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MINIMUM FLOW RECOMMENDATION FOR PASSAGE OF COLORADO SQUAWFISH AND RAZORBACK SUCKER IN THE 2.3-MILE REACH OF THE LOWER GUNNISON RIVER: REDLANDS DIVERSION DAM TO THE COLORADO RIVER CONFLUENCE

Final Report
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Recovery Implementation Program
for Endangered Fishes in the
Upper Colorado River Basin

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RECOVERY PROGRAM FOR THE ENDANGERED FISHES OF THE UPPER COLORADO

DISCLAIMER

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Cover Photograph: 2.3-mile reach of the Lower Gunnison River, 0.1-mile downstream of the Redlands Diversion Dam during low-flows, July 1988. Photo courtesy of D.B. Osmundson.

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EXECUTIVE SUMMARY

STUDY GOAL

The 2.3-mile reach of the Lower Gunnison River between the Redlands Diversion Dam and the confluence with the Colorado River is important habitat for Colorado squawfish and razorback sucker and is designated critical habitat for these two fishes. The purpose of this study was to recommend a minimum streamflow for passage of sub-adult and adult Colorado squawfish and razorback sucker during low-flows in this reach.

FIFTY-NINE SUB-ADULT AND ADULT COLORADO SQUAWFISH WERE CAPTURED; THE HIGHEST CATCH RATES WERE IN JUNE, JULY, AND AUGUST

A total of 59 sub-adult and adult Colorado squawfish were captured in the 2.3-mile reach between 30 March 1994 and 7 November 1995. A total of 40 sub-adult and adult Colorado squawfish were captured in 1994; another 10 were sighted but not netted. In 1995, 19 Colorado squawfish were collected and four were positively sighted. Twenty-three of these 59 fish had been captured previously. Seven fish had been recaptured twice and one had been recaptured three times.

The plunge pool immediately downstream of the Redlands Diversion Dam and a 0.2-mile section (river mile 2.9-2.7) immediately downstream of the plunge pool were high-use areas for adult Colorado squawfish during both years. In late-July 1994, 20 adult Colorado squawfish were found in the reach. The highest CPUE for sub-adult and adult Colorado squawfish in the 2.3-mile reach during 1994 and 1995 was in July (34 fish; 5.56 F/h), followed by June (8 fish; 1.68 F/h), and August (7 fish; 1.52 F/h). Sixty-two of the 73 fish captured and sighted were collected during these three months. The high number of adult Colorado squawfish found in the reach during late-July and early-August 1994 indicates that this reach provides sufficient seasonal habitat for "residency" at 300 cfs and also suggests that this reach is important as a spawning or post-spawning feeding area in addition as a passage corridor.

CRITICALLY LOW WATER DEPTHS OCCURRED AT THREE LOCATIONS IN THE 2.3-MILE REACH DURING LOW FLOWS IN 1994

Transects 9, 19, and 20 (river miles 2.7 and 1.4, respectively), had empirical maximum water depths of 0.8, 1.1, and 1 feet, respectively, at flows ranging from 245-276 cfs during late-July and early August 1994. Predicted maximum water depths were 1.1 feet at transects 9 and 19 at 300 cfs. Although there were two thalwegs across transect 9, only 7% of the channel width exceeded 1 foot at 300 cfs. A maximum water depth of 1 foot was exceeded at only one location at transect 9 at 300 and 400 cfs. A water depth of at least 1 foot would be maintained across 10% of the channel width at 500 cfs. A flow of 850 cfs was estimated to maintain a mean water depth of 1 foot through the entire transect.

At transect 19, the predicted mean and maximum water depth was 0.7 and 1 foot, respectively, at 300 cfs; only 5% (one predicted observation) of the channel width exceeded 1 foot. Seventy percent of the channel width had a mean water depth of 1 foot at 600 cfs. A flow of 1,400 cfs would be required to maintain a mean water depth of 2 feet. At transect 20, the empirical measured mean water depth was 0.6 at 266 cfs; none of the water depths exceeded 1 foot at 266 cfs.

CATCH RATE VERSUS FLOW WAS NOT PRACTICAL FOR IDENTIFYING MINIMUM FLOWS

A minimum "threshold flow" for fish passage could not be determined using catch rate and flows because a strong positive relationship between the two variables did not exist. Although flows were known on capture dates, this method did not provide the resolution to identify the flow endangered and native fishes might leave the reach and move downstream where more suitable habitat conditions existed. Instead, the relationships were a reflection of catch efficiency: higher catch rates occurred during low flows because fish were more vulnerable and easier to capture than during high flows.

A 300 CFS INSTANTANEOUS FLOW IS RECOMMENDED FOR THE 2.3-MILE REACH OF THE LOWER GUNNISON RIVER

Predicted and empirical water depths were used to recommend a 300 cfs minimum flow to provide passage in the 2.3-mile reach of the Lower Gunnison River using water releases from upstream Federal Reservoirs. A 300 cfs flow will maintain at least a 1-foot water depth in the entire reach. An instantaneous flow should be maintained rather than a mean daily flow of 300 cfs to eliminate possible daily fluctuations when flows may fall far below the recommended minimum. During low-flow periods, a uniform, constant flow of 300 cfs should be implemented. The 300 cfs minimum flow is especially important to maintain during the summer low-flow period so that endangered fish will have access to the fish passageway. This is based on the assumption that sub-adult and adult Colorado squawfish need at least a water depth of 1 foot to move both up- and downstream through areas within the reach that have critically shallow water depths.

RECOMMENDATIONS

Recommendations for the 2.3-mile reach of the Lower Gunnison River include: 1) provide a year-round, instantaneous 300 cfs minimum flow that will mimic a naturally-shaped hydrograph during low flows, 2) continue to obtain biological and hydrological data to evaluate the 300 cfs minimum flow for passage of sub-adult and adult Colorado squawfish that includes measuring water depths at critically shallow areas, correlating with known flows, and observing the response of both endangered and native fishes, and 3) collect habitat-use data from Colorado squawfish currently radiotagged at various low flows to refine or validate the minimum flow recommended for passage.

INTRODUCTION

Background

The Colorado River basin was originally occupied by only thirteen native fishes (Behnke and Benson 1983). However, today native fishes of the Colorado River basin have been adversely affected by major environmental changes from human alterations to the ecosystem. As a result of these changes, four of these endemic fishes to the Colorado River system, the Colorado squawfish[1], razorback sucker, bonytail, and humpback chub, are listed as endangered under the Endangered Species Act (ESA; U. S. Fish and Wildlife Service [FWS]). The Colorado squawfish has been extirpated from the lower basin, and it now occupies approximately 20% of its historic range (Tyus 1990). In the Lower Colorado River, below Glen Canyon Dam, a substantial population of razorback sucker persists in Lake Mohave but occurs only sporadically in riverine reaches (Marsh and Minckley 1989). In the Upper Colorado River Basin, the largest populations of both Colorado squawfish and adult razorback sucker are found in the Green and Yampa rivers (Holden and Wick 1982; Lanigan and Tyus 1989). A small remnant population of Colorado squawfish occurs in the San Juan River; no wild razorback sucker have been found there in recent times (Ryden and Pfeifer 1995). In the Upper Colorado River, only 25 adult razorback sucker were captured between 1980 and 1990 from riverine habitats (Valdez et al. 1982a); only seven adult fish have been captured since 1990 (Osmundson and Kaeding 1991; Burdick 1992; unpublished FWS data). Colorado squawfish continue to persist in the Upper Colorado River but it is uncertain whether recruitment is adequate to maintain a self-sustaining population. Humpback chub now exist only in five widely-separated canyon habitats. Bonytail, the rarest native fish in the Colorado River, is considered "virtually" extinct in the Upper Colorado River Basin. Bonytail now only occur in small numbers in Lakes Mohave and Havasu.

