. In the upper 60 miles of occupied habitat, 27 adults monitored during the spawning seasons of 1982-1985 moved an average of 13 miles (range = 1-37 mi) one way during the spawning season; at the end of the season, most returned to sites near their initial point of capture (McAda and Kaeding 1991). The spawning season, including the period of migrations, always occurs during summer; however, the dates of actual spawning vary widely among years and may be as early as late June or as late as early September depending on river conditions (McAda and Kaeding 1991; Osmundson and Kaeding 1989; Anderson 1994). In the upper reaches, spawning begins when water levels decrease to 15-30% of the maximum discharge for the year and main-channel temperatures warm to 18-22 C (McAda and Kaeding 1991). In general, the later the runoff period lasts, the longer spawning is delayed.

Known spawning sites in the Yampa River are characterized by riffles or shallow runs with well-washed coarse substrate (cobble) containing relatively deep interstitial voids (for egg deposition) in association with deep pools or areas of slow laminar flow used as staging areas by adults (Lamarra et al. 1985; Tyus 1990). Recent investigations at a spawning site in the San Juan River by Bliesner and Lamarra (1995) and at one in the upper Colorado River (USFWS unpublished) indicate a similar association of habitats. The most unique feature at the sites actually used for spawning, in comparison with otherwise similar sites nearby, is the degree of looseness of the cobble substrate and the depth to which the rocks are devoid of fine sediments; this appears consistent at the sites in all three rivers (Lamarra 1985; Bliesner and Lamarra 1995).

About four days after deposition and fertilization, the eggs hatch (Marsh 1985). Larvae emerge from within the cobbles and immediately begin to drift with the current (Tyus 1986). In the upper Colorado River, larvae are routinely captured throughout the length of the river from the Grand Valley downstream to the confluence with the Green River either in drift nets set in the current (Anderson 1994; Trammel unpublished) or seined from low-velocity habitats along shore where drifting larvae settle out (Haynes et al. 1984; McAda and Kaeding 1991; Osmundson and Kaeding 1989). By fall, most young-of-the-year squawfish are found in the lower reaches of the upper Colorado River where a lower gradient and warmer water provide more optimal nursery habitat (McAda et al. 1994).

About seven years are required for the fish to reach sexual maturity at about 450-500 mm in length (Seethaler 1978; Hawkins 1992). As they grow, habitat requirements change. Young adults begin to move and distribute themselves about the river, presumably seeking areas with more plentiful forage fishes and sites with physical characteristics more suitable to larger fish. Most older squawfish eventually end up establishing home ranges in the upper 60 miles of river (USFWS unpublished data).

When the spawning season ends, many adults return to localized areas where they spend the remainder of the summer, referred to in this report as the 'home range'. Unpublished data collected during the Osmundson and Kaeding (1989) study provides some insight into the size of the home range. Of 12 squawfish radio tracked throughout the entire summer period, nine remained in relatively localized reaches, while three could be considered 'wanderers', moving about over a wide area (8-20 miles). Of the nine fish exhibiting an affinity to a home range, smaller adults had more restricted ranges than did larger fish: five squawfish (450-585 mm TL) moved no more than 0.3 mile on average during the post-spawning, summer period; four larger squawfish (603-679 mm TL) had home ranges averaging 3.2 miles in length. During winter, home range size is relatively small regardless of fish size: eight squawfish (468-679 mm TL) with which radio contact was maintained throughout winter moved no more than 0.35 mile on average. Also, the winter range is not necessarily included within or overlaps with the summer range: three of eight squawfish tracked throughout summer and winter exhibited affinities for winter sites 6-15 miles removed from their respective summer ranges.

Recent mark-and-recapture studies indicate the population of adult squawfish to be relatively small in the 60 miles of occupied habitat upstream of Westwater Canyon. Preliminary analyses result in an estimate of 175-350 adults (USFWS unpublished data).

APPENDIX II

Table I. List of species that have been captured in the 15-mile reach during recent years.

Native	
Colorado squawfish	*Ptychocheilus lucius*
razorback sucker	*Xyrauchen texanus*
roundtail chub	*Gila robusta*
flannelmouth sucker	*Catostomus latipinnis*
bluehead sucker	*Catostomus discobolus*
speckled dace	*Rhinichthys osculus*
Non-native	
common carp	*Cyprinus carpio*
white sucker	*Catostomus commersoni*
channel catfish	*Ictaluras punctatus*
black bullhead	*Ictalurus melas*
northern pike	*Esox lucius*
rainbow trout	*Oncorhynchus mykiss*
brown trout	*Salmo trutta*
green sunfish	*Lepomis cyanellus*
largemouth bass	*Micropterus salmoides*
smallmouth bass	*Micropterus dolomieui*
bluegill	*Lepomis macrochirus*
plains killifish	*Fundulus zebrinus*
mosquitofish	*Gambusia affinis*
red shiner	*Cyprinella lutrensis*
sand shiner	*Notropis stramineus*
fathead minnow	*Pimephales promelas*
brassy minnow	*Hybognathus hankinsoni*

APPENDIX III

Table II. Definitions of habitat types.

Gravel pits
Flooded gravel pits are artificial backwater-like habitats that are only available to riverine fish during high water. They are calm (0.0 ft/sec), protected areas; those that are relatively shallow can become substantially warmer than the main channel, and are often warmer than natural backwaters.

Backwaters
Backwaters are calm areas (0.0 ft/sec) adjacent to the river channel, and are often created when a declining water level cuts off flow at the top end of a side channel and the bottom end is filled with slack water backed up at the mouth. Mouths of backwaters are included in this category unless a distinct counter-current (eddy) is present (mouths may have slight current: 0.0-0.35 ft/sec).

Eddies
Often at the mouths of backwaters, in coves, and in steep-walled canyons, eddies form where the main current forms a distinct whirlpool or counter current with a mean velocity > 0.35 ft/sec.

Pools
Pools are calm areas in the river channel and are often deep; they lie at the base of a riffle or off to one side of the main current. Velocity rather than depth is used to distinguish pools; a mean velocity of <0.35 ft/second was arbitrarily assigned as a consistent indicator of pool rather than run or eddy habitat.

Shorelines
In some cases habitat immediately adjacent (<1.0 m) to the shore is more influenced by the shoreline than the dominant habitat type nearby. Shoreline habitats are generally shallow and of lower velocity than the adjacent river channel. Most locations near shore are classed as the adjacent habitat type.

Slow Runs
A slow run is a stretch of water with a laminar flow and a noticeable downstream current. Average mean-column velocity is >0.35 ft/sec and <2.0 ft/sec. Depth is usually >2.0 ft.

Fast Runs
A fast run is a stretch of swift-moving water (> 2.0 ft/sec) with either a laminar or somewhat broken surface. Depth is >2.0 ft.

Riffles
Riffles occur where water is relatively shallow (<2.5 ft), the gradient is steep, and mean column velocities are >1.0 ft/sec. The water is broken into small waves by obstructions wholly or partly submerged. Depth and degree of surface agitation separates this habitat type from slow and fast runs.

Rapids
Rapids occur where water is relatively deep (> 2.5 ft.), swift-flowing and the gradient is steep. The surface is broken into waves by obstructions wholly or partly submerged. Greater depth and larger waves separate this habitat type from riffles.

Table II. Seasonal frequency (%) of use of macrohabitats in the Grand Valley by radiotagged adult Colorado squawfish, 1986-1989.

	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 squawfish

Table IV. Seasonal frequency (%) of use of macrohabitats in the Grand Valley by radiotagged adult razorback sucker, 1986-1989.

	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

APPENDIX IV

Time Period of Data Collection

The radiotelemetry data used in this study were collected prior to the acquisition of the habitat mapping data. The mapping study was initiated in early 1990, one year after the prior radiotelemetry study was completed (early 1989). For comparison purposes, fish habitat use data should be collected concurrently with habitat availability data. Due to time and cost limitations, as well as concerns over additional impacts to the local population, it was impractical to initiate an additional radiotelemetry study to run concurrently with the habitat mapping study. Because our observations indicated that the channel configuration had undergone no significant changes since the beginning of the radiotelemetry study (summer 1986), we felt it valid to assume that habitat availability during the mapping study was essentially the same as it was when fish were selecting habitats during the previous radiotelemetry study.

This five year period (summer 1986 - fall 1991) was a rather anomalous period in that very high spring flows, necessary for movement of coarse sediment, did not occur (Fig. I). If pools had been lost, riffles expanded, or backwaters created, comparisons between habitat use and availability could not be made because availability would have changed. However, it takes high

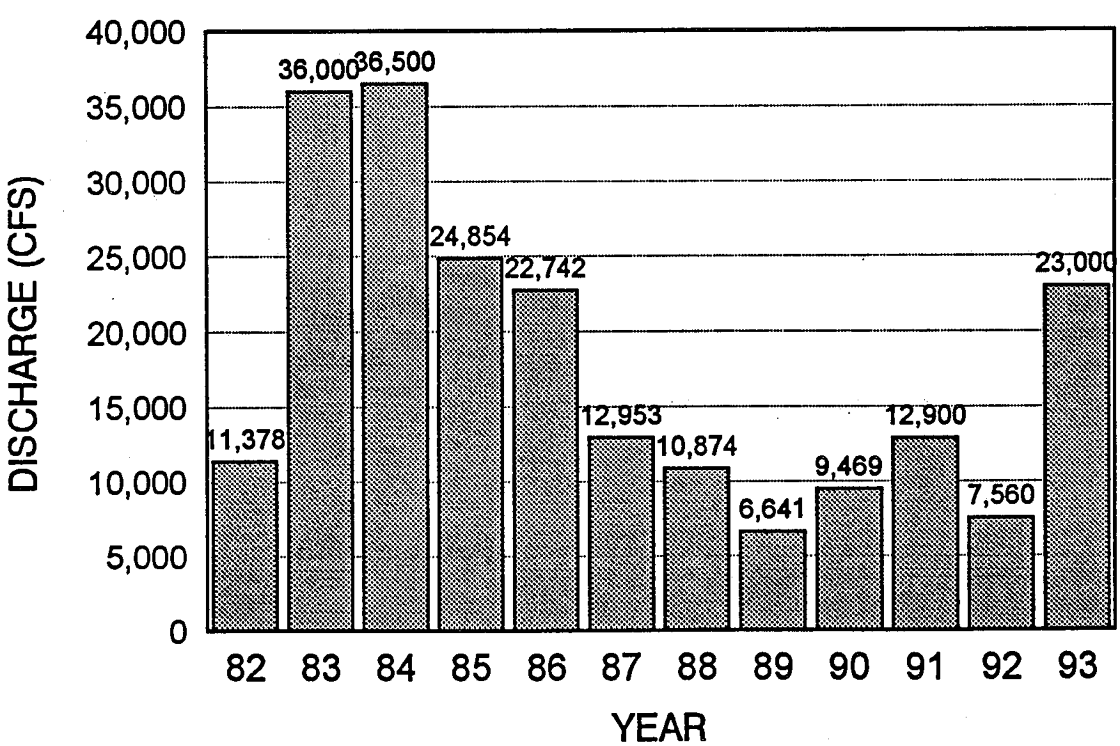


Figure I. Peak discharge (cfs) at the top of the 15-mile reach, 1982-1993. The 'peak' is defined here as the mean discharge on the highest flow day of the year. See Osmundson and Kaeding (1991) for formula used to calculate 15-mile reach flows prior to placement of gage at Palisade in 1991.

flows to make such changes and spring flows during this period did not reach such levels. The changes we did observe was the accumulation of fine sediment in low-velocity habitats (backwaters and pools). This affected depth of these habitats (as discussed in this report), but not habitat area which our habitat availability calculations are based upon. The sediment transport capacity of the Colorado River in the 15-mile reach during the period of study was essentially nonexistent (Fig. II). This illustrates that essentially no significant movement of the bed could have occurred after the spring flow of 1986 and before the spring flow of 1993. Thus, the assumption of stasis in channel configuration and habitat composition during the period of study is reasonable and the comparison of the two data sets, though not collected concurrently, is valid.

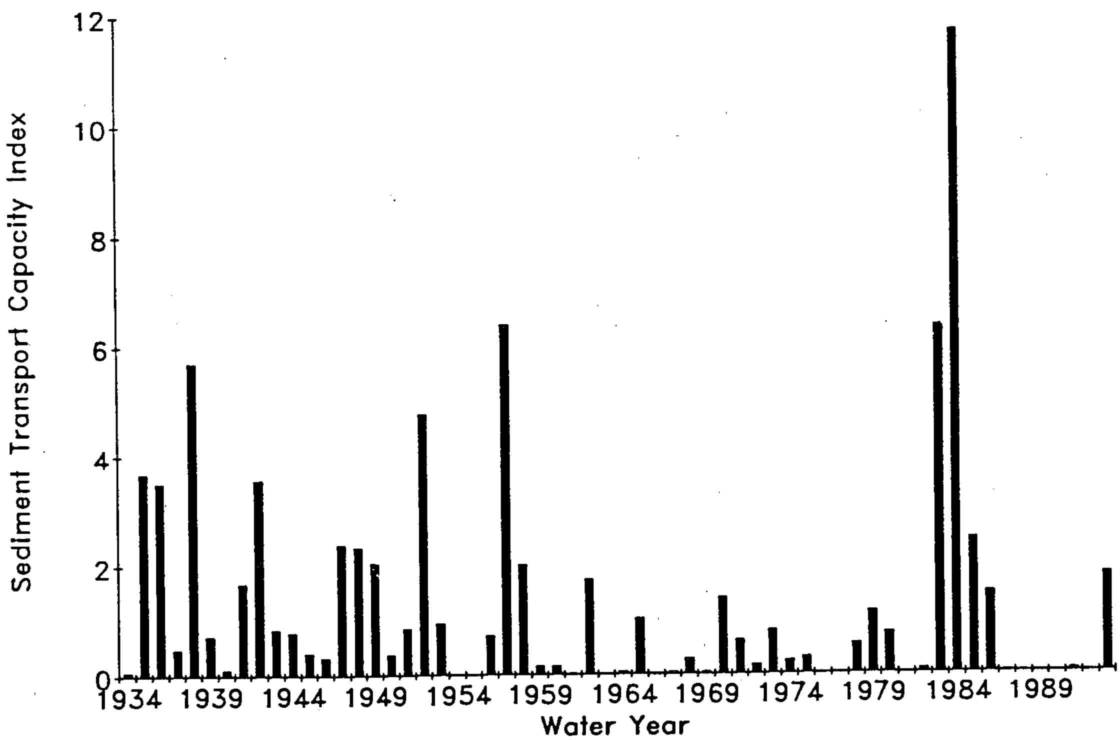


Figure II. Sediment transport capacity of the Colorado River just upstream of the 15-mile reach (based on discharge records from USGS gage at Cameo). The index for a given year is calculated by: STCI = SUM $((Q/QREF)^2)$ which takes the mean flow for each day that has a flow greater than a threshold level for transporting sediment (in this case a conservative estimate of 10,000 cfs was used as a threshold flow), subtracting the threshold level, then dividing by a reference discharge of 2,000 cfs (to scale the y-axis to a small number), and then squaring the result. Days with flows less than the threshold amount are considered zero. The values for each day of the year are then summed to provide an index for the year (Milhous 1992). Note: because of the diversions between the Cameo gage and the top of the 15-mile reach, daily flow records for the 15-mile reach, had they been available, would be lower than at Cameo and thus an even lower transport capacity would be indicated. Graph provided courtesy Robert Milhous.

APPENDIX V

Mapped Habitat Areas

Table V. Correction factors for scale problems associated with MIPS habitat area measurements. Flow at time of the video flight is regressed against total water area (TWA) of a study site; this predicts the total water area at each flow in the absence of scale problems. The predicted TWA at each flow is divided by the measured TWA to provide correction factors. The measured areas of each of the habitat types at a particular flow is then multiplied by the appropriate correction factor to arrive at the corrected habitat area.

SITE 01

VIDEO FLOW	MEASURED TOTAL WATER	OUTPUT	
11,200	73,381		
7,620	72,380	Constant	8.985
5,020	65,420	Std Err of Y Est	0.043
4,426	65,302	R Squared	0.973
2,969	55,216	No. of Observations	9
1,630	46,481	Degrees of Freedom	7
1,220	47,728		
1,160	43,477	X Coefficent(s)	0.244
557	36,960		

MAPPING FLOW	PREDICTED TOTAL WATER	CORRECTION FACTOR
11,200	77,651	1.0582
9,170	73,953	1.2160
7,620	70,686	0.9766
5,020	63,842	0.9759
4,426	61,910	0.9481
2,870	55,701	1.0088
1,630	48,519	1.0438
1,530	47,775	1.0010
1,240	45,387	1.0439
810	40,908	0.8580
557	37,336	1.0102

SITE 02

VIDEO FLOW	MEASURED TOTAL WATER	OUTPUT	
11,200	86,415		
7,620	74,350		
5,020	79,066	Constant	8.532
4,426	58,487	Std Err of Y Est	0.097
2,969	51,698	R Squared	0.918
1,630	54,140	No. of Observations	10
1,220	39,727	Degrees of Freedom	8
1,160	43,541		
810	37,723	X Coefficent(s)	0.303
557	35,883		

MAPPING FLOW	PREDICTED TOTAL WATER	CORRECTION FACTOR
11,200	85,568	0.9902
9,170	80,538	1.2846
7,620	76,144	1.0241
5,020	67,099	0.8486
4,426	64,587	1.1043
2,870	56,642	1.0956
1,630	47,719	0.8814
1,530	48,813	1.0465
1,240	43,925	1.0066
810	38,607	1.0234
557	34,466	0.9605

SITE 03

VIDEO FLOW	MEASURED TOTAL WATER	OUTPUT	
11,200	64,111		
7,620	62,406	Constant	8.300
5,020	55,371	Std Err of Y Est	0.058
4,426	52,616	R Squared	0.970
2,969	39,810	No. of Observations	10
1,630	36,396	Degrees of Freedom	8
1,220	35,772		
1,160	34,176	X Coefficent(s)	0.301
810	30,097		
557	27,212		

MAPPING FLOW	PREDICTED TOTAL WATER	CORRECTION FACTOR
11,200	66,598	1.0388
9,170	62,707	1.1643
7,620	59,308	0.9504
5,020	52,307	0.9447
4,426	50,381	0.9571
2,870	44,205	1.1104
1,630	37,283	1.0244
1,530	36,579	1.0225
1,240	34,338	1.0047
810	30,206	1.0036
557	26,987	0.9917

SITE 04

VIDEO FLOW	MEASURED TOTAL WATER	OUTPUT	
11,200	162,104		
7,854	164,015		
7,620	165,222	Constant	106.927
5,020	130,766	Std Err of Y Est	9.636
4,426	150,929	R Squared	0.839
2,969	128,715	No. of Observations	10
1,630	128,229	Degrees of Freedom	7
1,220	126,339		
1,160	124,155	X Coefficent(s)	10.529
557	101,785	XX Coefficient(s)	-0.482

MAPPING FLOW	PREDICTED TOTAL WATER	CORRECTION FACTOR
11,200	164,390	1.0141
9,170	162,947	0.9935
7,620	159,171	0.9634
5,020	147,636	1.1290
4,426	144,086	0.9547
2,870	133,175	1.0346
1,630	122,809	0.9577
1,530	121,908	0.9649
1,240	119,242	0.9604
810	115,139	0.9204
557	112,642	1.1067

Table VI. Measured and corrected mesohabitat total areas, by study site.

SITE NO. 1

UNADJUSTED

YEAR	91	90	91	91	90	90	91	90	91	90	91
DATE	JUN 13	JUN 12	JUN 06	JUN 26	JUN 18	JUN 27	JUL 17	NOV 29	SEP 18	SEP 19	AUG 26
FLOW(CFS)	11,200	9,170	7,620	5,020	4,426	2,870	1,630	1,530	1,240	810	557
FL. GRAVEL PIT	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
BACKWATER	1,539.0	1,021.9	593.0	0.0	0.0	0.0	225.0	341.6	781.0	118.0	159.0
EDDY	399.0	1,483.3	317.0	0.0	0.0	0.0	0.0	0.0	180.0	0.0	570.0
POOL	848.0	0.0	513.0	1,929.0	2,540.0	2,449.8	1,512.0	2,924.3	1,583.0	806.0	1,361.0
SLOW RUN	0.0	4,623.7	8,517.0	22,027.0	24,889.0	17,823.5	26,463.0	22,892.8	25,913.0	23,238.0	16,875.0
FAST RUN	68,653.0	51,228.5	58,718.0	33,564.0	12,268.0	21,215.9	9,146.0	13,630.4	5,893.0	9,101.0	2,701.0
RIFFLE	195.0	1,279.5	1,979.0	3,349.0	17,687.0	12,333.0	7,877.0	6,611.4	8,400.0	14,414.0	14,995.0
RAPID	1,747.0	1,177.5	1,743.0	4,551.0	7,918.0	1,393.6	1,258.0	1,327.2	727.0	0.0	299.0
TOTAL	73,381.0	60,814.4	72,380.0	65,420.0	65,302.0	55,215.9	46,481.0	47,727.7	43,477.0	47,677.0	36,960.0

ADJUSTED

YEAR	91	90	91	91	90	90	91	90	91	90	91
DATE	JUN 13	JUN 12	JUN 06	JUN 26	JUN 18	JUN 27	JUL 17	NOV 29	SEP 18	SEP 19	AUG 26
FLOW(CFS)	11,200	9,170	7,620	5,020	4,426	2,870	1,630	1,530	1,240	810	557
CORRECTION FACTOR	1.0582	1.2160	0.9766	0.9759	0.9481	1.0088	1.0438	1.0010	1.0439	0.8580	1.0102
FL. GRAVEL PIT	0	0	0	0	0	0	0	0	0	0	0
BACKWATER	1,629	1,243	579	0	0	0	235	342	815	101	161
EDDY	422	1,804	310	0	0	0	0	0	188	0	576
POOL	897	0	501	1,883	2,408	2,471	1,578	2,927	1,652	692	1,375
SLOW RUN	0	5,622	8,318	21,496	23,597	17,980	27,622	22,916	27,051	19,938	17,047
FAST RUN	72,649	62,294	57,344	32,755	11,631	21,403	9,547	13,644	6,152	7,809	2,729
RIFFLE	206	1,556	1,933	3,268	16,769	12,442	8,222	6,618	8,769	12,367	15,148
RAPID	1,849	1,432	1,702	4,441	7,507	1,406	1,313	1,329	759	0	302
TOTAL	77,652	73,950	70,686	63,843	61,913	55,702	48,517	47,775	45,386	40,907	37,337

Table VI (continued).

SITE NO. 2

UNADJUSTED

YEAR	91	90	91	91	90	90	91	90	91	90	91
DATE	JUN 13	JUN 12	JUN 06	JUN 26	JUN 18	JUN 27	JUL 17	NOV 29	SEP 18	SEP 19	AUG 26
FLOW(CFS)	11,200	9,170	7,620	5,020	4,426	2,870	1,630	1,530	1,240	810	557
FL. GRAVEL PIT	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
BACKWATER	17,400.0	14,851.2	22,268.0	20,022.0	11,590.0	10,113.2	7,414.0	6,209.0	4,412.0	0.0	607.0
EDDY	1,474.0	516.0	2,314.0	1,227.0	0.0	0.0	720.0	485.9	383.0	362.1	250.0
POOL	4,524.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	384.0	263.2	1,424.0
SLOW RUN	6,689.0	0.0	3,212.0	0.0	9,648.0	19,061.1	21,348.0	23,295.0	20,225.0	20,949.8	19,147.0
FAST RUN	45,778.0	46,506.5	45,288.0	56,026.0	32,324.0	10,309.0	4,661.0	5,662.4	4,139.0	4,210.6	2,270.0
RIFFLE	9,782.0	659.8	432.0	1,791.0	4,925.0	12,214.9	19,997.0	9,079.6	13,998.0	11,937.1	12,185.0
RAPID	768.0	159.3	836.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
TOTAL	86,415.0	62,692.6	74,350.0	79,066.0	58,487.0	51,698.1	54,140.0	44,731.8	43,541.0	37,722.7	35,883.0

ADJUSTED

YEAR	91	90	91	91	90	90	91	90	91	90	91
DATE	JUN 13	JUN 12	JUN 06	JUN 26	JUN 18	JUN 27	JUL 17	NOV 29	SEP 18	SEP 19	AUG 26
FLOW(CFS)	11,200	9,170	7,620	5,020	4,426	2,870	1,630	1,530	1,240	810	557
CORRECTION FACTOR	0.9902	1.2846	1.0241	0.8486	1.1043	1.0956	0.8814	1.0465	1.0088	1.0234	0.9605
FL. GRAVEL PIT	0	0	0	0	0	0	0	0	0	0	0
BACKWATER	17,229	19,078	22,805	16,991	12,799	11,080	6,535	6,524	4,451	0	583
EDDY	1,460	663	2,370	1,041	0	0	635	509	386	370	240
POOL	4,480	0	0	0	0	0	0	0	387	269	1,368
SLOW RUN	6,623	0	3,289	0	10,654	20,883	18,816	24,378	20,403	21,440	18,391
FAST RUN	45,329	59,742	46,379	47,544	35,695	11,295	4,108	5,925	4,175	4,310	2,180
RIFFLE	9,686	848	442	1,520	5,439	13,383	17,625	9,502	14,121	12,216	11,704
RAPID	760	204	856	0	0	0	0	0	0	0	0
TOTAL	85,568	80,534	76,142	67,095	64,587	56,640	47,719	46,838	43,924	38,606	34,466

Table VI (continued).

SITE NO. 3

UNADJUSTED

YEAR	91	90	91	91	90	90	91	90	91	90	91
DATE	JUN 13	JUN 12	JUN 06	JUN 26	JUN 18	JUN 27	JUL 17	NOV 29	SEP 18	SEP 19	AUG 26
FLOW(CFS)	11,200	9,170	7,620	5,020	4,426	2,870	1,630	1,530	1,240	810	557
FL. GRAVEL PIT	9,526.0	8,215.5	6,922.0	6,674.0	6,997.0	0.0	0.0	0.0	0.0	0.0	0.0
BACKWATER	469.0	2,720.0	4,222.0	7,428.0	4,992.0	2,687.1	3,219.0	2,330.1	2,711.0	775.2	1,625.0
EDDY	285.0	0.0	806.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
POOL	1,394.0	3,334.2	3,949.0	0.0	804.0	576.4	125.0	498.3	795.0	1,356.6	1,660.0
SLOW RUN	7,946.0	2,080.3	1,780.0	742.0	25,323.0	22,146.8	24,958.0	19,262.0	23,852.0	17,331.8	18,710.0
FAST RUN	40,463.0	35,764.8	39,575.0	37,979.0	11,370.0	8,477.0	0.0	5,116.6	1,476.0	7,152.2	516.0
RIFFLE	3,358.0	961.0	4,019.0	1,979.0	3,130.0	5,922.5	8,094.0	8,565.4	5,342.0	3,481.3	4,701.0
RAPID	670.0	781.7	1,133.0	569.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
TOTAL	64,111.0	53,857.4	62,406.0	55,371.0	52,616.0	39,809.8	36,396.0	35,772.4	34,176.0	30,097.1	27,212.0

ADJUSTED

YEAR	91	90	91	91	90	90	91	90	91	90	91
DATE	JUN 13	JUN 12	JUN 06	JUN 26	JUN 18	JUN 27	JUL 17	NOV 29	SEP 18	SEP 19	AUG 26
FLOW(CFS)	11,200	9,170	7,620	5,020	4,426	2,870	1,630	1,530	1,240	810	557
CORRECTION FACTOR	1.0388	1.1643	0.9504	0.9447	0.9571	1.1104	1.0244	1.0225	1.0047	1.0036	0.9917
FL. GRAVEL PIT	9,896	9,565	6,579	6,305	6,697	0	0	0	0	0	0
BACKWATER	487	3,167	4,013	7,017	4,778	2,984	3,298	2,382	2,724	778	1,612
EDDY	296	0	766	0	0	0	0	0	0	0	0
POOL	1,448	3,882	3,753	0	770	640	128	509	799	1,362	1,646
SLOW RUN	8,254	2,422	1,692	701	24,237	24,592	25,567	19,695	23,964	17,394	18,555
FAST RUN	42,033	41,641	37,612	35,879	10,882	9,413	0	5,232	1,483	7,178	512
RIFFLE	3,488	1,119	3,820	1,870	2,996	6,577	8,291	8,758	5,367	3,494	4,662
RAPID	696	910	1,077	538	0	0	0	0	0	0	0
TOTAL	66,599	62,706	59,311	52,309	50,359	44,205	37,284	36,577	34,337	30,205	26,986

Table VI (continued).

SITE NO. 4

UNADJUSTED

YEAR	91	90	91	91	90	90	91	90	91	90	91
DATE	JUN 13	JUN 12	JUN 06	JUN 26	JUN 18	JUN 27	JUL 17	NOV 29	SEP 18	SEP 19	AUG 26
FLOW(CFS)	11,200	9,170	7,620	5,020	4,426	2,870	1,630	1,530	1,240	810	557
FL. GRAVEL PIT	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
BACKWATER	3,022.0	3,163.2	4,649.0	2,877.0	1,644.2	2,451.6	1,974.0	963.9	7,680.0	5,700.8	4,564.0
EDDY	1,766.0	2,836.5	2,552.0	2,402.0	2,160.2	756.9	526.0	943.5	937.0	1,367.8	0.0
POOL	4,274.0	6,426.4	4,320.0	3,032.0	8,926.9	6,262.2	14,932.0	8,622.1	7,678.0	3,981.1	20,323.0
SLOW RUN	44,911.0	70,603.3	72,675.0	57,875.0	71,533.6	67,749.3	74,203.0	70,983.8	78,268.0	73,369.6	49,586.0
FAST RUN	82,633.0	51,660.7	62,818.0	35,397.0	24,260.7	21,366.9	5,914.0	14,405.5	3,894.0	11,205.7	4,771.0
RIFFLE	25,208.0	28,508.5	17,410.0	29,183.0	42,403.6	30,128.4	30,680.0	30,420.5	25,110.0	29,353.6	22,541.0
RAPID	290.0	816.3	798.0	0.0	0.0	0.0	0.0	0.0	588.0	124.4	0.0
TOTAL	162,104.0	164,014.8	165,222.0	130,766.0	150,929.1	128,715.3	128,229.0	126,339.2	124,155.0	125,103.0	101,785.0

ADJUSTED

YEAR	91	90	91	91	90	90	91	90	91	90	91
DATE	JUN 13	JUN 12	JUN 06	JUN 26	JUN 18	JUN 27	JUL 17	NOV 29	SEP 18	SEP 19	AUG 26
FLOW(CFS)	11,200	9,170	7,620	5,020	4,426	2,870	1,630	1,530	1,240	810	557
CORRECTION FACTOR	1.0141	0.9935	0.9634	1.1290	0.9547	1.0346	0.9577	0.9649	0.9604	0.9204	1.1067
FL. GRAVEL PIT	0	0	0	0	0	0	0	0	0	0	0
BACKWATER	3,065	3,142	4,479	3,248	1,570	2,537	1,890	930	7,376	5,247	5,051
EDDY	1,791	2,818	2,459	2,712	2,062	783	504	911	900	1,259	0
POOL	4,334	6,384	4,162	3,423	8,523	6,479	14,300	8,319	7,374	3,664	22,491
SLOW RUN	45,544	70,144	70,015	65,341	68,294	70,093	71,064	68,492	75,169	67,530	54,877
FAST RUN	83,798	51,325	60,519	39,963	23,162	22,106	5,664	13,899	3,740	10,314	5,280
RIFFLE	25,563	28,323	16,773	32,948	40,483	31,170	29,382	29,352	24,116	27,017	24,946
RAPID	294	811	769	0	0	0	0	0	565	114	0
TOTAL	164,390	162,947	159,175	147,635	144,093	133,169	122,805	121,905	119,238	115,146	112,645

Table VII. Total mesohabitat areas (adjusted) by site for each of 11 flow levels, organized by mesohabitat type.

	15-MILE REACH										
YEAR	91	90	91	91	90	90	91	90	91	90	91
DATE	JUN 13	JUN 12	JUN 06	JUN 26	JUN 18	JUN 27	JUL 17	NOV 29	SEP 18	SEP 19	AUG 26
FLOW (CFS)	11,200	9,170	7,620	5,020	4,426	2,870	1,630	1,530	1,240	810	557
FL. GRAVEL PIT											
SITE 1	0	0	0	0	0	0	0	0	0	0	0
SITE 2	0	0	0	0	0	0	0	0	0	0	0
SITE 3	9,896	9,565	6,579	6,305	6,697	0	0	0	0	0	0
SITE 4	0	0	0	0	0	0	0	0	0	0	0
TOTAL	9,896	9,565	6,579	6,305	6,697	0	0	0	0	0	0
BACKWATER											
SITE 1	1,629	1,243	579	0	0	0	235	342	815	101	161
SITE 2	17,229	19,078	22,805	16,991	12,799	11,080	6,535	6,524	4,451	0	583
SITE 3	487	3,167	4,013	7,017	4,778	2,984	3,298	2,382	2,724	778	1,612
SITE 4	3,065	3,142	4,479	3,248	1,570	2,537	1,890	930	7,376	5,247	5,051
TOTAL	22,410	26,630	31,876	27,256	19,147	16,601	11,958	10,178	15,366	6,126	7,407
EDDY											
SITE 1	422	1,804	310	0	0	0	0	0	188	0	576
SITE 2	1,460	663	2,370	1,041	0	0	635	509	386	370	240
SITE 3	296	0	766	0	0	0	0	0	0	0	0
SITE 4	1,791	2,818	2,459	2,712	2,062	783	504	911	900	1,259	0
TOTAL	3,969	5,285	5,905	3,753	2,062	783	1,139	1,420	1,474	1,629	816
POOL											
SITE 1	897	0	501	1,883	2,408	2,471	1,578	2,927	1,652	692	1,375
SITE 2	4,480	0	0	0	0	0	0	0	387	269	1,368
SITE 3	1,448	3,882	3,753	0	770	640	128	509	799	1,362	1,646
SITE 4	4,334	6,384	4,162	3,423	8,523	6,479	14,300	8,319	7,374	3,664	22,491
TOTAL	11,159	10,266	8,416	5,306	11,701	9,590	16,006	11,755	10,212	5,987	26,880

Table VII (continued).

	15-MILE REACH (CON'T)										
YEAR	91	90	91	91	90	90	91	90	91	90	91
DATE	JUN 13	JUN 12	JUN 06	JUN 26	JUN 18	JUN 27	JUL 17	NOV 29	SEP 18	SEP 19	AUG 26
FLOW (CFS)	11,200	9,170	7,620	5,020	4,426	2,870	1,630	1,530	1,240	810	557
SLOW RUN											
SITE 1	0	5,622	8,318	21,496	23,597	17,980	27,622	22,916	27,051	19,938	17,047
SITE 2	6,623	0	3,289	0	10,654	20,883	18,816	24,378	20,403	21,440	18,391
SITE 3	8,254	2,422	1,692	701	24,237	24,592	25,567	19,695	23,964	17,394	18,555
SITE 4	45,544	70,144	70,015	65,341	68,294	70,093	71,064	68,492	75,169	67,530	54,877
TOTAL	71,621	87,358	90,934	92,558	131,208	136,418	144,699	137,011	147,827	127,112	109,427
FAST RUN											
SITE 1	72,649	62,294	57,344	32,755	11,631	21,403	9,547	13,644	6,152	7,809	2,729
SITE 2	45,329	59,742	46,379	47,544	35,695	11,295	4,108	5,925	4,175	4,310	2,180
SITE 3	42,033	41,641	37,612	35,879	10,882	9,413	0	5,232	1,483	7,178	512
SITE 4	83,798	51,325	60,519	39,963	23,162	22,106	5,664	13,899	3,740	10,314	5,280
TOTAL	243,809	215,002	201,854	156,141	81,370	64,217	19,319	38,700	15,550	29,611	10,701
RIFFLE											
SITE 1	206	1,556	1,933	3,268	16,769	12,442	8,222	6,618	8,769	12,367	15,148
SITE 2	9,686	848	442	1,520	5,439	13,383	17,625	9,502	14,121	12,216	11,704
SITE 3	3,488	1,119	3,820	1,870	2,996	6,577	8,291	8,758	5,367	3,494	4,662
SITE 4	25,563	28,323	16,773	32,948	40,483	31,170	29,382	29,352	24,116	27,017	24,946
TOTAL	38,943	31,846	22,968	39,606	65,687	63,572	63,520	54,230	52,373	55,094	56,460
RAPID											
SITE 1	1,849	1,432	1,702	4,441	7,507	1,406	1,313	1,329	759	0	302
SITE 2	760	204	856	0	0	0	0	0	0	0	0
SITE 3	696	910	1,077	538	0	0	0	0	0	0	0
SITE 4	294	811	769	0	0	0	0	0	565	114	0
TOTAL	3,599	3,357	4,404	4,979	7,507	1,406	1,313	1,329	1,324	114	302

Table VIII. Total mesohabitat area (adjusted) for each of eight types at 11 different flow levels. All areas within the four study sites have been summed by mesohabitat type. Grand totals at bottom represent total water area for the four combined sites.

15-MILE REACH

YEAR	91	90	91	91	90	90	91	90	91	90	91
DATE	JUN 13	JUN 12	JUN 06	JUN 26	JUN 18	JUN 27	JUL 17	NOV 29	SEP 18	SEP 19	AUG 26
FLOW (CFS)	11,200	9,170	7,620	5,020	4,426	2,870	1,630	1,530	1,240	810	557
HABITAT TOTALS											
FL. GRAVEL PIT	9,896	9,565	6,579	6,305	6,697	0	0	0	0	0	0
BACKWATER	22,410	26,630	31,876	27,256	19,147	16,601	11,958	10,178	15,366	6,126	7,407
EDDY	3,969	5,285	5,905	3,753	2,062	783	1,139	1,420	1,474	1,629	816
POOL	11,159	10,266	8,416	5,306	11,701	9,590	16,006	11,755	10,212	5,987	26,880
SLOW RUN	71,621	87,358	90,934	92,558	131,208	136,418	144,699	137,011	147,827	127,112	109,427
FAST RUN	243,809	215,002	201,854	156,141	81,370	64,217	19,319	38,700	15,550	29,611	10,701
RIFFLE	38,943	31,846	22,968	39,606	65,687	63,572	63,520	54,230	52,373	55,094	56,460
RAPID	3,599	3,357	4,404	4,979	7,507	1,406	1,313	1,329	1,324	114	302
TOTAL	405,406	389,309	372,936	335,904	325,379	292,587	257,954	254,623	244,126	225,673	211,993

APPENDIX VI
Data and Computations for Habitat Use, Availability and Preference

Table IX. Squawfish habitat utilization data for the four study sites, 1986-1988. Data are partitioned into summer and winter observations; summer is further partitioned by flow level. Observations when discharge was < 389 cfs (*) were not included in preference calculations.