Some of the major factors that are suspected in reducing populations of these four "big river" endangered fishes include alteration of the hydrologic regime and reduced water quality, competition and predation from the introduction and proliferation of nonnative fishes, possible reproductive impairment from both human-produced contaminants and harmful natural trace elements (Hamilton and Waddell 1994; Waddell and May 1995), reduced or complete recruitment failure due to a loss of available spawning or nursery habitats, reduced food base, and angler-related mortality of adult fish.

Both the mainstem and the North Fork of the Gunnison River are regulated by Federal dams and reservoirs upstream of the warmwater reaches. The largest of these reservoirs is the Aspinall Unit, which is a series of three federal (U.S Bureau of Reclamation [BR]) reservoirs and dams on the upper South Fork or main Gunnison River. Taylor Park Reservoir is located upstream on the Taylor River. Other water development projects constructed by BR include Paonia Dam on the North Fork, Crawford Dam (Smith Fork Project) on the Smith Fork, Ridgeway Reservoir (Dallas Creek Project) on the Uncompahgre River, and Fruitgrower's Reservoir. Although the three major reservoirs of the Aspinall Unit and other

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[1] Scientific names and two-letter codes of all fishes mentioned in this report are given in Appendix A: Table A.1. Only common names for these fishes are used in the text.

smaller water projects occupy a portion of the Gunnison River upstream from historic habitat of the four endangered fish, alterations in water quality and quantity have had significant adverse affects on downstream warmwater reaches. The Dolores Project (McPhee Reservoir on the Dolores River) and Dallas Creek underwent Section 7 consultation, and were built with the stipulation that water from the Aspinall Unit (148,000 acre-feet [AF]) would be used to partially offset the impacts of these two projects on endangered fishes in downstream, warmwater reaches of the Gunnison and Colorado rivers (see section on "Interim Cooperative Water Agreement").

Historically, the Gunnison River was typical of Colorado River basin tributaries with high, turbid spring flows and clearer low flows from late summer through winter. However, the timing of water delivery has been significantly altered by water development projects. The greatest change caused by the Aspinall Unit is the reduced magnitude of spring runoff. The mean-monthly flows measured at the U. S. Geological Survey (USGS) gage at Whitewater, Colorado, have declined about 25% in May and 32% in June since construction of the Aspinall Unit. In contrast, flow during the remainder of the year has increased, particularly during the winter when average monthly flows are more than 100% greater than pre-Aspinall flows. In general, spring and early summer flows have declined, and fall and winter flows have increased (Figure 1).

Flows over 15,000 cfs are considered high flows for the Gunnison River. Flows of this magnitude were common in the earliest periods of record (prior to the Aspinall Units), and were frequent in the 1950's, but only four years, 1983, 1984, 1993, and 1995, have flows of this magnitude occurred since 1965 (Figure 1). Peak flow during May 1993 reached 20,500 cfs, the second highest annual flow since 1957. Flows of 20,000 cfs occur 10% prior to construction of the Aspinall Unit. The number of days with flows greater than 10,000 cfs, on average, prior to construction of the Aspinall Unit, was 3 weeks. The frequency of flows of 10,000 cfs following construction of the Aspinall Unit is now only 1 week (Cooper and Severn 1994).

A secondary effect is that water temperatures have decreased during summer and increased during winter. Summer water temperatures have been reduced from historic temperatures by a maximum of about 1.8°C in occupied habitat of Colorado squawfish and razorback sucker (McAda and Kaeding 1991). These modifications are typical of the ecological changes in upper basin rivers after the construction of large dams (Vanicek et al. 1970).

Large dams and diversion structures are also effective instream barriers that fragment stream reaches which reduces the range of native species by precluding both young and adult fish from returning upstream after they have migrated downstream. Barriers are particularly harmful to species that migrate long distances to fulfill life history requirements such as the potamodromous Colorado squawfish (Tyus 1984; Tyus 1990). Instream barriers can divert water from main channel rivers for irrigation and power generation and reduce the range of these species by rendering downstream reaches uninhabitable due to low flow. In upper basin rivers, this situation usually occurs downstream of diversion structures during low-flow years in mid-summer months when irrigation demands are high. In some reaches, reduced water volume has led to water quality degradation by increasing the water temperature and elevating concentrations of human-pro-

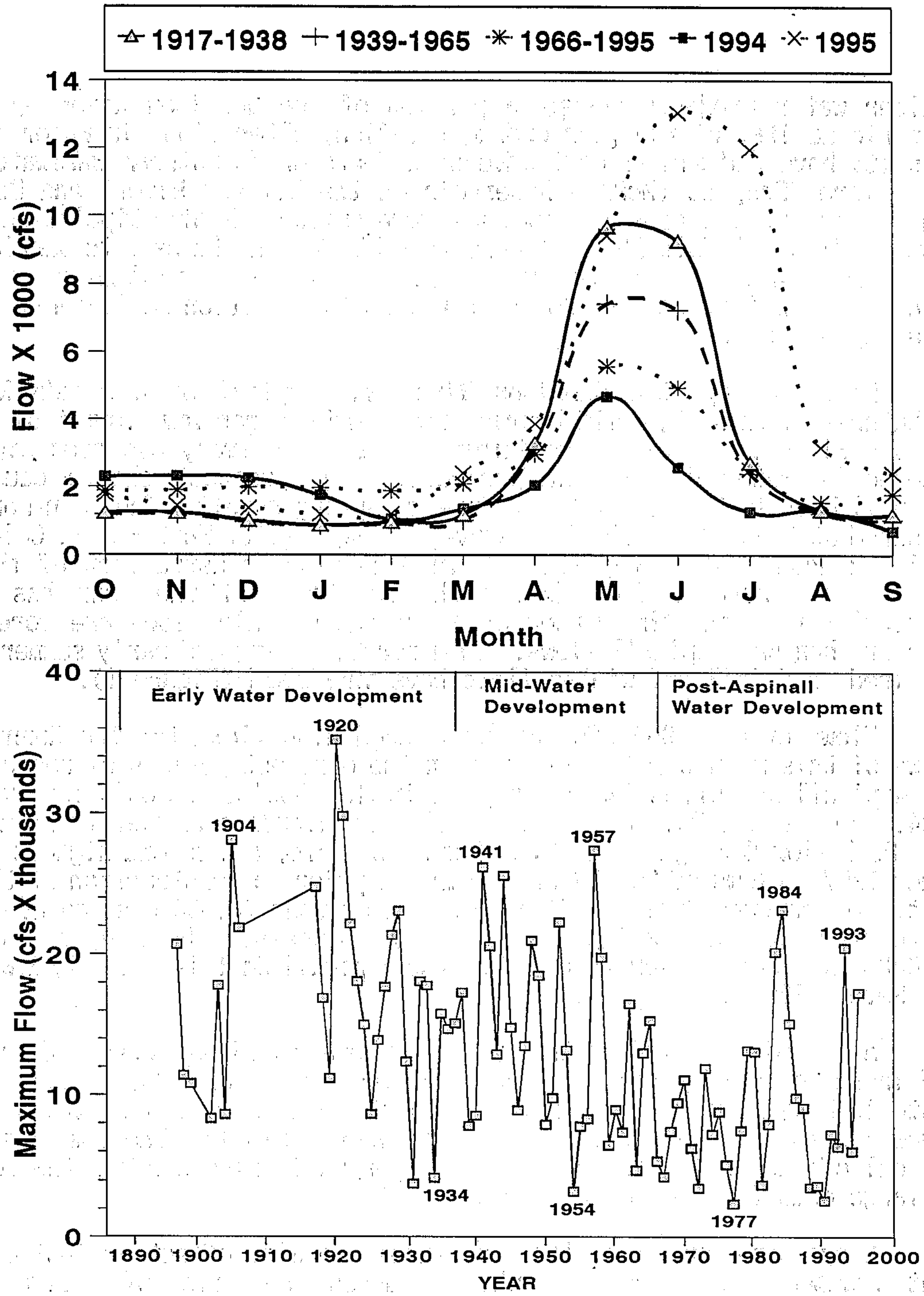

Figure 1. Mean monthly streamflow for the Gunnison River for three time periods: early development (1917-1938), middle development (1939-1965), and post-Aspinall development (1966-1995) and for two water years, 1994 and 1995, that this study was conducted (top), and the maximum daily streamflow for the period of record, 1897-1995 (bottom). Data were obtained from the Whitewater USGS gage near Grand Junction.

duced and naturally occurring trace elements (e.g., pesticides and selenium) above the species tolerance threshold, and elimination of adult habitats. During extreme low-water years, some reaches have entirely been dewatered for several continuous days during summer months resulting in loss of habitat, loss of migratory corridor, and possible stranding that may lead to mortality.

The intent of the Recovery Implementation Program (RIP) is to recover and delist the endangered fishes while allowing upper basin states to develop their entitled water under the Colorado River Compact. An important component of the Recovery Program is the determination of flows needed for recovery of these fishes. Furthermore, legal protection of sufficient instream flows for the maintenance and enhancement of riverine habitats to support self-sustaining populations of endangered fish is one of the primary goals of the RIP (FWS 1987). Flow manipulation has detrimentally impacted these fishes but planned management of flow manipulation (e.g., provision of a more naturally-shaped hydrograph) would benefit native endangered fishes.

Planned restoration efforts for the Gunnison River have begun. A two-year fishery inventory of 75 miles of warmwater reaches was conducted in 1992 and 1993 that included 14 months of movement data on radiotagged adult Colorado squawfish (Burdick 1995). Pond-reared razorback sucker have been stocked in the Gunnison River. Twenty-five adult fish, implanted with radiotags, were stocked in 1994 and 1995; 316 juvenile razorback sucker were stocked in 1995. An additional 287, 9-16-inch razorback sucker were stocked in October 1996 near Delta. Future stocking of different sizes of juvenile and sub-adult razorback sucker during 1996-2000 will determine the relationship between the size stocked and their subsequent survival in the wild. A fish passageway at the Redlands Diversion Dam, operational since June 1996, will provide both sub-adult and adult razorback sucker and Colorado squawfish access to 56 miles of historic habitat in the Gunnison River. Expanding the upstream range for these two fishes in the Gunnison River will assist recovery by providing additional physical habitat and an abundant source of native and nonnative fishes as prey for Colorado squawfish.

The warmwater reaches of the Gunnison River are historical habitat for the four endangered fishes in the Upper Colorado River Basin. Historically, humpback chub were not collected from the Gunnison River until one specimen was captured in 1993 (Burdick 1995); the nearest known population of humpback chub is located at Black Rocks in Ruby Canyon on the Colorado River 38 miles downstream from the Redlands Diversion Dam. Other fishery studies conducted over the past 15 years indicate that Colorado squawfish occupy both up- and downstream reaches from the Redlands Diversion Dam (Valdez et al. 1982b; Wick et al. 1985; Burdick 1995). No wild riverine razorback sucker have been collected in the Gunnison River since 1981 (Holden et al. 1981).

The population of Colorado squawfish in the Lower Gunnison River between the Redlands Diversion Dam (river mile [RM] 3.0) and the confluence with the Colorado River (RM 0.7)[2] is contiguous with the Upper Colorado River population.

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[2] Prior to the flood years of 1983 and 1984, the confluence of the Gunnison and Colorado rivers was 0.0. During these flood years, the Colorado River claimed 0.7 mile of a former side channel of the Gunnison River. Therefore, after 1984, the new confluence designation was 0.7 rather than 0.0.

In 1993, this 2.3-mile reach was identified as a priority area for instream flow protection. The Gunnison River from the confluence of the Colorado River upstream to the confluence of the Uncompahgre River (56 river miles) was designated critical habitat for both the Colorado squawfish and razorback sucker in 1994 (59 FR 13374-13400) under authority of the ESA.

The Redlands Diversion Dam, located 2.3 miles upstream of the confluence with the Colorado River, has prevented the upstream movement of all fishes and further reduced Colorado squawfish numbers in the Gunnison River by preventing movement upstream of the dam since it was constructed in 1918 (Wiltzius 1978; Valdez et al. 1982b). The Redlands Diversion Dam, privately owned and operated by the Redlands Water and Power Company, is a 12-foot high barrier that, prior to 1994, diverted 750 cfs of water from the Gunnison River into a canal on the left abutment for 50 weeks each year. In 1994, an additional 100 cfs was decreed to Redlands for hydroelectric generation. Except for occasional, prolonged low-flow periods in the Gunnison River drainage and one week each in the spring and fall in which the canal is drained for inspection and maintenance, an average of 750 to 800 cfs is diverted into the power canal year-round. This flow is conveyed down-canal for irrigation water (about 80 cfs) and hydroelectric generation (about 770 cfs). Thus, Redlands now can operate the diversion dam to divert a maximum of 850 cfs into the canal. During the winter, Redlands diverts about 750 cfs for hydroelectric use.