SUMMER - MODERATE FLOWS (1,378-2,368 CFS)

FISH	YEAR	MONTH	DAY	HABITAT	SITE	RIV MILE	CFS
446	87	AUG	4	ED	1	178.3	1,378
446	87	AUG	11	ED	1	178.3	1,463
462	86	AUG	6	BA	2	175.5	2,358
462	86	AUG	12	ED	2	175.5	1,920
462	86	AUG	19	ED	2	175.5	1,579
462	86	AUG	27	ED	2	175.5	1,956
462	86	SEP	3	ED	2	175.5	1,960
462	86	SEP	18	BA	2	175.7	1,493
462	86	SEP	30	BA	2	175.7	2,367
462	86	OCT	7	PO	2	175.9	2,368
462	86	OCT	20	BA	2	175.4	2,030
462	87	AUG	4	ED	2	175.5	1,378
462	87	AUG	11	ED	2	175.8	1,463
462	87	AUG	25	PO	2	175.9	1,609
491	86	AUG	6	FRU	4	174.2	2,358
491	86	SEP	3	SRU	4	174.3	1,960
491	86	SEP	18	SRU	4	174.3	1,493
491	86	SEP	30	FRU	4	174.2	2,367
491	86	OCT	7	PO	4	174.4	2,368
491	86	OCT	20	BA	4	174.4	2,030
491	87	AUG	4	BA	4	174.4	1,378
491	87	AUG	11	ED	4	174.4	1,463
541	86	SEP	30	ED	4	174.4	2,367
541	86	OCT	7	PO	4	174.4	2,368
541	86	OCT	20	ED	4	174.4	2,030
330	88	SEP	13	PO	3	175.1	1,706

SUMMER - LOW FLOWS (151-931 CFS)

FISH	YEAR	MONTH	DAY	HABITAT	SITE	RIV MILE	CFS
330	88	AUG	2	SRU	4	174.2	886
330	88	AUG	8	SRU	4	174.2	690
330	88	AUG	15	SRU	4	174.2	644
330	88	AUG	29	RI	2	175.4	268 *
330	88	SEP	6	SRU	4	174.3	270 *
330	88	SEP	19	SRU	2	175.5	391
330	88	SEP	26	SRU	4	174.1	316 *
446	88	AUG	2	FRU	1	178.2	886
446	88	AUG	29	FRU	1	178.0	268 *
462	87	AUG	17	SRU	2	175.8	931
491	87	AUG	17	SRU	4	174.2	931
536	87	OCT	9	SRU	4	174.4	801
541	87	OCT	9	SRU	4	174.3	801
541	87	OCT	30	SRU	4	174.2	422

Table IX (continued)

WINTER - (1,654 - 3,452 CFS)							
FISH	YEAR	MONTH	DAY	HABITAT	SITE	RIV MILE	CFS
462	86	NOV	23	BA	2	175.7	3,210
462	86	DEC	8	BA	2	175.7	2,871
462	87	JAN	6	BA	2	175.6	2,448
462	87	JAN	15	BA	2	175.6	2,417
462	87	JAN	23	BA	2	175.5	2,091
462	87	JAN	29	BA	2	175.5	2,298
462	87	FEB	9	BA	2	175.9	2,246
462	87	FEB	20	BA	2	175.9	2,221
462	87	MAR	11	BA	2	175.9	2,777
462	87	MAR	19	BA	2	175.5	2,546
462	87	MAR	26	BA	2	175.5	2,335
491	86	NOV	4	SRU	4	174.5	3,452
491	86	DEC	8	PO	4	174.4	2,871
491	87	JAN	12	PO	4	174.4	2,129
491	87	JAN	20	ED	4	174.4	2,066
491	87	JAN	27	PO	4	174.4	2,320
491	87	FEB	4	PO	4	174.5	2,437
491	87	FEB	17	PO	4	174.7	2,323
491	87	MAR	2	PO	4	174.6	2,208
491	87	MAR	18	ED	4	174.4	2,552
491	87	MAR	27	ED	4	174.3	2,346
536	87	NOV	17	PO	4	174.4	2,232
536	87	NOV	24	PO	4	174.4	2,137
536	87	DEC	3	PO	4	174.4	1,985
536	87	DEC	8	PO	4	174.4	2,059
536	87	DEC	14	PO	4	174.4	1,654
536	88	JAN	8	PO	4	174.5	1,760
536	88	JAN	13	PO	4	174.5	1,858
536	88	JAN	19	PO	4	174.4	1,769
536	88	JAN	27	SRU	4	174.4	1,739
536	88	FEB	4	PO	4	174.5	1,710
536	88	FEB	9	PO	4	174.5	1,710
536	88	FEB	19	PO	4	174.5	1,780
536	88	FEB	24	PO	4	174.5	1,728
536	88	MAR	1	PO	4	174.4	2,204
536	88	MAR	10	SRU	4	174.4	1,950
536	88	MAR	17	SRU	4	174.4	1,835
536	88	MAR	22	SRU	4	174.4	2,025
536	88	MAR	31	PO	4	174.4	2,250
541	86	NOV	5	PO	4	174.5	3,292
541	87	NOV	9	SRU	4	174.4	2,465
541	87	NOV	17	PO	4	174.4	2,232
541	87	NOV	24	PO	4	174.4	2,137

Table IX (continued)

FISH	YEAR	MONTH	DAY	HABITAT	SITE	RIV MILE	CFS
541	86	DEC	8	PO	4	174.4	2,871
541	87	DEC	3	PO	4	174.4	1,985
541	87	DEC	8	PO	4	174.4	2,059
541	87	DEC	14	PO	4	174.4	1,654
541	87	JAN	12	PO	4	174.4	2,129
541	87	JAN	20	ED	4	174.4	2,066
541	87	JAN	27	PO	4	174.4	2,320
541	88	JAN	8	PO	4	174.4	1,760
541	88	JAN	13	PO	4	174.4	1,858
541	88	JAN	19	PO	4	174.4	1,769
541	88	JAN	27	PO	4	174.4	1,739
541	87	FEB	4	ED	4	174.4	2,437
541	87	FEB	17	BA	4	174.4	2,323
541	88	FEB	4	PO	4	174.4	1,710
541	88	FEB	9	PO	4	174.4	1,710
541	88	FEB	19	PO	4	174.4	1,780
541	88	FEB	24	PO	4	174.4	1,728
541	87	MAR	2	PO	4	174.4	2,208
541	87	MAR	18	BA	4	174.6	2,552
541	87	MAR	27	PO	4	174.6	2,346
541	88	MAR	1	SRU	4	174.3	2,204
541	88	MAR	10	PO	4	174.4	1,950
541	88	MAR	17	PO	4	174.4	1,835
541	88	MAR	22	SRU	4	174.3	2,025

Table X. Frequency of use calculations for squawfish utilization of habitat types within the four study sites.

	LOCATION	BACKWATER		EDDY		POOL		SLOW RUN		FAST RUN		RIFFLE		RAPID	
	NO.	NO.	FREQ	NO.	FREQ	NO.	FREQ	NO.	FREQ	NO.	FREQ	NO.	FREQ	NO.	FREQ
SUMMER - MODERATE FLOWS															
FISH 330	1	0	0.000	0	0.000	1	1.000	0	0.000	0	0.000	0	0.000	0	0.000
FISH 446	2	0	0.000	2	1.000	0	0.000	0	0.000	0	0.000	0	0.000	0	0.000
FISH 462	12	4	0.333	6	0.500	2	0.167	0	0.000	0	0.000	0	0.000	0	0.000
FISH 491	8	2	0.250	1	0.125	1	0.125	2	0.250	2	0.250	0	0.000	0	0.000
FISH 541	3	0	0.000	2	0.667	1	0.333	0	0.000	0	0.000	0	0.000	0	0.000
MEAN			0.117		0.458		0.325		0.050		0.050		0.000		0.000
SE			0.073		0.182		0.177		0.050		0.050		0.000		0.000
SUMMER - LOW FLOWS															
FISH 330	7	0	0.000	0	0.000	0	0.000	6	0.750	0	0.000	1	0.125	0	0.000
FISH 446	2	0	0.000	0	0.000	0	0.000	0	0.000	2	1.000	0	0.000	0	0.000
FISH 462	1	0	0.000	0	0.000	0	0.000	1	1.000	0	0.000	0	0.000	0	0.000
FISH 491	1	0	0.000	0	0.000	0	0.000	1	1.000	0	0.000	0	0.000	0	0.000
FISH 541	2	0	0.000	0	0.000	0	0.000	2	1.000	0	0.000	0	0.000	0	0.000
FISH 536	1	0	0.000	0	0.000	0	0.000	1	1.000	0	0.000	0	0.000	0	0.000
MEAN			0.000		0.000		0.000		0.792		0.167		0.021		0.000
SE			0.000		0.000		0.000		0.164		0.167		0.021		0.000
WINTER															
FISH 462	11	11	1.000	0	0.000	0	0.000	0	0.000	0	0.000	0	0.000	0	0.000
FISH 491	10	0	0.000	3	0.300	6	0.600	1	0.100	0	0.000	0	0.000	0	0.000
FISH 536	18	0	0.000	0	0.000	14	0.778	4	0.222	0	0.000	0	0.000	0	0.000
FISH 541	28	2	0.071	2	0.071	21	0.750	3	0.107	0	0.000	0	0.000	0	0.000
MEAN			0.268		0.093		0.532		0.107		0.000		0.000		0.000
SE			0.424		0.123		0.182		0.045		0.000		0.000		0.000

Table XI. Habitat availability calculations for each of four study sites during medium- and low-flow summer conditions and during winter flow conditions. Availability is expressed as percent composition. Mean frequencies are used for comparison with frequency of use in preference calculations. One fish, No. 330, used three contiguous sites; thus, for comparison with frequency of use, the percent composition of the three sites combined was calculated.

SUMMER

SITE 1

MOD-FLOW	BA	ED	PO	SR	FR	RI	RA
2,870 cfs	0.0000	0.0000	0.0444	0.3228	0.3842	0.2234	0.0252
1,630	0.0048	0.0000	0.0325	0.5693	0.1968	0.1695	0.0271
1,530	0.0072	0.0000	0.0613	0.4797	0.2856	0.1385	0.0278
1,240	0.0180	0.0041	0.0364	0.5960	0.1355	0.1932	0.0167
MEAN	0.0075	0.0010	0.0436	0.4920	0.2505	0.1811	0.0242
SE	0.0038	0.0010	0.0064	0.0616	0.0542	0.0180	0.0026
LOW FLOW							
810	0.0025	0.0000	0.0169	0.4874	0.1909	0.3023	0.0000
556	0.0043	0.0154	0.0368	0.4566	0.0731	0.4057	0.0081
MEAN	0.0034	0.0077	0.0269	0.4720	0.1320	0.3540	0.0040
SE	0.0009	0.0077	0.0100	0.0154	0.0589	0.0517	0.0040

SITE 2

MOD-FLOW	BA	ED	PO	SR	FR	RI	RA
2,870	0.1956	0.0000	0.0000	0.3687	0.1994	0.2363	0.0000
1,630	0.1369	0.0133	0.0000	0.3943	0.0861	0.3693	0.0000
1,530	0.1393	0.0109	0.0000	0.5205	0.1265	0.2029	0.0000
1,240	0.1013	0.0088	0.0088	0.4645	0.0951	0.3215	0.0000
MEAN	0.1433	0.0082	0.0022	0.4370	0.1268	0.2825	0.0000
SE	0.0195	0.0029	0.0022	0.0344	0.0257	0.0382	0.0000
LOW FLOW							
810	0.0000	0.0096	0.0070	0.5554	0.1116	0.3164	0.0000
556	0.0169	0.0070	0.0397	0.5336	0.0633	0.3396	0.0000
MEAN	0.0085	0.0083	0.0233	0.5445	0.0874	0.3280	0.0000
SE	0.0085	0.0013	0.0164	0.0109	0.0242	0.0116	0.0000

SITE 3

MOD-FLOW	BA	ED	PO	SR	FR	RI	RA
2,870	0.0675	0.0000	0.0145	0.5563	0.2129	0.1488	0.0000
1,630	0.0885	0.0000	0.0034	0.6857	0.0000	0.2224	0.0000
1,530	0.0651	0.0000	0.0139	0.5385	0.1430	0.2394	0.0000
1,240	0.0793	0.0000	0.0233	0.6979	0.0432	0.1563	0.0000
MEAN	0.0751	0.0000	0.0138	0.6196	0.0998	0.1917	0.0000
SE	0.0054	0.0000	0.0041	0.0419	0.0482	0.0229	0.0000
LOW FLOW							
810	0.0258	0.0000	0.0451	0.5758	0.2376	0.1157	0.0000
556	0.0597	0.0000	0.0610	0.6876	0.0190	0.1727	0.0000
MEAN	0.0427	0.0000	0.0530	0.6317	0.1283	0.1442	0.0000
SE	0.0170	0.0000	0.0080	0.0559	0.1093	0.0285	0.0000

Table XI (continued).

	BA	ED	PO	SR	FR	RI	RA
			SITE 4				
MOD-FLOW	BA	ED	PO	SR	FR	RI	RA
2,870	0.0191	0.0059	0.0487	0.5264	0.1660	0.2341	0.0000
1,630	0.0154	0.0041	0.1164	0.5787	0.0461	0.2393	0.0000
1,530	0.0076	0.0075	0.0682	0.5619	0.1140	0.2408	0.0000
1,240	0.0619	0.0075	0.0618	0.6304	0.0314	0.2022	0.0047
MEAN	0.0260	0.0063	0.0738	0.5743	0.0894	0.2291	0.0012
SE	0.0122	0.0008	0.0148	0.0216	0.0312	0.0091	0.0012
LOW FLOW							
810	0.0456	0.0109	0.0318	0.5865	0.0896	0.2346	0.0010
556	0.0448	0.0000	0.1997	0.4872	0.0469	0.2215	0.0000
MEAN	0.0452	0.0055	0.1157	0.5368	0.0682	0.2280	0.0005
SE	0.0004	0.0055	0.0839	0.0497	0.0214	0.0066	0.0005
		COMBINED SITES 2,3 AND 4 FOR FISH 330					
810 CFS	BA	ED	PO	SR	FR	RI	RA
SITE 2	0	370	269	21440	4310	12,216	0
SITE 3	778	0	1362	17394	7178	3,494	0
SITE 4	5247	1259	3664	67530	10314	27,017	114
TOTAL	6025	1629	5295	106364	21802	42,727	114
556 CFS							
SITE 2	583	240	1368	18391	2180	11,704	0
SITE 3	1612	0	1646	18555	512	4,662	0
SITE 4	5051	0	22491	54877	5280	24,946	0
TOTAL	7246	240	25505	91823	7972	41,312	0
LOW FLOW							
810	0.0328	0.0089	0.0288	0.5782	0.1185	0.2323	0.0006
556	0.0416	0.0014	0.1465	0.5274	0.0458	0.2373	0.0000
MEAN	0.0372	0.0051	0.0876	0.5528	0.0822	0.2348	0.0003
SE	0.0044	0.0037	0.0589	0.0254	0.0364	0.0025	0.0003
			WINTER				
			SITE 2				
FLOW	BA	ED	PO	SR	FR	RI	RA
2,870	0.1956	0.0000	0.0000	0.3687	0.1994	0.2363	0.0000
1,630	0.1369	0.0133	0.0000	0.3943	0.0861	0.3693	0.0000
MEAN	0.1666	0.0067	0.0000	0.3815	0.1428	0.3028	0.0000
SE	0.0293	0.0067	0.0000	0.0128	0.0567	0.0665	0.0000
			SITE 4				
FLOW	BA	ED	PO	SR	FR	RI	RA
2,870	0.0191	0.0059	0.0487	0.5264	0.1660	0.2341	0.0000
1,630	0.0154	0.0041	0.1164	0.5787	0.0461	0.2393	0.0000
MEAN	0.0172	0.0050	0.0825	0.5525	0.1061	0.2366	0.0000
SE	0.0018	0.0009	0.0339	0.0262	0.0599	0.0026	0.0000

Table XII. Habitat preference calculations. Habitat type availability (as a fraction of total water area) is subtracted from frequency of use for each fish. Differences are later averaged across fish to arrive at a mean preference.

SUMMER - MODERATE FLOWS

HAB TYPE	FISH 462 USAGE	SITE 2 AVAIL	DIFF	FISH 491 USAGE	SITE 4 AVAIL	DIFF	FISH 446 USAGE	SITE 1 AVAIL	DIFF	FISH 541 USAGE	SITE 4 AVAIL	DIFF	FISH 330 USAGE	SITE 3 AVAIL	DIFF
BA	0.3333	0.1433	0.1900	0.2500	0.0260	0.2240	0.0000	0.0075	-0.0075	0.0000	0.0260	-0.0260	0.0000	0.0751	-0.0751
ED	0.5000	0.0082	0.4918	0.1250	0.0063	0.1187	1.0000	0.0010	0.9990	0.6667	0.0063	0.6604	0.0000	0.0000	0.0000
PO	0.1667	0.0022	0.1645	0.1250	0.0738	0.0512	0.0000	0.0438	-0.0438	0.3333	0.0738	0.2595	1.0000	0.0138	0.9862
SR	0.0000	0.4370	-0.4370	0.2500	0.5743	-0.3243	0.0000	0.4920	-0.4920	0.0000	0.5743	-0.5743	0.0000	0.6196	-0.6196
FR	0.0000	0.1268	-0.1268	0.2500	0.0894	0.1606	0.0000	0.2505	-0.2505	0.0000	0.0894	-0.0894	0.0000	0.0998	-0.0998
RI	0.0000	0.2825	-0.2825	0.0000	0.2291	-0.2291	0.3333	0.1811	0.1522	0.0000	0.2291	-0.2291	0.0000	0.1917	-0.1917
RA	0.0000	0.0000	0.0000	0.0000	0.0012	-0.0012	0.0000	0.0242	-0.0242	0.0000	0.0012	-0.0012	0.0000	0.0000	0.0000

SUMMER - LOW FLOWS

	FISH 446 USAGE	SITE 1 AVAIL	DIFF	FISH 330 USAGE	SITES 2,3,4 AVAIL	DIFF	FISH 541 USAGE	SITE 4 AVAIL	DIFF	FISH 538 USAGE	SITE 4 AVAIL	DIFF	FISH 462 USAGE	SITE 2 AVAIL	DIFF	FISH 491 USAGE	SITE 4 AVAIL	DIFF
BA	0.0000	0.0034	-0.0034	0.0000	0.0372	-0.0372	0.0000	0.0452	-0.0452	0.0000	0.0452	-0.0452	0.0000	0.0085	-0.0085	0.0000	0.0452	-0.0452
ED	0.0000	0.0077	-0.0077	0.0000	0.0051	-0.0051	0.0000	0.0055	-0.0055	0.0000	0.0055	-0.0055	0.0000	0.0083	-0.0083	0.0000	0.0055	-0.0055
PO	0.0000	0.0269	-0.0269	0.0000	0.0876	-0.0876	0.0000	0.1157	-0.1157	0.0000	0.1157	-0.1157	0.0000	0.0233	-0.0233	0.0000	0.1157	-0.1157
SR	0.0000	0.4720	-0.4720	1.0000	0.5528	0.4472	1.0000	0.5368	0.4632	1.0000	0.5368	0.4632	1.0000	0.5445	0.4555	1.0000	0.5368	0.4632
FR	1.0000	0.1320	0.8680	0.0000	0.0822	-0.0822	0.0000	0.0682	-0.0682	0.0000	0.0682	-0.0682	0.0000	0.0874	-0.0874	0.0000	0.0682	-0.0682
RI	0.0000	0.3540	-0.3540	0.0000	0.2348	-0.2348	0.0000	0.2280	-0.2280	0.0000	0.2280	-0.2280	0.0000	0.3280	-0.3280	0.0000	0.2280	-0.2280
RA	0.0000	0.0040	-0.0040	0.0000	0.0003	-0.0003	0.0000	0.0005	-0.0005	0.0000	0.0005	-0.0005	0.0000	0.0000	0.0000	0.0000	0.0005	-0.0005

WINTER

	FISH 462	SITE 2	DIFF	FISH 491	SITE 4	DIFF	FISH 538	SITE 4	DIFF	FISH 541	SITE 4	DIFF
BA	1.0000	0.1666	0.8334	0.0000	0.0172	-0.0172	0.0000	0.0172	-0.0172	0.0714	0.0172	0.0542
ED	0.0000	0.0067	-0.0067	0.3000	0.0050	0.2950	0.0000	0.0050	-0.0050	0.0714	0.0050	0.0664
PO	0.0000	0.0000	0.0000	0.6000	0.0826	0.5174	0.7780	0.0826	0.6954	0.7500	0.0826	0.6674
SR	0.0000	0.3815	-0.3815	0.1000	0.5525	-0.4525	0.2220	0.5525	-0.3305	0.1071	0.5525	-0.4454
FR	0.0000	0.1428	-0.1428	0.0000	0.1061	-0.1061	0.0000	0.1061	-0.1061	0.0000	0.1061	-0.1061
RI	0.0000	0.3028	-0.3028	0.0000	0.2366	-0.2366	0.0000	0.2366	-0.2366	0.0000	0.2366	-0.2366
RA	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000

Table XIII. Mean habitat preference rating for each of eight mesohabitat types by adult Colorado squawfish. Difference between habitat use and availability (see Table XII) for each fish is averaged across all fish. Mean ratings greater than zero indicate preference for that type.

	HABITAT TYPE						
FISH	BA	ED	PO	SR	FR	RI	RA
			MODERATE SUMMER FLOWS				
462	0.190	0.492	0.165	-0.437	-0.127	-0.283	0.000
491	0.224	0.119	0.051	-0.324	0.161	-0.229	-0.001
446	-0.008	0.999	-0.044	-0.492	-0.251	0.152	-0.024
541	-0.026	0.660	0.260	-0.574	-0.089	-0.229	-0.001
330	-0.075	0.000	0.986	-0.620	-0.100	-0.192	0.000
MEAN	0.061	0.454	0.284	-0.489	-0.081	-0.156	-0.005
SE	0.061	0.182	0.183	0.052	0.067	0.078	0.005
			LOW SUMMER FLOWS				
446	-0.003	-0.008	-0.027	-0.472	0.868	-0.354	-0.004
330	-0.037	-0.005	-0.088	0.447	-0.082	-0.235	-0.000
541	-0.045	-0.006	-0.116	0.463	-0.068	-0.228	-0.001
536	-0.045	-0.006	-0.116	0.463	-0.068	-0.228	-0.001
462	-0.009	-0.008	-0.023	0.456	-0.087	-0.328	0.000
491	-0.045	-0.006	-0.116	0.463	-0.068	-0.228	-0.001
MEAN	-0.031	-0.006	-0.081	0.303	0.082	-0.267	-0.001
SE	0.008	0.001	0.018	0.155	0.157	0.024	0.001
			WINTER FLOWS				
462	0.833	-0.007	0.000	-0.382	-0.143	-0.303	0.000
491	-0.017	0.295	0.517	-0.453	-0.106	-0.237	0.000
536	-0.017	-0.005	0.695	-0.331	-0.106	-0.237	0.000
541	0.054	0.066	0.667	-0.445	-0.106	-0.237	0.000
MEAN	0.213	0.087	0.470	-0.402	-0.115	-0.253	0.000
SE	0.207	0.071	0.161	0.029	0.009	0.017	0.000

Table XIV. Calculations for determining weighted area of preferred habitats at different flow levels. Total area in the four study sites (from Table VIII) of each of the mesohabitat types found to be preferred multiplied by the mean preference rating for each (from Table XIII).

HABITAT	2,870 CFS			1,630 CFS			1,530 CFS			1,240 CFS		
MODERATE SUMMER FLOWS												
	AREA	PREF	WT AREA	AREA	PREF	WT AREA	AREA	PREF	WT AREA	AREA	PREF	WT AREA
BA	16,601	0.061	1,013	11,958	0.061	729	10,178	0.061	621	15,366	0.061	937
ED	783	0.454	355	1,139	0.454	517	1,420	0.454	645	1,474	0.454	669
PO	9,590	0.284	2,724	16,006	0.284	4,546	11,755	0.284	3,338	10,212	0.284	2,900
SUM			4,092			5,792			4,604			4,507
LOW SUMMER FLOWS												
				810 CFS			557 CFS					
				AREA	PREF	WT AREA	AREA	PREF	WT AREA			
SR				127,112	0.303	38,515	109,427	0.303	33,156			
FR				29,611	0.082	2,428	10,701	0.082	877			
SUM						40,943			34,034			
WINTER												
	2,870 CFS			1,630 CFS			1,530 CFS			1,240 CFS		
	AREA	PREF	WT AREA	AREA	PREF	WT AREA	AREA	PREF	WT AREA	AREA	PREF	WT AREA
BA	16,601	0.213	3,536	11,958	0.213	2,547	10,178	0.213	2,168	15,366	0.213	3,273
ED	783	0.087	68	1,139	0.087	99	1,420	0.087	124	1,474	0.087	128
PO	9,590	0.470	4,507	16,006	0.470	7,523	11,755	0.470	5,525	10,212	0.470	4,800
SUM			8,111			10,169			7,816			8,201

APPENDIX VII
Variation in Depth at Stream Bed Cross Sections With Change in Discharge

Table XV. Maximum and average depth of 12 stream bed cross sections at different flow levels. All transects are within the four 15-mile reach study sites. Some transects are divided into a north (N) and south (S) section if they crossed different channels or distinctly different habitat types. Those sites that experienced substantial change in bed elevation are listed for both years (90 and 91).

15-MILE REACH MAX DEPTHS

	FLOW		TRANSECT NO. - SIDE OF RIVER - YEAR								
DATE	YR	CFS	1A-N	1B-S	2-N	3-N	4-N	5-N	6-N	7-S	8-S-90
JUN 13	91	11,200	6.05	7.63	10.21	5.64	5.64	12.78	9.79	6.38	5.58
MAY 30	91	9,250	5.32	7.04	9.67	5.06	5.11	12.22	9.35	5.73	5.17
JUN 12	90	9,170	5.28	6.98	9.63	5.03	5.09	12.19	9.31	5.70	5.14
JUN 6	91	7,620	4.69	6.35	9.06	4.55	4.53	11.75	8.79	5.16	4.72
JUN 26	91	5,020	3.88	4.96	7.72	3.32	3.61	10.74	7.57	4.02	3.61
JUN 18	90	4,426	3.66	4.61	7.23	3.03	3.20	10.38	7.20	3.73	3.31
JUN 27	90	2,870	3.17	3.74	6.19	2.12	2.35	9.49	6.28	2.97	2.55
JUL 17	91	1,630	2.85	3.02	5.32	1.58	1.67	8.80	5.52	2.48	2.03
NOV 29	90	1,530	2.82	2.94	5.24	1.52	1.57	8.73	5.42	2.37	1.96
SEP 18	91	1,240	2.71	2.74	5.04	1.30	1.27	8.46	5.11	2.23	1.61
OCT 31	90	900	2.51	2.41	4.73	0.83	0.73	7.86	4.69	2.08	1.05
SEP 19	90	810	2.37	2.28	4.46	0.73	0.51	7.61	4.56	2.04	0.87
AUG 26	91	557	2.22	2.22	3.99	0.71	0.37	7.32	4.23	1.51	0.01

DATE	YR	CFS	8-S-91	10-N	10-S-90	10-S-91	11-N	12-W-90	12-W-91
JUN 13	91	11,200	8.10	9.25	8.34	8.83	9.91	6.80	8.00
MAY 30	91	9,250	7.69	8.73	7.90	8.39	9.62	6.34	7.54
JUN 12	90	9,170	7.66	8.68	7.89	8.38	9.60	6.31	7.51
JUN 6	91	7,620	7.24	8.25	7.52	8.01	9.30	5.86	7.06
JUN 26	91	5,020	6.38	7.34	6.42	7.14	8.41	4.73	5.93
JUN 18	90	4,426	6.09	7.08	6.09	6.86	8.13	4.40	5.60
JUN 27	90	2,870	5.29	6.35	5.32	6.08	7.55	3.58	4.78
JUL 17	91	1,630	4.55	5.88	4.62	5.35	7.01	2.92	4.05
NOV 29	90	1,530	4.48	5.82	4.55	5.27	6.99	2.85	3.99
SEP 18	91	1,240	4.24	5.64	4.25	4.98	6.76	2.79	3.82
OCT 31	90	900	3.89	5.34	3.81	4.61	6.47	2.48	3.55
SEP 19	90	810	3.73	5.19	3.61	4.49	6.34	2.35	3.47
AUG 26	91	557	3.19	5.07	2.89	4.07	5.99	2.05	3.08

15-MILE REACH AVE DEPTHS

	FLOW		TRANSECT NO. - SIDE OF RIVER - YEAR								
DATE	YR	CFS	1A-N	1B-S	2-N	3-N	4-N	5-N	6-N	7-S	8-S-90
JUN 13	91	11,200	4.66	5.74	6.20	3.22	2.99	7.17	3.73	3.55	3.74
MAY 30	91	9,250	4.09	5.15	5.93	2.64	2.58	6.93	3.37	4.02	3.33
JUN 12	90	9,170	4.04	5.09	5.89	2.61	2.67	6.90	3.33	3.99	3.30
JUN 6	91	7,620	3.46	4.46	5.32	2.30	2.64	6.64	3.51	3.45	3.14
JUN 26	91	5,020	2.76	3.07	4.19	1.48	1.99	6.48	3.85	2.99	2.63
JUN 18	90	4,426	2.54	2.95	3.70	1.31	1.84	6.12	3.64	2.70	2.33
JUN 27	90	2,870	2.05	2.32	2.79	0.93	1.19	5.57	3.18	1.94	1.82
JUL 17	91	1,630	1.80	1.96	2.07	1.56	1.16	5.56	2.88	1.86	1.30
NOV 29	90	1,530	1.77	2.10	1.94	1.50	1.06	5.49	2.78	1.75	1.39
SEP 18	91	1,240	1.66	1.90	1.74	0.87	0.89	5.22	2.62	1.61	1.21
OCT 31	90	900	1.46	1.57	1.43	0.81	0.35	4.97	2.20	1.46	0.65
SEP 19	90	810	1.32	1.44	1.23	0.71	0.24	4.72	2.07	1.42	0.57
AUG 26	91	557	1.17	1.38	1.46	0.69	0.17	4.43	1.87	1.31	0.01

DATE	YR	CFS	8-S-91	10-N	10-S-90	10-S-91	11-N	12-W-90	12-W-91
JUN 13	91	11,200	5.24	6.56	5.15	5.70	4.30	3.34	3.39
MAY 30	91	9,250	4.83	6.04	4.71	5.26	4.20	2.88	3.00
JUN 12	90	9,170	4.80	5.99	4.70	5.25	4.18	2.85	2.97
JUN 6	91	7,620	5.02	5.56	4.33	4.88	3.88	2.59	2.89
JUN 26	91	5,020	4.16	4.65	3.57	4.01	5.53	2.32	2.90
JUN 18	90	4,426	3.87	4.39	3.24	3.73	5.25	2.59	3.12
JUN 27	90	2,870	3.07	3.66	2.47	3.32	4.89	1.99	2.30
JUL 17	91	1,630	3.33	3.37	1.77	2.92	4.56	1.33	1.89
NOV 29	90	1,530	3.26	3.31	1.70	2.84	4.54	1.26	1.95
SEP 18	91	1,240	3.02	3.13	2.37	3.25	4.31	1.20	1.89
OCT 31	90	900	2.67	2.83	1.93	2.88	4.02	1.00	2.50
SEP 19	90	810	2.51	2.68	1.73	2.76	3.89	0.87	2.42
AUG 26	91	557	1.97	2.56	1.77	2.34	3.72	0.95	2.29

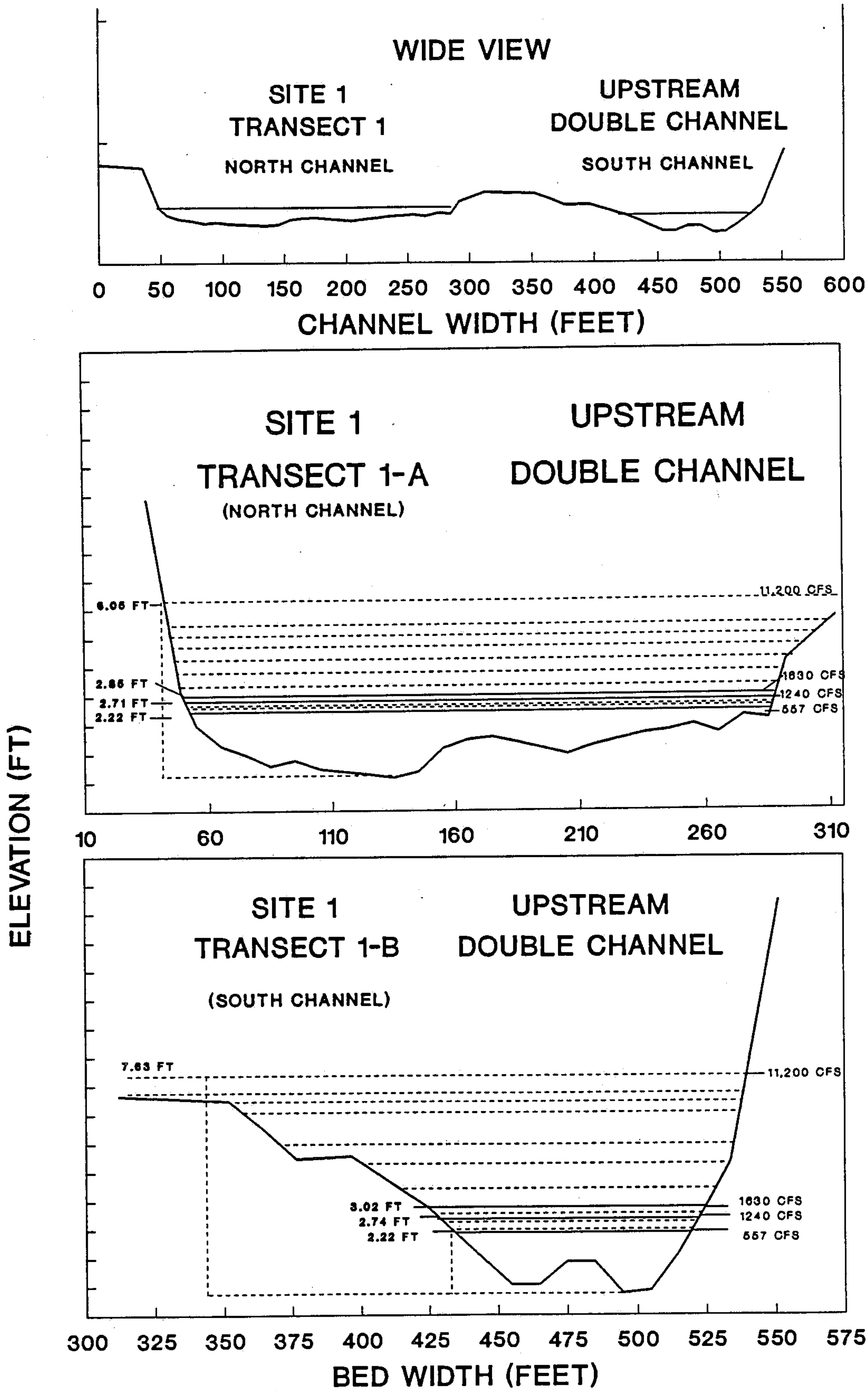
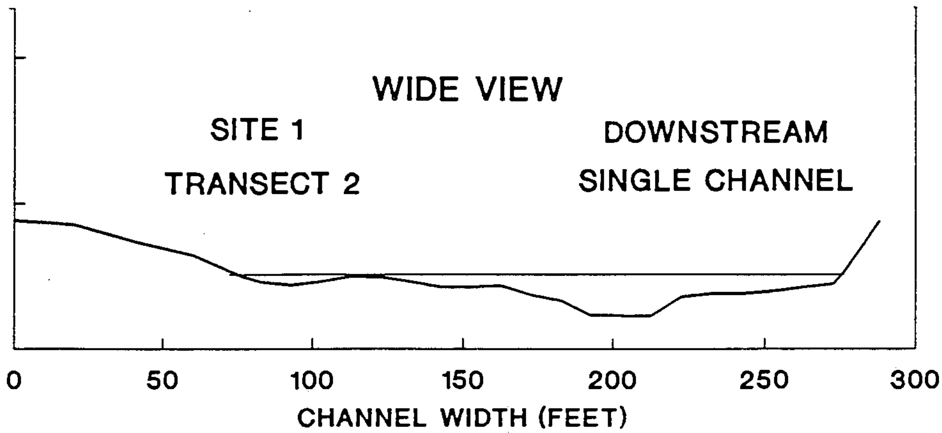


Figure III. Variation in stage and maximum depth with flow level at Transect No. 1. This transect crossed a north (1-A) and south (1-B) channel.



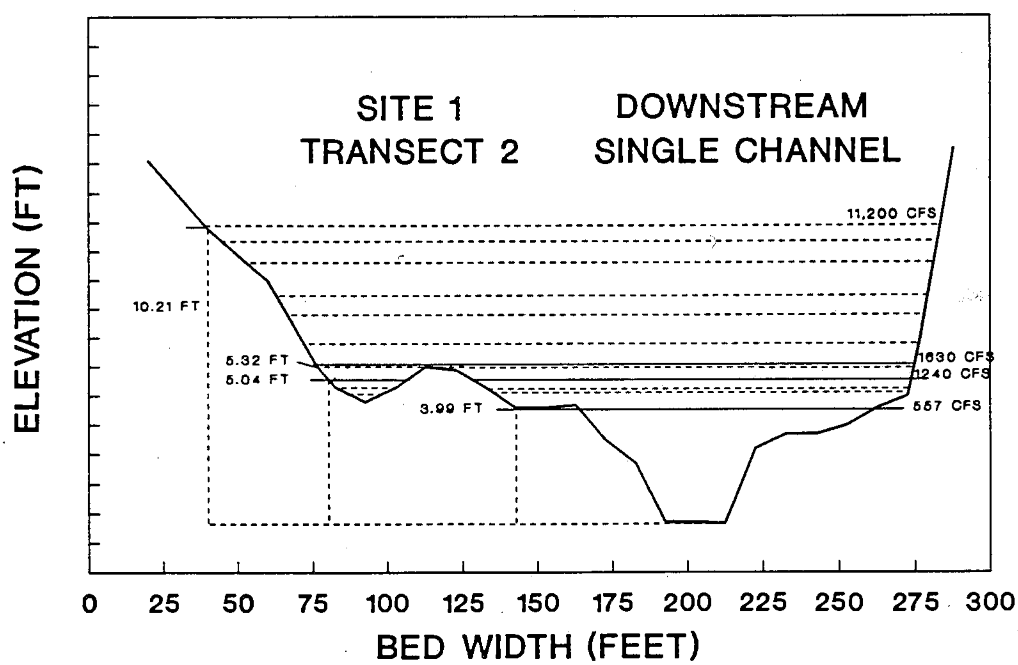


Figure IV. Variation in stage and maximum depth with flow level at Transect No. 2.

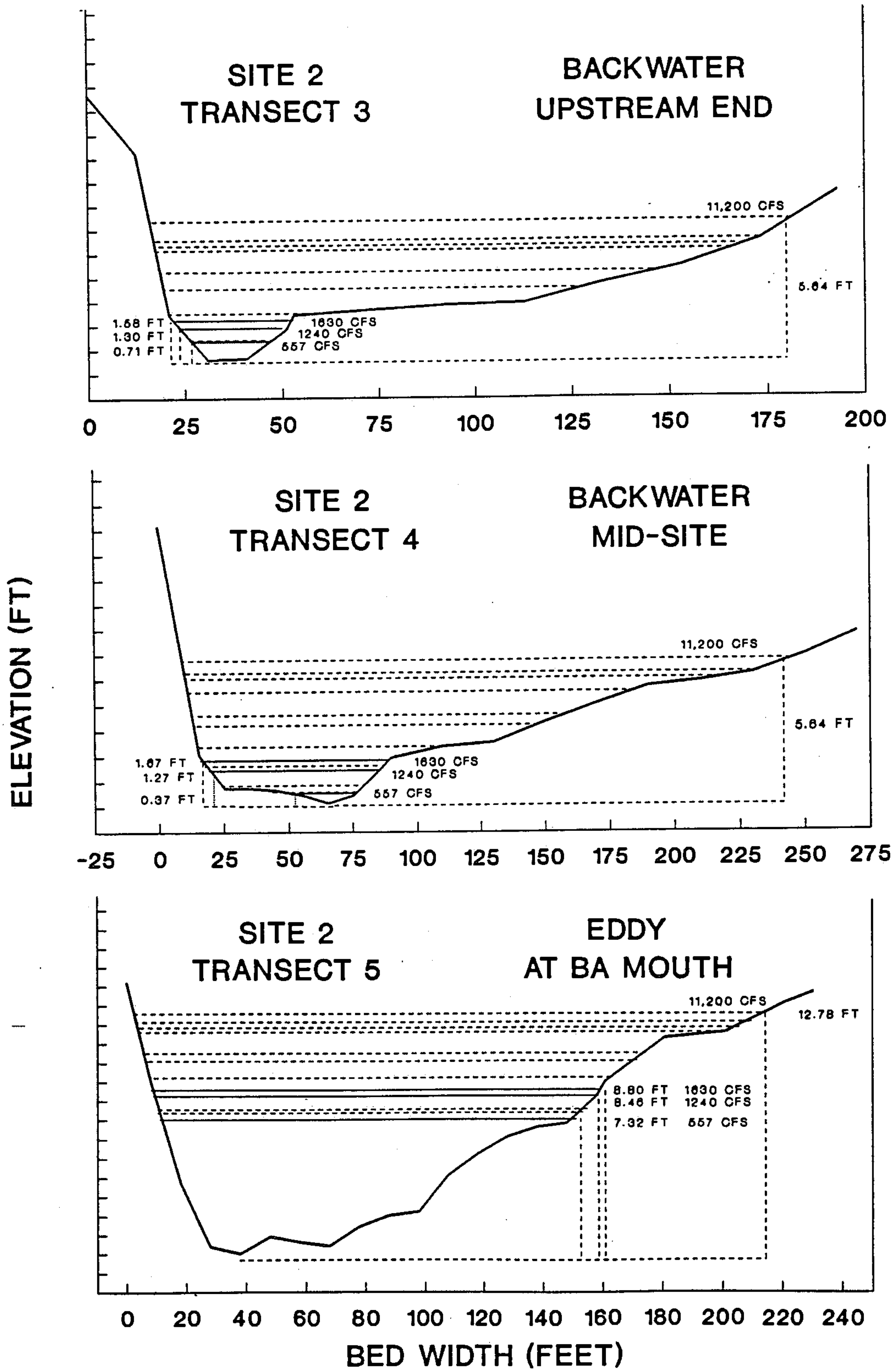


Figure V. Variation in stage and maximum depth with flow level at Transect Nos. 3, 4 and 5.