During low-flow periods, water flow has essentially ceased for several days in the 2.3-mile because water was withdrawn from the river by the Redlands Canal. Dewatering routinely occurred in the summer months of June through September when irrigation demands were highest. Flows are lowest during July and August since construction of the Aspinall Unit reservoirs upstream. This resulted in loss of habitat, loss of passage for fishes attempting to move upstream or downstream to the Colorado River, and possible stranding in the plunge pool and 2.3-mile reach.

Interim Cooperative Water Agreement

A 5-year memorandum of agreement among the BR, FWS, and the Colorado Water Conservation Board was finalized in August 1995 to furnish water from the Aspinall Unit for the benefit of endangered fishes in the Gunnison and Colorado rivers (Contract No. 95-07-40-R1760). This interim contract is designed to provide 300 cfs during "low-flow conditions" for July through October in the 2.3-mile reach of the Lower Gunnison River downstream of the Redlands Diversion Dam. Moreover, this agreement is an important step because it provides legal protection of flows in critical habitat that will protect and enhance aquatic habitat to benefit endangered fish.

Purpose and Objectives

The purpose of this investigation is to establish a minimum streamflow recommendation that will allow passage of sub-adult and adult Colorado squawfish and razorback sucker by obtaining biological and hydrological data in the 2.3-mile reach of the Lower Gunnison River.

Specific objectives were to:

1. retrieve and summarize former data on capture, positive sightings, and locations used by radiotagged Colorado squawfish in the plunge pool immediately downstream of the Redlands Diversion Dam (RM 3.0) and in the 2.2-mile reach downstream of the Redlands Diversion Dam and correlate these data with flows during the dates of occupancy,

2. obtain seasonal distribution information for sub-adult and adult Colorado squawfish from March to October in the plunge pool and in the 2.2-mile reach,

3. obtain microhabitat use by sub-adult and adult Colorado squawfish including depth, velocity, and substrate,

4. correlate catch rates of native and nonnative fishes with various water depths and flows, and

5. obtain empirical water depth profiles across various transects during low-flow periods identified by the hydrological model and by direct observation as having critical water depths for passage of sub-adult and adult Colorado squawfish.

STUDY AREA

General

The Gunnison River, a major tributary to the upper Colorado River, arises at the junction of the East and Taylor rivers near Almont in southwest Colorado. It flows for about 150 miles, primarily in a west-northwest direction, before it empties into the Colorado River at Grand Junction. The basin derives its water supply primarily from the large snow packs that accumulate in the high mountains during the winter. The Gunnison River watershed includes the West Elk Mountains, northern San Juan Mountains, the southern portion of the Grand Mesa, and the eastern side of the Uncompahgre Plateau. The Gunnison River drains about 7,928 square miles (Wiltzius 1978) and contributes approximately 1.85 X 10^6 AF of water or about 14 percent of the total average annual runoff of the Colorado River measured at Lees Ferry, Arizona (Cooper and Severn 1994). Between 1970 and 1996, it contributed about 40 percent of the total average annual flow to the Colorado River at the confluence of the two rivers at Grand Junction (Personal communication, Mike Whiteman, USGS).

As is typical of tailwaters below large dams, the river downstream of Crystal Dam is too clear and too cold to support warmwater endangered fish. These cold waters extend downstream to the confluence with the North Fork where water temperatures are somewhat ameliorated.

Lower Gunnison River (2.3-Mile Reach)

A fishery investigation was completed for 75 miles of the Gunnison River in 1993 by FWS that collected 21 species of fishes: 7 native, 14 nonnative, and three catostomid hybrids (Burdick 1995). The 2.3-mile reach corresponds to Reach 1 of that study and former FWS studies (Valdez et al. 1982b) and extends from the Redlands Diversion Dam downstream to the confluence with the Colorado River. Former capture and radiotelemetry data indicate adult Colorado squawfish utilize the Lower Gunnison River and plunge pool from April to September.

Larval Colorado squawfish have been collected up- and downstream of the Redlands Diversion Dam. One larval Colorado squawfish was collected immediately downstream of the Redlands Diversion Dam in 1986 (28 August; Osmundson and Kaeding 1989). Two other larval Colorado squawfish were collected in this reach in 1992 (2 and 10 July; Anderson 1994). Six larval Colorado squawfish were collected in 1995 and eight in 1996 (Personal communication, Richard Anderson). In 1995, five were captured upstream of Redlands, two at RM 5.2 (16 August) and three at RM 29.3 (16, 17, and 18 August). The one downstream specimen was collected at RM 2.6. In 1996, one was captured at RM 29.3, four at RM 5.2, and three at RM 2.6. The capture of larval fish in 1995 and 1996 indicates spawning of Colorado squawfish is occurring in the Gunnison River upstream of Redlands Diversion Dam, possibly as far as Bridgeport (RM 29.3). Of the large-sized fishes, four other native and nine nonnative fishes occupy the reach with Colorado squawfish. The most common of these large fish include the native bluehead sucker, flannelmouth sucker, and roundtail chub.

Compared to adjacent areas in the 15- and 18-mile reaches of the Upper Colorado River that have been generally classified as a heterogenous habitat (Osmundson et al. 1995), the 2.3-mile reach could be classified as a homogeneous habitat, comprised primarily of long, laminar runs. The average gradient is 7.0 ft/mi compared to 9.0 ft/mi in the 15-mile reach. The reach has only two side channels, one at RM 2.9, the other at RM 1.3. The plunge pool and site of the former "Black Bridge" are the only areas where deep pools are found, even during periods when the reach has been dewatered. Slow run and riffle habitats become noticeable only during flows less than 600 cfs. Stream braiding is non-existent. The Clymer's ditch returns a small irrigation flow to the Gunnison at RM 1.3. Tamarisk and Russian olive are the predominant vegetation type whereas willow occurs infrequently.

METHODOLOGY

Biological

Electrofishing

Electrofishing was used to collect sub-adult and adult fish. Sampling was conducted from an outboard-powered, aluminum electrofishing jon boat, equipped with a 5-kilowatt generator and a Coffelt VVP-15 voltage pulsator to adjust the voltage and amperage transmitted to the water. The electrofishing boat used two spherical anodes (about 9-inch diameter) suspended from fiberglass booms in front and two 7-ft cathodes (0.25-inch diameter twisted cable) suspended from each side of the boat. The boat was also used as a cathode in conjunction with the droppers. Both the anode and cathode were stainless steel. Investigators used direct current and tried not to exceed 300 volts or 12 amps to minimize injury to fish, while maximizing electrofishing effectiveness. Motorized electrofishing jon boats facilitated maneuvering around the plunge pool, into eddy habitats, fast velocities of shorelines, and traveling upstream to sample fish.