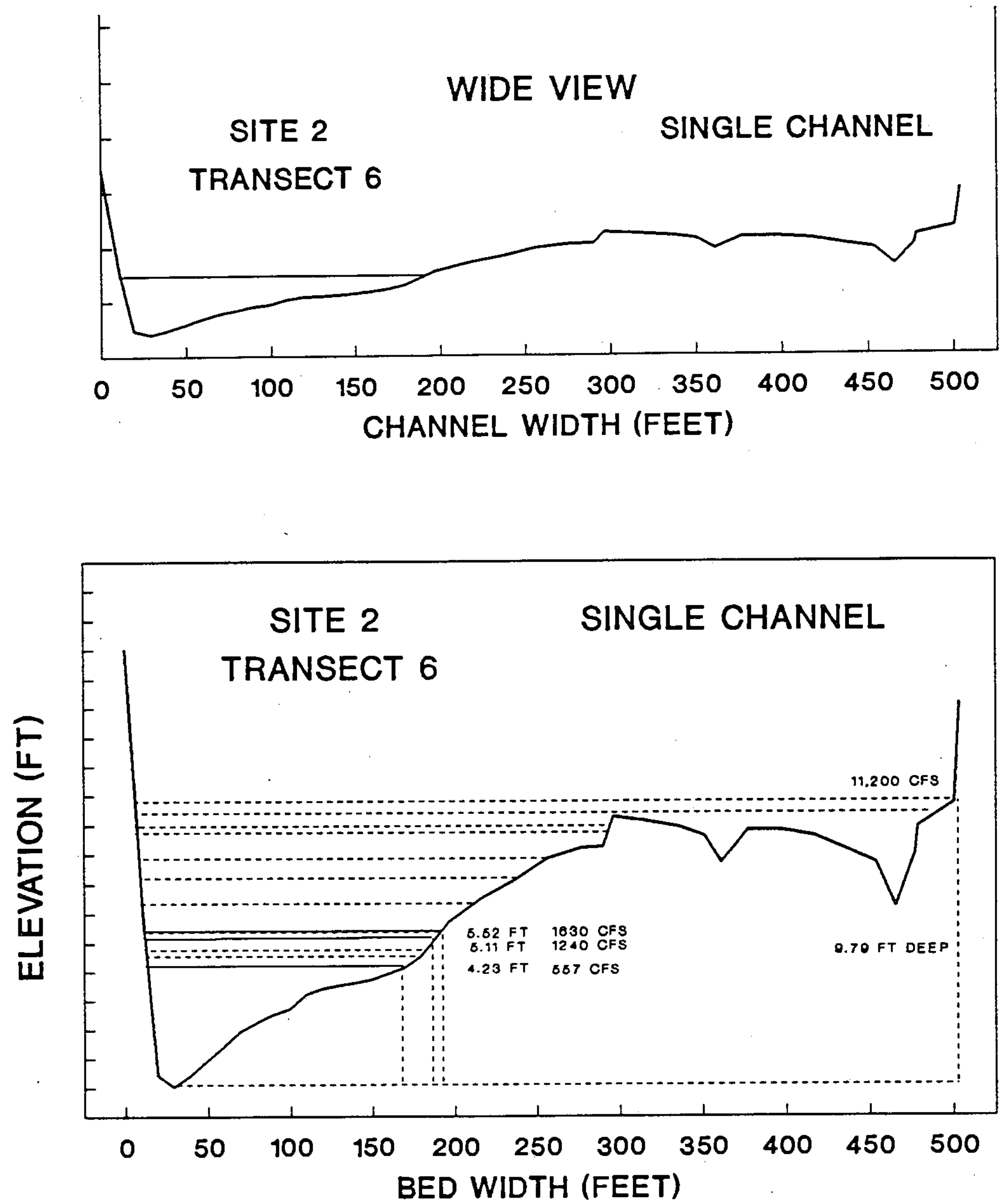


Figure VI. Variation in stage and maximum depth with flow level at Transect No. 6.

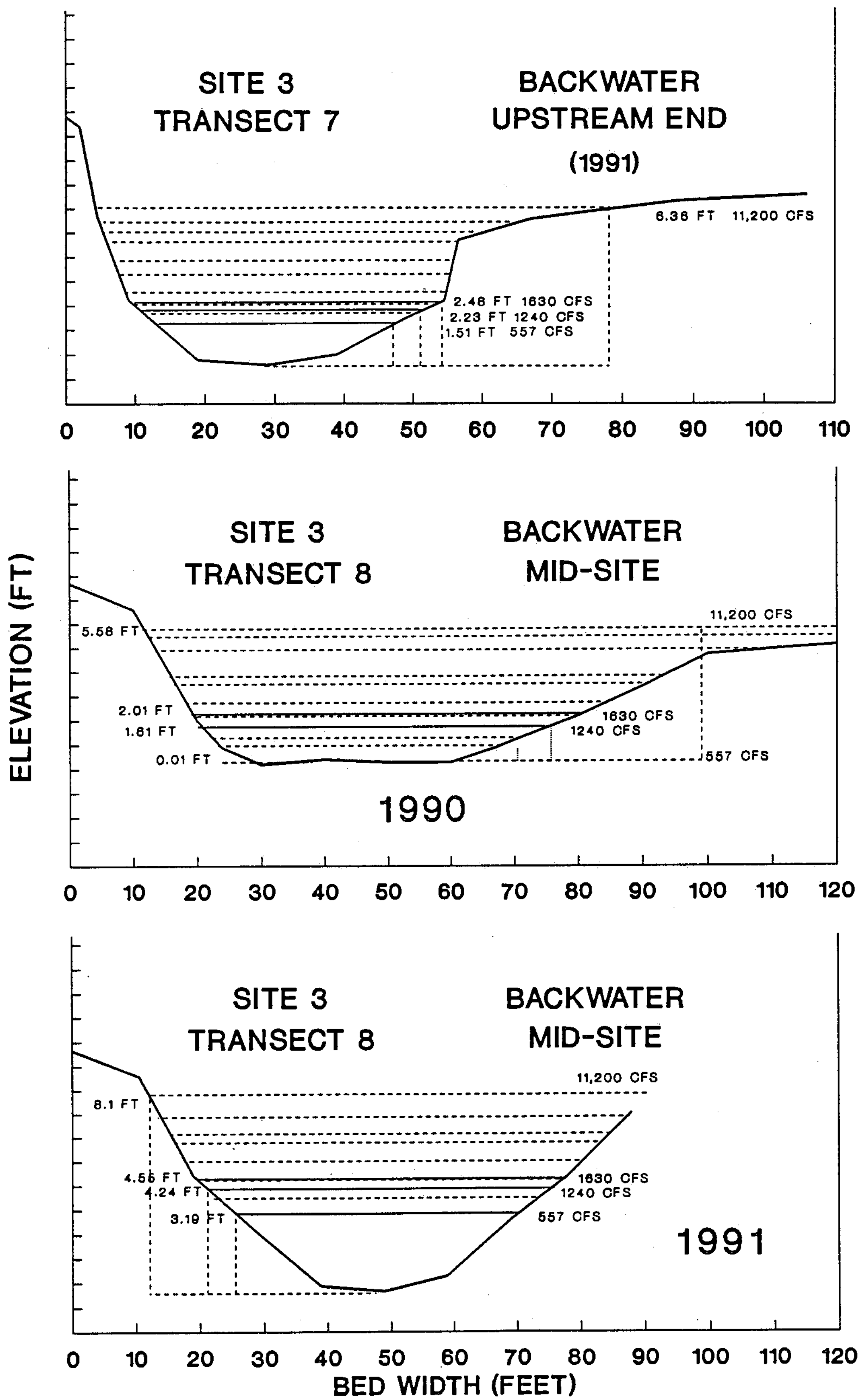


Figure VII. Variation in stage and maximum depth with flow level at Transect Nos. 7 and 8. Transect No. 8 is shown for 1990 and 1991 because of a significant change in bed elevation.

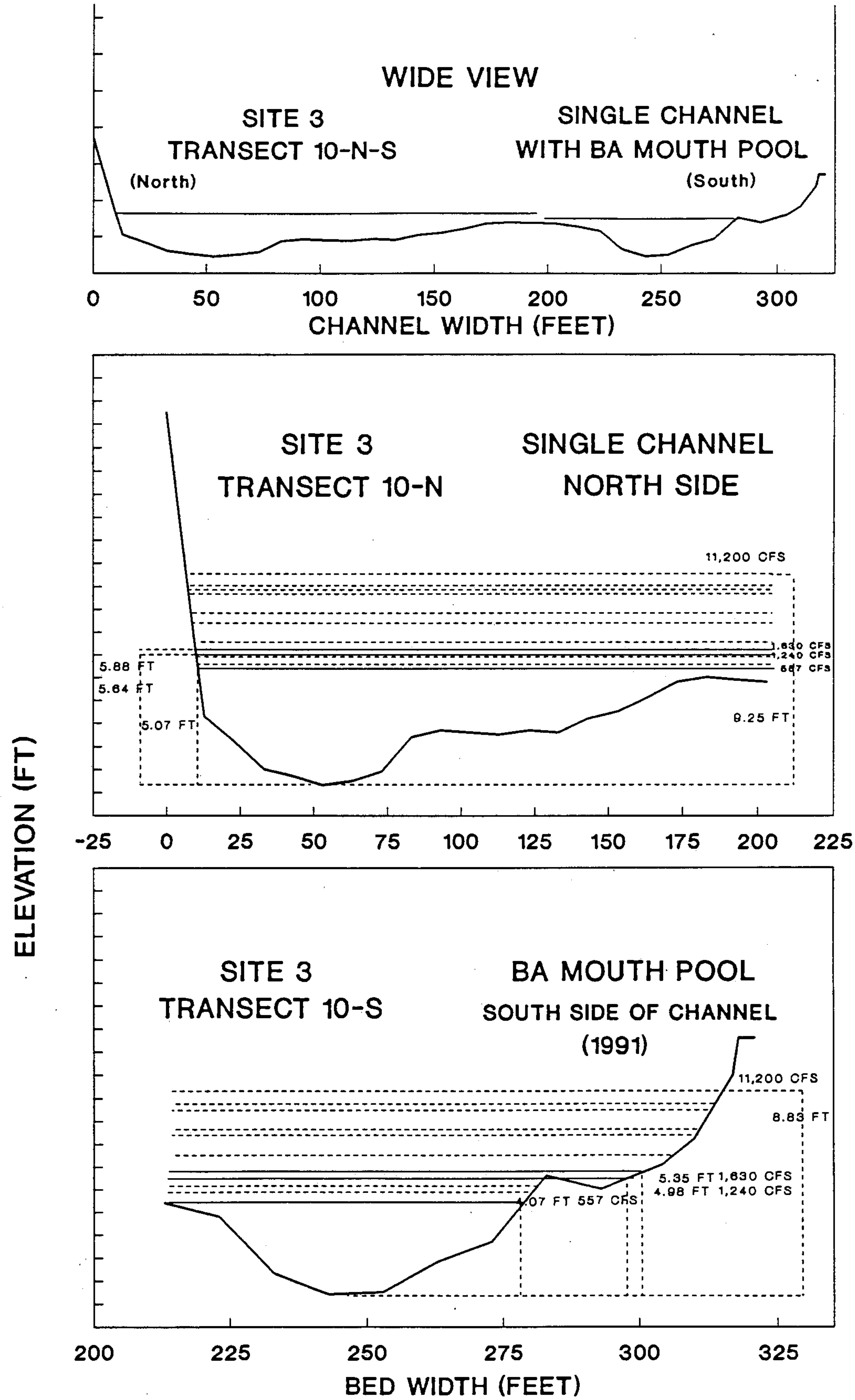


Figure VIII. Variation in stage and maximum depth with flow level at Transect No.10. This transect crossed a riffle in the middle of the channel separating a run on the north side (10-N) from a pool outside of a backwater on the south side (10-S).

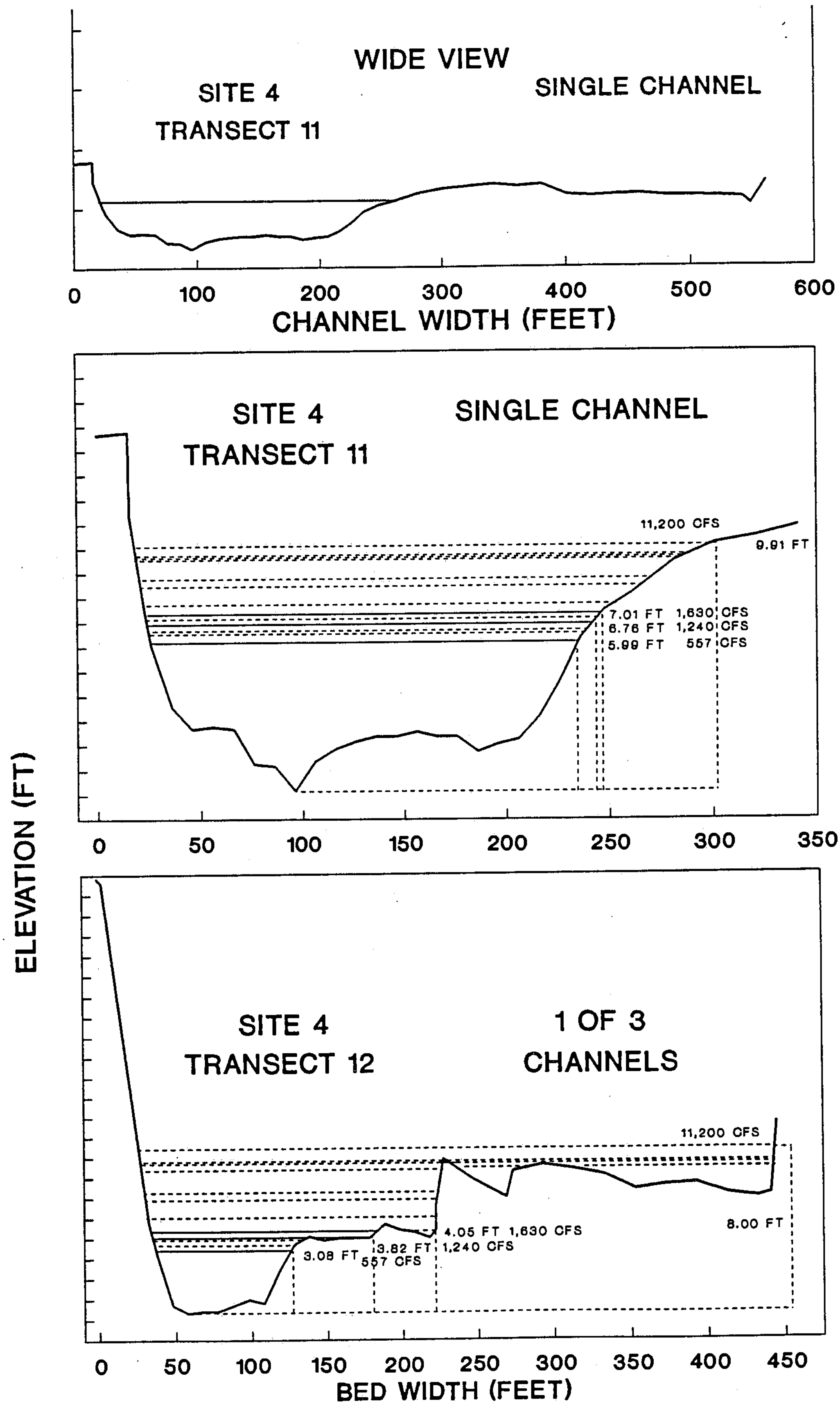


Figure IX. Variation in stage and maximum depth with flow level at Transect Nos. 11 and 12.

APPENDIX VIII

Stream Bed Cross Section Monitoring

Transect No. 1 (Fig. X)

This transect was placed across the width of the channel at RM 178.4 within site No. 1 and spanned a primary channel on the north, an island, and a secondary channel on the south. The north bank consisted of a cobble terrace; the south bank was bounded by a steep cliff.

<u>1990-1991</u>
Some scour occurred in the shallow cobble bed on the south side of the north channel and some sediment was deposited on the north side of the island. The south channel did not change.

<u>1991-1992</u>
Some sediment was redeposited in the shallow area on the south side of the north channel. Scour on the north bank of the south channel resulted in a slight widening of the channel there.

<u>1992-1993</u>
Large shifts in the bed occurred as a result of the high spring flows of 1993. The north bank was eroded back approximately 30 ft.; deposition on the south bed of the north channel created an emergent bar which in turn created an additional channel between the bar and the existing island. The island was eroded on the north side and built up with deposition on the south side. This resulted in a narrowing of the south channel.

Transect No. 2 (Fig. XI)

This transect was placed across the width of the channel at RM 178.3 immediately downstream of where the two channels of Transect No. 1 came together. Here, the river is constricted in one channel between a steep cobble bank on the north shore and a nearly perpendicular cliff on the south shore.

<u>1990-1992</u>
No perceptible stream-bed changes occurred during either 1991 or 1992.
1992-1993. Elevation of the bed could not be resurveyed in 1993 because the north headpin was lost during the spring flood when high water transformed the top of the cobble terrace.

Transect No. 3 (Fig. XII)

This transect was placed across a backwater in site No. 2 at RM 175.8. It was located near the upstream end of the backwater. The north bank consisted of a steep, artificial dike composed of boulders and chunks of concrete; the transect extended south to a high point on the adjacent island.

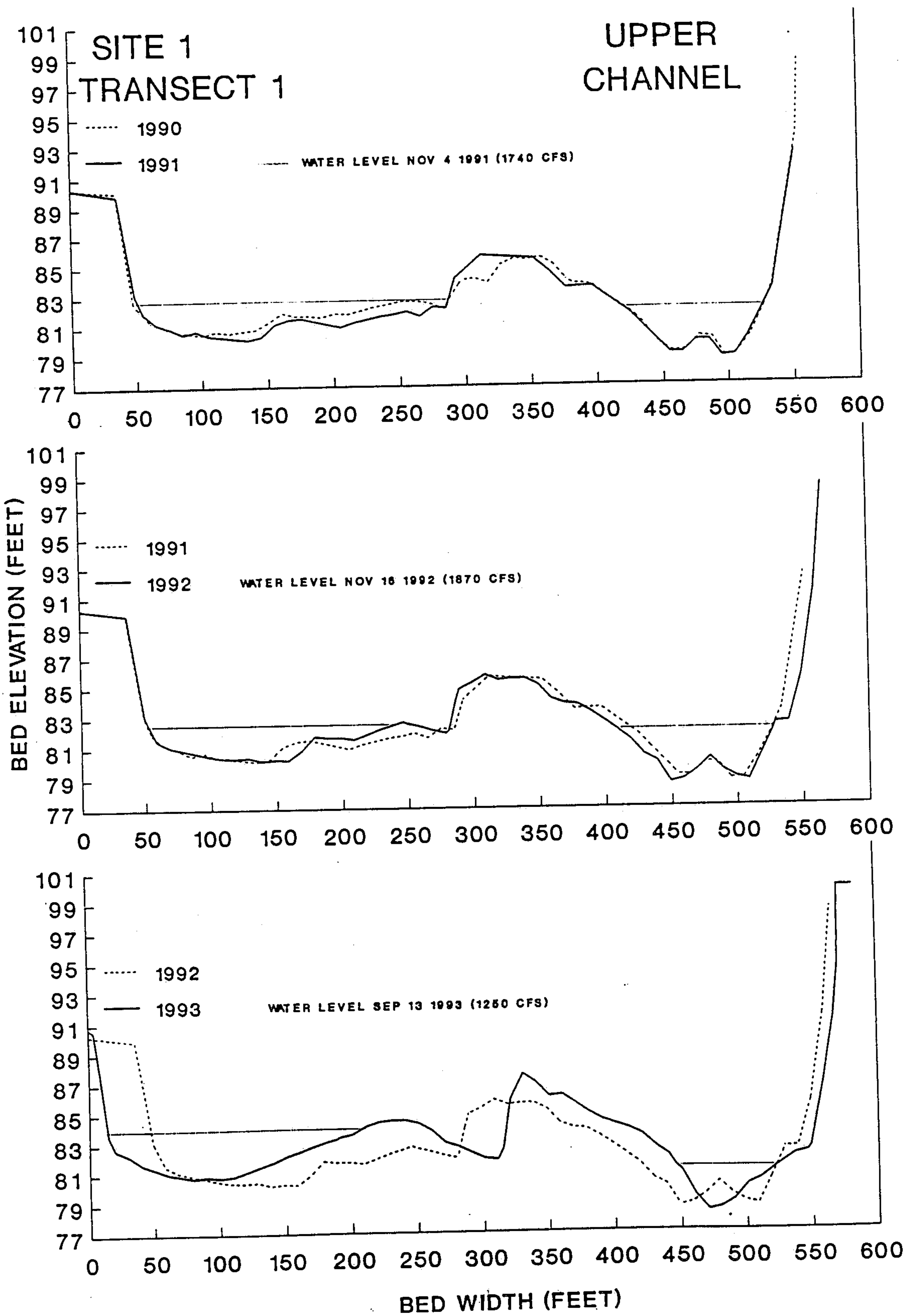


Figure X. Changes in bed elevation at Transect No. 1. Measured each fall, 1990-1993.

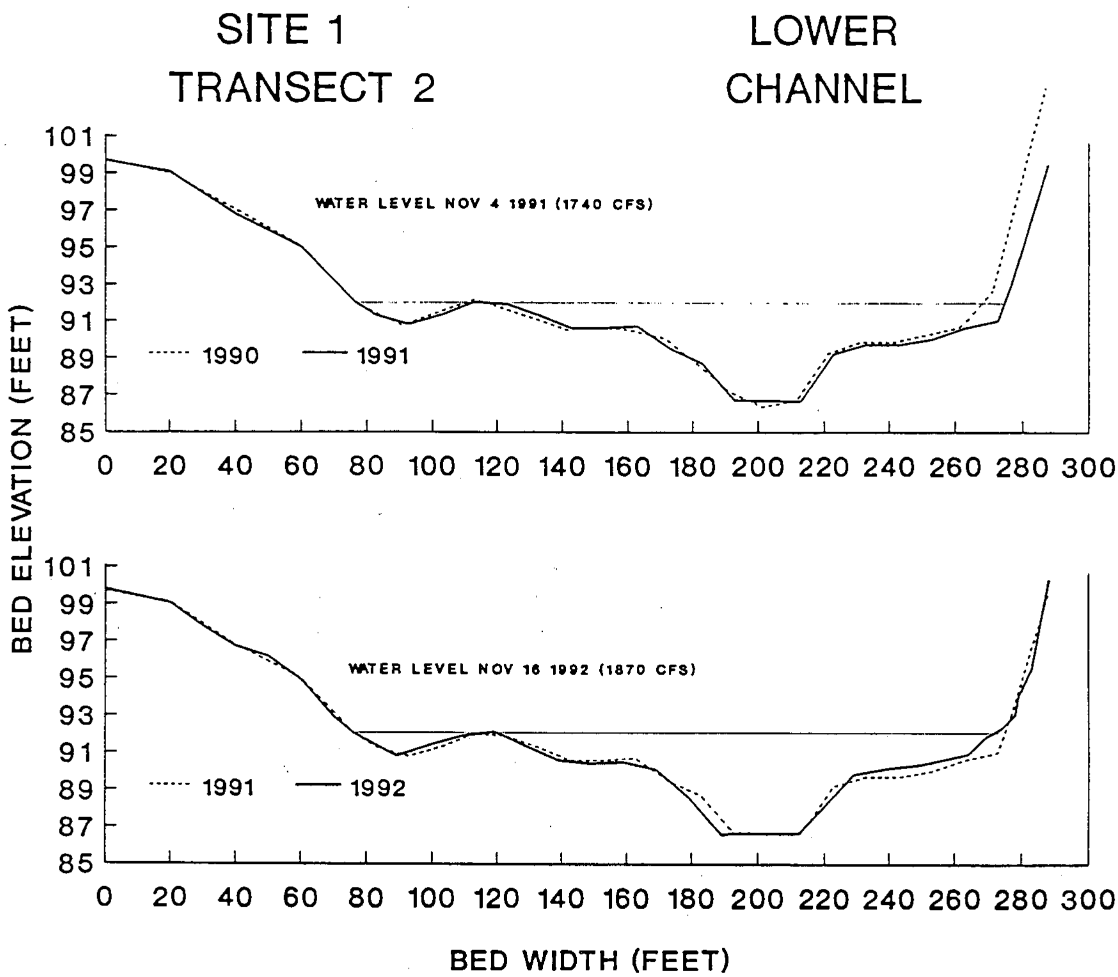


Figure XI. Changes in bed elevation at Transect No. 2. Measured each fall, 1990-1992.

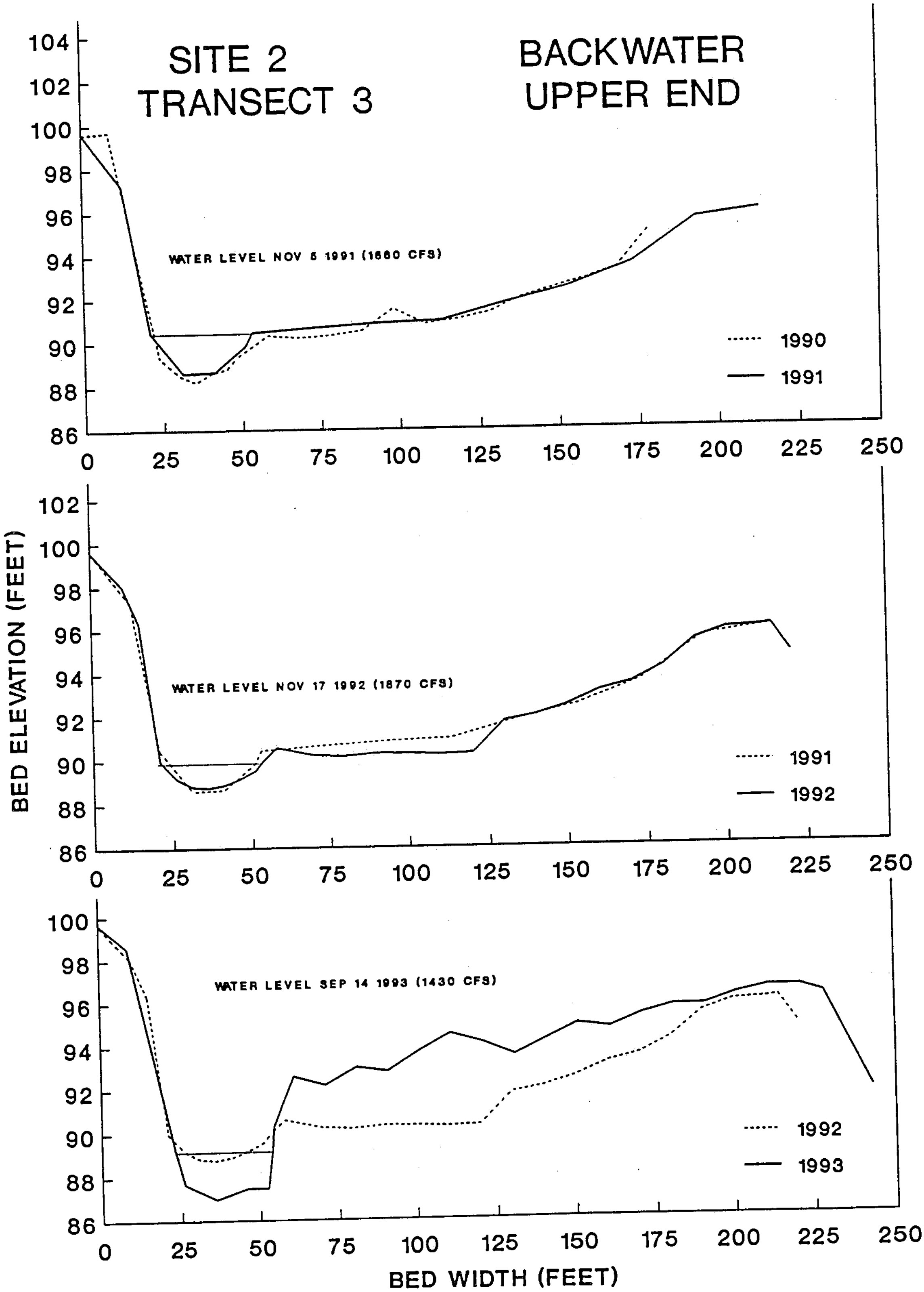


Figure XII. Changes in bed elevation at Transect No. 3. Measured each fall, 1990-1993.

1990-1991
No significant changes to the bed occurred.

1991-1992
Limited deposition of fine sediment occurred on the low-lying portion of the island adjacent to the deep point of the backwater.

1992-1993
Fine sediments were scoured from the bed of the backwater in spring, 1993. By fall, the bed was still two feet lower than it had been the previous year. Significant amounts of fine sediment was deposited on the island effectively narrowing that portion of the backwater most subject to low-water inundation.

Transect No. 4 (Fig. XIII)

This transect was also located across the large backwater within Site No. 2 (RM 175.6). It was about half way between Transect No. 3 and the mouth of the backwater. The north and south ends of the transect were placed atop the same rock dike and island as Transect No. 3.

1990-1991
A small net gain of fine sediment raised the level of the bed slightly. No perceptible change to the adjacent island occurred.

1991-1992
No change in bed elevation occurred along the length of the transect.

1992-1993
Sediment was scoured from the bed leaving a net change in depth of 1-2 ft. within the deep portion of the backwater channel making the backwater deeper during low water conditions. Fine sediment was deposited on the island raising its height 2-3 ft. Width of the deeper portion of the backwater, normally inundated at low water, did not change; width of the southern portion, inundated only at high water, narrowed and was made more shallow.

Transect No. 27 (Fig.XIV)

This transect was added in 1992. We had observed that after several years of back-to-back low flows, sediment was accumulating at the mouth of the large backwater described above (RM 175.5). The mouth, an interface zone between the zero-velocity habitat of the backwater and the recirculating eddy just outside, is a site often used by adult squawfish. This mouth area was slowly being constricted by a silt bar that was building from the island and migrating across the backwater channel toward the north shore. The opening that provided fish access to the backwater behind the bar was becoming smaller each year and vegetation was colonizing and stabilizing the bar. The transect was placed across the narrowest point of the opening and extended south to the downstream end of the island.

1992-1993
Considerable scouring of fine sediments and rooted vegetation occurred during the 1993 spring

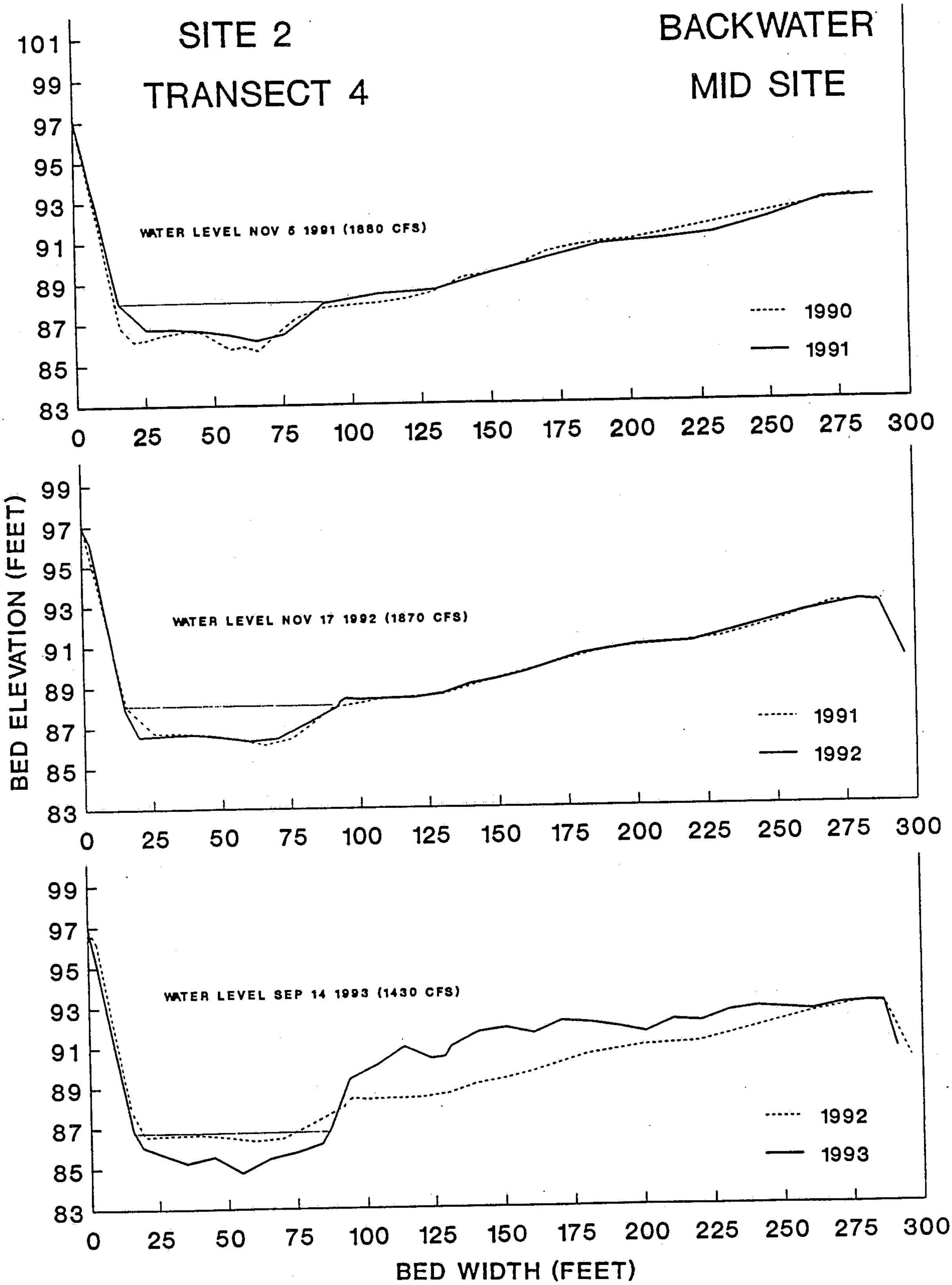


Figure XIII. Change in bed elevation at Transect No. 4. Measured each fall, 1990-1991.

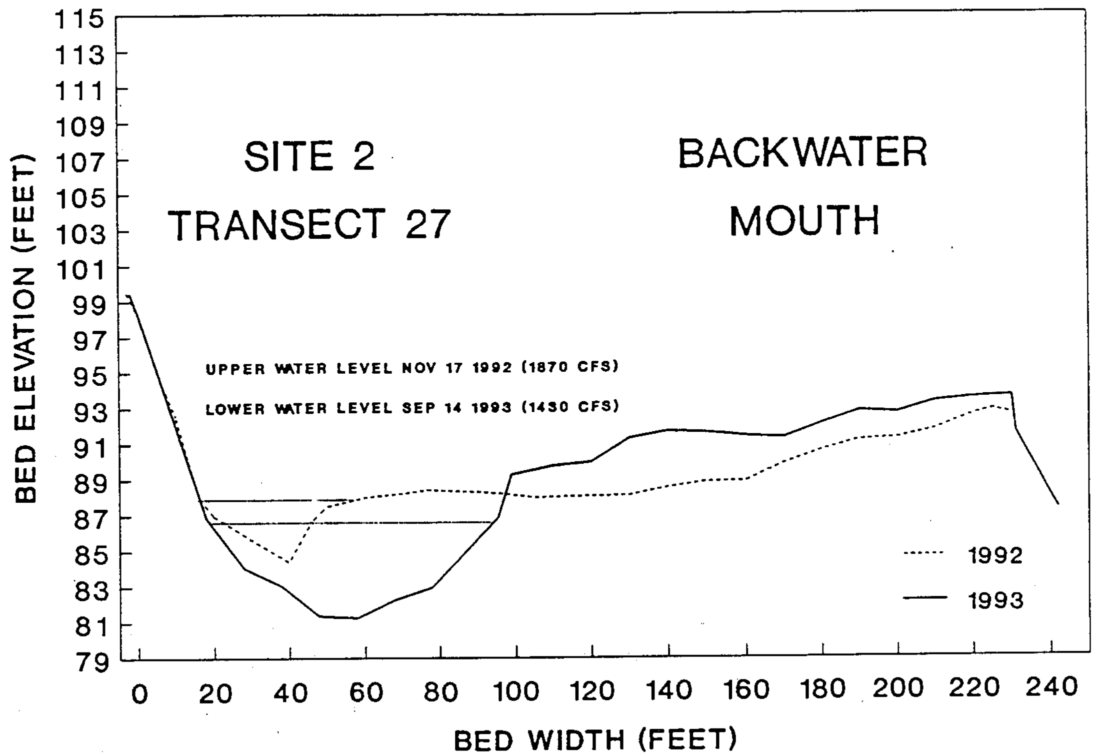


Figure XIV. Change in bed elevation at Transect No. 27. Measured in fall, 1992 and 1993.

runoff season. The opening to the backwater tripled in width from 23 ft. to 73 ft. (measured at a stage of 1,430 cfs). Depth also dramatically increased from a maximum of 2.1 ft. in 1992 to 5.3 ft. in 1993. On that portion of the island that was not eroded, sediment was deposited to a depth of 1.5-3.0 ft.

Transect No. 5 (Fig. XV)

This transect bisected the eddy that recirculated just outside the mouth of the large backwater described above. It was located at RM 175.5 also. Again, the north end of the transect was on top of a rock dike and the transect extended south to the high point on the downstream tip of the island that separated the backwater from the main channel.

<u>1990-1991</u>
There was a slight narrowing (5 ft. at 1,630 cfs) of the eddy due to accumulation of silt on the bank of the island. Bed elevation in general did not change.

<u>1991-1992</u>
Additional deposition on the island side of the bed resulted in further (30 ft.) narrowing of the eddy. Maximum depth did not change.

<u>1992-1993</u>
Erosion of fines from the island resulted in a 22 ft. widening of the eddy over 1992 conditions. Additional deposition of fines atop the island raised the elevation of the island by 0.8-1.8 ft. Movement of rock into the eddy during spring runoff raised the bed elevation in the center of the eddy by four feet; maximum depth of the bed decreased only slightly.

Transect No. 6 (Fig. XVI)

This transect was located at RM 175.4 immediately downstream of Transect No. 5 described above. The river is confined to one channel at this site; the thalweg, or deepest point, is against the north bank which again consists of a rock and concrete dike. The transect extended south to the top of a silt terrace past a small secondary channel that flows only during high water.

<u>1990-1991</u>
A minor amount of material was deposited atop the bar over which water runs from the main channel to the secondary channel during the spring runoff period. No detectable change occurred to the bed within the main channel.

<u>1991-1992</u>
No net change of the bed occurred.

<u>1992-1993</u>
A significant amount of cobble and gravel was transported from the channel bed at this site. Bed elevation dropped 1.7 ft. at the deepest point, and as much as 3.3 ft. along other portions of the transect. Some deposition of gravel, silt and debris raised the elevation of the bar that separated the main channel from the small secondary channel to the south.