Because the study area was only 2.3 miles long, the entire reach was sampled during each trip. Information was collected and recorded separately for the 0.1-mile plunge pool and the downstream 2.2-mile reach. The plunge pool was defined as the riverine area immediately downstream of the Redlands Diversion Dam and extended downstream for 0.1 mile. In the 2.2-mile reach, the electrofishing boat was maneuvered downstream slowly in an "S"-shaped manner from one shoreline to the other to sample mid-channel habitats. The numbers of fish by species and age category (young-of-the-year [YOY], sub-adult [JUV], or adult [ADU]) were recorded on field data sheets at the end of each sample effort. Age-class groupings established in 1979-1981 by the Colorado River Fishery Project (CRFP; Miller et al. 1982; Appendix B; Table B.1.) were used. Effort was recorded in seconds which was later converted to hours electrofished. All fish collections were accompanied with detailed information regarding location, date, time of day, habitat type, conductivity, water temperature, and voltage and amperage output of electrofishing equipment. All Colorado squawfish and northern pike that were collected were initially checked for a PIT tag, weighed (g), and measured (total length [TL]). Colorado squawfish and northern pike that had not been previously captured were PIT tagged. All Colorado squawfish were scanned for a coded-nose-wire tag (Northwest Marine Technology®) to determine if they were hatchery-produced fish previously stocked in the river. Other native and nonnative fishes collected during this study were not weighed or measured because length and weight data had been recorded for a large number of native and nonnative fishes captured in this reach during 1992 and 1993 (Burdick 1995). All fish were released alive. Data sheets were completed and the elapsed-time clock on the VVP-15 was reset after each sample effort.

Hydrological

BR Transects

Twenty-seven cross sections were surveyed in April 1993 by BR personnel from the Redlands Diversion Dam to the confluence with the Colorado River to describe the geometry and flow characteristics of the river in the 2.3-mile reach. These 27 transects which provided maximum coverage of the reach were integrated into this study. For each of the 27 transects, the mean and maximum water depth and the number of water depths that exceeded 1 foot and 2 feet between 100 and 600 cfs were computed from the HEC-2 (Hydrologic Engineering Center) output. Eleven of the 27 transects that were believed to provide habitat or might have critically shallow water depths during low-flow periods were graphed and further analyzed.

A backwater profile was developed using the HEC-2 water surface profile program developed by the U. S. Army Corps of Engineers. This program calculates water surface profiles for steady, gradually varied flow in natural or human-made channels with irregularly shaped cross sections. In essence, the program predicts velocity and maximum depths with various corresponding flows. Staff gages were placed at three different locations in the reach (at RM's 2.7, 1.4, and 0.7) to establish stage versus discharge relationships.

Kevlar cable was stretched across the entire channel between two steel fence posts. Channel cross sections encompassed the entire river channel and usually extended to the high-water mark. Transects were surveyed from high points from the right shoreline to the left shoreline. Elevation was correlated with known control points and recorded as absolute (feet above sea level). For each transect, a person in a one-man kayak held a staff rod with a reflecting laser prism and worked from one shoreline to the other. All distance and elevation measurements were recorded with an EDM (electronic distance meter), that corrected for up- and downstream distances from the transect. Data were calibrated with 1,100 cfs in the study reach.

FWS Transects

During low-flow periods in July and August 1994, water depths were measured across six transects identified by the hydrological model (HEC-2) and by direct observation as having critically shallow water depths to adequately provide passage for sub-adult and adult Colorado squawfish. These field surveys were conducted during experimental low flows to determine, 1) if the water depths and corresponding streamflows predicted by the HEC-2 model were comparable to the empirical water depths measured at known flows, and 2) at what flow level and locations insufficient depth might become limiting for passing sub-adult and adult Colorado squawfish in the reach.

Kevlar cable was stretched across the entire channel between two steel fence posts. The transect line was usually located at the upstream end of a hydraulic control, which was not necessarily perpendicular to the channel. Water depths, recorded to the nearest 0.1 ft, were taken every 1- to 2 feet across the transect from the waterline of the right shoreline to the left shoreline by a person wading with a depth rod. While the orientation to the channel (e.g., 30°, 45°, or 60° vs. 90°), may have varied between the FWS and BR transects, the locations corresponded closely. Other information recorded included surface water temperature, total width of the river channel (high-water mark), and total width of the wetted area.

Data Compilation and Analysis

Fishery Data

Past Sampling. Data from 1979, 1981-82, 1986-1988, and 1991-1995 were used. Capture data, positive sightings, and locations of radiotagged Colorado squawfish in the 2.3-mile reach from CRFP files are summarized, and correlated with streamflows in the reach on dates of occupancy (Appendix; Tables D.1-D.3). Catch rates (total catch per unit effort [CPUE]: total fish collected/total hours sampled [Fish/h=F/h]), is summarized by sampling date and by the number of fish captured in the plunge pool and from the 2.2-mile reach (Appendix; Tables D.1-D.2). Finally, monthly totals were summed for all years. Because effort was not always recorded for sampling trips during some earlier years, some method was needed to calculate relative effort from past data. When effort was not recorded, equal effort was assumed for the plunge pool and downstream reach. Therefore, the number of fish captured and sighted per trip was calculated as well as traditional CPUE when effort was recorded.

Current Sampling. Fishery data were recorded in the field on standardized data forms. These data were then stored in the database management system, DBASE III+, to facilitate access and analyses as well as to provide data compatible with the computer system and format used by the ISMP database. Computer diskettes containing the corresponding DBASE III+ files from this study are available upon request through the ISMP database manager, FWS, CRFP, Grand Junction, Colorado. Hydrological data generated by the HEC-2 computer program that predicts various surface elevations, bed profiles, velocities, and maximum water depths with corresponding streamflows are available from the BR, Western Colorado Area Office, Northern Division, Grand Junction.

Total CPUE was used to determine relative density of fish in electrofishing collections. CPUE was calculated for each fish species and hybrid collected in the plunge pool and 2.2-mile reach. Species composition and relative abundance (expressed as a percent) were used to describe the fish community in the plunge pool and 2.2-mile reach. Total CPUE was plotted against flow for dates sampled in 1994 and 1995 for four native fishes and three nonnative fishes collected in the plunge pool and 2.2-mile reach. The four native species included bluehead sucker, flannelmouth sucker, roundtail chub, and Colorado squawfish; the three nonnative fishes included common carp, white sucker, and channel catfish. CPUE was regressed against flow for sub-adult and adult Colorado squawfish collected between 1987-1988 and 1991-1995. A combined total CPUE was also determined for the four native fishes and for the three nonnative fishes. This combined total CPUE for native and nonnative fishes was regressed against flow for dates sampled in the plunge pool and 2.2-mile reach.

Discharge

Streamflow records for the Gunnison River were obtained from the USGS stream gaging station at Whitewater, Colorado (No. 9152500). Data for flows diverted by the Redlands Canal were obtained from the State of Colorado, Division of Water Resources (CDWR). In this report, two different methods were used to determine the flow in the 2.3-mile reach. The first method subtracted the Redlands Canal flow from the streamflow at the USGS gage at Whitewater. Where water records were not available for the canal, 750 cfs was used. A streamflow gage installed by BR in March 1994 at RM 2.6 (CDWR No. GUNREDBCO) provided a direct means of determining streamflows in the reach. Mean-daily streamflow was obtained for the dates when water depth-transect data were recorded and for dates when fish were sampled. Monthly flow exceedence was determined from mean daily flows for the post-Aspinall water development period, 1967-1994. The mean daily flow was the mean of 24 hourly discharge values.