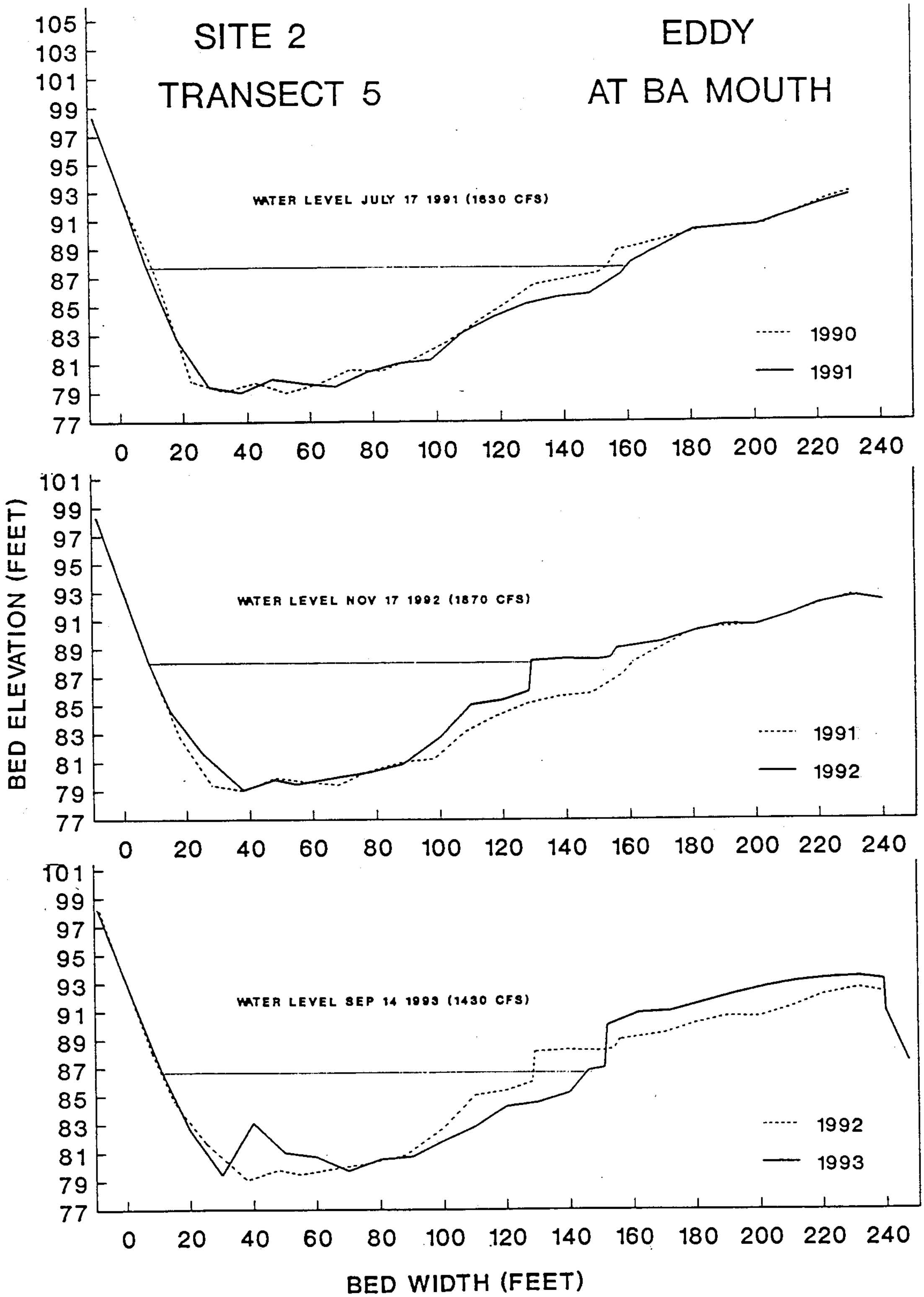


Figure XV. Change in bed elevation at Transect No. 5. Measured each fall, 1990-1993.

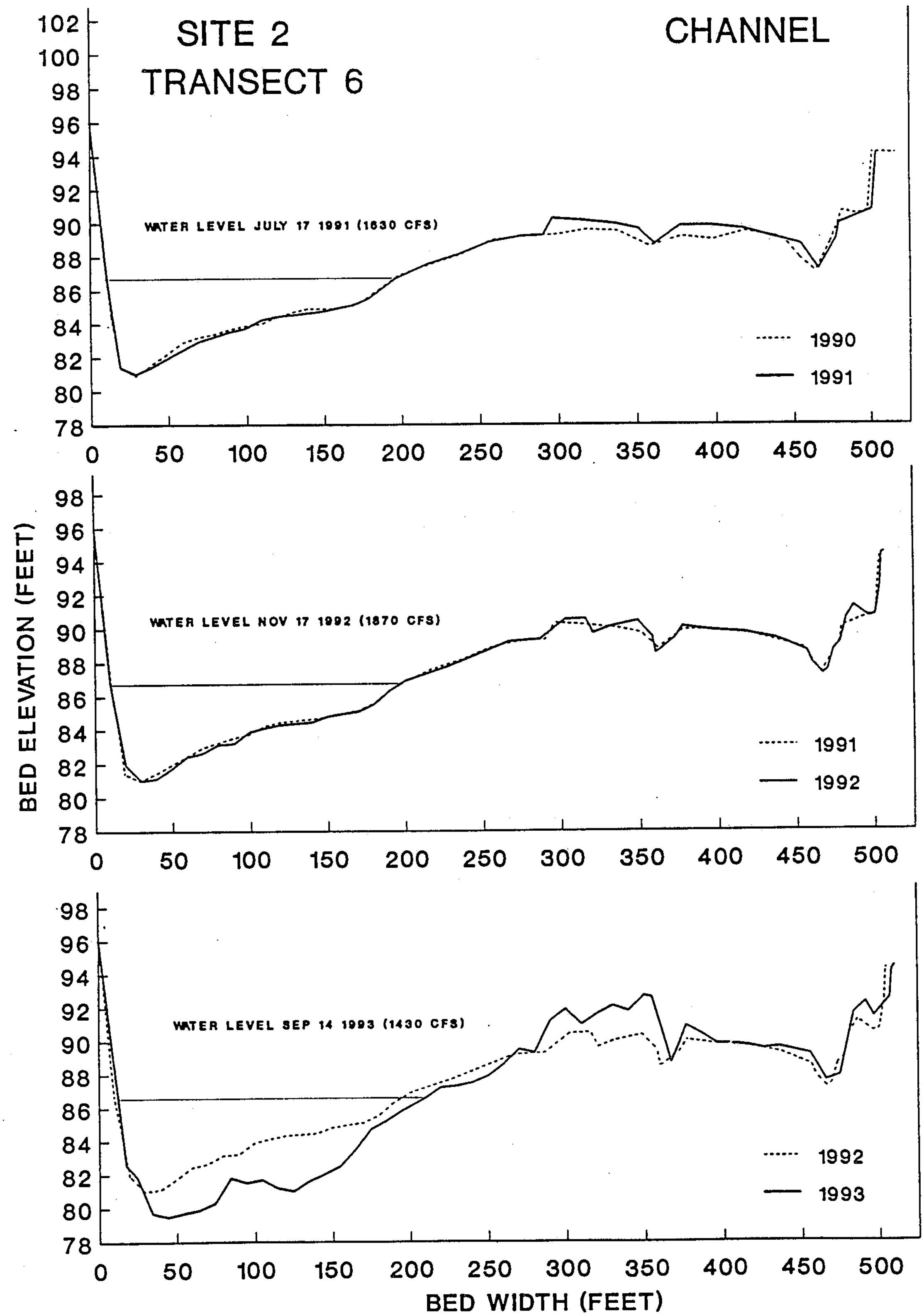


Figure XVI. Change in bed elevation at Transect No. 6. Measured each fall, 1990-1993.

Transect No. 7 (Fig. XVII)

This transect was placed at RM 175.4 across the top end of a large backwater in Site No. 3. During 1990, this end of the backwater was connected to the rest of the backwater at low flow; however, in 1991 it became separated by a silt bar that formed as water cut across the island during spring runoff and poured into the backwater just downstream of the transect. Since then the top end of the backwater has been an isolated pool during the non-runoff season. The south end of the transect was atop a vegetated, silt terrace that dropped steeply into the water; on the north side of the backwater, the transect extended half way across the island that separated the backwater from the main channel.

<u>1990-1991</u>
Some silt was deposited on the north side of the backwater bed as well as on top of the adjacent island.

<u>1991-1992</u>
Some silt was eroded from the north side of the backwater bed where it had been deposited the year before, but more was laid down on the south side. Maximum depth was unchanged.

<u>1992-1993</u>
Width of the backwater (isolated pool) was halved from 46 ft. to 22 ft. following the 1993 spring runoff season. A large amount of sediment was deposited on the north side extending the width of the island out into the backwater channel. Some fine sediment was removed from the backwater bed on the south side leaving the maximum depth unchanged.

Transect No. 8 (Fig. XVIII)

This transect was placed at RM 175.3 across the same backwater in Site No. 3 described above. It crossed upstream of the mouth, about one-third the way towards the top end of the backwater, at approximately the widest and deepest point. The south bank was a vegetated, low-lying cottonwood bottomland; the north bank, an island densely covered with young willow.

<u>1990-1991</u>
The site was relatively shallow (3.3 ft.) when it was first surveyed in 1990 and we suspect fine sediment had accumulated there during the preceding two low-water years. Spring flows in 1991 scoured a substantial amount of sediment from the backwater bed, and by fall, bed elevation at the deepest point was still 2.7 ft. lower than in 1990. Thus, maximum depth of the backwater at a flow of 1,630 cfs increased from 3.3 ft. to 6.0 ft. Deposition on the island resulted in narrowing the backwater by 13% when river discharge was 1,630 cfs.

<u>1991-1992</u>
Lower spring discharge in 1992 resulted in a net increase in bed sediment by fall, i.e., sediment deposition during the year was greater than sediment removal during spring. Elevation of the bed was raised 2.1 ft. Maximum water depth was only 2.6 ft. at a flow of 1,870 cfs. Width of the backwater was relatively unchanged.

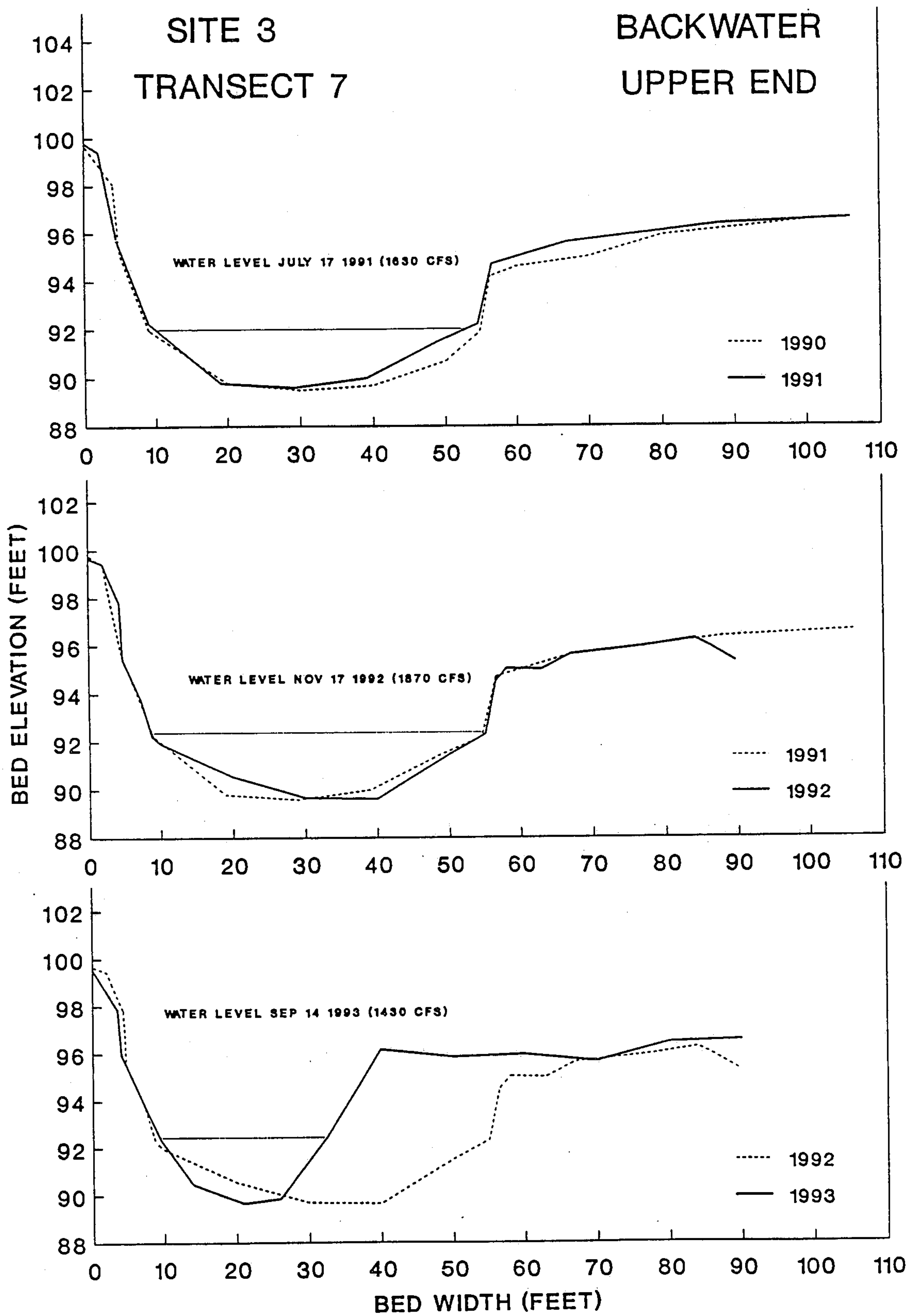


Figure XVII. Change in bed elevation at Transect No. 7. Measured each fall, 1990-1993.

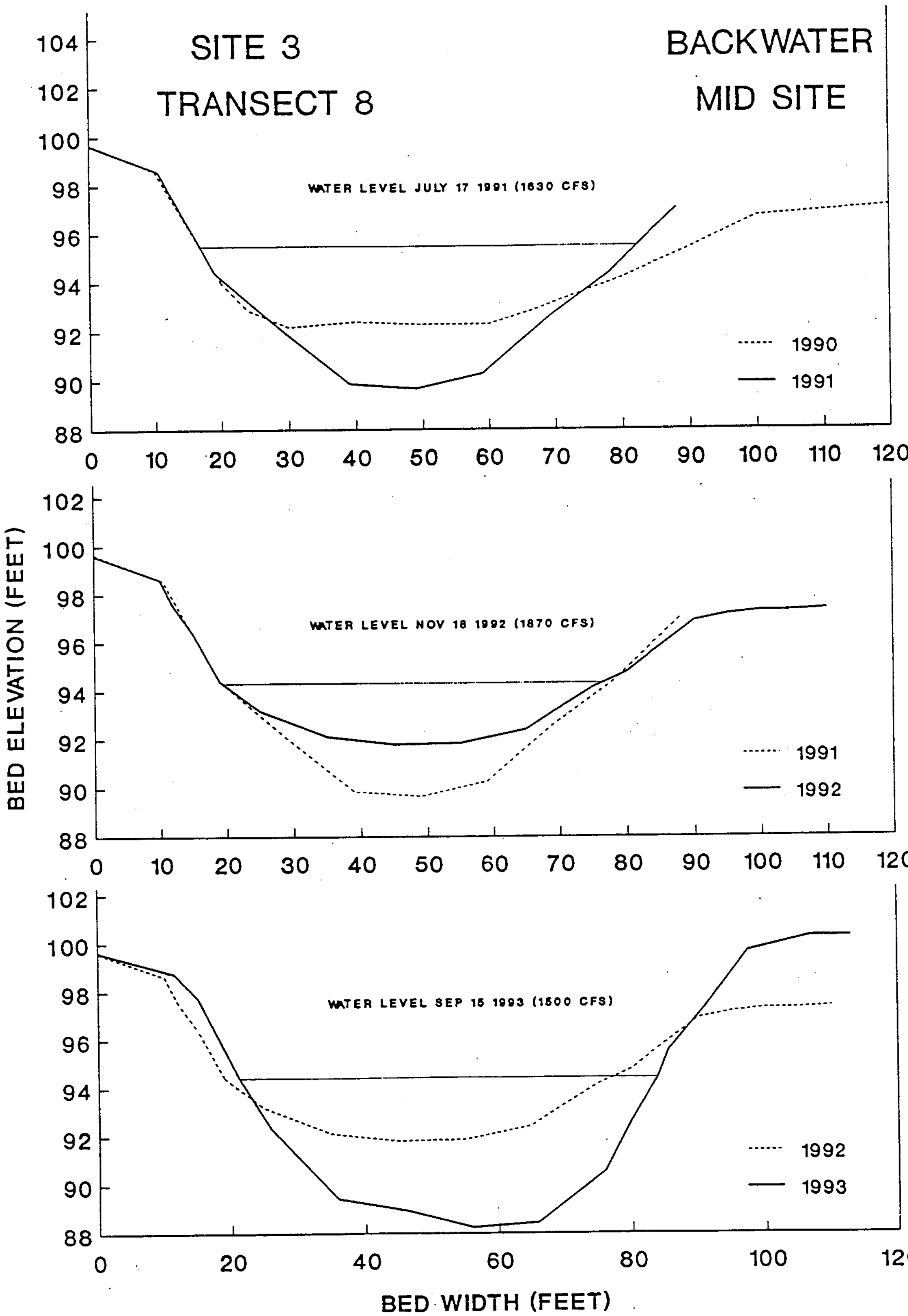


Figure XVIII. Change in bed elevation at Transect No. 8. Measured each fall, 1990-1993.

1992-1993

High discharge in spring 1993 scoured a large amount of sediment from the bed again. By fall, the bed was still as much as 4.0 ft. lower than it had been the previous year. This provided a water depth of 6.3 ft. at a flow of 1,500 cfs. Width of the backwater was relatively unchanged. Deposition of fine sediment around the base of the dense willow trunks increased the height of the island by 3.0 ft.

Transect No. 9 (Fig. XIX)

This transect was also placed across the backwater in Site No. 3. However, it was laid out diagonally instead of perpendicular to the long axis of the backwater: the south end was near the mouth of the backwater while the north end shared a common point with the north end of Transect No. 8.

1990-1993

Changes in the bed were similar to Transect No. 8 in most respects with the exception of deposition of sediment on the south bank in 1991.

Transect No. 28 (Fig. XX)

This was an additional transect established in fall of 1992. Like the mouth of the backwater at site No. 2 described previously, the opening to the channel here was slowly being bridged by a silt bar that extended from the south shore to the downstream end of the island. At a river flow of 1,430 cfs, only a small, 19-ft.-wide by 2.0-ft.-deep channel remained to allow fish access to the backwater. During the low flows of summer, it was impassable. In addition, vegetation was becoming established across the top of the bar.

1992-1993

High spring flows of 1993 were successful at uprooting tamarisk seedlings and removing the silt bar. In fall, the width of the backwater mouth at 1,430 cfs had increased to 134 ft.; maximum water depth had increased from 2.0 ft. to 5.2 ft.

Transect No. 10 (Fig. XXI)

This transect crossed the river at RM 175.3 within site No. 3. The south end was located just outside the mouth of the backwater described above. From there it crossed a pool, a cobble riffle and a main channel run. The north bank was a steep dike composed of chunks of discarded concrete. Most of the main channel flowed along the base of the dike; some flowed to river left, where it dropped across a submerged, cobble-bar riffle and into the pool. More squawfish have been captured in recent years from this pool and adjoining backwater than from any other site in the 15-mile reach.

1990-1991

The run and riffle stream bed showed no sign of change. However, the pool was deepened by 0.5 ft. and widened by 14 ft. (22%) by scour of bottom and bank sediments.

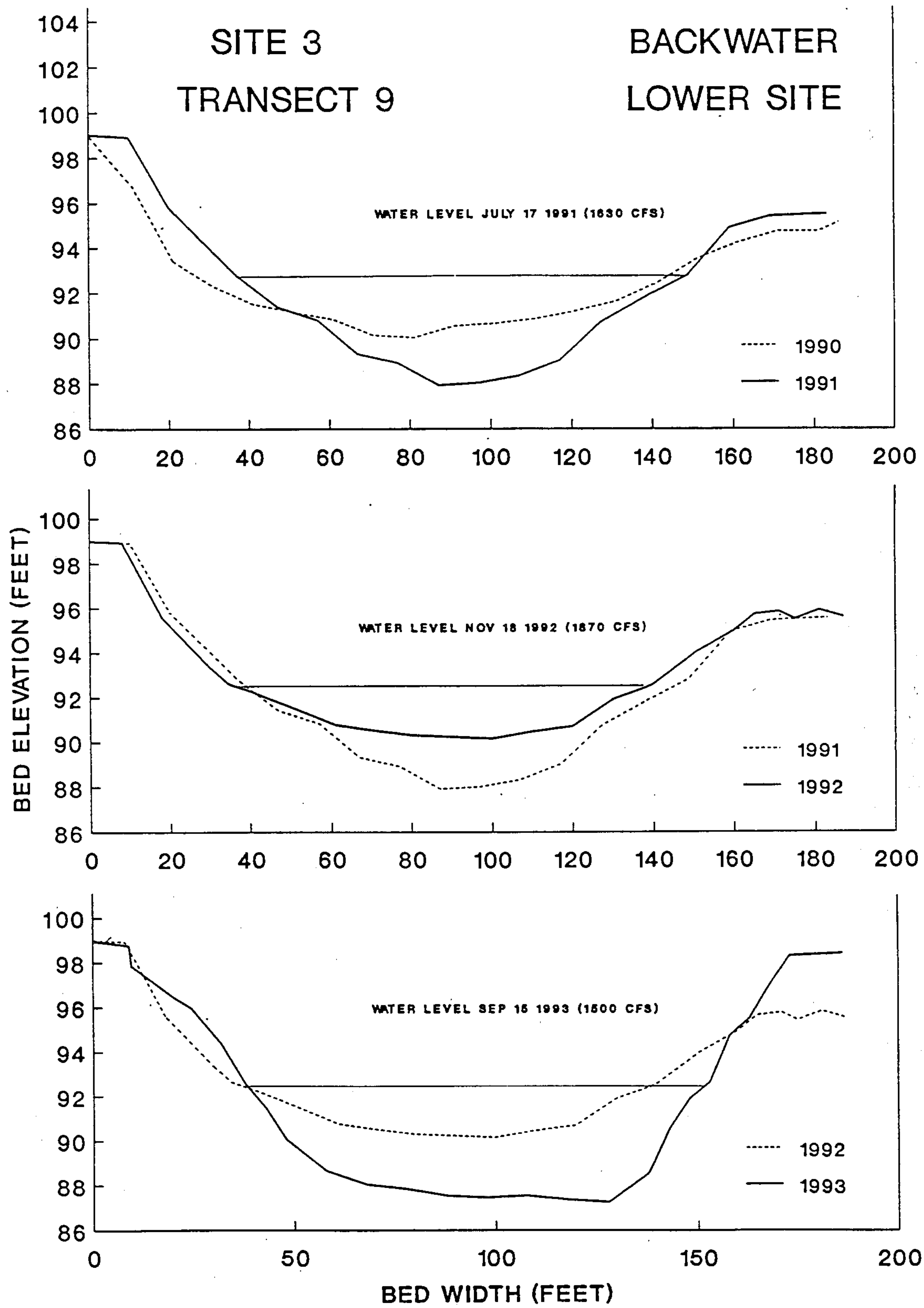


Figure XIX. Change in bed elevation at Transect No. 9. Measured each fall, 1990-1993.

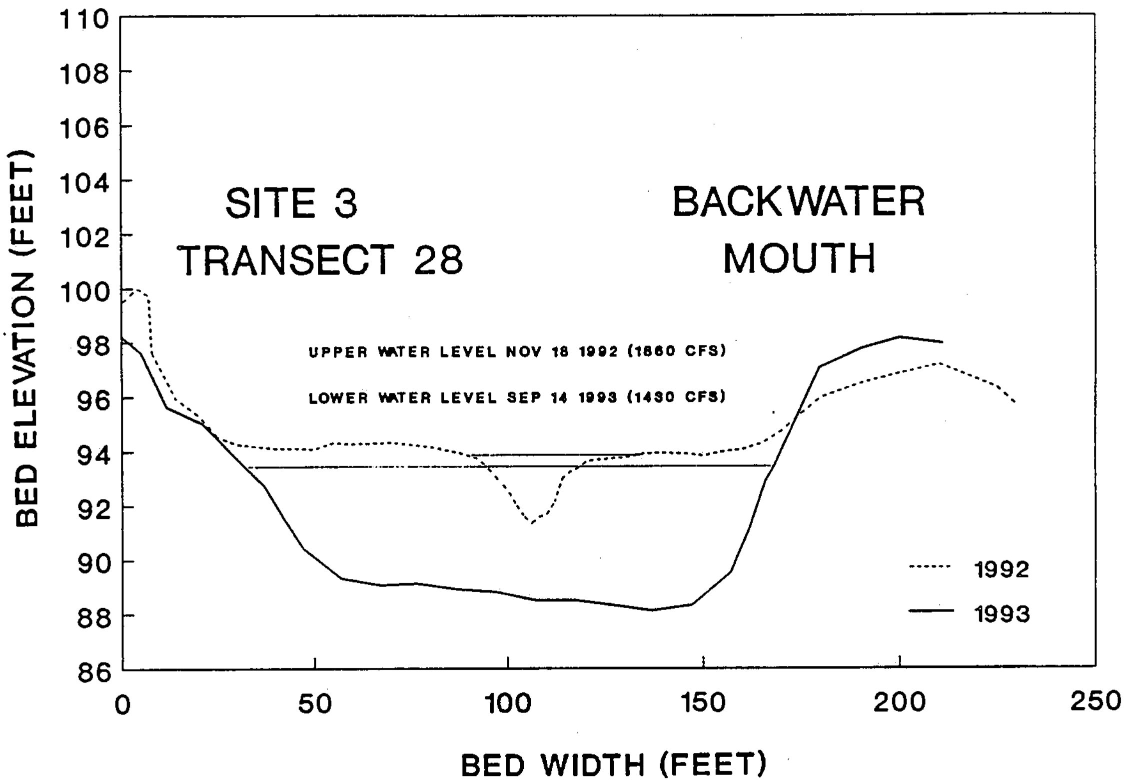


Figure XX. Change in bed elevation at Transect No. 28. Measured in fall of 1992 and 1993.

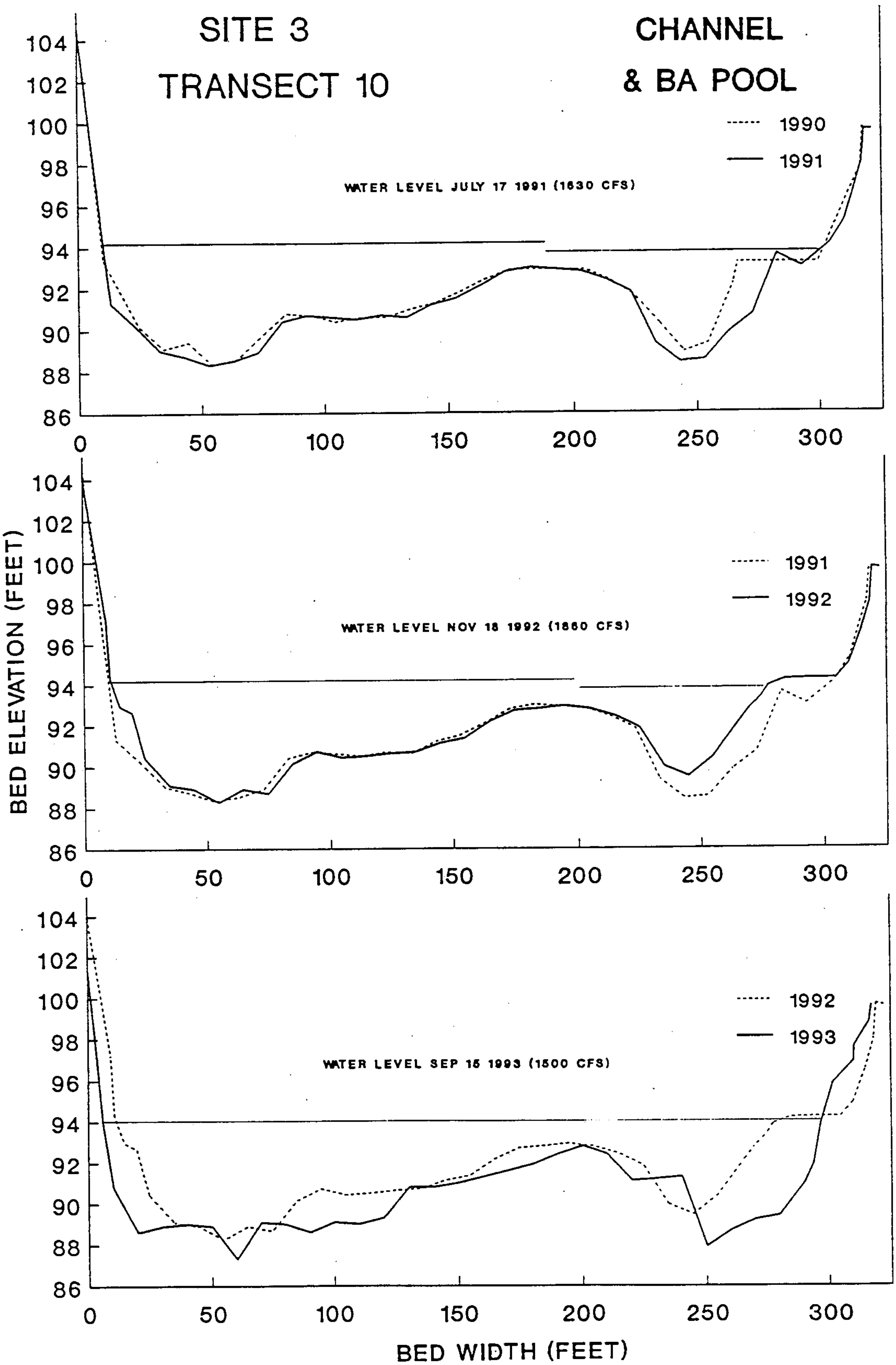


Figure XXI. Change in bed elevation at Transect No. 10. Measured each fall, 1990-1993.

1991-1992
Bottom contours of the run and riffle again did not change. However, fine sediment settled out in the low-velocity pool and water depth and pool width decreased.

1992-1993
Coarse bed material was evidently mobilized during the high spring flows of 1993: the entire bed cross section significantly changed. The main-channel river bed was lowered and portions of each side of the submerged cobble bar were removed. At flows of 1,500 cfs, the riffle was largely gone and the gradient from the run to the pool was reduced. Considerable erosion of fine sediments from the south side of the pool left the pool widened and deepened. At 1,500 cfs, maximum pool depth was increased by about two feet.

Transect No. 11 (Fig. XXII)

This transect was located in Site No. 4 at RM 174.8. The river, confined to a single channel, is a slow run at most flows, a fast run at high flows, and can become a pool at extremely low flows. The north end of the transect was atop a steep bank that was the remains of an old gravel-pit dike that was sheared off during the high runoff period in 1983. After crossing the primary channel, the transect extended south across a wide, low-lying, cobble area that becomes submerged only at very high flows. The transect ended on a raised piece of ground that also was part of the dike that surrounded the gravel pit prior to the high water year of 1983.

1990-1992
Elevation of the bed did not change in either 1991 or 1992.

1992-1993
Some of the coarse sediment transported from sites upstream during the high water of 1993 settled in this spot raising the elevation of the bed by as much as 2.5 ft. The channel was slightly narrowed by deposition on the south bank.

Transect No. 12 (Fig. XXIII)

This transect crossed a channel at RM 174.4 in Site No. 4. This is a complex portion of river that was formerly a large gravel pit pond prior to the high runoff year of 1983. The river that year carved a channel into one pond, mentioned above, and then into this larger pond. The entire river changed its course and has since flowed through what was once the bottom of these two ponds. The channel splits here and each resulting channel bifurcates again to form a total of four distinct channels. Transect No. 12 was placed across the primary channel where it flows to the south around a large island that was once the downstream dike of the larger pond. The west end of the transect was atop the steep-banked dike; the south end, on some raised ground on an island. The transect crossed a fast run, a shallow pool, and then across a relatively flat expanse of silt colonized by an extremely dense stand of tamarisk. By the end of the study, these tamarisk were 10-15 ft. high.

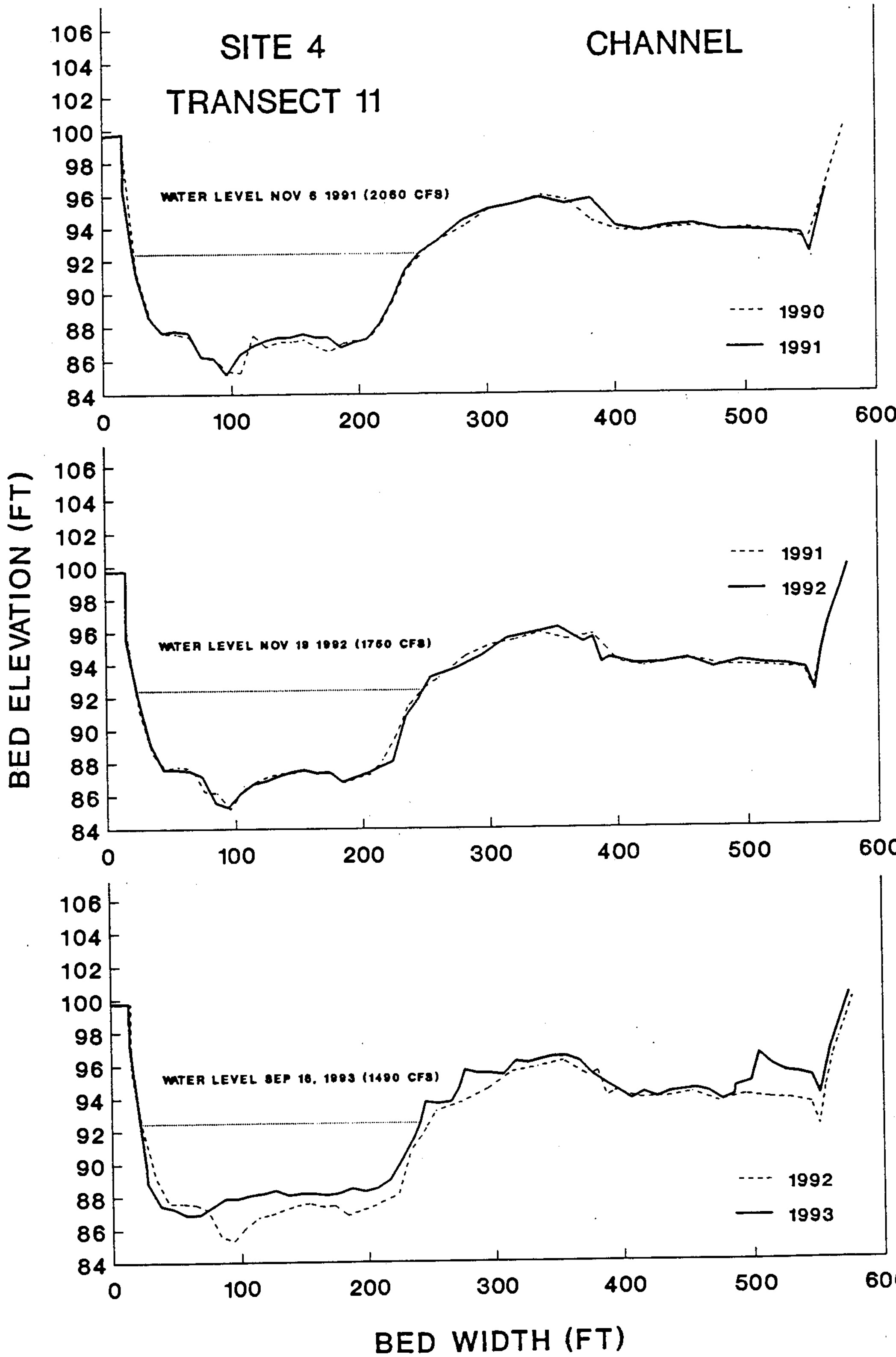


Figure XXII. Change in bed elevation at Transect No. 11. Measured each fall, 1990-1993.

1990-1991

Bed materials in the channel at the base of the dike consisted of loose cobble. These mobilized and were transported downstream during 1991, resulting in a significantly deeper channel. Deposition of fine sediment in the shallow pool narrowed the effective width of the channel. No change in elevation of the tamarisk flat was noted.

1991-1992

Scour and fill was reversed in 1992. Some sediment was deposited in the deep portion of the channel while the shallow pool area was deepened.

1992-1993

Significant bed and bank cutting upstream of the transect site had been occurring for several years resulting in a redirection of much of the flow into a separate channel. By the end of spring 1993, the channel that transect No. 12 spanned was no longer the primary channel. A significant reduction in depth and width resulted from deposition across the entire channel. The bed was raised approximately two feet within the active channel as well as across the tamarisk flat.

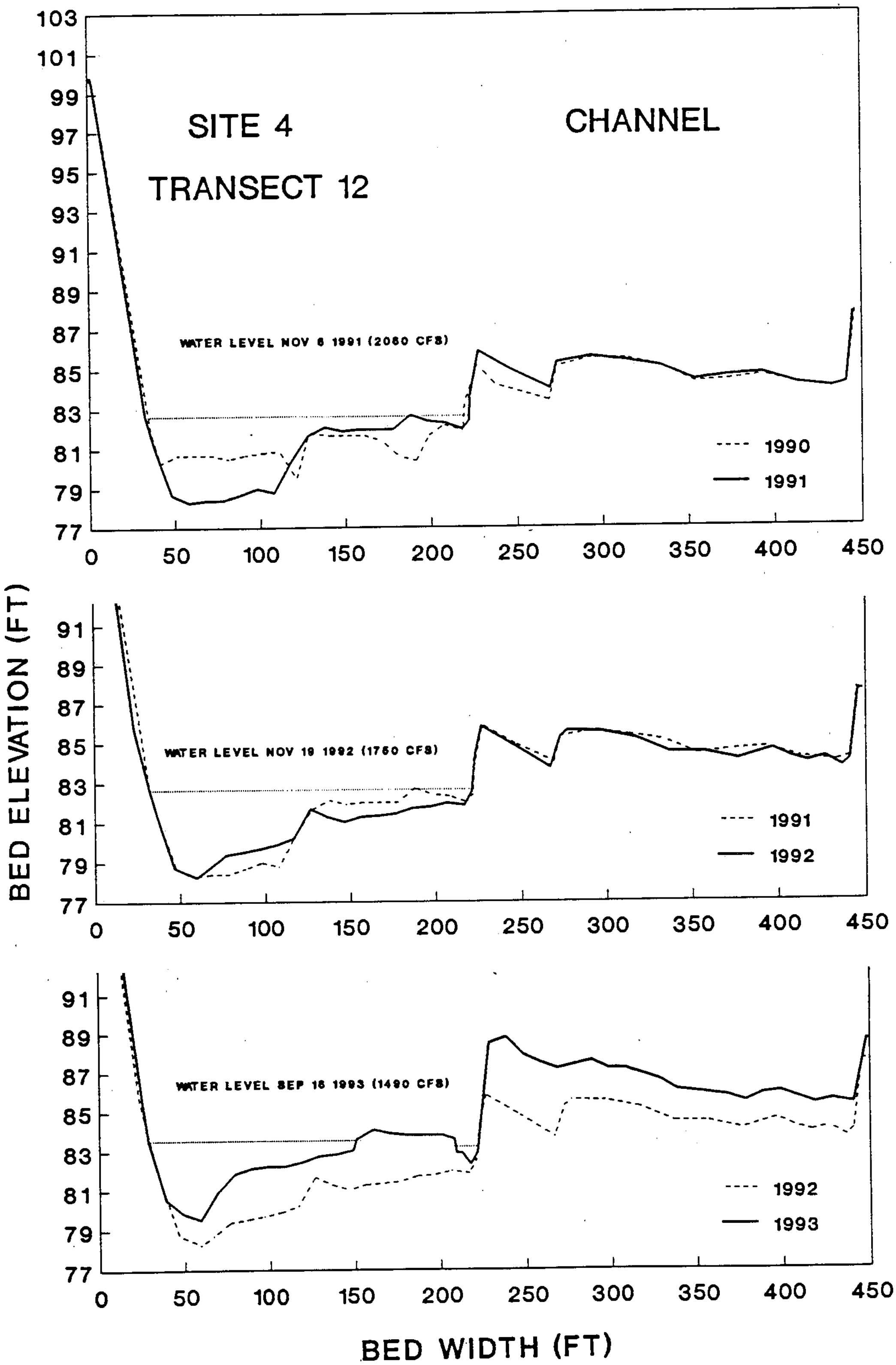


Figure XXIII. Change in bed elevation at Transect No.12. Measured each fall, 1990-1993.