Approach For Recommending Minimum Streamflow

Minimum flow recommended in this study is defined as one providing passage for sub-adult and adult Colorado squawfish in the 2.3-mile reach. Determination of a minimum flow for passage was developed from 1) fish observations and collections and 2) empirically recorded water depths during low-flow periods and modeled hydrologic data. With the fish passage at Redlands operational, it is imperative that a minimum flow for passing Colorado squawfish and razorback sucker be identified to allow unimpeded up- and downstream movement of the endangered fishes between the passage facility and confluence with the Colorado River.

The minimum flow passage recommendation in this study was based on the following assumptions:

1. Low-flow conditions make passage for sub-adult and adult Colorado squawfish and other native fishes in the reach impossible. Fish become displaced and move downstream to the Colorado River until flows increase and habitat conditions improve. During periods of sustained low flows, both habitat quantity and quality are reduced. Increases in water temperatures and low oxygen can create suboptimal conditions for fish.

2. Sub-adult and adult Colorado squawfish require a water depth of at least 1 foot to negotiate shallow-water locations in the reach. The body depth of a large, female Colorado squawfish can be approximately 6-10 inches. A fish with a body depth of 10 inches would physically require at least 1 foot of water to swim and negotiate shallow-water habitats. The 1-foot water depth was arbitrarily selected by professional judgment.

3. Water depth was used solely to determine if suitable habitat existed during various low flows for sub-adult and adult Colorado squawfish passage. This study collected microhabitat data (i.e., depth, velocity, and substrate) from each Colorado squawfish collected. General habitat types (i.e., backwaters, eddies, pools) from captured fish were recorded but not used. It is acknowledged that depth, velocity, and substrate are all important habitat components in determining habitat preference. However, microhabitat-use data from sampling with electrofishing or netting are less accurate and reliable than use data from radiotagged fish because the location and habitat used prior to and following capture may differ greatly. Therefore, electrofishing data were not used to determine habitat use.

4. The 2.3-mile reach is within critical habitat and has importance in addition to a passage corridor based on the high use by sub-adult and adult Colorado squawfish from March to September from past radiotelemetry contacts and from fish capture and sighting data. Although it is uncertain how far upstream larval Colorado squawfish originated, the capture of larval fish in 1986 and 1992 from this reach suggests that management should include consideration of its value as potential feeding and spawning habitat.

This report does not recommend flows necessary for enhancing or maintaining the various life stages of endangered fishes in the 2.3-mile reach. Very little information is available for razorback sucker use in the 2.3-mile reach. For this reason, the minimum flow recommendation in this report is primarily for sub-adult and adult Colorado squawfish passage only. Until information can be obtained for razorback sucker in the reach, it is assumed that flows recommended suitable for Colorado squawfish will also benefit razorback sucker.

RESULTS AND DISCUSSION

Fish Captures

Colorado squawfish

Past Sampling. For the 11 years analyzed between 1979 and 1995, July had the highest catch rate for Colorado squawfish collected in the plunge pool (7.1 F/h) and 2.2-mile reach (3.3 F/h; Appendix; Table D.2.). August had the second highest catch rate for Colorado squawfish collected in the plunge pool (2.4 F/h; Appendix; Table D.2). The lowest flow months in the 2.3-mile reach occur in July and August. There were 111 days when flow was less than 300 cfs in this reach during July and August from 1979-1995. The higher catch rates and densities reported for these two months may be related to spawning in the reach or to increased capture vulnerability during low-flow periods. In other words, Colorado squawfish may be easier to catch during low-flow conditions compared to high-flow stages.

Instances have occurred during low-flow periods of Colorado squawfish occupying the plunge pool. In 1981, there were 93 days when flows were less than 300 cfs in the reach, extending from 20 March to 30 August. In 1981, when flow was 192 cfs, a large adult Colorado squawfish (TL=827 mm) was captured in the plunge pool (Appendix; Table D.1.). Between 14 and 20 May, there were six days when the flow was less than 300 cfs, the lowest being 69 cfs on 15 May. On 12 August 1988, a radiotagged Colorado squawfish (TL=750, radio frequency=40.470) was located in the plunge pool when the flow was 23 cfs (Appendix; Table D.3.). The plunge pool was probably isolated from downstream reaches of the Lower Gunnison River at that time. This fish was probably "held hostage" in the plunge pool for 14 more days until 27 August when the flow increased to 238 cfs and the plunge pool was hydrologically reconnected to the downstream reach. It is uncertain when this fish entered the pool or how long it had been in the plunge pool prior to 12 August because radio contact had not been made with this fish during July and August and it is unknown if and when the plunge pool was hydrologically isolated from the downstream reach. Prior to 12 August, the flow had been less than 200 cfs for the first 11 days of August. The flow between the 15 and 31 July had been less than 100 cfs; 12 of those 17 days the flow ceased in the reach.

The plunge pool provides deep-water habitat even during low-flow periods. A depth profile of the plunge pool indicates that a mean and maximum depth of 6.7 and 9.7 feet, respectively, is available at 100 cfs. During low-flow periods the plunge pool may become isolated from the downstream reach and if Colorado squawfish do not travel downstream to "wait out" the low-flow period, they may become stranded in the plunge pool. During such times, Colorado squawfish are confined with other native and nonnative fishes and are not free to utilize the resources of the entire reach. The plunge pool provides a temporary refuge for short periods during low flow. However, if low flows persist for several continuous days, water quality could deteriorate possibly causing mortality.

Current Sampling. Sampling of the plunge pool and 2.2-mile reach was conducted bi-weekly April through September, and monthly in March, October, and November in 1994. In 1995, the same areas were sampled bi-weekly May through September and monthly in April, October, and November. Similar effort was expended sampling both the plunge pool and downstream 2.2-mile reach in 1994 and 1995. A total of 22.02 hours of electrofishing was expended in 1994 and 1995. In 1994, 3.57 h of effort was expended electrofishing in the plunge pool; in 1995, 3.18 h. In 1994, 7.01 h were expended sampling the 2.2-mile reach; in 1995, 8.26 h.

A total of 40 sub-adult and adult Colorado squawfish was captured in 1994; another 10 were sighted but not netted (Table 1; Appendix; Table C.1.). In 1995, only 19 Colorado squawfish were collected and four were positively sighted (Table 2; Appendix; Table C.1.). A total of twenty-three of these 59 fish had been captured previously--14 in 1994 and nine in 1995. Seven fish had been recaptured twice and one had been recaptured three times (Appendix; Table C.2.). No coded-nose-wire tags were detected in any Colorado squawfish captured during this study.

The plunge pool and a 0.2-mile section (RM 2.9-2.7) immediately downstream of the plunge pool were high-use areas for adult Colorado squawfish during both years. Twenty-one of the 40 Colorado squawfish in 1994 were captured in the plunge pool. In 1995, five of the 19 fish were captured in the plunge pool. Fifty-one of the 59 squawfish (86%) collected during the 2-year study were captured in the plunge pool or the 0.2-mile section immediately downstream (Tables 1 and 2; Figure 2). Between 6 and 22 July 1994, a total of 20 adult Colorado squawfish were found in this 0.3-mile area. At the same time, an aggregation of Colorado squawfish was observed in the Colorado River (RM 169). Although none of the fish handled in the Lower Gunnison River had expressible gametes, the high number of fish observed during this time suggest spawning or post-spawning activity.

The highest CPUE for sub-adult and adult Colorado squawfish in the 2.3-mile reach during 1994 and 1995 was in July (34 fish; 5.56 F/h), followed by June (8 fish; 1.68 F/h), and August (7 fish; 1.52 F/h; Appendix; Table D.1.). Sixty-two of the 73 fish captured and sighted were collected during these three months (Appendix; Table C.3.).

Other Common Fishes

In addition to Colorado squawfish, four other native fishes, nine nonnative fishes, and three sucker hybrid fishes were collected (Appendix; Table A.1.). A total of 6,757 fish was captured, 2,540 from the plunge pool and 4,212 from the reach (Appendix; Tables A.2. and A.3.) Flannelmouth sucker were the most common species (33.9%), followed by bluehead sucker (31.9%), common carp (13.4%), and roundtail chub (12.6%). Only one adult northern pike was collected (PIT-tag No. 1F1F7D162F). Eighty-five adult channel catfish were captured, which comprised only 1.3% of the catch.

Table 1. Sampling summary of sub-adult and adult Colorado squawfish (CS) captured and positively sighted while electrofishing in the Redlands Diversion Dam plunge pool (river mile [RM] 3.0) and in the 2.2-mile reach of the Gunnison River immediately downstream between the Redlands Diversion Dam plunge pool and Colorado River confluence, 30 March to 14 November 1994.

Total Number Captured	Total Number Sighted	Total Number Recaptured Once	Total Number Recaptured Twice	Total Number Recaptured Thrice	Number of CS Initially Captured in the 2.3-Mile Reach	Number of CS Captures by RM			
						3.0	2.9-2.7	2.6-2.0	1.9-0.7
40	10	9	4	1	3 of 40	21	17	2	0

Table 2. Sampling summary of sub-adult and adult Colorado squawfish (CS) captured and positively sighted while electrofishing in the Redlands Diversion Dam plunge pool (river mile [RM] 3.0) and in the 2.2-mile reach of the Gunnison River immediately downstream between the Redlands Diversion Dam plunge pool and Colorado River confluence, 13 April to 7 November 1995.

Total Number Captured	Total Number Sighted	Total Number Recaptured Once	Total Number Recaptured Twice	Total Number Recaptured Thrice	Number of CS Initially Captured in the 2.3-Mile Reach	Number of CS Captures by RM			
						3.0	2.9-2.7	2.6-2.0	1.9-0.7
19	4	6	3	0	6 of 19	5	8	2	4

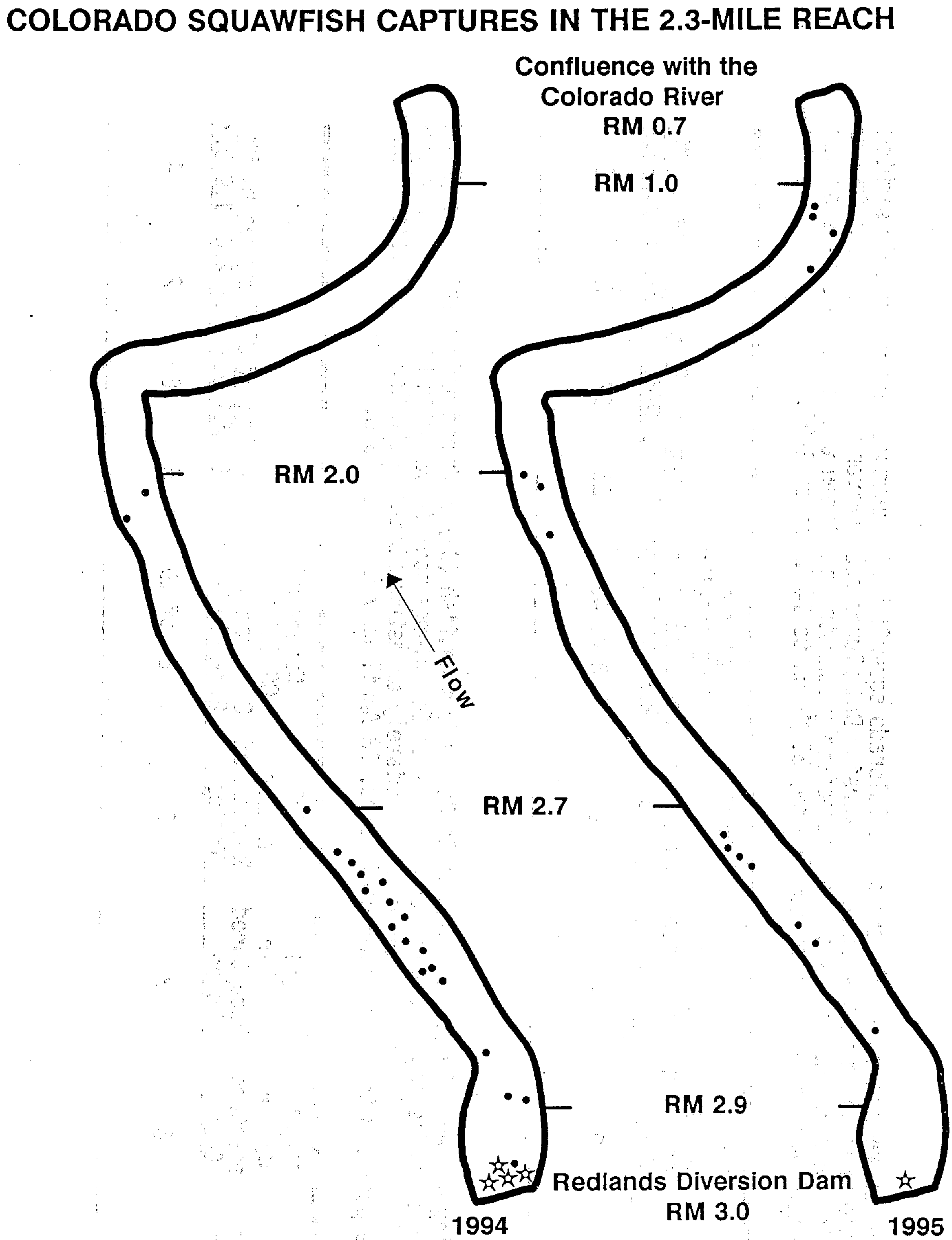


Figure 2. Distribution of sub-adult and adult Colorado squawfish captures within the 2.3-mile reach of the lower Gunnison River, Colorado, 1994 and 1995. Each dot represents an individual fish; open stars represent 5 fish.