APPENDIX IX

U. S. Fish and Wildlife Service 1991 report on spring and winter flow recommendations.

RECOMMENDATIONS FOR FLOWS IN THE 15-MILE REACH DURING OCTOBER-JUNE FOR MAINTENANCE AND ENHANCEMENT OF ENDANGERED FISH POPULATIONS IN THE UPPER COLORADO RIVER

FINAL REPORT
April 1991

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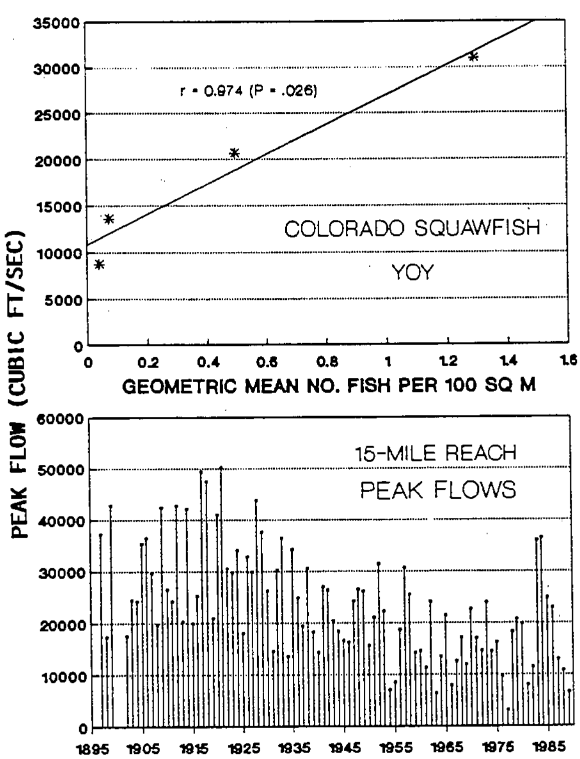

U. S. FISH AND WILDLIFE SERVICE

RECOVERY PROGRAM FOR THE ENDANGERED FISHES OF THE UPPER COLORADO

U.S. Fish and Wildlife Service • P.O. Box 25486 • Denver Federal Center • Denver, Colorado 80225 • (303) 236-2985

PROLOGUE

This is the second of two reports that collectively provide recommendations for year-round flows in the 15-mile reach of the upper Colorado River. The conclusions and recommendations presented in the report are based on the best available biological information. A study is currently being conducted that will help refine these recommendations. This study will relate habitat quality, quantity, and diversity to incremental river discharge levels. A third report will be prepared in 1992 that will include the results of the new study, summarize recommendations made in the two preceding reports, and include appropriate modifications to the flow recommendations based on the new information.

Future studies in the upper Colorado River subbasin will no doubt provide additional information and improve our understanding of the relationships between flow and the well-being of endangered fish populations. As a result, there will be a continuing effort to refine the recommendations for flows needed to recover these species. A more riverwide approach will be needed which would include the flow needs of humpback and bonytail chub, species that do not inhabit the Grand Valley and are therefore not considered in these reports.

The Recovery Program's Implementation Committee has the responsibility for implementing the flow recommendations contained in this report. Consequently, the report will be transmitted to the Implementation Committee for their immediate consideration.

Director, Colorado River Recovery
Implementation Program

U.S. Fish and Wildlife Service • U.S. Bureau of Reclamation • Western Area Power Administration
Colorado • Utah • Wyoming • Environmental Groups • Upper Basin Water Users

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ACKNOWLEDGEMENTS

We thank George Smith and Jim Rinne of U.S. Fish and Wildlife Service, Dan Collins of U.S. Geological Survey, and Phil Bertran of Grand Valley Irrigation Company for providing current and historic hydrology records. Charles McAda provided much valuable assistance with data analyses, and Cheryl Harris provided administrative support. We also thank the 10 reviewers (Appendix Table XI) who provided comments on earlier drafts of this report.

INTRODUCTION

Use of the 15-Mile Reach

The 15-mile reach of the upper Colorado River between Palisade, Colorado and the confluence of the Colorado and Gunnison rivers at Grand Junction is habitat for the endangered Colorado squawfish (*Ptychocheilus lucius*) and the very rare razorback sucker (*Xyrauchen texanus*), a species proposed for listing as endangered (Fed. Reg. Vol. 55 No. 99). A summary of rare-fish use of the 15-mile reach was recently provided by Osmundson and Kaeding (1989). Adult squawfish use the reach year-round; razorback sucker may also use the reach year-round, but are found there predominately during their spawning season (April-June). An aggregation of ripe Colorado squawfish within the reach in 1982 and the subsequent capture that year of larval squawfish there indicates that the reach can provide spawning habitat for the species. Main-channel temperatures of 20-22 C, apparently necessary for Colorado squawfish spawning and important in egg-hatching success (Hamman 1981, Tyus and McAda 1984, Haynes et al. 1984, Marsh 1985) consistently occur in the 15-mile reach (Appendix Fig. I and Table IX). No young razorback sucker have been found in the reach, nor anywhere within the upper Colorado River in the past 27 years. Such apparent lack of recruitment portends the imminent extirpation of this population (Valdez et al. 1982). However, two running-ripe adult razorback sucker were captured in a flooded gravel pit in the 15-mile reach during 1986 and the movement of others to and from the reach during and after the presumed spawning period indicate that razorback suckers routinely spawn or attempt to spawn there. The Grand Valley in general, of which the 15-mile reach is a part, has been a concentration area for razorback suckers

(Valdez et al. 1982, Osmundson and Kaeding 1989) and thus may be one of the most important stretches of the upper Colorado River for this rapidly declining species.

Attempts to recover the populations of both the Colorado squawfish and razorback sucker will require identification of the causes of their continued decline, followed by management efforts aimed at removing or ameliorating, in whatever manner feasible, those factors identified as detrimental.

Importance of Flow Regimes

Most variables within the fishes riverine environment are strongly influenced by the timing, duration and magnitude of river flows. Flow regimes shape the gross physical structure of the river, such as channel morphology and substrate type; this structure in turn determines the quantity and quality of various habitat types available for use by fish. The magnitude of flow also influences the properties of the medium in which the fish live, the water itself: its quality, velocity, depth, temperature, turbidity, etc. In addition, the fishes biotic environment is also greatly influenced by flows. Just as squawfish and razorback sucker have physical habitat preferences and limitations, so do the other species of aquatic life with which they interact, either favorably or unfavorably. Densities of food items, predators, and competitors of the rare fish increase or decrease depending on how well the flow regime suits their species-specific needs.

Modern man's alteration of natural flow regimes in the Colorado River basin has no doubt had a profound effect on the environment of the indigenous aquatic species there. Though flows in the Colorado have always fluctuated widely throughout the year, they do so in a predictable, cyclic manner. Evolution has allowed the native species of fish there to adapt to and flourish under such fluctuating conditions. Unfortunately, the successful specialization for life in the unique environment of the Colorado River has left some species ill-equipped to live or reproduce under the new conditions. Changes in the system have proceeded too rapidly for evolution to allow the species to adjust. However, as manipulation of flow and temperature regimes have acted negatively on the native fish and allowed introduced species to flourish, so too might new, carefully planned manipulations of flow be used to benefit the natives and perhaps aid in controlling the populations of introduced ones.

The U.S. Fish and Wildlife Service (USFWS) is responsible for developing year-round flow recommendations for the aforementioned 15-mile reach of the Colorado River upstream of the confluence of the Gunnison River. Kaeding and Osmundson (1989) recently provided provisional flow recommendations for the months of July, August and September. We now continue with this process and here present recommendations for flows during the remainder of the year (October-June). Methodologies used to arrive at recommendations for these months differed from those used previously for the summer months. The reasoning behind our selection of the methods used is outlined in the section entitled 'Rationale for Methodologies' included as Appendix I. The primary difference is the reliance on empirical data for the spring and winter recommendations rather than on the analytical model used in the development of summer flow recommendations. USFWS is currently developing a new method for relating flow levels to availability of various important habitat types. Recommendations provided in this report and the previous one will be refined and summarized after results of this new technique are available.

Colorado squawfish and razorback sucker exhibit seasonal patterns in their selection of various habitat types and characteristics (Osmundson and Kaeding 1989). We can thus partition the water year according to these patterns. Although razorbacks and squawfish may have somewhat different seasonal habitat use patterns, our data on squawfish are more extensive and therefore more reliable. We therefore have chosen to partition the year according to the seasonal use habits of Colorado squawfish. Three major periods and two short transitional periods emerge. Though timing of changes in squawfish behavior varies slightly from year to year according to flow and temperature conditions, a pattern of winter habitat use occurs roughly from November through February; spring habitat use, from April through June; summer habitat use, from July through September. October and March appear to be transition periods for squawfish going into and coming out of winter; patterns of habitat use during these two months are similar, though squawfish use somewhat deeper water during October than during March. As mentioned above, provisional flow recommendations for the summer months have already been provided. Flows for the spring, winter and transition periods are considered here.

SPRING FLOWS (APRIL-JUNE)

Colorado Squawfish

General

Flows in the 15-mile reach start to rise slightly in late March due to the beginning of spring runoff; however, in early April, the irrigation season in the Grand Valley begins and flows in the 15-mile reach are reduced. During late April to early May, flows from spring-runoff increase greatly and the high-flow period in the 15-mile reach begins and lasts through early July. Radiotelemetry data indicate that as flows increase in late April, there is a substantial increase in use of backwaters by Colorado squawfish (Osmundson and Kaeding 1989). In May and June, flows increase dramatically and riverside gravel pits become flooded; many squawfish then move into these protected off-channel habitats. The use of gravel pits and backwaters reaches a yearly peak at this time. Though this is the period of highest river flow, deep-water (≥ 4.5 ft.) sites are little used, particularly during April and May. Off-channel, protected sites are of zero or low (< 1.0 ft./sec) velocities. The Physical Habitat Simulation Methodology (PHABSIM), used to develop summer flow recommendations, cannot be used in developing flow recommendations for the spring period because gravel pits, backwaters, and eddies collectively comprised 53.5% of the habitat used by adult squawfish during this time, habitat types that are not represented in the current PHABSIM site and which PHABSIM has difficulty modeling. Perhaps most importantly, spring flow recommendations should not be based solely on the spring habitat needs of adult squawfish. High flows during spring provide other important benefits to the system, that is, year-round benefits perhaps of overriding importance to the overall population.

Spring Flow Effects on Habitat Complexity

High flows during spring create and maintain the braided channel morphology that provides a variety of important habitat types, such as side channels, pools and backwaters. Without these high flows, the channel would become simplified with a concurrent loss of habitat heterogeneity. Pools also need to be routinely scoured or will fill with accumulated sediments (Reiser et al. 1989). The creation and maintenance of backwaters is obviously an important function of high flows; these backwaters provide nursery habitat for early life stages of Colorado squawfish. For adult squawfish, the mosaic of habitat types provided by a braided channel also appears to be important.

We observed during our past radiotelemetry studies that adult Colorado squawfish were often located in multi-channel areas or large, off-channel habitats connected to the river. We hypothesized that adult squawfish were selecting for sites with habitat heterogeneity over relatively homogeneous, single-channel habitats. To test this, we used data from our 1986-1989 studies and mapped the locations of radio-tagged squawfish in the Grand Valley to determine if complex or simple channel types were selected in greater proportion than their relative availability. Using aerial photos taken on 30 April 1986 and aerial video filmed on 2 August 1989, we estimated the amount (percent) of river consisting of simple and complex channel types during the higher flow conditions of spring and base flows of summer and winter (we assumed winter channel conditions were similar to summer conditions). We partitioned the river into 0.4-mile segments, beginning at the Loma boat launch (RM 153.6) and proceeding upstream to the Price Stubb Dam (RM 188.3). Each of the 89 segments was categorized as either complex, if one or more islands, large backwaters, or side channels were present, or simple if the segment consisted of a single channel with no obvious secondary, macrohabitat features. Locations of radio-tagged fish either fell within a complex or simple 0.4-mile segment.

Results of our analysis indicated that the river consisted of approximately equal proportions of complex and simple channel segments, though during spring there was a slightly higher proportion (53.9%) of complex channel segments and during summer and winter there was a slightly higher proportion (55.1%) of simple channel segments (Table 1). Using a binomial chi-square test (Huntsberger et al. 1975), we found that adult Colorado squawfish were located in the complex channel areas significantly ($P < .001$) more often than would be predicted from the relative availability of those habitats. Of 174 fish locations (21 different squawfish) during the spring period, 84.5% were in complex-channel segments; of 169 summer locations (17 squawfish), 71.0% were in complex segments; of 85 winter locations (eight squawfish), 62.4% were in complex areas (Figure 1). We presume that selection for such sites during spring was due to the use of warmer, sheltered environments (backwaters, flooded gravel pits and side channels) that serve as refuge from the high-velocity flows of the main channel. During summer, braided areas provide a greater diversity of habitats for squawfish to exploit; the downstream end of islands provide slack water areas for resting while allowing close proximity to swifter areas for foraging. This may also be important in winter, though possibly less so due to the fishes lower activity level at the lower temperatures.

A reduction of peak flow allows vegetation to establish itself on areas previously inundated by floods. This vegetation can stabilize the banks and bars, thereby cutting off much of the course sediment which feeds growth of bars and islands. Stabilized islands can become attached to the floodplain resulting in reduction of braiding and simplification of the channel (Schumm and Meyer 1979).

Table 1. Comparison between two channel types in frequency of use by Colorado squawfish (CS). Sites are 0.4-mile river segments where radio-tagged adult squawfish were located during 1986-1989 (n = number of different Colorado squawfish for which locations were made; SD = standard deviation).

	Spring (n = 21)		Summer (n = 17)		Winter (n = 8)	
	Simple	Complex	Simple	Complex	Simple	Complex
No. sites	41	48	49	40	49	40
% total sites	46.1	53.9	55.1	44.9	55.1	44.9
No. CS locations	27	147	49	120	32	53
% CS locations	15.5	84.5	29.0	71.0	37.6	62.4
No. sites used	11	21	16	22	8	3
% sites used	34.4	65.6	42.1	57.9	72.7	27.3
Mean No. locations per used site (SD)	2.45 (1.69)	7.00 (13.45)	3.06 (2.62)	5.45 (6.60)	4.00 (3.25)	17.67 (20.31)
Mean No. diff fish located per site (SD)	1.27 (0.47)	2.90 (3.27)	1.75 (1.24)	2.32 (1.46)	1.00 (0.00)	1.67 (1.15)

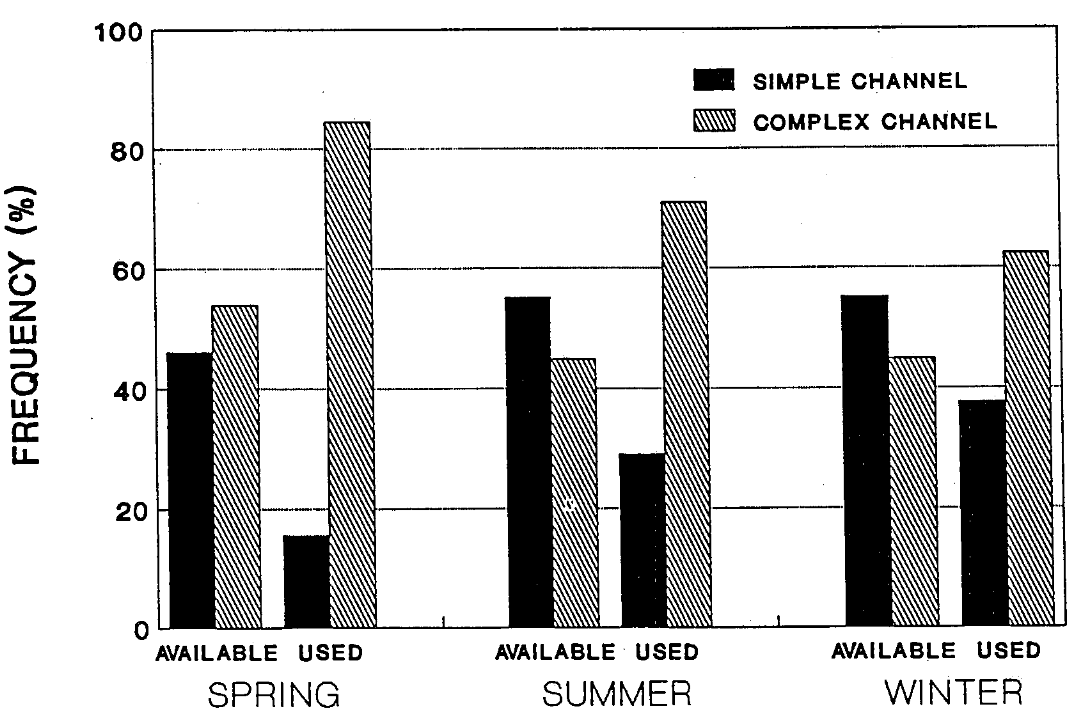


Figure 1. Frequency of use of simple and complex channel types by adult Colorado squawfish. Data from Table 1.

Thus we view high spring flows as important in shaping and maintaining the river bed, resulting in a complex of braided channels important to adult squawfish; with descending flow, some of these side channels are cut off at their upstream end and backwaters are formed at the mouth, resulting in important potential nursery habitat for young squawfish. In addition, backwaters may provide refugia for young squawfish so they are not entrained in main channel currents and transported long distances downstream.

When storage projects are located in the headwaters above major sources of sediment, such as in the upper Colorado River, they have little effect on reducing sediment recruitment to downstream segments. Coupled with a reduced flow regime, sediment input rates are likely to exceed transport rates and sediment depositional problems (aggradation) are likely to occur with time (Reiser et al. 1989). Vegetation encroaches on stream channels during periods of low flow, thereby stabilizing areas of deposition (Maddock 1978). When such situations persist over a period of years, riparian encroachment into the active channel can occur, resulting in a change in channel size and shape. Flushing flows for channel maintenance are needed when vegetation encroachment begins to affect flow transport capacity and channel shape thus predisposing the reach to further encroachment and sedimentation (Reiser et al. 1989).

Peak flows in the 15-mile reach in 1988 and 1989 were only 10,796 and 6,641 cfs, respectively. During these years, many pools and mouths of backwaters in the Grand Valley silted in and tamarisk and willow seedlings became established on new sand/silt bars. During 1990, maximum daily peak flow was estimated at 9,469 cfs in the 15-mile reach and was insufficient to dislodge tamarisk seedlings that had become established during the previous two low-water years or flush large backwaters of accumulated sediments (Osmundson, personal observation). Establishment of tamarisk is viewed as a threat to habitat complexity because of its stabilizing effect on banks, which in turn leads to further channelization of the bed and narrowing of the stream channel (Graf 1978, Valdez 1990, U.S. Fish and Wildlife Service 1990). Flushing flows of some magnitude higher than 11,000 cfs, or perhaps of a longer duration, are evidently needed. At present, we do not know the precise magnitude or duration of flushing flows necessary that will prevent channelization and promote habitat heterogeneity. Such studies are needed. However, it is clear that in the upper Colorado River where sediment loads are high, flushing flows of adequate magnitude and duration are needed to occur at a greater frequency than that observed during recent years.

Spring Flow Effects on Young Fishes

Background

High spring flows also appear to be important in enhancing reproductive success and/or survival of young of some native species, including Colorado squawfish. Haynes et al. (1984) sampled larval Colorado squawfish in the upper Colorado River (Loma to the Colorado/Utah State line) during 1979-1981 and in the Yampa River during 1980-1981. In the Colorado River, catch rates of larval Colorado squawfish were highest in 1979 and 1980, years in which State-line peak flows were approximately 35,000 and 30,000 cfs, respectively. In both rivers, catch rates were lowest in 1981, a year of low spring flows. In the Colorado River, only one larvae was collected in 1981 despite the highest sampling effort of the three years. Discharge on the highest flow day of 1981 averaged 11,200 cfs at the Colorado/Utah

State line (hereafter referred to as 'State line') gage (Appendix Table I). As discussed below, recent studies have corroborated these earlier observations.

High spring flows also appear to be the only means available to reduce the numbers of some prolific non-native fish species. Several species of introduced minnows predominate in backwater nursery habitats of Colorado squawfish. In addition, predatory centrarchids, though not abundant, are commonly found in backwater habitat in the Grand Valley area (Valdez et al. 1982, Valdez and Wick 1983, Osmundson and Kaeding 1989, Nesler 1990). Many researchers have speculated on the negative effects these introduced species may have on native fishes, particularly competition for food resources and predation (Holden 1973, McAda 1977, Seethaler 1978, Valdez et al. 1982, Wick et al. 1982, Valdez and Wick 1983, McAda and Tyus 1984, Osmundson 1987, Osmundson and Kaeding 1989, Tyus and Karp 1989, Valdez 1990, Karp and Tyus 1990). In laboratory studies, Karp and Tyus (1990) found that green sunfish (*Lepomis cyanellus*), red shiner (*Notropis lutrensis*) and fathead minnow (*Pimephales promelas*) displayed far more interspecific aggressive behavior than young Colorado squawfish, and suggested that squawfish young would be competitively inferior in a resource-limited environment. Current studies conducted by the Colorado State Larval Fishes Laboratory (CSLFL) have revealed the high susceptibility of Colorado squawfish and razorback sucker larvae to predation by red shiner, young green sunfish, and young channel catfish (*Ictaluras punctatus*) under aquaria conditions (Robert Muth, personal communication); predation by other common, non-native species has yet to be tested by CSLFL. Osmundson (1987) documented predation by largemouth bass, green sunfish and black bullhead on yearling-size squawfish in riverside ponds. Coon (1965) found young Colorado squawfish in the stomachs of channel catfish collected from the Dolores River and Taba et al. (1965) found young squawfish in the stomachs of black bullhead from the Colorado River near Moab. Marsh and Langhorst (1988) reported that 40% of green sunfish sampled from a back-water in Lake Mohave contained razorback sucker larvae in their stomachs. Mosquitofish (*Gambusia affinis*) typically extirpate native topminnows (*Poeciliopsis occidentalis*) in southwestern streams via predation within 1-3 years after introduction (Meffe 1984); however, their effect on upper Colorado River species is unknown.

Elimination of these predacious species from the river is currently not possible (Valdez 1990). However, data suggests that periodic, high river flows can control numbers of some non-native fishes. Minckley and Meffe (1984) reported that several introduced fishes, particularly predatory sunfishes and catfishes, were reduced in number or eliminated completely by flooding in six unregulated Arizona streams of various size, while native fishes were little affected. Meffe (1984) reported that replacement of native topminnows by introduced mosquitofish is most rapid in areas that rarely flood, while long-term coexistence may occur in frequently flooded habitats.

Without high flows, some introduced species proliferate. Osmundson and Kaeding (1989) noted changes in fish community structure in the Grand Valley (Loma to Palisade) in a three-year study (1986-88) during which spring peak and summer flows progressively declined. There was a marked increase in the three most abundant non-native minnow species, red shiner, fathead minnow and sand shiner (*Notropis stramineus*), a concurrent decrease in young of two common native fishes, bluehead sucker (*Catostomus discobolus*) and speckled dace (*Rhinichthys osculus*), and a decrease in young Colorado squawfish. During 1989, another year of low flows in the Colorado River, abundance of the three common introduced minnows further increased (Fig. 2.) Valdez (1990) noted a similar relationship between flows and abundance of red shiners, fathead minnows and sand shiners in lower reaches of the upper Colorado River (Potash to lower Cataract Canyon) during 1985-1988.

McAda and Kaeding (1989) examined the relationship between peak flows and the relative abundance of post-larval fishes in the upper Colorado River (Green River confluence to Grand Junction). They regressed peak discharge against mean numbers of fish per area seined. Their results indicated differing responses to peak flow among species, and between upper and lower river reaches within species. The overall pattern, however, supported earlier observations that the more common non-native fish species were in greatest abundance in summers following low spring flows and were in lowest densities during periods following high spring flows. Unfortunately, even following extremely high record flows, these non-natives were not eliminated. Nonetheless, the importance of high flows in reducing densities of these species was demonstrated. For Colorado squawfish, however, the trend was reversed: abundance of young-of-the year (YOY) squawfish in the lower reach increased with increased peak flows, although it was reduced following record-high discharges (Fig. 3). When the two record high-flow years were excluded from the analysis, catch rates of YOY were highly correlated with peak flow ($r = 0.98$; $P < .01$). Years of highest squawfish YOY abundance were 1985 and 1986 when peak flows at the State line gage were 38,200 and 32,800 cfs, respectively. McAda and Kaeding,

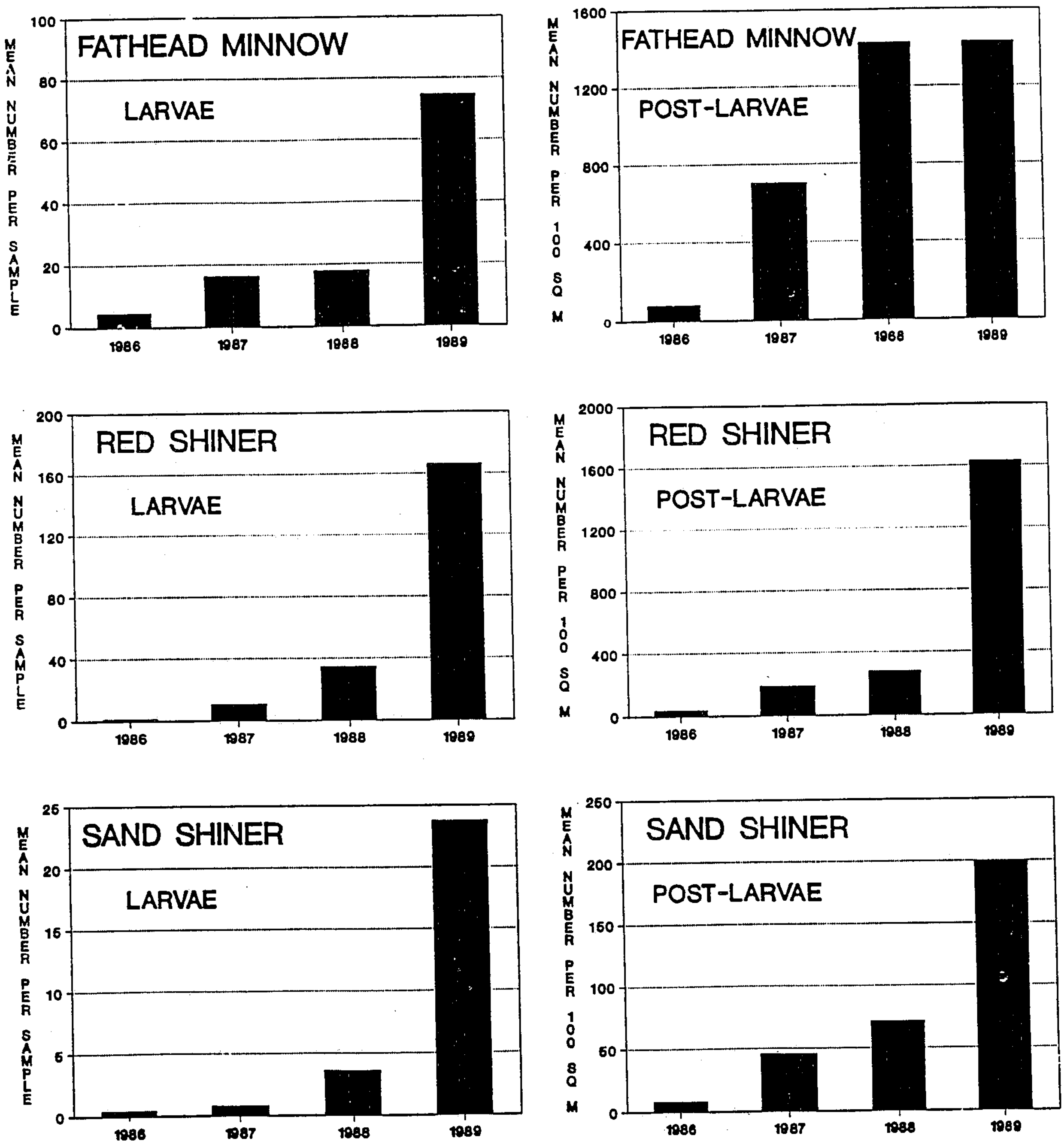


Figure 2. Relative catch-per-effort for three introduced minnow species in the 18-mile reach of the Colorado River near Grand Junction, Colorado, 1986-1989. Larval fishes include only specimens < 21 mm long; post-larval fishes are juveniles and adults.

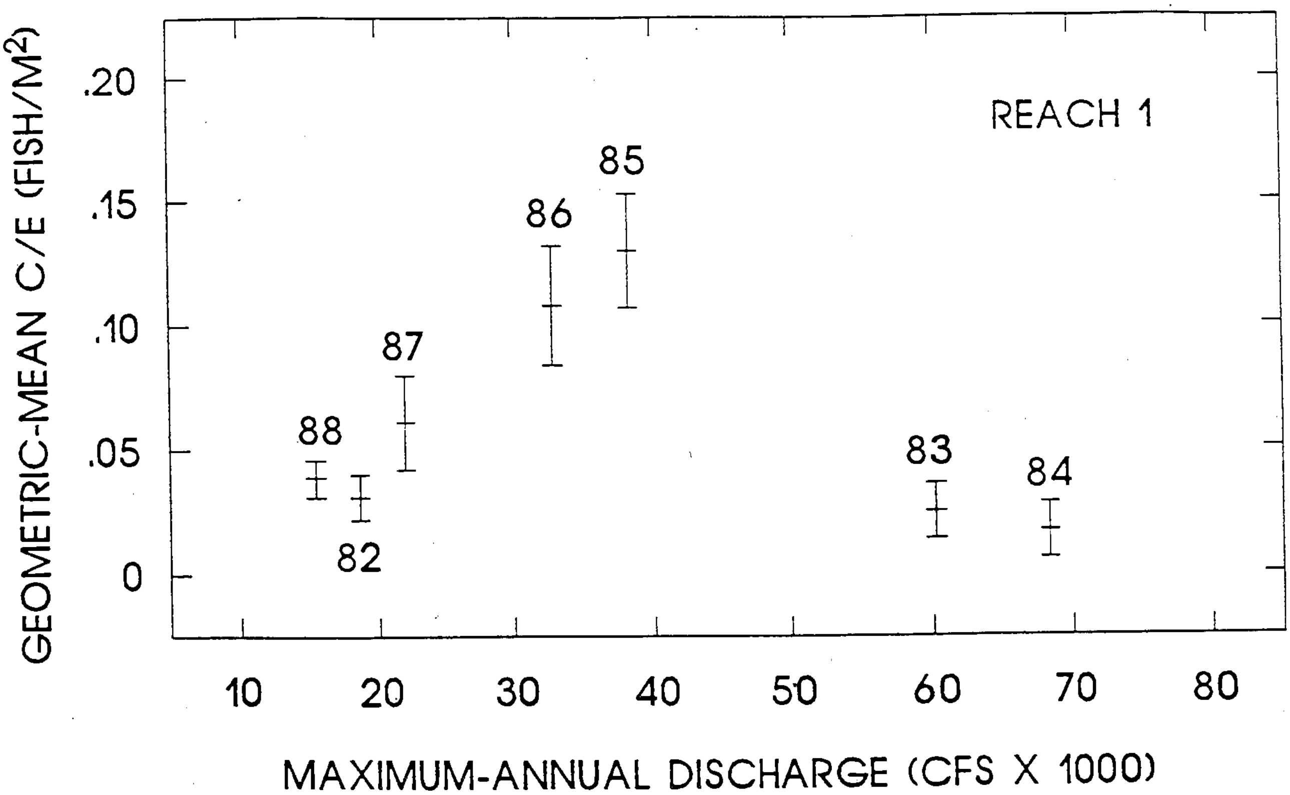


Figure 3. Plot of geometric-mean catch-per-effort (C/E) versus maximum-annual discharge for post-larval Colorado squawfish collected during October, Colorado River, 1982-1988. Lines indicate ± 1 standard error. Figure from McAda and Kaeding (1989). Reach 1 includes Colorado river-miles 0-110 (confluence with the Green River to lower end of Westwater Canyon).

rounding to the nearest 10,000 cfs, therefore recommended a peak discharge of 30,000-40,000 cfs (measured at the State line) to maximize production of young Colorado squawfish.

<u>New Information</u>

We similarly analyzed data on larvae collected during July and August and post-larval fish collected during late September from three river reaches in the Grand Valley: the 15-mile reach, the lower 18-mile reach, and the Gunnison River downstream of the Redlands Diversion. Sampling methods were previously described in Osmundson and Kaeding (1989) and U.S. Fish and

Wildlife Service (1987a). The term 'post-larval fishes', as used here, refers only to YOY of large-size species such as Colorado squawfish, and in addition, includes juveniles and adults of small-size species such as fathead minnows, mosquitofish, etc. Correlations were performed on annual peak flow (mean flow of the highest day) versus annual mean number of larvae per sample, and annual peak flow versus annual mean number of post-larval fish per 100 m^2 seined. Data for species that mature within the first year of life were first log-transformed because trends indicated that the increase in number of some species was more exponential than linear. We expect that the degree of increase from one year to the next in rapidly maturing species would be related to the number of adults that survived from the previous year. For late-maturing species, year-to-year variation in adult numbers is probably not great, and exponential-like increases in young were not noted. For these species, catch rates were first transformed to geometric means to improve normality of the data (see McAda and Kaeding 1989). The reaches were analyzed separately because each had a different flow regime. Our results indicate a relationship between abundance of larval and post-larval fishes and peak flow exists for certain species but not for others and the strength of these relationships varies among reaches.

Larvae. Those native species that showed a consistent response to high flows in the three reaches were bluehead sucker and speckled dace; the introduced species were fathead minnow, sand shiner and red shiner (Table 2). Catch rates of larvae of the two native species increased with increased peak flow while those of the three introduced minnows decreased. Abundance of Colorado squawfish larvae increased with increased peak flow

Table 2. Pearson correlation coefficients (*r*) of larval (0-20 mm long) fish abundance (mean number per sample) and yearly peak flow for three Grand Valley river reaches. Data collected in 1986, 1987, 1988 and 1989. Means of log-transformed data were used for species maturing within their first year of life and geometric means for late-maturing species.

	15-Mile Reach		18-Mile Reach		Lower Gunnison	
	r	*P*	*r*	*P*	*r*	*P*
			Native species			
Colorado squawfish[1]	0.000	(-)	0.931	(.069)*	0.644	(.356)
Roundtail chub[1]	0.288	(.712)[ns]	-0.806	(.194)	0.751	(.249)
Bluehead sucker[1]	0.970	(.030)**	0.884	(.116)	0.683	(.317)
Speckled dace[e]	0.962	(.038)**	0.773	(.227)	0.986	(.014)**
Flannelmouth sucker[1]	-0.013	(.987)[ns]	0.165	(.835)[ns]	-0.057	(.943)[ns]
			Introduced Species			
White sucker[1]	-0.111	(.889)[ns]	0.861	(.139)	0.433	(.567)[ns]
Common carp[1]	-0.804	(.196)	-0.676	(.324)	-0.564	(.436)
Green sunfish[1]	-0.499	(.501)[ns]	-0.678	(.322)	-0.564	(.436)
Mosquitofish[e]	-0.688	(.312)	-0.831	(.169)	-0.586	(.414)
Fathead minnow[e]	-0.842	(.158)	-0.924	(.076)*	-0.962	(.038)**
Sand shiner[e]	-0.790	(.210)	-0.843	(.157)	-0.936	(.064)*
Red shiner[e]	-0.919	(.081)*	-0.952	(.048)**	-0.782	(.218)
Black crappie[1]	0.000	(-)	0.861	(.139)	0.000	(-)

ns not significant ($P > .5$)
* ($P < .10$)
** ($P < .05$)
e early-maturing
1 late-maturing

in the 18-mile reach (Fig. 4), though none were found in the 15-mile reach. Flannelmouth sucker (*C. latipinis*) had consistently low correlations. Correlations for roundtail chub (*Gila robusta*) were inconsistent: larval abundance decreased with increased peak flow in the 18-mile reach but increased in the lower Gunnison, while in the 15-mile reach there was no correlation. For some species, high correlations were not biologically meaningful because values of three of the four data points were zero, thereby falsely producing a high r value when only one or a few individuals were captured. This was the case for white sucker (*Catostomus commersoni*) and black crappie (*Pomoxis nigromaculatus*) in the 18-mile reach.

Because sample size (4 years) was low, few of the correlations were highly significant; r values had to be 0.900 or greater to be significant at the 0.10 level, 0.950 at the 0.05 level, and 0.990 at the 0.01 level. Speckled dace, bluehead sucker, and red shiner in the 15-mile reach, speckled dace, fathead minnow, and sand shiner in the lower Gunnison, and red shiner, fathead minnow, and Colorado squawfish in the 18-mile reach were significant ($P < 0.10$). Larval fish samples were also collected during 1990, but identification of these fishes is not yet complete. Additional data will be collected in 1991. If the correlation coefficients are maintained as more years of data are collected, the number of significant relationships will increase; for instance, for six years of data, r values of 0.729 or greater will be significant at the 0.10 level; $\geq .811$, at the .05 level. However, even with only four years of data, catch rates of larval Colorado squawfish were highly correlated ($r = .931$; $r^2 = .867$; $P = .069$) with annual peak flow (Fig. 5). Thus we conclude with 93% confidence that 87% of the annual variation in abundance of larval Colorado squawfish in the 18-mile reach can be explained by variation in annual peak discharge.

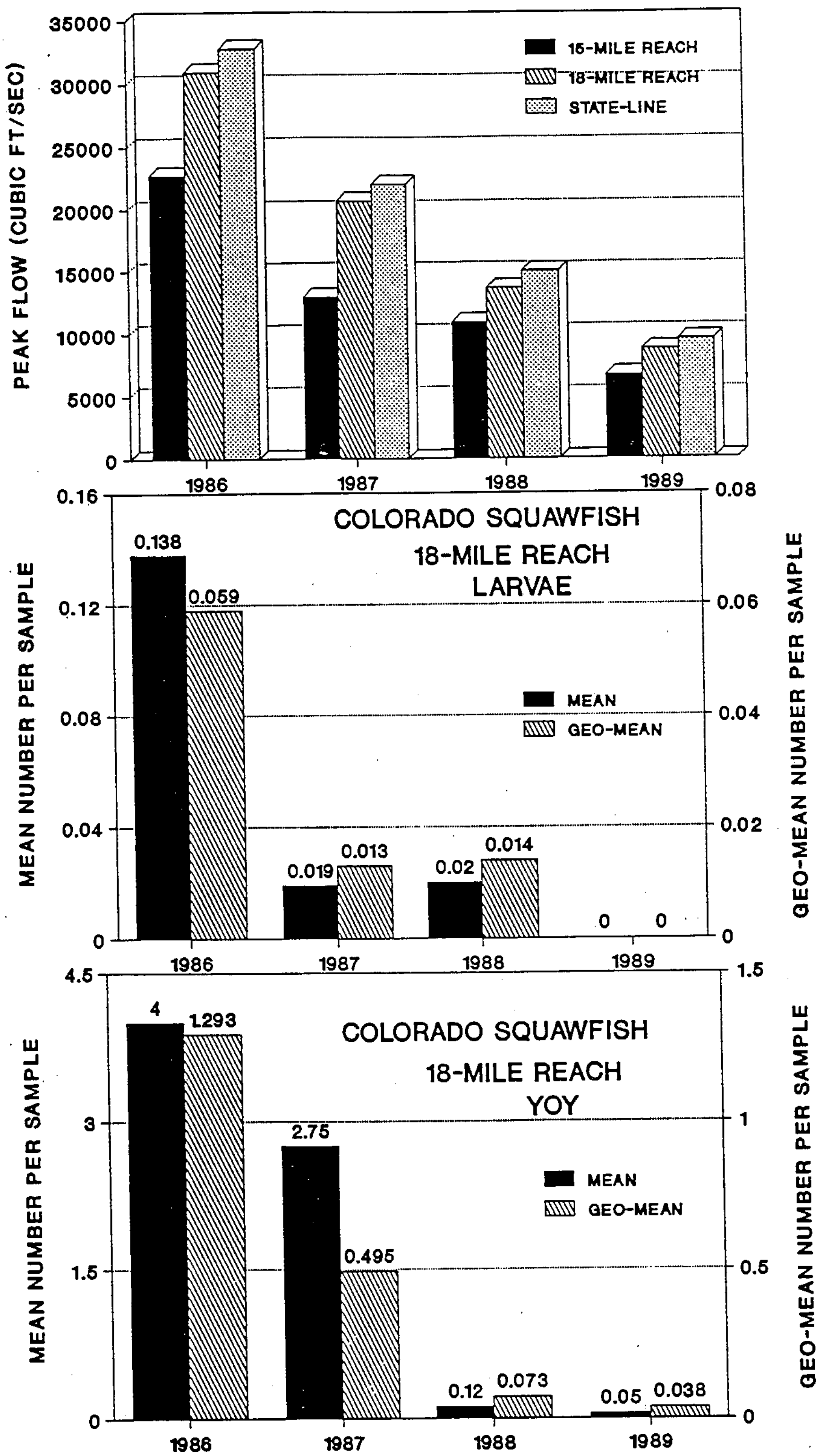


Figure 4. Peak flows (mean flow on highest flow day of the year) and catch rates of Colorado squawfish larvae and young-of-the-year (YOY) in the 18-mile reach (Gunnison confluence to Loma) of the upper Colorado River, 1986-1989. Peak flows in the 15-mile reach and at the USGS gage near the Colorado-Utah State line are provided for comparison. Geo-mean = geometric mean (catch data transformed using $\log_e((\text{number}/100\ m^2)+1)$.

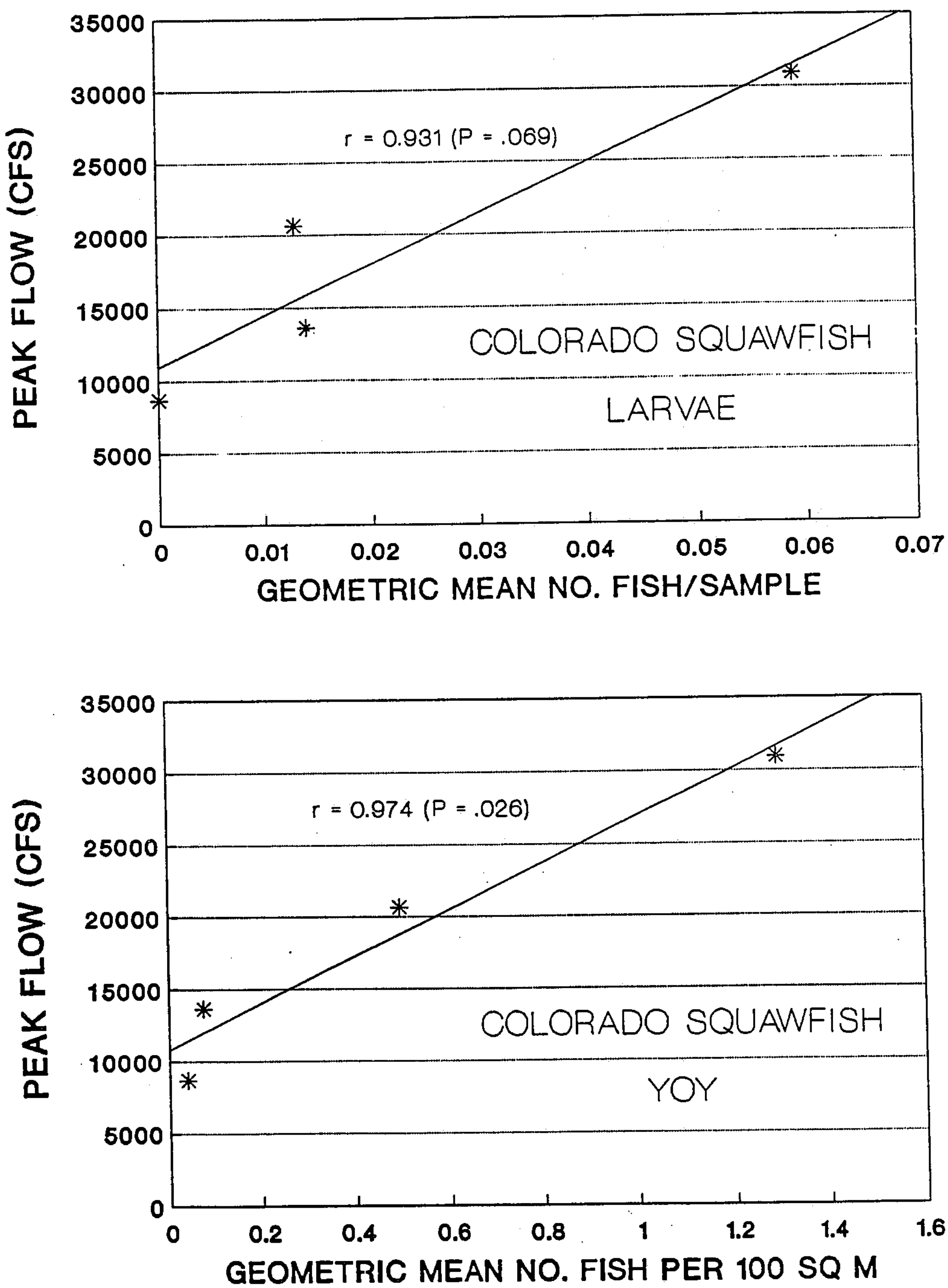


Figure 5. Correlations of peak flow and catch rates of larval and young-of-the-year Colorado squawfish in the 18-mile reach (Gunnison confluence to Loma) of the upper Colorado River, 1986-1989. Data from Fig. 4.

Post-larval fishes. Similar trends were evident in fish densities in backwaters during fall. Again, densities of native species were generally positively correlated with peak flows, while introduced species were negatively correlated (Table 3). In general, *r* values were lower than for the larvae data. This is perhaps not surprising because by the time fall sampling occurs other mortality factors have had time to operate and fish abundance by then is less influenced by reproductive success alone. However, the correlation for Colorado squawfish young-of-the-year (YOY) in the 18-mile reach was very similar to that for larvae; abundance was highly correlated with peak discharge ($r = 0.974$; $r^2 = .925$; $P = .026$; indicating that production of young and/or survival of young until fall was higher during years of increased peak flow (Fig. 5). We can thus conclude with 97.4% confidence that 92.5% of the annual variation in Colorado squawfish YOY densities in the 18-mile reach during fall can be explained by variation in annual peak flow.

Discussion. Of the four years in which larvae were collected, 1986 was the year of highest catch rates of larval Colorado squawfish and bluehead sucker, and of lowest catch rates of larval red shiner, sand shiner, and fathead minnow. Colorado squawfish YOY abundance was also highest during 1986. Peak flows during this year were 32,800 cfs at the State line gage, an estimated 30,928 cfs in the 18-mile reach, and 22,742 cfs at the top of the 15-mile reach.

Why high spring flows are correlated with reproductive success of various species is not well understood. McAda and Kaeding (1989) cautioned that these correlations do not necessarily establish cause and effect relation-

Table 3. Correlation coefficients (r) of fish densities (no. fish per 100 m^2) in backwaters during fall and yearly peak flow for two Grand Valley river reaches. Data collected in 1986, 1987, 1988 and 1989. Means of log-transformed data were used for species maturing within their first year of life and geometric means for late-maturing species.

Species	15-Mile Reach		18-Mile Reach	
	r	P	r	P
	Native Species			
Colorado Squawfish[l]	0.000	(-)	0.974	(.026)**
Roundtail chub[l]	0.886	(.114)	0.664	(.336)
Bluehead sucker[l]	0.920	(.080)*	0.876	(.124)
Speckled dace[e]	0.821	(.179)	0.930	(.070)*
Flannelmouth sucker[l]	0.663	(.367)	0.749	(.251)
	Introduced Species			
White sucker[l]	-0.557	(.443)[ns]	-0.762	(.238)
Common Carp[l]	-0.618	(.382)	0.043	(.957)[ns]
Green sunfish[l]	-0.346	(.654)[ns]	0.237	(.763)[ns]
Mosquitofish[e]	-0.828	(.172)	-0.871	(.129)
Fathead minnow[e]	-0.226	(.774)[ns]	-0.878	(.122)
Sand shiner[e]	-0.585	(.415)	-0.822	(.178)
Red shiner[e]	-0.434	(.566)[ns]	-0.938	(.062)*
Plains kilifish[e]	-0.606	(.394)	-0.676	(.324)
Brassy minnow[l]	0.908	(.092)*	0.000	(-)
Channel catfish[l]	0.000	(-)	-0.584	(.416)
Black bullhead[l]	-0.687	(.313)	0.861	(.139)
Largemouth bass[l]	-0.068	(.937)[ns]	0.178	(.822)[ns]
Bluegill[l]	0.000	(-)	-0.335	(.665)[ns]

ns not significant ($P > .5$)
* ($P < .10$)
** ($P < .05$)

e early-maturing
l late maturing

ships. Other important variables, such as magnitude of summer flows and temperature regimes are correlated with peak flows, and these in turn could have a direct effect on larval production of some species or possibly retainment of larvae within the study area (high summer flows might facilitate long-distance transport of young). Thus, peak flows may be more of an index to the type of water year rather than the controlling factor itself. One possible direct-effect scenario for Colorado squawfish is that some magnitude and duration of high flow may be necessary to prepare the spawning substrate (Haynes et al. 1984). Though spawning may occur every year, hatching success could vary depending on the degree to which the cobble substrate is flushed of sediments. Results of studies on other systems have demonstrated inverse relationships between accumulation of fine sediment in fish spawning and rearing habitats versus fish survival and abundance (Reiser et al. 1989). Studies are needed to determine the importance of this variable for Colorado squawfish in the upper Colorado River. Another possibility is that as numbers of non-natives increase in years of low flow, predation-related mortality on squawfish might increase (Valdez 1990).

One might expect that numbers of larval Colorado squawfish transported out of the reach via river currents would be higher in years of relatively high summer flows, thus resulting in fewer YOY squawfish found in the Grand Valley during fall of such years. Though flow effect on percent larvae transported out of the reach is unknown, it is of interest to note that total numbers of larvae and YOY were highest in 1986 despite relatively high summer flows that year (mean flow during August 1986 in the 18-mile reach downstream of the mouth of the Redlands power return canal was an estimated 4,217 cfs compared with mean flows in 1988 of 2,445 cfs in July and 1,634 cfs in August).

For introduced minnows, low flows are probably beneficial because these species may be more adapted to stable environments, such as those provided by unflooded backwaters. We concur with Valdez (1990), who suggested that high flows probably flush these fish from their otherwise protected micro-habitats and into the main channel, and that turbulent conditions and delayed warming of the river during years of high flow may interfere in some way with their ability to reproduce and recruit. Why correlations for a given species were not identical among reaches might be due to differences in reach characteristics such as flow regime and channel morphology (gradient, substrate, degree of channelization, availability of refugia habitats, etc.). Difference in water temperatures between the 15-mile and 18-mile reaches was slight (Osmundson and Kaeding 1989), and probably would not account for differences in fish abundance.

Abundance of ictalurid larvae and YOY was not correlated with peak flow. No larvae of channel catfish or black bullhead were detected during the four-year study, though YOY black bullhead were collected in both the 15-mile and 18-mile reaches. Channel catfish YOY were collected only from the 18-mile reach. Because channel catfish adults are numerous in the Grand Valley (Valdez et al. 1982), the rarity of young in samples may reflect their preference for habitat types other than those that we sampled rather than an actual scarcity in the river. Or, larval drift and later recolonization by adults from downstream reaches might explain discrepancies in age-structure of the local population of this species. In either case, our sampling design may not have been suitable to test for flow effects on channel catfish reproduction.

Larval and post-larval mosquitofish were negatively correlated with peak flow in all reaches, though not significantly so. Their numbers were highest in 1989, the year of lowest flow. Correlations for catch rates in fall (juveniles and adults) were relatively high and might become significant with a greater sample size. Meffe (1984) documented the susceptibility of mosquitofish to mortality from flash-flooding in desert streams. Effects from flushing flows during spring runoff in the upper Colorado River may be less acute due to the gradual rather than sudden increase in flow, and perhaps due to a greater availability of off-channel, refugia habitats.

Numbers of young centrarchids were not correlated with peak flows. Correlations for both larval and YOY green sunfish and YOY largemouth bass, though negative, were generally not significant, regardless of the reach. This, coupled with the apparent rarity of adults in riverine habitats (Nesler 1990), indicates that reproduction occurs in protected off-channel habitats, removed from but connected to the main channel. No larvae of largemouth bass were ever detected in river backwaters during our four years of study. Green sunfish and largemouth bass inhabit ponds throughout the Grand Valley (Osmundson 1987), and green sunfish are abundant in irrigation return canals (USFWS unpublished data). Thus, chronic immigration of young to the river from these ponds and canals probably accounts for their continued presence in backwaters rather than from significant riverine reproduction (Osmundson 1987, Nesler 1990). The abundance of young would therefore not be strongly influenced by high spring flow events. However, we speculate that even relatively low spring flows may be influential in preventing most juvenile centrarchids from surviving to adulthood in riverine habitats.

Schlosser (1985) studied flow regime effects on fish community structure in a second-order, warmwater stream in Illinois; his results were similar to ours: low flows there resulted in a large increase in the numbers of two minnow species, the striped shiner (*N. chrysocephalus*) and the bluntnose minnow (*P. notatus*), species with prolonged breeding seasons. He concluded that stochastic events such as high flows strongly affect the assemblage structure of stream fishes, and the relative influence of flow regime varies among species and age groups within species. He concluded that differences among species in their ability to reproduce under high flow conditions are likely related to differences in their reproductive behavior and reproductive physiology and in the habitat requirements of larval and juvenile fish.

Muth and Nesler (in press) have recently analyzed larval data collected in the early 1980's from the Yampa River in an effort to determine if trends observed in the Colorado River would also apply to another river system containing a similar fish community. Their preliminary analyses are supportive of ours and those of McAda and Kaeding (1989) in that abundance of larvae of non-native minnow species was negatively correlated with magnitude of spring flows.

Despite our poor understanding of the mechanisms involved, data collected to date strongly support our current conclusion that in the upper Colorado River high spring flows are important in enhancing production of some native fishes including Colorado squawfish while evidently not affecting others; at the same time, high flows may be the only available means by which to reduce production of several prolific and potentially detrimental introduced species.

Reduction of Historic Peak Flows

During recent times, spring flows in the Colorado and Gunnison rivers have been significantly reduced as a result of upstream water development projects, primarily transmountain diversions and reservoir storage. Large changes in the upper Colorado River first began during the 1943-1953 period when various storage and diversion facilities related to the Colorado-Big Thompson Project were being put on line. Closure of the first dam, Green Mountain, was in fall 1942; closure of the last western slope dam associated with the project, Willow Creek, was in spring 1953 (Water and Power Reasources 1981). Though other projects built since this period have further impacted Colorado River flows, we felt this was a reasonable block of years to use for separating historic from recent periods for comparison purposes. When we compared yearly discharge records for the 36 years following this period with the 41 years prior to this period for which records exist, we found that the mean peak flow in the 15-mile reach is now only 56 percent of the pre-development mean (Table 4, Fig. 6 and Appendix Table I). Major changes have also occurred in the Gunnison River basin, which affects flows of the Colorado River downstream of the 15-mile reach. During the 24 years since completion of Blue Mesa and Morrow Point reservoirs in 1966, the mean yearly peak flow at the mouth of the Gunnison River has been reduced to 52 percent of that which occurred prior to completion of the first major water project in the Gunnison River headwaters (Taylor Reservoir in 1937).

Table 4. Summary of recent and historic mean monthly river discharge for the Colorado River at the top of the 15-mile reach and at the Colorado/Utah state line, and for the Gunnison River near Grand Junction (including Redlands power canal). Different years of record for historic and recent periods for the three reaches is due to different upstream, water development histories for the Colorado and Gunnison rivers and due to differences in dates of gage installation. Standard deviation in parentheses.

		Mean			
Years	No. years	High day	April	May	June
		15-mile reach			
1954-1989	36	16,524 (8,051)	2,206 (1,575)	7,571 (3,990)	10,654 (5,978)
1902-1942	41	29,554 (9,946)	3,145 (1,359)	13,091 (4,245)	19,379 (7,823)
recent/historic		55.9 %	70.1 %	57.8 %	55.0 %
		Gunnison			
1966-1989	24	8,778 (5,342)	2,978 (1,792)	5,351 (3,226)	4,706 (3,559)
1897-1936	28	17,021 (7,370)	3,167 (1,491)	9,651 (4,225)	9,580 (4,544)
recent/historic		51.6 %	94.0 %	55.4 %	49.1 %
		State line			
1966-1989	24	25,504 (14,895)	6,128 (3,317)	14,115 (8,014)	17,061 (10,058)
1908-1923	16	49,100 (17,468)	7,219 (1,982)	24,191 (7,522)	33,384 (12,146)
recent/historic		51.9 %	84.9 %	58.4 %	51.1 %

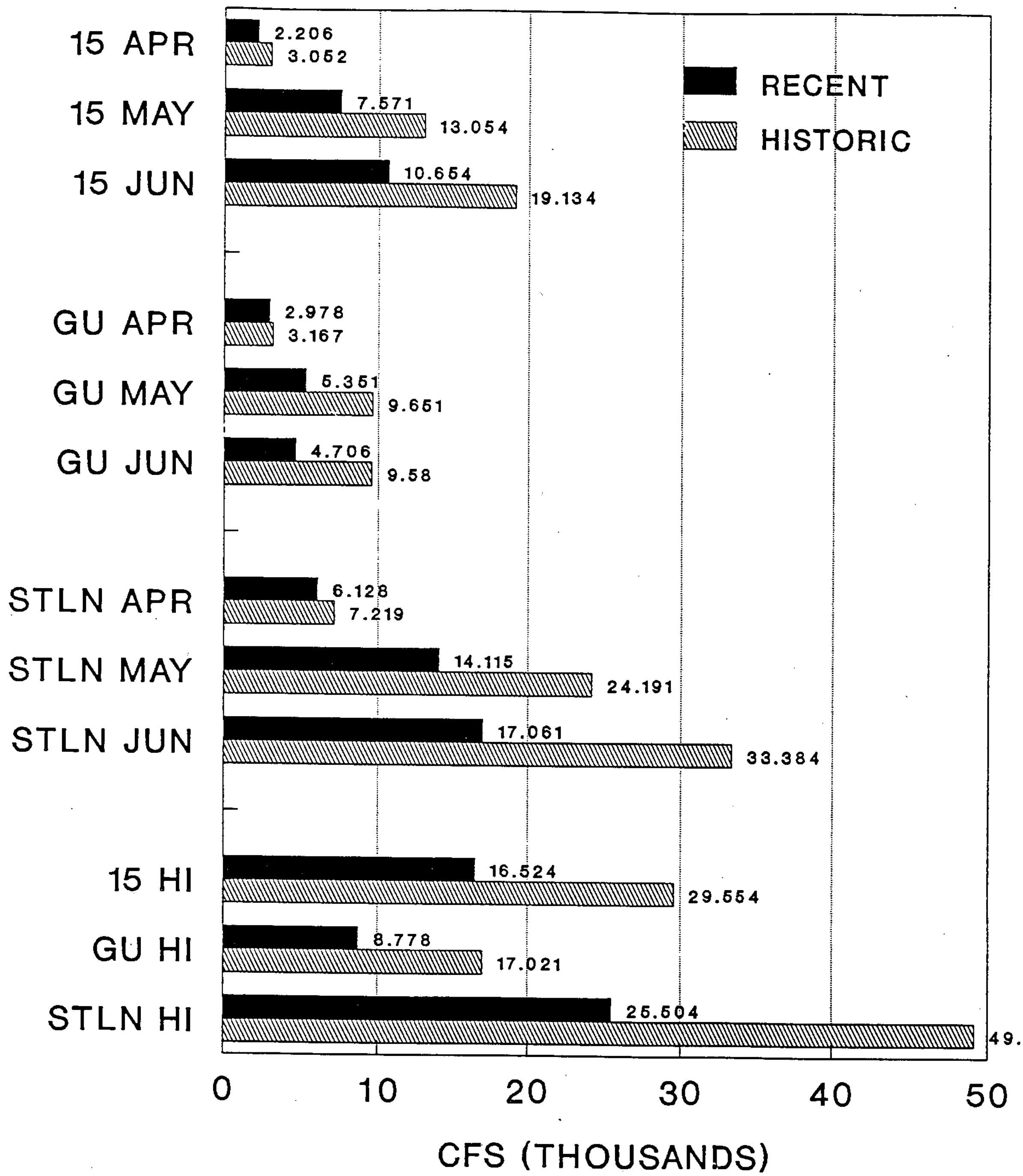


Figure 6. Recent and historic spring flows in the upper Colorado River at the top of the 15-mile reach (15) and near the Colorado/Utah state line (STLN), and in the Gunnison River (GU) near Grand Junction (including Redlands power canal). The top three bar series are mean monthly flows for April, May, and June for each of the three reaches; the bottom series includes the mean peak flow for each reach. Recent and historic years of record are those listed in Table 4.

At the State line gage on the Colorado River, the mean peak flow is now 52 percent of its historic mean. The greatest loss of natural flows occurs during the months of May and June (Table 4). Fortunately, the frequency of years when the peak flow at the State line gage reaches the level at which maximum squawfish production has been recorded (30,000-40,000 cfs) has not changed significantly; as during historic times, peak flows within this 'window' still occur in about one of every four years. What has changed is the loss of the frequent high-volume years, which are important in keeping the abundance of some of the non-native species in check and in maintaining channel complexity. Prior to 1937, the annual peak flow at the State line (16 years of record) exceeded 30,000 cfs 81% of the time, and exceeded 40,000 cfs 56% of the time; in recent years (after 1965), peak flows exceeded 30,000 cfs 33% of the time, and exceeded 40,000 cfs only 8% percent of the time (Fig. 7). During the 16 years of historic record, peak flows at the State line were never less than 26,000 cfs (Fig. 8). During

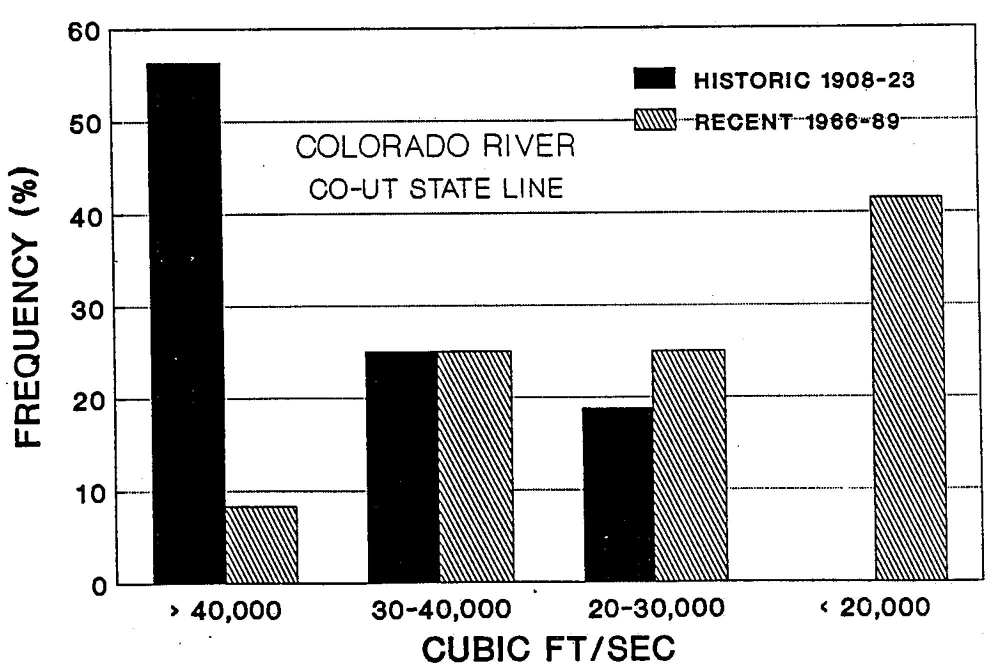
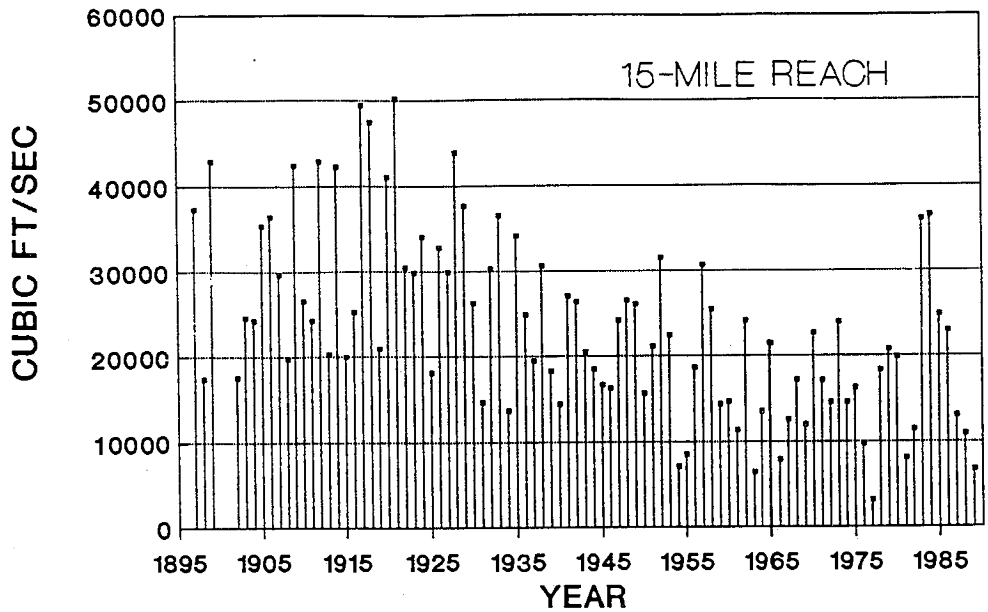


Figure 7. Recent and historic frequencies of peak flows (highest flow day of the year) of various magnitudes. Data from Appendix Table I.



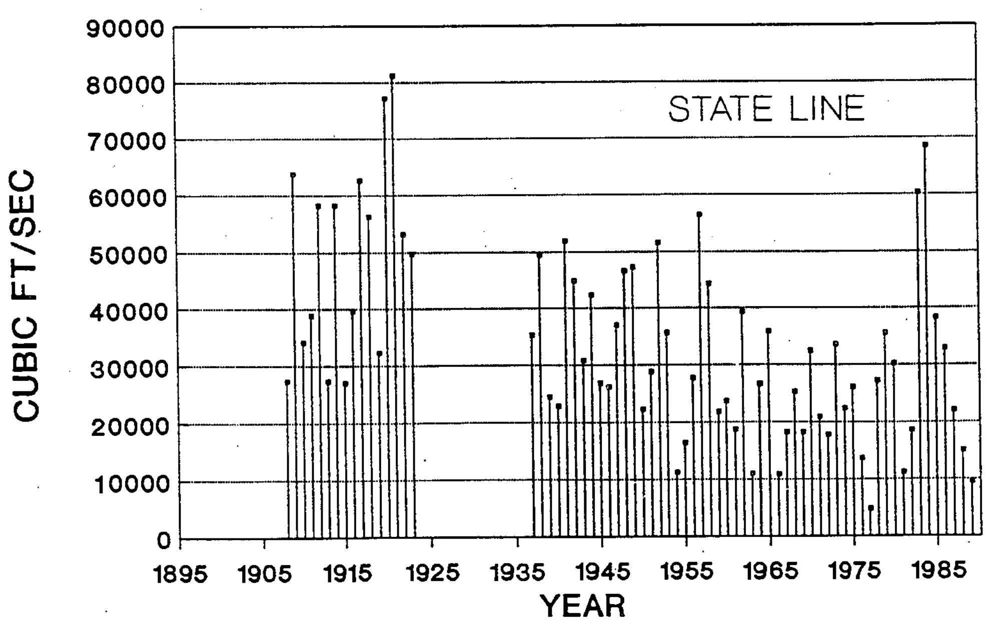


Figure 8. Time series of peak flows in the upper Colorado River at the top of the 15-mile reach and at the Colorado/Utah State line, 1897-1989. Data from USGS gage records (see Appendix Table I).

the past 24 years, peak flows have been less than this 58% of the time. During the low water years of 1988 and 1989, when the abundance of introduced minnows greatly increased, peak flows at the State line were 15,000 and 9,480 cfs, respectively. Peak flows of 15,000 cfs or less at the State line now occur at a rate of about 25%, or an average of once every four years (Fig. 8). We believe the now-common occurrence of these low-flow years has greatly aided the proliferation of these introduced fishes.

In determining optimal flows for the 15-mile reach we need to consider not only the habitat affected within the reach itself but also the contribution that flows there make to the Colorado River downstream. Though the Colorado River picks up substantial inflow from the Gunnison River, the majority of Colorado River flow downstream of the Grand Valley is comprised of upper Colorado and not Gunnison River water (Fig. 9 and Appendix

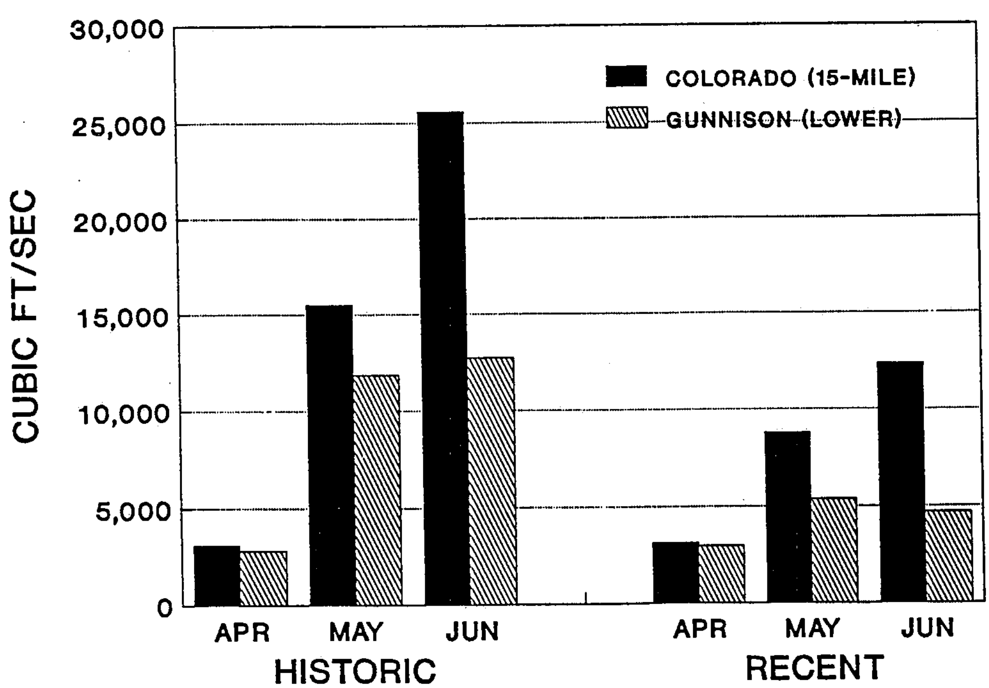


Figure 9. Recent and historic mean monthly flows in the Colorado River at the top of the 15-mile reach and in the Gunnison River near Grand Junction, Colorado. Data from Table 5.

Table II), and the date of the yearly peak flow is thus determined by the date of the high flow in the 15-mile reach. Flows at the top of the 15-mile reach comprise an average of 37.2% in April, 54.9% in May, and 65.4% in June of flows at the USGS gage near the Colorado/Utah State line (Table 5). When the return flows from upstream irrigation removal are added back throughout the length of the Grand Valley, flows from the upper Colorado drainage are calculated to comprise 53.3%, 63.3%, and 74.3% of State line flows during April, May, and June, respectively. During historic times, before major upstream dams and transmountain diversions were in place, the relative contributions of the two rivers were not substantially different from their relative contributions today (Table 5 and Fig. 9). To provide peak flows of 30,000 to 40,000 cfs at the State line, the flow of the Colorado River near Cameo, including the contribution of Plateau Creek just downstream, needs to be approximately 21,000 to 26,000 cfs and approximately 19,500 to 25,000 cfs in the upper end of the 15-mile reach (Table 6). However, this assumes that the average input from the Gunnison River and the amount removed for and returned from local irrigation remain at current levels. To maintain the status quo, these flows will have to occur at a frequency averaging one in four years. To improve Colorado squawfish reproduction downstream, and ultimately increase the chances for species recovery, the frequency of peak flows of this magnitude will need to be increased.

Thus, we believe that high spring flows from the Colorado River drainage upstream from the mouth of the Gunnison River are necessary to create and maintain habitat for adult Colorado squawfish both within the 15-mile reach and in the important reaches of the Colorado River downstream. These high flows not only create the diversity of habitat seemingly required by

Table 5. Percent flow contribution to the mainstem Colorado River from its two major tributaries, the Gunnison River and the upper Colorado River above Grand Junction, April-June, 1966-1989 and 1917-1923. 15M = upper end of 15-mile reach; GU = Gunnison River including power canal return; STL-GU: amount measured at state-line gage minus the amount contributed by the Gunnison River (assumes Redlands irrigation returns to be negligible), i.e., 15-mile reach plus all returns from Colorado River diversions.

	APR			MAY			JUN		
	15M	GU	STL-GU	15M	GU	STL-GU	15M	GU	STL-GU
				1966-1989					
N (yr)	24	24	24	24	24	24	24	24	24
Range	25-58	33-59	41-66	41-70	25-49	51-75	53-80	16-34	66-84
Mean	37.2	46.8	53.3	54.9	36.7	63.3	65.4	25.7	74.3
SD	(7.8)	(7.9)	(7.9)	(8.0)	(7.1)	(7.1)	(6.8)	(5.6)	(5.6)
				1917-1923					
N (yr)	7	7	7	7	7	7	7	7	7
Range	40-58	42-49	51-58	49-65	39-47	53-63	59-82	30-39	61-70
Mean	50.2	44.8	55.2	57.6	42.9	57.1	67.6	33.6	66.4
SD	(6.1)	(2.3)	(2.3)	(5.9)	(3.9)	(3.9)	(8.3)	(3.1)	(3.1)

Table 6. Comparison of river discharge at the State-line gage with that at Cameo (plus Plateau Creek) and with that at the top of the 15-mile reach for the high day of the year. Records are for those years when the peak flow at the State-line gage was between 30,000 and 40,000 cfs. Discharge at Cameo prior to 1933 was calculated using data from an earlier gage at Palisade and adding diversions immediately upstream.

Year	Stln	Cameo	15-mile	Year	Stln	Cameo	15-mile
1986	32,800	24,380	22,880	1953	35,600	23,856	22,356
1985	38,200	26,354	24,300	1947	36,971	25,638	24,138
1980	30,200	21,240	19,740	1943	30,739	21,906	20,406
1979	35,400	22,140	19,450	1937	35,274	20,810	19,360
1973	33,500	25,400	23,900	1919	32,200	21,400	20,850
1970	32,300	24,090	22,640	1916	39,600	25,800	25,200
1965	35,800	22,880	21,380	1911	38,800	24,800	24,200
1962	39,200	25,540	24,090	1910	34,100	27,100	26,500

adult fish but also the backwater nursery areas critically important to the young. Perhaps most importantly, production of young is highest in summers following springs with peak flows that result in 30,000 to 40,000 cfs at the State line. There also appears to be a strong relationship between years of reduced peak flows and abundance of non-native minnows, including red shiner, a species believed by many researchers to have a negative effect on the rare native fish.

If recent changes to the natural hydrograph have had a negative impact on populations of Colorado squawfish in the Colorado River as we have concluded, similar changes would be expected to produce similar results in other river systems. Indeed, when we plotted recent and historic mean monthly discharge data for the San Juan River, where populations of Colorado squawfish have also seriously declined (Platania 1990), a similar alteration of the natural hydrograph was revealed (Fig. 10). As in the Colorado River, spring flows have been greatly reduced in the San Juan River; in addition, unlike the Colorado River, average base flows during the remainder of the year have increased. In the Green River, Colorado squawfish populations have not declined as appreciably as they have in the other two river systems; spring electrofishing data from the Interagency Standardized Monitoring Program indicates that catch rates of adult Colorado squawfish in the Green River are about five times as high on average as they are in the Colorado River (U.S. Fish and Wildlife Service 1987b, 1988, 1989, 1990). Plotting recent and historic mean monthly discharge reveals that reduction of spring flows in the Green River has not been nearly as significant as in the other two rivers (Fig. 10). Change in mean peak flow is also much less in the Green River than in the other two

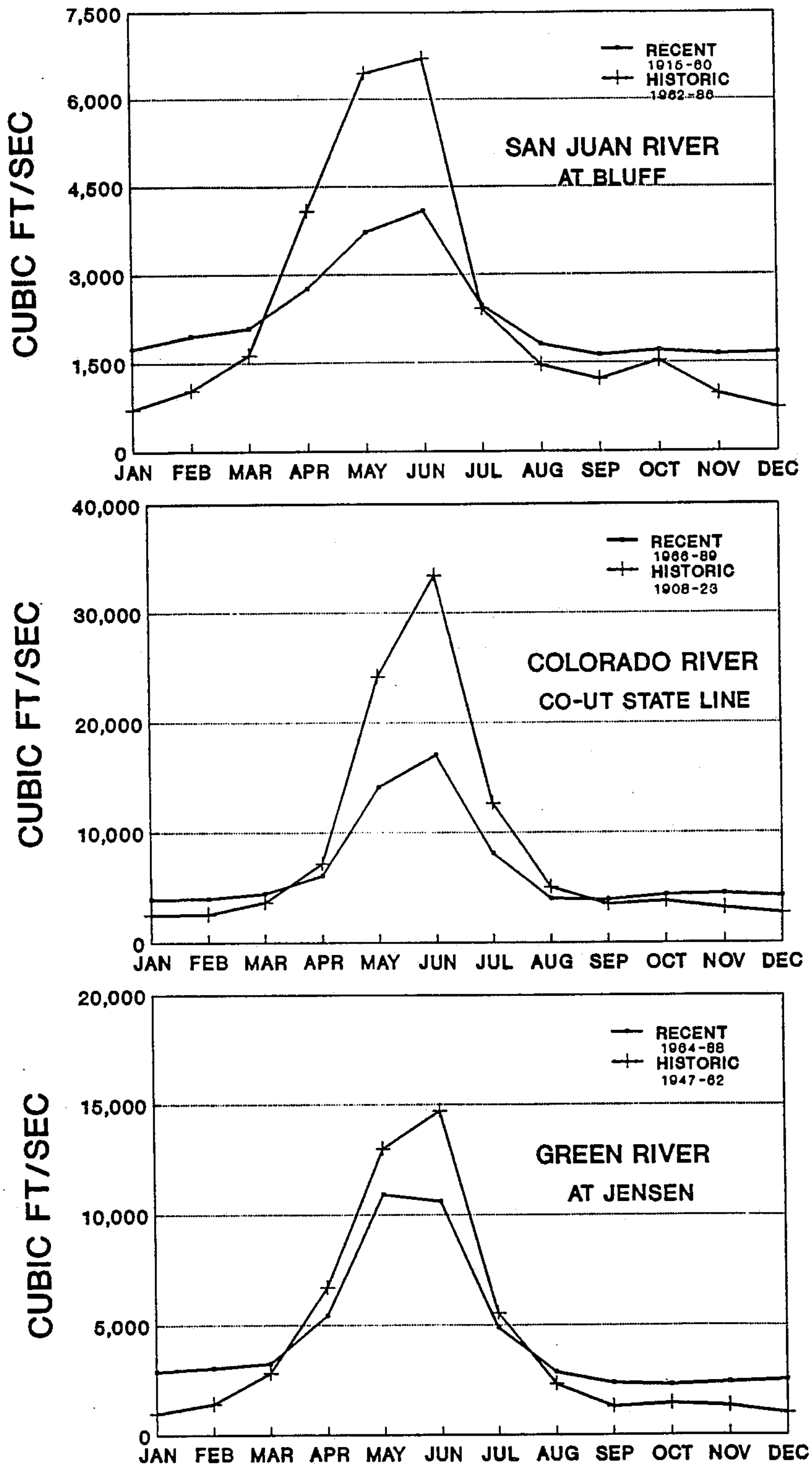


Figure 10. Mean monthly discharge at USGS gaging stations on three upper Colorado River basin rivers. Recent and historic hydrographs are from years during pre- and post-development periods for which records are available. San Juan River periods are pre- and post-Navaho Dam; Green River periods are pre- and post-Flaming Gorge dam.

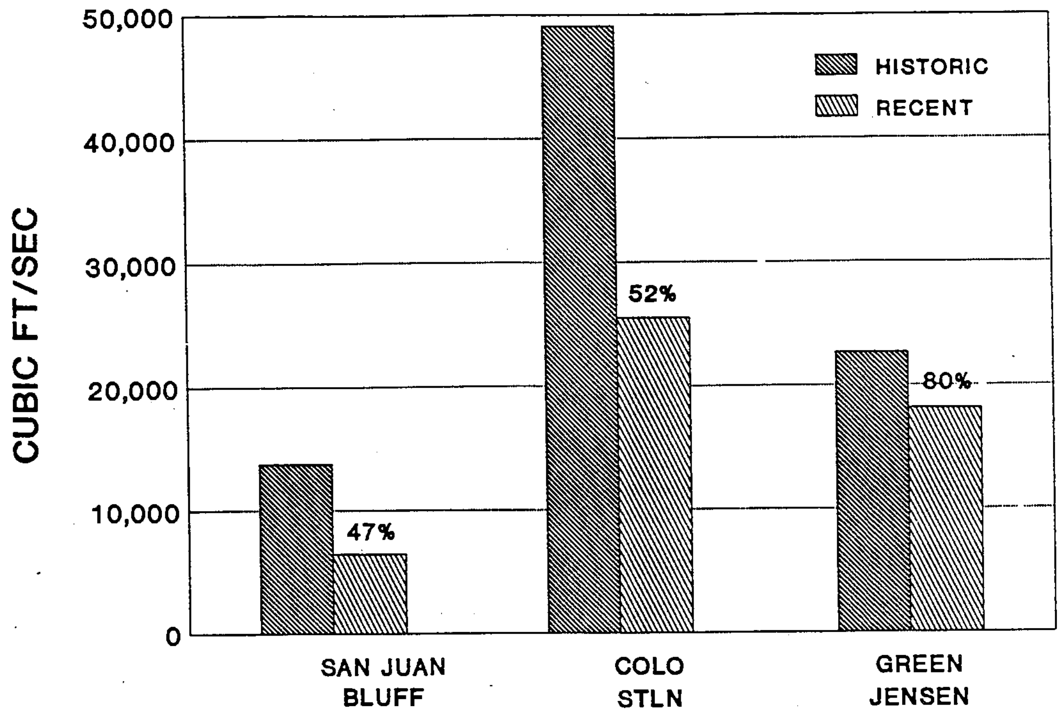


Figure 11. Change in mean peak flow (highest flow day of the year) for three upper Colorado River basin rivers. Historic and recent periods for each river are given in Figure 10. Percentages describe proportion of historic mean peak flow that recent mean peak flow provides.

rivers (Fig. 11). Although other factors are no doubt associated with the decline of these species, we hypothesize that differences in the present status of endangered fish populations among rivers is in part related to the degree of alteration of the natural hydrograph.

<u>Razorback Sucker</u>

The razorback sucker, the other rare fish that inhabits the Grand Valley, has repeatedly exhibited spawning behavior within the 15-mile reach (George Kidd personal communication, Valdez et al. 1982, Osmundson and Kaeding 1989). The status of this species is very precarious. Though adults probably spawn, no young have been reported in the upper Colorado River in the past 27 years and captures of adults in the Grand Valley have decreased dramatically in the last 17 years (Fig. 12 and Appendix Table IV). Our evaluation of existing information leads us to believe that the decline of this fish is linked to the reduction in spring flows.

Razorback suckers spawn in spring. It is not known whether gonadal maturation and degree of ripeness is primarily controlled by photoperiod or water temperature. Bulkley and Pimentel (1983) found that the preferred temperature of adults is between 22.9 and 24.8 C. Hamman (1985) suggested that egg incubation temperature was a critical factor in the reproductive cycle of the razorback sucker; his work and that of Inslee (1982) indicated that optimum temperatures for reproduction were 20-22 C. Marsh (1985)

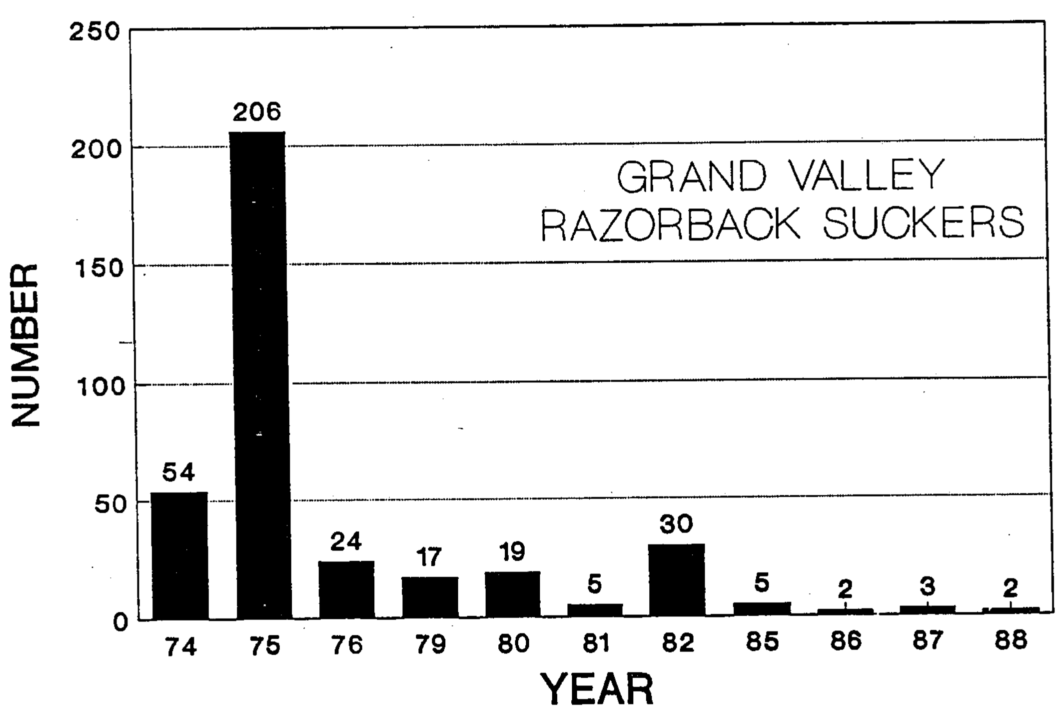


Figure 12. Razorback sucker captures from the Colorado River between Loma and Palisade, Colorado (RM 152.8-185.1), 1974-1990. Effort among years was not constant. Individuals captured upstream or downstream of the Grand Valley are not included. Missing years are due to either no effort expended (1977-1978), or no fish caught despite minimal effort (1983 and 1989) or extensive effort (1984 and 1990). Data from Appendix Table IV.

experimentally controlled temperature to determine effects on percent hatch of razorback sucker eggs; of six temperatures studied, 20 C resulted in highest hatch success, followed by 25 C. There was a significantly lower hatching success at 15 C, and complete mortality of eggs at 5, 10, and 30 C. Results for Colorado squawfish were almost identical. One major difference between the two species, however, is that upper basin Colorado squawfish spawn in the summer and razorback suckers spawn in the spring.

Though Kidd (1977) did not note whether the razorbacks he captured were ripe, subsequent researchers did; of 157 captured during studies by McAda and Wydoski (1980), Valdez et al. (1982), USFWS (unpublished data), and Osmundson and Kaeding (1989), 42 were in spawning condition (38 from flooded gravel pits, one from a backwater, and two from a main channel shoreline). Of the 42 running ripe fish, 40 (95%) were caught between 24 May and 17 June (Fig. 13); the two remaining ripe razorbacks were males and were captured between 3 and 10 April in the Walker Wildlife Area. Colorado squawfish spawn when main-channel temperatures reach 19-22 C after spring flows have decreased; when this occurs varies greatly among years (late June to early September) depending on river and weather conditions. However, razorback suckers always come into spawning condition in spring even though main-channel temperatures are far from the optimum required for maximum egg hatching success. The explanation that we offer for this is that the razorback sucker has evolved a reproductive strategy that differs from that of the Colorado squawfish. Both are warmwater species and spawning is thus timed such that resulting young are hatched under conditions that favor rapid growth. However, whereas Colorado squawfish wait for main-channel temperatures to rise to the optimum level before spawning occurs, razorback suckers seek out off-channel habitats containing optimum temperatures earlier in the season. Spawning migrations and gonadal maturation of razorback suckers may largely be initiated by photoperiod, with warm temperatures hastening final gonad maturation. In the Grand Valley, sexual ripeness of razorbacks coincides with the period of peak runoff (Fig. 13). Only during high flow conditions can razorbacks of the upper basin find their optimum spawning temperatures in spring, but they must leave the main channel to do so. The main channel during peak flow averages 13.0 C (USGS gage data at Cameo; Appendix Table V). Razorback suckers can find water warmed to 20 C in off-channel habitats when high spring flows flood low-lying areas adjacent to the river. These still-water sites are warmed by direct sunlight and ambient air temperatures and are generally much warmer than the main channel. Water tempera-

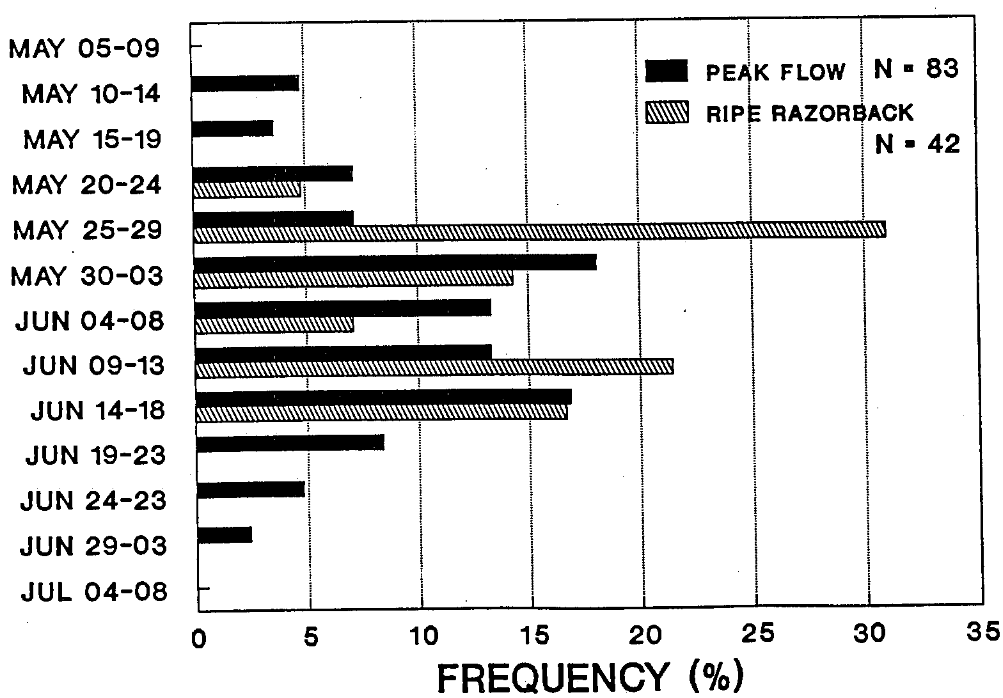


Figure 13. Frequency of Colorado River peak flow dates during 1907-1989 (N = 83 years) and capture dates during 1975-1988 of razorback suckers (N = 42 fish) in spawning condition (expressible sex products present) in the Grand Valley, Colorado. Two ripe razorback suckers captured in early April 1975 are not represented. Data from McAda and Wydoski (1980), Valdez et al. (1982), USFWS (unpublished), and Osmundson and Kaeding (1989).

ture of the flooded gravel pit in the 15-mile reach from which two running ripe razorbacks were captured in 1986 was 22.5 C, while the main channel temperature was 13-13.5 C.

We believe the razorback sucker evolved to exploit the ephemeral but predictable flooded bottomland habitat type as part of its reproductive strategy. Today, the magnitude of spring flows has been reduced to little more than half of that which occurred historically resulting in much loss of lowland flooding. Those areas in the Grand Valley that might still routinely flood, and thus provide potential spawning habitat for razorback suckers, have been diked by land owners. Razorback suckers must now spawn in suboptimum habitats such as gravel-pit ponds, where carp (*Cyprinus carpio*) and introduced predators are abundant, or in the main channel where temperatures are low and the opportunity for hybridization with flannelmouth suckers is increased.

As mentioned above, the frequency of years in which peak flows of 30,000-40,000 cfs are attained at the State line (or 19,500-25,000 cfs in the 15-mile reach) has not changed significantly from historic times, but the frequency of years with peak flows higher than this has been greatly reduced (Fig. 7 and 8). Spawning requirements of razorback sucker that are uniquely tied to very high flows in spring would greatly help to explain why the population of razorback sucker has collapsed while a small population of Colorado squawfish has managed to persist. Historically, peak flows greater than 40,000 cfs at the State line occurred in 56% of the years; in recent times, they have occurred in only 8% of the years.

To recover razorback sucker in the upper Colorado River, the process of river channelization must be reversed so that suitable spawning habitat is once again available to the population. This will require a combination of higher spring flows and management of the Grand Valley floodplain. The leasing or purchase of key riverfront areas in the Grand Valley where dikes could be removed and the adjacent low-lying lands allowed to flood should be explored. Natural draining of such areas after runoff would prevent the establishment of resident populations of predacious fish.

Recommendations

Analyse- of data collected in the Grand Valley (Osmundson and Kaeding 1989, and new data presented here) and in downstream reaches of the Colorado River (McAda and Kaeding 1989) have revealed a strong relationship between flows and the annual abundance of Colorado squawfish young. The high-flow years of 1983 and 1984 resulted in low catch rates of young Colorado squawfish, as did the low-water years of 1988 and 1989. Peak flows during 1983 and 1984 at the State line gage were 60,200 and 68,300 cfs, respectively; during 1988 and 1989, peak flows there were 15,000 and 9,480 cfs, respectively. Based on data currently available, we feel that flow conditions of 1985 should be viewed as optimal for maximum production of Colorado squawfish young, followed by those of 1986. It is not known whether flows somewhat higher than those provided during these years, but not as high as 1983 and 1984 levels, would result in even greater production of young. It is also possible that physical as well as biotic changes brought about by the high flows of 1983 and 1984 provided the necessary conditions that were conducive to the relatively high reproductive success realized in the succeeding two years. Flow conditions and production of young should never fall below 1987 levels (State line peak of 22,000 cfs); except during years of extreme drought, such flows should be viewed as the minimum acceptable.

In light of the above discussion, we recommend the following:

1) to maintain or increase the current 25% frequency rate of peak flows (high day of the year) within the 30,000-40,000 cfs range (at State line) for optimum production of Colorado squawfish young, and for reducing numbers of introduced fishes,

2) to increase the frequency of years with peak flows in excess of 40,000 cfs (at State line) from the current one in 12 years (8%) to one in four years (25%) to improve razorback sucker reproduction, maintain complex habitats for adult Colorado squawfish and backwaters for young, and flush otherwise protected habitats of undesirable, introduced fishes,

3) and the remaining 50% of the years should have peak flows in excess of 22,000 cfs (at State line) to provide minimally acceptable production of Colorado squawfish young, to keep tamarisk from becoming rooted in sand bars so as to prevent further channelization of the river, and to keep in check the yearly abundance of introduced fishes.

Peak flows of sufficient magnitude and frequency are needed in the 15-mile reach to provide benefits there as well as to help provide the target peak flows at the State line. To arrive at corresponding flows for the two reaches, average peak flows in the 15-mile reach were calculated from several years during which the target peak flows at the State line were similar (see Tables 7, 8 and 9). Recommended peak flows in the 15-mile reach are as follows:

1) 20,500 to 23,500 cfs in at least one of four years (25%),

2) peak flows in excess of 23,500 cfs in at least one of four years (25%).

3) and 14,800 to 20,500 cfs to occur at a frequency of no more than two of four years on average (50%),

Table 7. Peak flows and mean monthly flows in the upper end of the 15-mile reach during years in which peak flows at the State line gage were about 40,000 cfs. Data from Appendix Tables I and II.

Year	Stateline peak	15-mile peak	Mean monthly April	May	June
1985	38,200	24,854	5,456	15,563	16,214
1962	39,200	24,090	7,946	13,708	13,998
1958	44,200	25,420	2,063	13,766	12,617
1944	42,192	18,410	974	8,912	14,483
1916	39,600	25,200	4,294	13,160	20,570
1911	38,800	24,200	2,602	12,190	19,320
Mean	40,365	23,696	3,889	12,883	16,200
SD	2,329	2,643	2,552	2,235	3,145

Table 8. Peak flows and mean monthly flows in the upper end of the 15-mile reach during years in which peak flows at the State line gage were about 30,000 cfs. Data from Appendix Tables I and II.

Year	Stateline peak	15-mile peak	Mean monthly April	May	June
1986	32,800	22,880	6,234	12,468	16,660
1980	30,200	19,740	2,297	9,623	14,119
1970	32,300	22,640	1,599	13,274	13,004
1956	27,600	18,583	2,101	10,145	9,326
1951	28,800	21,040	1,469	7,680	13,174
1943	30,739	20,406	3,146	7,328	14,475
1919	32,200	19,360	4,350	12,850	9,083
1913	27,300	20,250	4,802	12,740	12,550
Mean	30,242	20,612	3,250	10,764	12,799
SD	2,157	1,515	1,718	2,404	2,552

Table 9. Peak flows and mean monthly flows in the upper end of the 15-mile reach during years in which peak flows at the State line gage were about 22,000 cfs. Data from Appendix Tables I and II.

Year	Stateline peak	15-mile peak	Mean monthly		
			April	May	June
1987	22,000	12,950	3,039	7,847	6,668
1974	22,400	14,495	2,203	10,492	9,664
1971	20,900	17,007	4,113	7,535	13,846
1959	21,800	14,232	982	5,319	10,104
1950	22,187	15,566	2,629	5,913	12,187
1940	22,782	14,320	1,420	12,860	7,512
Mean	22,012	14,762	2,398	8,328	9,997
SD	641	1,259	1,132	2,862	2,720

Though we believe peak flows are important, they actually describe the flows of only one day during the year. Obviously, one day of high water would not be enough to maintain channels, flush introduced fish, prepare the spawning substrate, prevent establishment of tamarisk seedlings, or provide enough time for razorback suckers to spawn in flooded bottomlands. In addition to these peak flows, recommendations for monthly flows during April, May and June must be provided and would necessarily be something less than that of the high day. To arrive at these, we employed the method used above in arriving at peak flow recommendations, that is, to average the mean monthly flows for those years used in the peak-flow recommendations. To obtain peak flows at the State line in the 30,000-40,000 cfs range, we would expect mean monthly flows in the 15-mile reach of approximately 3,200-3,900 cfs in April, 10,800-12,900 cfs in May and 12,800-16,200 cfs in June (Tables 7 and 8). Years that have provided the minimally acceptable peak flows of about 22,000 cfs at the State line, or an average of 14,800 at the top of the 15-mile reach, have mean monthly flows averaging about 2,400 cfs in April, 8,300 cfs in May, and 10,000 cfs in June (Table 9). Years with mean monthly flows that have provided peak flows of around 40,000 cfs at State line (about 23,500 at the top of the 15-mile reach), which we recommend as a minimum peak to occur at a rate of one in four years, average about 3,900 cfs in April, 12,900 cfs in May, and 16,200 cfs in June (Table 7). Thus our spring flow recommendations for the top of the 15-mile reach are summarized in Table 10.

The advantage of recommending a flow 'window', or range of acceptable flows, rather than one set number, is that it allows flexibility in meeting that recommendation; only in a completely regulated river could one expect a set flow to be met with any certainty. The danger of recommending a flow window is that it is commonly interpreted to mean that any flow within the window is equally beneficial. This, however, is not the case here. Based on the relationship between peak flow and abundance of squawfish young, a flow of 30,000 cfs at the State line is not as good as a flow of 38,200 cfs. Thus, the window 'sill', or low end of the range, should not be interpreted as the recommendation. We therefore recommend

Table 10. Recommendations for spring flows (in cfs) in the 15-mile reach.

		Mean monthly discharge		
Frequency (percent years)	Peak day	April	May	June
≥ 25%	> 23,500	> 3,900	> 12,900	> 16,200
≥ 25%	20,500-23,500	3,200-3,900	10,800-12,900	12,800-16,200
≤ 50%	14,800-20,500	2,400-3,200	8,300-10,800	10,000-12,800

that the mean monthly flows fall within the ranges listed above with the desired frequency such that, over time, the mid-point between the low and high end of each range is the targeted flow. Thus, during some years, mean flows would be in the upper end of the range, in other years, the lower end; the result would be a long-term average in the middle of each range.

Although a return of the spring hydrograph to its historic level would be the safest recommendation to assure recovery, we do not believe it is necessary. On the other hand, current spring flows are inadequate: the squawfish population has apparently declined since historic times and the razorback sucker population is practically extirpated. Obviously, maintaining the status quo will not be enough. Based on existing data and our current state of knowledge, we believe that meeting the above recommendations will be the minimum necessary to reverse the decline of these populations and bring about recovery.

WINTER FLOWS (NOVEMBER-FEBRUARY)

General

Optimum winter flows for the Colorado squawfish and razorback sucker in the 15-mile reach are difficult to estimate. As discussed above, high flows during spring are critical in shaping the river channel, in determining substrate composition, and in influencing the abundance of various species for the remainder of the year. Both spring and summer flows are critical in influencing quality and quantity of spawning habitat for the two species. Summer flows are important in providing good feeding and resting habitat at a time when metabolic demands, activity, and growth are at their yearly high. During winter, however, activity is much reduced due to water temperatures near zero. Colorado squawfish and razorback suckers are primarily in a maintenance mode during this time; though not entirely dormant, their movements are localized and probably involve minimal feeding activity and avoidance of moving ice (Wick and Hawkins 1989, Valdez and Masslich 1989).

Review of Winter Habitat Use

During winter in the Grand Valley, adult Colorado squawfish primarily occupy pools and slow runs; large backwaters are also used but are few in number (Osmundson and Kaeding 1989). Habitats occupied at this time vary in depth, but are generally deeper than habitats occupied at other times of the year. Mean depth by month at the locations of radiotelemetered squawfish during 1986-1989 was 5.1 ft for November, 5.0 ft for December, 4.7 ft for January, and 3.8 ft for February. Data also indicated that squawfish were more likely to use shallow sites if there was ice cover. Most sites (> 50%) were of very low velocity (< 0.35 ft/sec); the mean-column velocity of some sites was relatively high (1.0-1.95 ft/sec), but we suspect that the fish may have been residing on the bottom where velocities would be much lower.

For razorback suckers, pools and eddies were primarily used throughout the winter, though we did note an increased use of runs during February. Sites used were generally deeper than those used by Colorado squawfish. Mean depth of sites where radiotelemetered razorback suckers were located was 6.4 ft during November, 7.2 ft during December, 6.4 ft during January, and 6.8 ft during February.

Recommendations

Availability of good winter habitat has probably not been a limiting factor for adult Colorado squawfish or razorback sucker in the upper Colorado River. We believe the decline of these populations is in part related to the reduction of spring flows, as discussed previously. Unlike spring flows, mean monthly flows during winter have actually increased since historic times (Table 11 and Fig. 14). We are not aware of negative effects on the endangered fishes that may have resulted from these increased flows. Though average velocities increase with higher flows, there is probably an adequate number of low-velocity pools, runs, and microhabitats available at present winter discharge levels. Whether the increase in flows has had a beneficial effect on winter habitats of the rare fish in the 15-mile reach is not known. One possible benefit of higher flows would be the increased availability of large backwaters for use by

Table 11. Summary of recent and historic discharge for the Colorado River at the top of the 15-mile reach during the months of November-March. Values are means of monthly means for period of record (data from Appendix Table VI).

Years	No. years	NOV	DEC	JAN	FEB	MAR
Recent 1954-1989 (SD)	36	2,161 (492)	1,889 (420)	1,765 (368)	1,781 (409)	2,006 (541)
Historic 1902-1942 (SD)	41	1,789 (317)	1,414 (248)	1,322 (195)	1,346 (194)	1,786 (459)
Recent/historic		121%	134%	134%	132%	112%

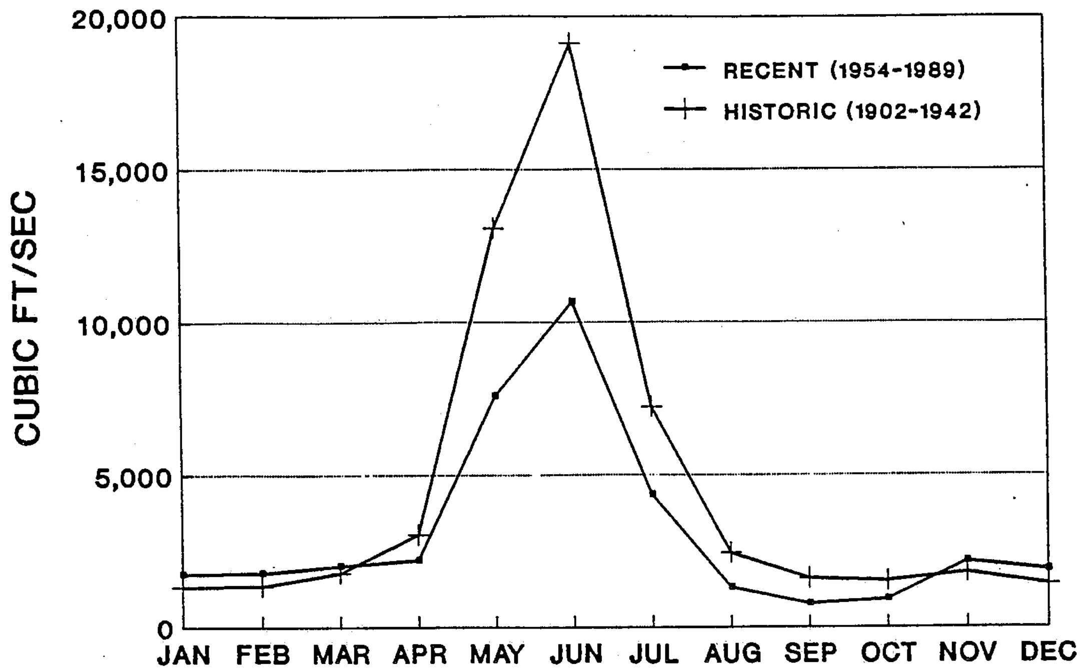


Figure 14. Mean monthly discharge of the Colorado River at the top of the 15-mile reach during recent (1954-1989) and historic (1902-1942) times. Values are from Tables 4, 11 and 12.

adult squawfish. The amount of deep-water habitats suitable for razorback sucker use has also probably increased as a result of increased flows. How these increased flows may affect nursery habitat both within and downstream of the reach has not been determined. We are currently using aerial/video imagery to quantify backwater habitats as a function of various flow regimes. Whether backwater habitats are important to YOY Colorado squawfish during the winter period has not yet been determined.

At present, we see no cause for concern with the current winter flow conditions in the 15-mile reach. We assume that historic conditions also provided adequate winter habitat for adult fish. We do not know the degree that winter flow levels could be reduced below current or historic levels without having a negative effect on winter habitats. To provide deep-water habitats, particularly for razorback sucker, our tentative recommendation is for winter flows to not fall below historic levels, i.e., between about 1,000 and 2,000 cfs and averaging about 1,470 cfs. If operation of upstream storage facilities allowed, a seasonal redistribution of the surplus winter flows might be beneficial, i.e., store winter flows in excess of historic levels and later release this additional water during spring to help meet the spring flow recommendations.

Though mean flows during November were greater than 1,470 cfs both historically (1,789 cfs) and recently (2,161 cfs), we see no evidence in our Colorado squawfish or razorback sucker habitat-use data to indicate the need for higher flows during November than during the other winter months. Our current habitat studies in the Grand Valley will provide more definitive information on the flows that maximize optimum winter habitat types.

TRANSITION MONTH FLOWS (OCTOBER AND MARCH)

October

Mean monthly flows for October in the 15-mile reach have decreased since historic times: the average mean monthly flow now is approximately 61% of what it was during 1902-1942 (Table 12). Runs and pools comprised 85% of the habitat types used by radiotelemetered Colorado squawfish during October in the 15-mile reach during 1986-1988. October is apparently a transitional period for squawfish in their selection of habitat types. Adult squawfish were located in pools 13-18% of the time during the summer months of July, August and September, but 30% of the time in October; in winter they were located in pools 46-62% of the time depending on the month. Depth of sites was not substantially different from those used

Table 13. Summary of recent and historic river discharge for the Colorado River at the top of the 15-mile reach during the months of July-October. Values are means of monthly means for period of record (data from Appendix Tables 5 and 6; negative values in Appendix tables were converted to zeros before averages for time periods were calculated).

Years	No. years	JUL	AUG	SEP	OCT
Recent					
1954-1989	36	4,341	1,311	762	924
(SD)		(4,132)	(1,323)	(713)	(759)
Historic					
1902-1942	41	7,212	2,446	1,609	1,522
(SD)		(4,200)	(1,540)	(1,139)	(894)
Recent/Historic		60%	54%	47%	61%

during the summer months, but velocities were generally reduced. For razorback sucker, there appeared to be no major difference in habitat use between October and the preceding three summer months (Osmundson and Kaeding 1989). We suspect that present flow conditions, or those recommended for the summer months, are satisfactory for maintaining adequate adult habitat during October.

March

Like October, March appears to be a transitional month for Colorado squawfish; use of pools is decreasing at this time and the use of runs is increasing. During March, water temperature is rising and fish activity levels are increasing from those during the winter period. Use of deep-water habitat is decreasing but, as in winter, sites with low velocity are preferred. Habitat use by razorback suckers is similar to that during winter, though during March, the use of backwaters begins. Deep-water sites are still preferred and average 6.1 ft deep with low velocities (Osmundson and Kaeding 1989).

Flows in the 15-mile reach during March have increased since the early part of the century, much as winter flows have (Table 12). The mean flow in March is now 2,006 cfs. This amounts to an average increase of 220 cfs. For the reasons cited above for winter flows, this increase in March is not deemed detrimental to the native fishes. Based on the apparent need for deep-water habitats by razorback sucker, we recommend maintaining the current March flow regime. Future March flows might be reduced to historic levels or those levels of the historic winter months with little negative effect. However, flows as low as those previously recommended for the summer months (700-1200 cfs) would probably not provide an adequate amount of deep-water habitat. We hope the results of our current flow-vs-habitat studies will allow us to further refine this recommendation.

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APPENDIX I

RATIONALE FOR METHODOLOGIES

Concurrent with our earlier efforts in developing flow recommendations for the summer months, USFWS was also responsible for developing recommendations for flows in the Yampa River (Tyus and Karp 1989, U.S. Fish and Wildlife Service 1990b). Due to the differences in the two river systems and the status of the rare fish in each, a different approach was used for the Yampa River system. The Yampa River currently contains the most viable population of Colorado squawfish left in the basin, widely attributed to the fact that the Yampa River system has the least altered flow regime of any river in the basin historically occupied by Colorado squawfish. Thus, to insure the continued integrity of this important population, USFWS concluded that the appropriate river management plan is to maintain the current, largely undeveloped status of the Yampa River, and that "Major deviations from the current environmental baseline flows will likely eliminate any hope for recovery and maintenance of the rare fishes in the Yampa and Green River basins" (U.S. Fish and Wildlife Service 1990b). Flow regimes within the 15-mile reach of the upper Colorado River, on the other hand, have been highly modified by upstream dams and diversions and it is generally believed that populations of Colorado squawfish and razorback sucker have significantly declined there since historic times. We recognized that the 15-mile reach will continue to be a highly regulated portion of the Colorado River and that the endangered fish would be lost there without the implementation of active management efforts. Thus, unlike the Yampa River, the situation in the 15-mile reach requires habitat enhancement rather than maintenance of the status quo. Our task therefore is to improve conditions for the fish in an altered river system.

In developing provisional recommendations for the summer months (Kaeding and Osmundson 1989), we explored various options to help us estimate the magnitudes of flows that would best benefit the fish in the 15-mile reach. We chose to develop our recommendations based on 1) current biological theory about factors limiting Colorado squawfish in the reach, 2) empirical data and observations, and 3) analytical models that relate flow to habitat. The Physical Habitat Simulation Methodology (PHABSIM), a technique often employed within the larger Instream Flow Incremental Methodology (IFIM) was the best model available to estimate a flow window that would optimize adult squawfish habitat during summer.

PHABSIM uses fish microhabitat data to develop suitability index (SI) curves which represent the relative use of various water depths, velocities and substrates for a given life stage of a species of fish (e.g., adult Colorado squawfish in this case). These habitat suitability curves are compared with depth, velocity and substrate data collected along transects across the river channel at a site or sites meant to be representative of the entire reach; this allows the determination of the relative amount of suitable depth, velocity and substrate types available under various flow scenarios (Hann and Rose 1989).

The PHABSIM model calculated that the maximum aggregate amount of pool, run and riffle habitat for adult Colorado squawfish during the summer months in the 15-mile reach occurred at flows of 900-1100 ft3/sec (cfs). We felt that an acceptable flow window would be one that provided at least

95% of the maximum amount of pool, run and riffle habitats; this was estimated to be 700-1200 cfs. We were unable to use PHABSIM in estimating optimal summer flows for razorback sucker, however, due to an insufficient amount of habitat use data for that species.

Using PHABSIM was an attractive option because it was capable of utilizing and basing its output on existing Colorado squawfish, habitat-use data collected specifically from the 15-mile reach. However, the method was originally developed for use in high-gradient trout streams and has some inherent shortcomings when applied to large turbid rivers like the Colorado. These shortcomings have been outlined by Orth (1987) and discussed in relation to the 15-mile reach by Kaeding and Osmundson (1989). We feel it necessary to review some of these limitations; they include:

1) In a turbid river, radiotelemetry (as opposed to direct observation, e.g., using SCUBA) is the only practical method for identifying microhabitats used by the fish. Measurements taken at the locations of radiotelemetered fish are used to develop the habitat suitability curves. Though depth and substrate can be adequately measured at these sites, velocity at the precise location of the fish is unknown. Instead, mean-column velocity is used in developing the SI curves and it is suspected that the two variables, nose and mean-column velocities, may often be significantly different if fish normally reside near the bottom where velocities are generally reduced.

2) Colorado squawfish probably require a variety of habitat types in close proximity to one another so that they can minimize time and energy expenditures while traveling among feeding and resting sites. Habitat measurements at locations of radio-telemetered Colorado squawfish were only taken

if the fish was stationary for 10 or more minutes. As a result, we may have inadvertently biased our data by over-representing resting sites; presumably, squawfish are moving when they feed and thus habitat information in feeding areas would be difficult to obtain. Resting areas would likely be of lower velocity than other important habitats nearby. Colorado squawfish apparently use a variety of habitats with a range of depths and velocities. PHABSIM implies that a homogeneous environment (i.e., of uniform depth and velocity) is ideal for the target organism, which is likely not the case.

3) Some important habitats, such as eddies, backwaters and flooded gravel pits could not be included in the analysis because the model software was not designed to simulate shoreline or off-channel habitats with zero or negative (moving in a general upstream direction, as in eddies) velocities. For instance, to maximize the amount of habitats with zero velocity, such as backwaters or gravel pits, the model output recommends a river with no flow.

4) If the 0.6-mile PHABSIM site from which the baseline depth, velocity and substrate data were collected was not representative of the 15-mile reach as a whole, the model outcome would be erroneous to some unknown degree. An additional site might have provided better representation or perhaps validation of the first site. Also, those habitats used by Colorado squawfish that were not present in the representative site, such as rapids and backwaters, could not be modeled. In addition, it is difficult if not impossible for PHABSIM to work with complex sites (i.e., areas with multiple channels and islands), yet these complex areas were where squawfish were most often located during our summer radiotelemetry studies.

5) Squawfish use of deep-water sites would not be represented in the SI depth curve because radio receivers are limited in their ability to detect a transmitter in deep (>8-10 ft) water; thus, the depth curves may be slightly biased due to over-representation of the shallower sites.

6) PHABSIM defines fish habitat as depth, velocity, and substrate. Though these three variables are no doubt very important, habitat as a whole is much more complex; it includes other physical variables such as temperature, turbidity, and cover, as well as biotic factors such as the presence of competitors, predators and food organisms.

Thus, in using PHABSIM we had to assume that the transect site was representative and that preferred nose-velocities would be automatically provided if the recommended mean-column velocities were provided. We had to use the model to recommend flows that would maximize pool, run, and riffle habitat while neglecting the need for backwaters, eddies and rapids. The model output may have recommended a flow window that maximized resting habitat and neglected foraging habitat. Also, the flow and habitat needs of important food organisms of Colorado squawfish were not included in our analysis. Despite these limitations, we felt that PHABSIM was still the best method available to objectively provide a recommendation based on existing habitat use data. Although this model is sophisticated, we recognize that it is simplistic in comparison to the complexity of large river systems and how fish utilize the habitats they contain. However, an important caveat is that the recommendations we provided should be considered provisional, and subject to modification as new data become available and model output can be validated.

As we begin to develop flow recommendations for the other months of the year, we must first ask ourselves whether PHABSIM can again be used. Though we had reservations about using PHABSIM for developing flow recommendations for the summer months, we felt the model was largely representative of the depths, velocities, and substrates used by adult Colorado squawfish during the summer. In lieu of strong empirical relationships involving summer flow needs of the fish, we felt the model output provided a reasonable basis for a provisional recommendation for summer flows. However, after examination of the winter and spring habitat use data, we have concluded that our reservations in using PHABSIM in the development of flow recommendations for these months are too great. Instead, we decided that estimation of optimal flows for the winter and spring periods would more appropriately be derived using available, empirical relationships rather than model simulation.

Table I. Peak flows (mean flow of the highest day) in the top end of the 15-mile reach, in the Gunnison River near Grand Junction, and at the Colorado/Utah State line.

	15-mile reach			Gunnison			State line		
Year	Month	Day	cfs	Month	Day	cfs	Month	Day	cfs
1989	May	31	6,641	Apr	22	3,590	May	31	9,480
1988	Jun	6	10,874	May	19	3,460	May	19	15,000
1987	May	17	12,953	May	2	9,070	May	18	22,000
1986	Jun	7	22,742	May	5	9,780	Jun	8	32,800
1985	Jun	10	24,854	May	5	15,050	May	6	38,200
1984	Jun	26	36,500	Jun	8	23,140	May	27	68,300
1983	Jun	26	36,000	Jun	27	20,140	Jun	27	60,200
1982	Jun	29	11,378	May	5	7,910	Jun	19	18,600
1981	Jun	10	7,969	May	4	3,660	Jun	9	11,200
1980	Jun	13	19,740	May	24	13,050	May	25	30,200
1979	May	29	20,690	May	28	13,150	May	30	35,400
1978	Jun	16	18,242	May	17	7,460	Jun	17	27,200
1977	Jun	9	3,066	May	11	1,020	Jun	10	4,720
1976	Jun	6	9,652	May	18	5,070	Jun	7	13,600
1975	Jun	9	16,195	May	21	8,780	Jun	9	26,000
1974	May	10	14,495	May	11	7,210	May	11	22,400
1973	Jun	15	23,900	May	21	11,850	Jun	16	33,500
1972	Jun	9	14,520	Jun	9	3,400	Jun	9	17,700
1971	Jun	25	17,007	Apr	15	6,230	Jun	23	20,900
1970	May	23	22,640	Jun	28	11,040	May	24	32,300
1969	May	28	11,876	Apr	25	9,430	Jun	26	18,200
1968	Jun	6	17,100	Jun	4	7,390	Jun	7	25,200
1967	May	26	12,530	May	27	4,470	May	27	18,200
1966	May	10	7,824	May	8	5,310	Jun	1	10,800
1965	Jun	19	21,380	May	23	15,250	Jun	20	35,800
1964	May	27	13,390	May	10	4,680	May	27	26,600
1963	May	20	6,387	May	27	12,950	May	20	11,000
1962	May	13	24,090	May	13	16,450	May	13	39,200
1961	Jun	1	11,257	May	29	7,340	May	31	18,700
1960	Jun	5	14,592	May	14	8,940	Jun	5	23,600
1959	Jun	10	14,232	Jun	16	6,420	Jun	10	21,800
1958	May	30	25,420	May	24	19,750	May	30	44,200
1957	Jul	1	30,640	Jun	7	27,340	Jun	9	56,300
1956	Jun	3	18,583	Jun	4	8,270	Jun	4	27,600
1955	Jun	14	8,465	May	9	7,740	Jun	10	16,400
1954	May	23	7,056	May	23	3,170	May	23	11,200
1953	Jun	14	22,356	Jun	14	13,140	Jun	15	35,600
1952	Jun	9	31,460	May	6	22,250	Jun	9	51,400
1951	Jun	22	21,040	May	29	9,740	Jun	22	28,800
1950	Jun	17	15,566	Apr	24	7,890	Jun	4	22,187
1949	Jun	19	26,060	Jun	20	18,440	Jun	21	47,156
1948	May	23	26,520	May	22	20,950	May	23	46,474
1947	Jun	22	24,138	Jun	22	13,440	Jun	22	36,971
1946	Jun	18	16,166	Jun	8	8,88	Jun	19	26,109
1945	Jun	25	16,592	May	12	14,750	May	13	26,815

Table I continued. Peak flows.

	15-mile reach			Gunnison			State Line		
1944	Jun	2	18,410	May	17	25,550	May	17	42,192
1943	Jun	3	20,406	May	5	12,850	Jun	4	30,739
1942	Jun	8	26,330	May	27	20,550	May	28	44,716
1941	May	15	27,030	May	14	26,150	May	15	51,810
1940	Jun	3	14,320	May	13	8,510	May	14	22,782
1939	May	23	18,189	May	6	7,780	May	24	24,405
1938	Jun	7	30,550	May	30	17,275	Jun	6	49,374
1937	May	18	19,360	May	17	15,075	May	17	35,274
1936	Jun	1	24,858	May	7	14,675			
1935	Jun	16	34,130	Jun	16	15,775			
1934	May	11	13,538	May	12	4,165			
1933	Jun	2	36,500	Jun		17,775			
1932	May	23	30,250	May		18,075			
1931	Jun	8	14,600	May		3,735			
1930	Jun	1	26,200	May		12,375			
1929	Jun	10	37,600	May		23,075			
1928	Jun	1	43,800	May	3	21,375			
1927	May	20	29,850	May	19	17,675			
1926	Jun	8	32,800	Jun	5	13,875			
1925	May	31	18,050	Apr	18	8,635			
1924	Jun	14	34,000	Jun	7	14,975			
1923	Jun	17	29,800	May	28	18,075	May	29	49,600
1922	May	29	30,450	May	7	22,175	May	29	53,100
1921	Jun	16	50,200	Jun	15	29,775	Jun	16	81,100
1920	Jun	1	41,000	May	23	35,175	May	23	77,100
1919	May	30	20,850	May	22	11,175	May	29	32,200
1918	Jun	14	47,400	Jun	14	16,875	Jun	15	56,200
1917	Jun	19	49,400	Jun	18	24,775	Jun	20	62,500
1916	Jun	14	25,200				Jun	14	39,600
1915	Jun	21	19,900				Jun	21	26,900
1914	Jun	3	42,200				Jun	2	58,100
1913	May	31	20,250				May	28	27,300
1912	Jun	9	42,800				Jun	6	58,100
1911	Jun	10	24,200				Jun	10	38,800
1910	Jun	1	26,500				Jun	4	34,100
1909	Jun	20	42,400				Jun	9	63,600
1908	Jun	12	19,700				Jun	13	27,300
1907	Jun	18	29,600						
1906	Jun		36,400	Jun		21,875			
1905	Jun		35,300	Jun		28,075			
1904	May		24,250	May		8,605			
1903	Jun		24,500	Jun		17,775			
1902	May		17,450	May		8,325			
1901									
1900									
1899	Jun		42,800	May		15,675			
1898	Jun		17,300	Jun		11,375			
1897	May		37,200	May		20,675			

Table II. Mean monthly flows (cfs) for April, May, and June in the Colorado River at the top end of the 15-mile reach and at the Colorado/Utah State Line, and in the Gunnison River near Grand Junction, 1897-1989.

	APR			MAY			JUN		
Yr	Pal	Gun	Stl	Pal	Gun	Stl	Pal	Gun	Stl
89	2,411	2,512	5,731	4,036	1,828	6,651	4,060	1,332	6,234
88	2,134	2,504	5,788	5,136	2,247	8,551	6,412	1,727	9,108
87	3,039	5,225	9,163	7,847	6,270	15,520	6,668	3,301	11,080
86	6,234	5,587	13,070	12,468	8,308	22,370	16,660	5,529	24,070
85	5,456	7,907	15,600	15,563	10,650	28,570	16,214	7,691	25,280
84	3,227	4,318	9,017	19,413	13,750	37,960	24,884	14,520	43,120
83	1,287	2,482	4,574	8,521	7,909	17,540	25,255	13,520	41,400
82	1,363	2,544	4,836	5,944	5,056	12,340	10,663	4,137	16,370
81	900	1,155	2,727	1,983	1,461	4,600	4,067	1,269	6,516
80	2,297	3,777	6,551	9,623	9,059	20,300	14,119	6,763	22,290
79	2,000	4,653	7,914	9,039	8,232	18,650	14,313	6,492	22,760
78	1,933	2,199	5,260	5,950	4,700	11,540	13,075	5,224	19,690
77	764	550	1,631	1,120	648	2,283	1,479	556	2,688
76	1,701	1,366	3,555	5,373	3,321	8,843	6,237	2,087	8,881
75	1,616	2,623	5,155	5,435	6,416	13,150	11,645	5,579	18,710
74	2,203	2,338	5,452	10,492	4,201	15,230	9,664	1,976	12,120
73	1,089	1,533	3,731	9,141	7,360	17,710	13,711	6,900	21,540
72	1,935	1,095	3,325	5,144	1,827	7,386	9,786	1,914	12,310
71	4,113	4,437	9,013	7,535	3,351	11,570	13,846	3,497	18,010
70	1,599	2,279	4,804	13,274	6,523	19,720	13,004	6,917	21,430
69	3,280	5,083	8,796	8,107	5,345	13,490	7,396	3,202	11,440
68	1,207	1,114	3,258	4,276	4,313	8,895	11,635	4,279	16,730
67	1,237	1,415	3,146	4,075	2,280	6,899	7,779	2,491	11,460
66	1,449	2,765	4,982	5,000	3,378	8,995	3,264	2,036	6,215
65	1,786	3,810	6,677	6,796	9,411	16,886	14,575	11,390	26,140
64	778	1,689	2,981	5,690	3,009	12,520	6,483	1,490	12,600
63	1,083	1,277	3,259	3,903	6,744	7,579	2,683	5,244	5,226
62	7,946	6,608	15,010	13,708	9,295	23,650	13,998	7,951	22,990
61	680	1,089	2,559	4,639	4,283	9,300	5,742	3,447	10,160
60	3,246	4,503	8,628	6,109	4,167	11,170	9,941	5,585	16,790
59	982	897	2,425	5,319	2,670	8,337	10,104	4,241	15,300
58	2,063	4,245	7,379	13,766	14,150	28,820	12,617	9,517	23,960
57	1,559	2,247	4,878	8,755	8,954	18,710	23,989	19,570	43,830
56	2,101	2,355	5,056	10,145	5,216	15,640	9,326	4,335	14,270
55	1,379	1,781	4,265	5,447	4,210	10,130	6,272	3,616	10,760
54	1,351	1,141	3,013	3,778	1,746	6,256	1,983	600	3,481
53	1,286	1,413	3,557	4,685	3,693	8,905	13,850	7,286	22,051
52	4,516	5,712	11,290	15,533	13,260	30,500	21,622	12,690	36,080
51	1,469	1,016		7,680	4,255	12,340	13,174	5,374	19,960
50	2,629	3,653	7,135	5,913	4,979	11,538	12,187	5,306	18,043
49	2,557	3,925	7,370	8,674	7,776	17,760	17,316	10,880	29,136
48	3,515	5,415	10,023	14,937	13,530	28,402	13,030	9,119	23,574
47	2,052	1,580	4,612	12,864	7,345	21,037	16,315	8,369	25,586
46	3,996	3,035	7,822	6,351	3,665	11,313	10,340	5,333	16,719
45	971	1,495	3,362	9,343	10,160	20,166	12,585	6,781	21,110
44	974	1,684	3,573	8,912	12,270	22,220	14,483	11,600	27,194

Table II continued. Mean monthly flows for April, May, and June.

Yr	APR			MAY			JUN		
	Pal	Gunn	Stl	Pal	Gunn	Stl	Pal	Gunn	Stl
43	3,146	4,668	8,585	7,328	6,272	14,501	14,475	6,617	21,859
42	5,217	9,154	14,313	12,694	12,300	23,913	20,055	11,500	30,151
41	1,296	6,380	5,399	15,656	26,150	29,278	12,732	11,940	23,018
40	1,420	2,127	4,399	8,042	5,410	14,744	7,512	2,671	11,601
39	2,610	3,567	6,990	12,860	6,077	18,837	9,662	3,846	14,347
38	3,985	5,944	10,819	13,838	10,455	25,451	24,187	12,565	38,150
37	1,600	2,718	5,475	11,520	10,125	22,198	8,647	4,124	13,829
36	4,632	4,874		18,213	10,205		14,488	5,049	
35	877	968		4,754	4,292		20,577	9,772	
34	2,277	1,221		8,983	2,495		2,829	552	
33	962	1,238		7,392	5,822		24,880	9,283	
32	3,495	5,722		17,730	11,415		20,050	8,104	
31	1,121	1,000		5,033	2,085		8,593	2,108	
30	6,352	6,514		9,480	6,563		16,340	7,449	
29	3,746	3,385		17,860	14,435		27,310	12,885	
28	2,559	3,040		22,300	14,145		21,190	9,339	
27	2,848	3,709		18,910	11,835		20,880	9,171	
26	4,620	4,380		14,900	8,818		21,940	8,584	
25	4,429	4,153		10,480	6,101		12,230	5,186	
24	3,338	3,459		12,920	10,265		20,620	9,724	
23	2,565	2,137	4,618	14,350	11,555	25,840	24,200	11,315	36,860
22	2,618	2,957	6,547	15,840	14,885	32,010	19,790	10,215	30,600
21	2,576	2,123	4,951	17,020	10,275	28,000	32,170	17,305	52,770
20	1,931	1,838	4,198	21,050	18,845	41,530	27,600	15,995	46,580
19	4,350	4,285	8,731	12,850	8,195	20,990	9,083	4,885	13,990
18	3,198	2,703	6,420	14,230	9,007	21,760	30,820	11,105	37,380
17	4,530	3,455	7,761	13,240	10,265	21,930	35,140	18,285	46,490
16	4,294		9,272	13,160		23,010	20,570		32,090
15	2,998		6,966	7,072		12,830	15,220		21,520
14	3,890		8,485	20,280		33,500	29,060		41,430
13	4,802		10,420	12,740		19,200	12,550		17,790
12	2,265		5,662	15,030		28,440	30,020		42,790
11	2,602		6,000	12,190		22,520	19,320		28,980
10	5,401		10,810	12,580		21,430	13,740		19,320
09	2,242		6,532	12,540		23,180	32,660		45,480
08	3,448		8,128	6,173		10,890	13,970		20,080
07	4,798			9,960			24,200		
06	4,284	4,565		18,030	14,785		22,950	14,375	
05	2,194	2,469		12,530	12,695		23,840	16,785	
04	3,456	2,223		12,250	5,598		15,880	4,577	
03	1,871	2,238		8,430	8,141		18,980	12,505	
02	1,248	2,058		11,640	5,903		8,046	2,946	
01									
00									
99	3,940	3,525		19,380	9,645		31,310	10,775	
98	4,300	2,475		7,130	5,292		13,700	8,825	
97	3,478	5,975		27,480	16,675		23,270	11,135	

Table III. Key to discharge records provided in Tables I and II. Flows are either direct USGS gage records or gage records with corrections for inflow or irrigation withdrawal.

	15-Mile Reach
1897-1899	Gage at the 5th St. bridge just above the lower end of the 15-mile reach. Direct records.
1902-1933	Gage at highway bridge in Palisade. Corrected for Grand Valley Diversion withdrawal downstream of gage: 450 cfs subtracted from April records; 550 cfs subtracted for May; 600 cfs subtracted for June.
1934-1989	Gage records at Cameo and Plateau Creek were added, downstream diversions were subtracted, and Orchard Mesa Power Canal return added. Monthly correction used was to subtract 1150 cfs for April records, 1450 cfs for May, and 1500 cfs for June except for the 1986-1988 peak flows when daily withdrawal records were available. In 1934 and 1935, there were no records for Plateau Creek near Cameo, so Plateau Creek at Collbran plus Buzzard Creek at Collbran was used. All Plateau Creek records were unavailable for 1984 and 1985; we substituted with Plateau Creek 30-year average.
	Gunnison Inflow
1897-1899	Gage near mouth of Gunnison. Direct records.
1902-1906	Gage at Whitewater. Direct records.
1917-1938	Gage downstream of Redlands diversion (built in 1917) and on Redlands Power canal; gage data combined in USGS records. An additional 25 cfs was subtracted for Redlands irrigation withdrawal.
1939-1989	Gage at Whitewater minus Redlands irrigation withdrawals: -30 cfs during April, -50 cfs during May, and -60 cfs during June.
	Colorado/Utah State Line
1908-1923	Gage at Fruita. Direct records. Some minor irrigation returns between gage and state line; no corrections made.
1937-1950	Gage at Cisco minus Dolores inflow (Gateway gage) divided by correction factor X; the correction was used to account for inflows between state line and Cisco; X = 0.972 for April, 0.967 for May, and 0.974 for June. Correction factors were derived by averaging differences between reaches during years when records were available (1951-1960) for state line gage, Cisco gage and Dolores at Cisco gage (Colo. at Cisco minus Dolores at Cisco divided by Colo. at state line).
1951-1989	Gage near Colorado/Utah State line. Direct records.

Table IV. Razorback sucker captures from the Colorado River between Loma and Palisade, Colorado (RM 152.8-185.1), 1974-1990. Effort among years was not constant. Individuals captured upstream or downstream of the Grand Valley are not included. Missing years are due to either no effort expended (1977-1978), or no fish caught despite minimal effort (1983 and 1989) or extensive effort (1984 and 1990).

	Year										
Location	74	75	76	79	80	81	82	85	86	87	88
Palisade Labor Camp											
Kidd 1977	4	21	3								
Clifton Pond											
Kidd 1977		60									
Valdez et al. 1982					13						
USFWS unpub. data							9				
Connected Lakes pit											
Kidd 1977		3									
USFWS unpub. data							7				
Walker W A											
Kidd 1977	28	75	16								
McAda and Wydoski 1980	22	47	5								
Valdez et al. 1982				17	6	1					
USFWS unpub. data						1	9	2			
Other sites											
Valdez et al. 1982						2					
USFWS unpub. data						1	5	3			
Osmundson and Kaeding 1989									2	3	2
Total	54	206	24	17	19	5	30	5	2	3	2

Table V. Main channel temperature in the Colorado River near Cameo on the day of maximum annual discharge. Data provided by USGS; table includes all available records. Temperatures for 1983-1989 are means of the daily maximum and minimum; temperatures for earlier years are direct measurements taken once-daily.

Year	Month	Day	Temp (C)	Year	Month	Day	Temp (C)
1989	May	31	13.6	1969	May	28	13.0
1988	Jun	06	14.1	1968	Jun	06	12.0
1987	May	17	13.1	1967	May	26	11.7
1986	Jun	07	13.0	1966	May	10	12.2
1985	Jun	10	13.8	1965	Jun	19	12.2
1984	Jun	26	13.5	1964	May	27	-
1983	Jun	26	12.8	1963	May	20	-
1982	Jun	29	15.0	1962	May	13	-
1981	Jun	10	16.0	1961	Jun	01	-
1980	Jun	13	12.0	1960	Jun	05	-
1979	May	29	11.0	1959	Jun	10	-
1978	Jun	16	11.0	1958	May	30	12.8
1977	Jun	09	-	1957	Jul	01	14.4
1976	Jun	06	13.0	1956	Jun	03	13.9
1975	Jun	09	10.0	1955	Jun	14	-
1974	May	10	12.0	1954	May	23	14.4
1973	Jun	15	12.0	1953	Jun	14	14.4
1972	Jun	09	12.0	1952	Jun	09	14.4
1971	Jun	25	14.0	1951	Jun	22	13.9
1970	May	25	11.5				

Table VI. Mean monthly flows (cfs) in the Colorado River at the top of the 15-mile reach for the months of November-March, 1902-1989. Values for the 1934-1989 period are the sum of records for the Colorado River at Cameo and Plateau Creek USGS gages; values for the 1902-1933 period are direct gage records from the USGS gage at Palisade. Values for both periods assume no downstream diversion withdrawals during these months.

WATER YEAR	NOV	DEC	JAN	FEB	MAR
1989	1,812	1,616	1,554	1,557	1,964
1988	2,219	1,894	1,739	1,758	2,013
1987	3,198	2,625	2,258	2,349	2,523
1986	3,063	2,529	2,482	2,900	3,567
1985	3,366	3,098	2,703	2,562	2,943
1984	2,646	2,488	2,312	2,281	2,817
1983	2,632	2,016	1,806	1,806	1,942
1982	1,714	1,500	1,596	1,437	1,667
1981	1,905	1,738	1,447	1,253	1,263
1980	2,233	2,059	1,891	2,037	2,130
1979	1,954	1,567	1,396	1,570	1,916
1978	1,430	1,452	1,342	1,367	1,630
1977	2,037	1,862	1,767	1,604	1,360
1976	2,342	2,050	1,962	2,080	2,350
1975	2,233	1,958	1,837	1,845	2,111
1974	2,499	2,165	2,094	2,042	2,626
1973	2,669	2,174	1,989	1,974	2,143
1972	2,450	2,229	2,182	2,176	2,584
1971	2,737	2,387	2,355	2,100	2,580
1970	2,336	2,080	1,815	1,824	2,010
1969	2,011	1,778	1,814	1,638	1,669
1968	1,847	1,717	1,539	1,617	1,637
1967	1,656	1,485	1,472	1,415	1,816
1966	2,468	2,381	1,952	1,880	2,306
1965	1,657	1,588	1,565	1,478	1,481
1964	1,594	1,209	983	1,004	1,142
1963	2,587	1,974	1,662	1,670	1,718
1962	2,314	2,051	1,931	2,553	2,716
1961	1,729	1,692	1,647	1,583	1,461
1960	2,027	1,670	1,670	1,646	2,297
1959	1,666	1,484	1,614	1,644	1,431
1958	2,218	1,785	1,605	1,857	2,144
1957	1,449	1,227	1,343	1,459	1,412
1956	1,646	1,512	1,364	1,365	1,770
1955	1,716	1,390	1,253	1,252	1,482
1954	1,751	1,564	1,606	1,530	1,598
1953	1,959	1,699	1,682	1,511	1,736
1952	1,800	1,780	1,623	1,519	1,925
1951	1,711	1,656	1,615	1,653	1,671
1950	1,909	1,710	1,579	1,682	2,011
1949	1,897	1,573	1,692	1,592	1,726
1948	2,383	2,005	1,956	2,014	1,998

Table VI continued. Mean monthly flows (cfs) for November-March.

YEAR	NOV	DEC	JAN	FEB	MAR
1947	1,831	2,036	1,398	1,552	1,855
1946	2,217	1,995	1,854	1,704	1,736
1945	1,786	1,674	1,346	1,382	1,646
1944	2,030	1,811	1,268	1,404	1,414
1943	1,702	1,467	1,333	1,419	1,554
1942	2,267	1,832	1,562	1,664	1,792
1941	1,515	1,291	1,145	1,291	1,442
1940	1,370	1,070	1,077	1,160	1,367
1939	1,856	1,786	1,573	1,423	1,947
1938	1,823	1,574	1,357	1,364	2,030
1937	1,576	1,303	1,197	1,318	1,537
1936	1,658	1,282	1,279	1,258	1,322
1935	1,128	1,084	1,074	1,018	1,119
1934	1,525	1,495	1,493	1,446	1,584
1933	1,819	1,046	1,080	1,030	1,473
1932	1,127	1,000	950	1,100	1,542
1931	1,606	1,250	1,100	1,080	1,159
1930	2,363	1,929	1,701	1,718	1,727
1929	2,103	1,458	1,459	1,409	2,238
1928	2,283	1,732	1,711	1,729	1,942
1927	1,607	1,372	1,250	1,401	1,583
1926	2,100	1,576	1,418	1,410	1,713
1925	1,869	1,502	1,500	1,500	2,367
1924	2,260	1,801	1,770	1,664	1,707
1923	1,781	1,634	1,570	1,508	1,710
1922	1,959	1,900	1,300	1,320	2,143
1921	2,207	1,380	1,290	1,704	2,412
1920	1,650	1,500	1,350	1,280	1,604
1919	2,063	1,550	1,400	1,350	2,077
1918	2,056	1,647	1,450	1,550	2,527
1917	2,245	1,748	1,300	1,350	1,769
1916	1,573	1,357	1,380	1,300	2,640
1915	1,835	1,220	1,230	1,270	1,372
1914	1,711	1,250	1,300	1,350	1,872
1913	2,015	1,350	1,340	1,300	1,858
1912	1,918	1,350	1,400	1,380	1,758
1911	1,657	1,256	1,350	1,465	1,860
1910	2,082	1,450	1,500	1,400	3,475
1909	1,602	1,323	1,337	1,196	1,564
1908	1,817	1,366	1,450	1,316	1,626
1907	1,820	1,450	1,320	1,550	2,235
1906	1,650	1,150	1,150	1,220	1,800
1905	1,500	1,150	1,200	1,100	1,450
1904	1,650	1,100	1,100	1,150	1,500
1903	1,100	1,050	950	950	1,200
1902	1,600	1,400	1,250	1,200	1,200

Table VII. Calculated mean monthly discharge (cfs) for the Colorado River at the top of the 15-mile reach during the months of July-October, 1954-1989. Flows during the irrigation season are calculated using the following formula: Colorado River at Cameo + Plateau Creek - Grand Valley Project - Grand Valley Irrigation canal + return flow from Orchard Mesa Power plant. Orchard Mesa (OM) return flow is calculated as follows: when Cameo + Plateau Creek > 2140 cfs the OM return is 581 cfs; when Cameo + Plateau Creek is 1831-2140 cfs the OM return is 270 cfs; when Cameo + Plateau Creek is 1720-1831 cfs the OM return is 161 cfs; when Cameo + Plateau Creek < 1720 cfs the OM return is 0 cfs. Records of mean monthly diversion flows to the Grand Valley Irrigation canal were available for all years; mean monthly flows to the Grand Valley Project diversion (Govt. Highline Canal) were available only for years 1975-1989. For years 1954-1974, the mean of the mean monthly flows from the 1975-1989 period were used. Negative results during the 1975-1989 period are attributed to inaccurate gauging devices and/or errors in record keeping; negative results for the 1954-74 period are due to similar error and/or the use of Govt. Highline Canal means rather than actual flow data, i.e., during years of very low flow, Govt. Highline probably diverted less than the 1975-1989 mean of monthly means.

YEAR	JUL	AUG	SEP	OCT
1989	1,247	824	128	-
1988	1,430	588	542	178
1987	1,768	1,214	812	733
1986	7,036	2,040	1,868	2,223
1985	5,702	2,064	1,128	1,997
1984	13,953	5,092	2,890	2,539
1983	15,454	5,292	1,441	1,519
1982	5,260	1,873	1,611	1,814
1981	831	-193	105	268
1980	3,883	864	638	354
1979	6,989	1,413	426	365
1978	4,273	651	53	265
1977	-119	-6	-89	-367
1976	1,904	871	812	895
1975	7,707	1,677	934	1,033
1974	3,126	1,111	700	906
1973	7,787	1,916	988	1,198
1972	2,009	806	1,143	1,517
1971	5,810	1,425	1,499	1,251
1970	4,393	1,248	1,779	1,609
1969	4,289	995	835	1,696
1968	2,657	2,284	687	888
1967	3,188	752	723	317
1966	1,040	135	-124	233
1965	8,468	3,061	1,653	1,638
1964	2,080	1,046	238	-7
1963	-65	105	205	-262
1962	7,409	1,529	319	1,618
1961	663	85	1,692	2,225

Table VII continued. Calculated mean monthly flows, July-Oct, 1954-1989.

YEAR	JUL	AUG	SEP	OCT
1960	1,967	108	-143	98
1959	1,912	613	-94	973
1958	1,587	-140	-41	165
1957	16,387	4,180	1,351	1,184
1956	1,287	104	-523	-316
1955	1,940	1,150	-337	-367
1954	851	-175	-1	610

Table VIII. Calculated mean monthly discharge (cfs) for the Colorado River at the top of the 15-mile reach during the months of July-October, 1902-1942. Discharge for the 1934-1942 period was calculated using the formula described in legend of Table VII for the 1954-1974 period. For the 1902-1933 period, discharge was calculated by subtracting the Grand Valley diversion withdrawal from the Colorado River discharge as measured at the Palisade gage. Grand Valley records for the period are available in average cfs for the irrigation season and not by month; records of average withdrawal were available for the 1921-1942 period; prior to this, records are scant; one 1916 record indicated the canal accommodated only 300 cfs at the time and 251 cfs was the average discharge for the season; we used 250 cfs for each month for the 1902-1920 period.

YEAR	JUL	AUG	SEP	OCT
1942	5,263	907	-435	-229
1941	3,739	990	793	1,761
1940	1,146	-683	-73	475
1939	1,605	-358	-56	-265
1938	6,935	1,312	1,794	394
1937	3,495	297	230	419
1936	4,173	2,394	348	91
1935	6,181	995	124	89
1934	-568	-627	-756	-720
1933	5,739	155	-94	-184
1932	8,784	2,626	834	697
1931	1,529	114	395	737
1930	4,313	4,162	1,464	1,574
1929	9,615	4,742	5,062	2,833
1928	9,900	2,222	1,367	1,622
1927	8,218	4,025	2,547	2,142
1926	8,716	2,093	830	1,151
1925	5,396	2,221	2,591	2,217
1924	5,278	870	829	1,591
1923	11,470	4,660	2,376	2,557
1922	5,002	2,288	1,407	1,143
1921	9,804	4,351	2,680	1,644
1920	10,460	3,791	2,018	1,820
1919	3,423	1,767	1,280	1,134
1918	8,415	2,187	2,216	1,961
1917	17,510	3,927	2,290	1,967
1916	9,267	5,325	2,574	3,559
1915	6,881	1,915	1,112	1,551
1914	10,600	4,037	2,275	3,057
1913	4,676	1,601	2,004	1,866
1912	16,990	5,207	2,196	2,269
1911	8,316	2,394	1,822	3,169
1910	3,461	2,082	1,987	1,584
1909	14,190	4,935	4,622	2,316
1908	5,423	3,298	1,506	1,642
1907	16,730	4,643	2,351	2,389
1906	9,571	3,554	3,088	2,605

Table VIII continued. Calculated mean monthly flows, July-Oct, 1902-1942.

1905	5,834	2,277	1,580	1,497
1904	7,151	2,992	2,404	1,891
1903	8,530	1,974	2,020	1,805
1902	1,949	963	967	1,164

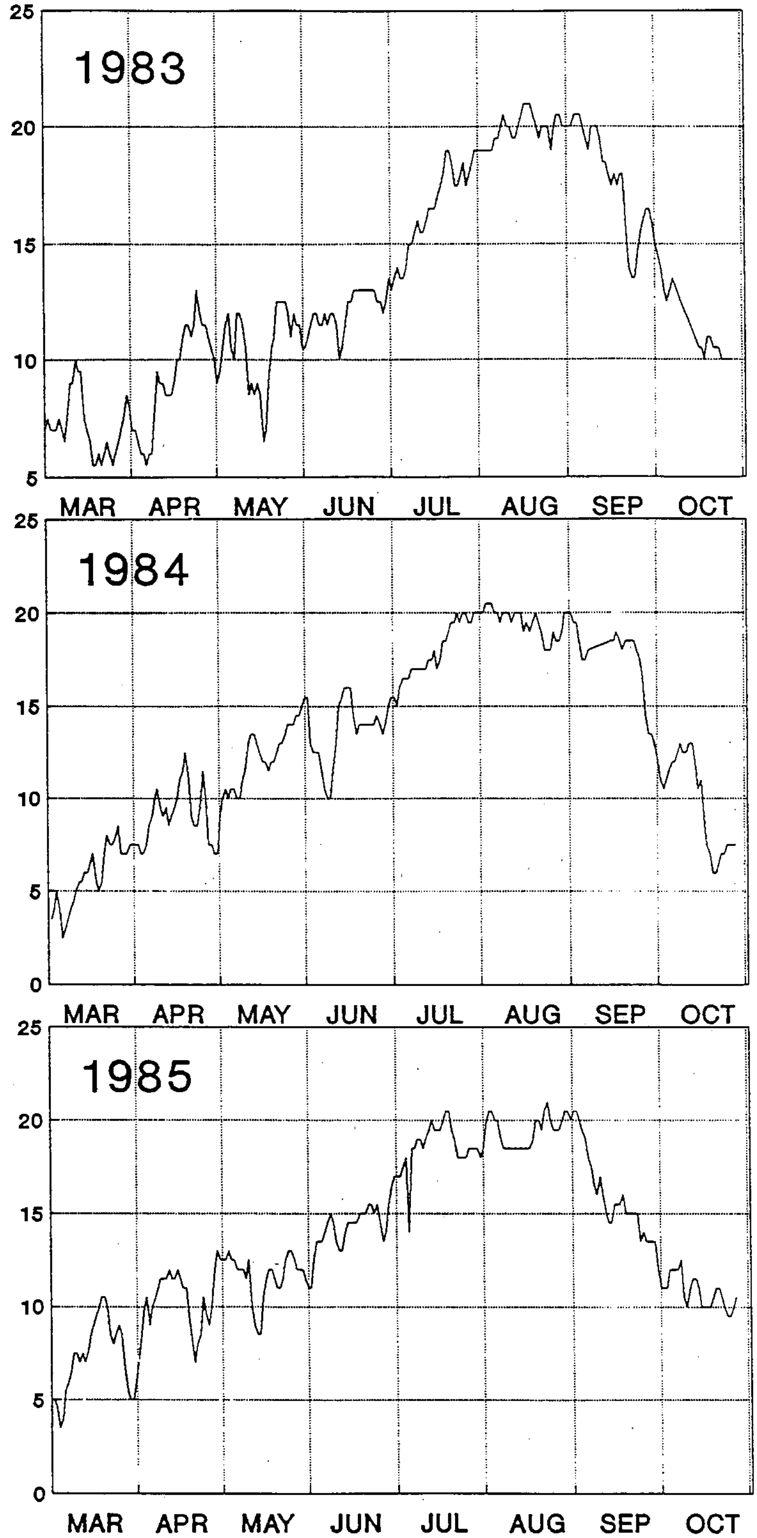

Figure I. Daily-mean, main-channel temperatures in the upper Colorado River in or near the 15-mile reach, 1983-1990. Data for 1983-1985 from USGS gage near Cameo at RM 197 (12 miles upstream of the 15-mile reach); daily means are the daily maximum and minimum averaged. Data for 1986-1990 from USFWS thermograph downstream of Palisade at RM 182.0; daily means are the average of six (1986-1988) or 12 (1989-1990) daily readings.

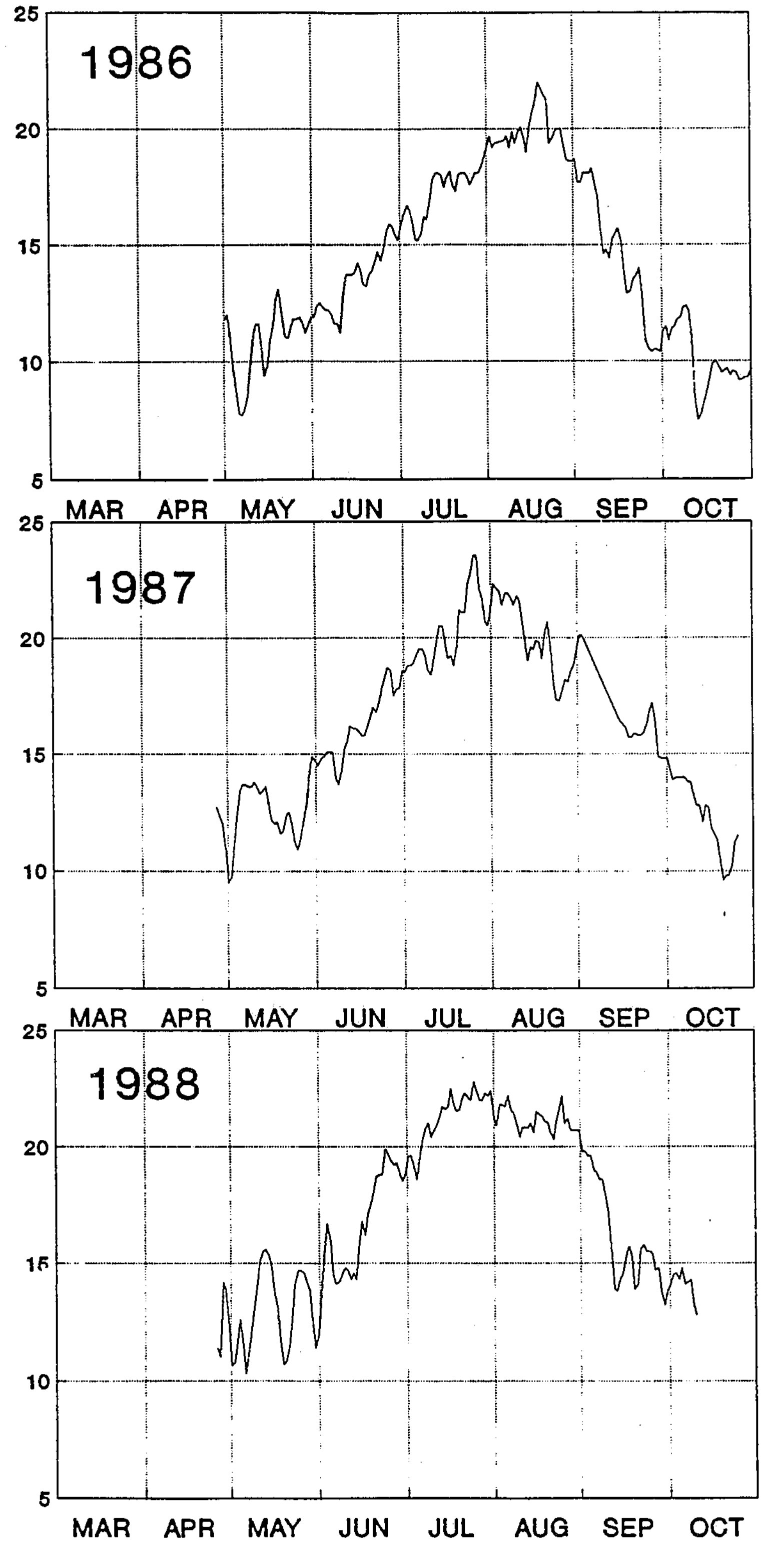

Figure I continued. Main-channel temperatures, 1983-1990.

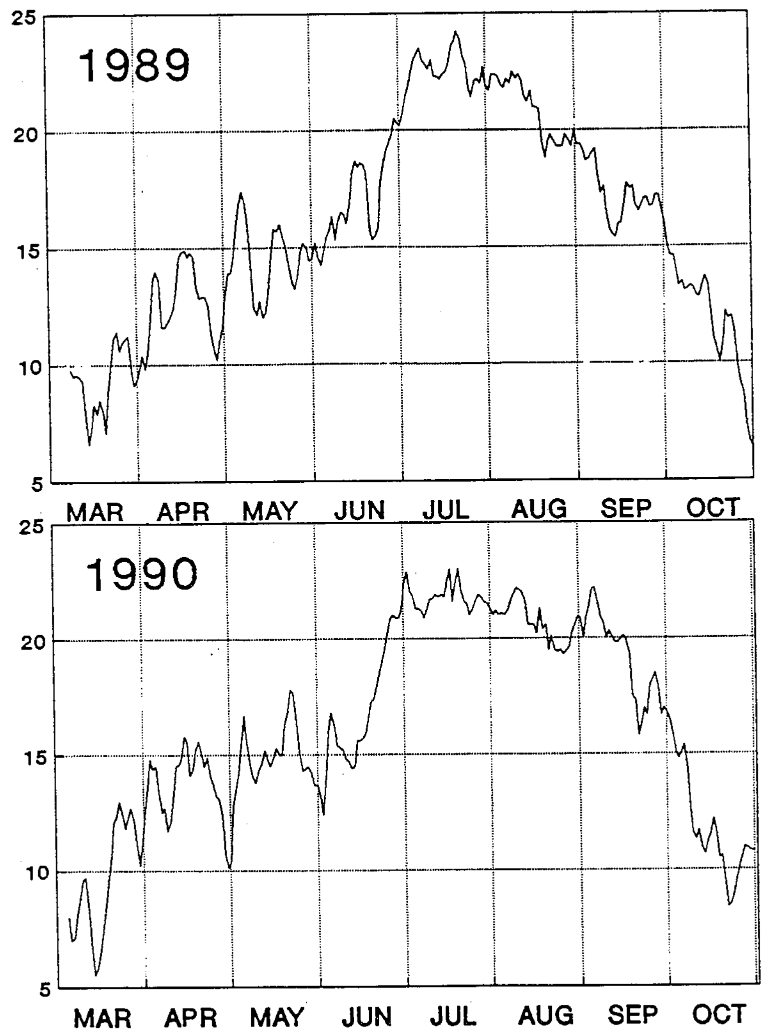

Figure I continued. Main-channel temperatures, 1983-1990.

Table IX. Summary of main channel temperatures $\geq$ 20 C in the upper Colorado River in or near the 15-mile reach, 1983-1990. Data for 1983-1985 from USGS gage at Cameo; daily means are the daily maximum and minimum averaged. Data for 1986-1990 from USFWS thermograph downstream of Palisade (RMI 182.0); daily means are the average of 6 (1986-1988) or 12 (1989-1990) daily readings.

	Earliest Date of >20 C		Max Annual Temp		No. days >20 C	
YR	Daily Max	Daily Mean	Daily Max	Daily Mean	Daily Max	Daily Mean
1983	JUL 20	AUG 09	22.5	21.3	46	23
1984*	JUL 17	JUL 30	21.5	20.3	44	9
1985*	JUL 07	JUL 17	22.5	20.8	43	20
1986	AUG 01	AUG 08	23.5	22.2	23	13
1987*	JUN 27	JUL 15	26.0	23.5	57	29
1988	JUN 24	JUN 24	26.0	22.0	74	46
1989	JUN 26	JUN 30	28.8	23.7	77	49
1990	APR 15	JUN 25	27.4	23.0	106	74

* records incomplete

1984 7 days in SEP missing
1985 7 days in AUG missing
1987 11 days in SEP missing

Table X. Monthly summary of diversions (mean discharge in cubic ft/sec) to the Grand Valley Irrigation Company canal (RM 185.1) from the Colorado River during the irrigation season, 1950-1988

YEAR	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV
88		549.8	622.2	646.7	650.1	644.3	629.2	620.9	640.5
87		505.6	620.3	648.0	652.2	645.2	636.8	601.5	622.0
86		573.6	611.2	635.0	590.9	620.6	619.4	565.0	370.0
85		479.4	580.9	638.7	638.6	644.6	618.4	575.3	563.0
84		429.3	555.9	611.6	636.4	614.3	596.5	582.7	563.0
83		502.6	563.0	589.4	629.8	622.0	617.3	582.9	563.0
82		539.3	609.1	629.8	647.2	679.1	704.1	641.1	648.4
81	498.5	562.3	627.5	640.6	645.8	637.6	623.5	639.9	
80		438.8	546.1	615.5	649.8	642.9	632.1	611.6	642.0
79		441.2	576.2	620.5	630.7	635.6	633.2	612.1	
78		519.2	585.7	636.0	642.0	635.2	619.1	604.0	
77	394.5	560.9	617.0	640.3	592.6	587.9	575.6	553.1	
76		547.4	619.8	663.3	621.1	631.2	600.5	553.8	
75		448.2	584.4	623.0	635.9	642.0	627.3	593.3	
74		503.9	632.4	642.0	625.2	639.4	618.2	599.4	
73		420.3	568.1	623.0	642.0	642.0	623.7	571.9	
72	336.0	600.5	632.0	635.7	642.0	639.1	569.3	487.0	
71	259.0	534.1	591.1	619.5	642.0	635.9	601.9	553.6	
70		533.4	604.3	623.7	644.6	632.0	587.0	552.3	
69		449.7	577.5	578.9	647.9	632.1	593.8	522.0	
68		432.3	583.8	610.2	633.0	579.9	601.5	526.5	
67	259.0	511.7	568.7	529.9	607.5	605.1	557.6	534.0	
66		459.4	596.4	603.9	595.0	609.2	579.3	534.1	
65		380.9	550.2	585.5	599.4	562.9	548.3	476.4	
64		389.5	575.9	605.8	614.5	583.4	577.8	576.4	
63		435.1	588.2	594.4	608.0	571.6	523.9	517.2	
62		475.6	577.9	594.4	612.9	611.8	580.6	511.5	
61		407.4	572.4	594.7	623.8	578.4	481.5	395.9	
60		513.4	585.4	591.2	601.2	574.5	558.7	474.0	
59		408.9	546.1	582.3	615.3	608.5	562.0	537.0	
58		447.5	552.1	578.1	612.5	595.9	525.0	493.0	
57		203.3	468.0	499.0	550.7	499.9	496.5	401.4	
56		312.0	535.3	574.2	572.3	531.7	526.4	478.1	
55		371.7	521.5	549.6	576.5	510.8	555.6	508.1	
54		465.9	556.2	579.3	557.6	553.2	445.5	398.9	
53		397.4	578.6	605.6	636.6	554.5	537.1	465.8	
52		436.1	544.2	589.6	635.2	556.6	531.8	540.4	
51		459.4	543.6	507.8	590.1	564.6	519.5	464.8	353.0
50		495.2	543.2	560.9	539.4	546.2	498.4	487.4	

* Mean data was derived from daily records on file at the Grand Valley Irrigation Co. office in Grand Junction.
* Averages are only of days when water was diverted. For example, if water was diverted in March only during the last two days of the month, the flow for each of those days was summed and divided by two not by the total number of days in the month (31).

Table XI. Persons who provided comments on drafts of this report.

Name	Affiliation	Date of Response
Kieth Rose	USFWS	AUG 10, 1990
Pat Nelson	USFWS	AUG 16, 1990
Larry Shanks	USFWS	SEP 10, 1990
John Hamill	USFWS	AUG 1990
Charles McAda	USFWS	AUG 1990
Kevin Bestgen	CSLFL	OCT 1990
Thomas Nesler	CDOW	NOV 30, 1990
Eddie Kochman	CDOW	DEC 4, 1990
Jim Bennett	CDOW	DEC 4, 1990
Rich Valdez	BIO/WEST	MAR 7, 1991
Tomm Pitts	Water Users	MAR 22, 1991
Gene Jencsok	CWCB	APR 22, 1991