Catch Rate versus Flow

One objective (no. 4) was to determine if there was a "threshold low flow" that would trigger Colorado squawfish and other large native fishes to leave the reach and move downstream into the Colorado River where more water was available and habitat conditions appear more suitable. This would be important because if a strong correlation between flow and number of fish collected in the plunge pool and reach existed, this would provide pivotal information for recommending a minimum flow for passage. If detecting biological responses during planned low test flows became difficult because sufficient numbers of Colorado squawfish could not be collected, determining if there was a relationship between individual and collective catch rates of native fishes versus flow might provide useful information for when conditions in the reach became unsuitable for sustaining fish life. A low catch rate associated with flows below the threshold would indicate unsuitable conditions.

Three different ranges of flows were analyzed for fish collected in the plunge pool (89-1,000, 89-2,000, and 89-13,900 cfs) and 2.2-mile reach (217-1,000, 217-2,000, and 217-13,900 cfs). There was no apparent relationship between total CPUE versus flow for the four native fishes or three nonnative fishes collected in the plunge pool or reach (Figures 3, 4, and 5). Catch rate was highest for Colorado squawfish in the plunge pool during July 1994 at 650 cfs. Although the correlation coefficient ("r") was highest at flows less than 2,000 cfs during 1994 and 1995 for Colorado squawfish collected in the plunge pool (-0.62; Appendix; Table E.1.), the relationship indicated that the Colorado squawfish catch rate generally decreased with an increase in flow. Relationship between CPUE and flow was poor for Colorado squawfish collected in the reach at all flows analyzed (Appendix; Table E.2. and Figure E.3.). The highest relationship for flannelmouth sucker collected from the plunge pool (r=-0.74) and reach (r=-0.54) was between 217-1,000 cfs. However, in both instances, catch rate decreased as flow increased (Appendix; Tables E.1. and E.2.). For nonnative fishes, there was no distinguishable pattern of a positive or negative relationship between catch rate and flow. The relationship of total CPUE for native and nonnative fishes versus the different range of flows analyzed by sampling date in 1994 and 1995 is provided (Appendix; Tables E.1. and E.2.; Figures E.1.-E.5.).

These analyses did not offer any clear associations or identify threshold low flows when fish might vacate the reach and move downstream where more suitable habitat conditions existed. These results indicate that comparability of CPUE data can be highly variable even at similar flows. While high Colorado squawfish catch rates during low flows may be due to their being more vulnerable to capture, the high number of adult Colorado squawfish found in the reach during late-July and early-August 1994 does indicate that this reach provides temporary, seasonal habitat for "residency" at 300 cfs. There were only four sampling dates in 1995 when flows were less than 1,000 cfs. Flows between 100 and 600 cfs are needed to determine when endangered and other native use this reach and when fish might leave this reach because habitat conditions are unsuitable.

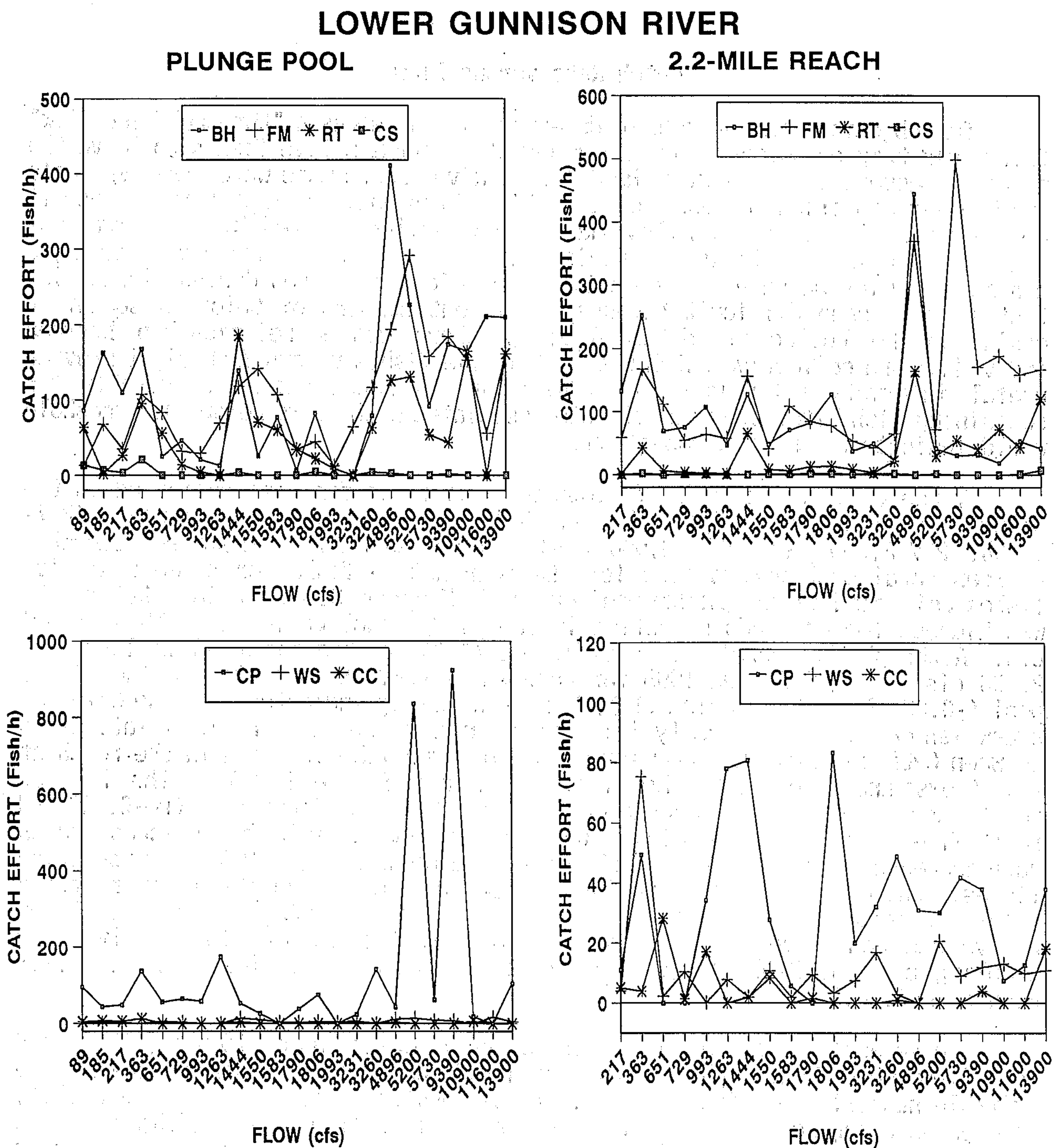


Figure 3. Individual catch per unit effort (Fish/h) versus flow (cfs) for four sub-adult and adult native fishes and three sub-adult and adult nonnative fishes collected with electrofishing in the plunge pool and 2.2-mile reach of the Lower Gunnison River, 30 March 1994 to 7 November 1995. Note: refer to Appendix; Table A.1 for two-letter species code.

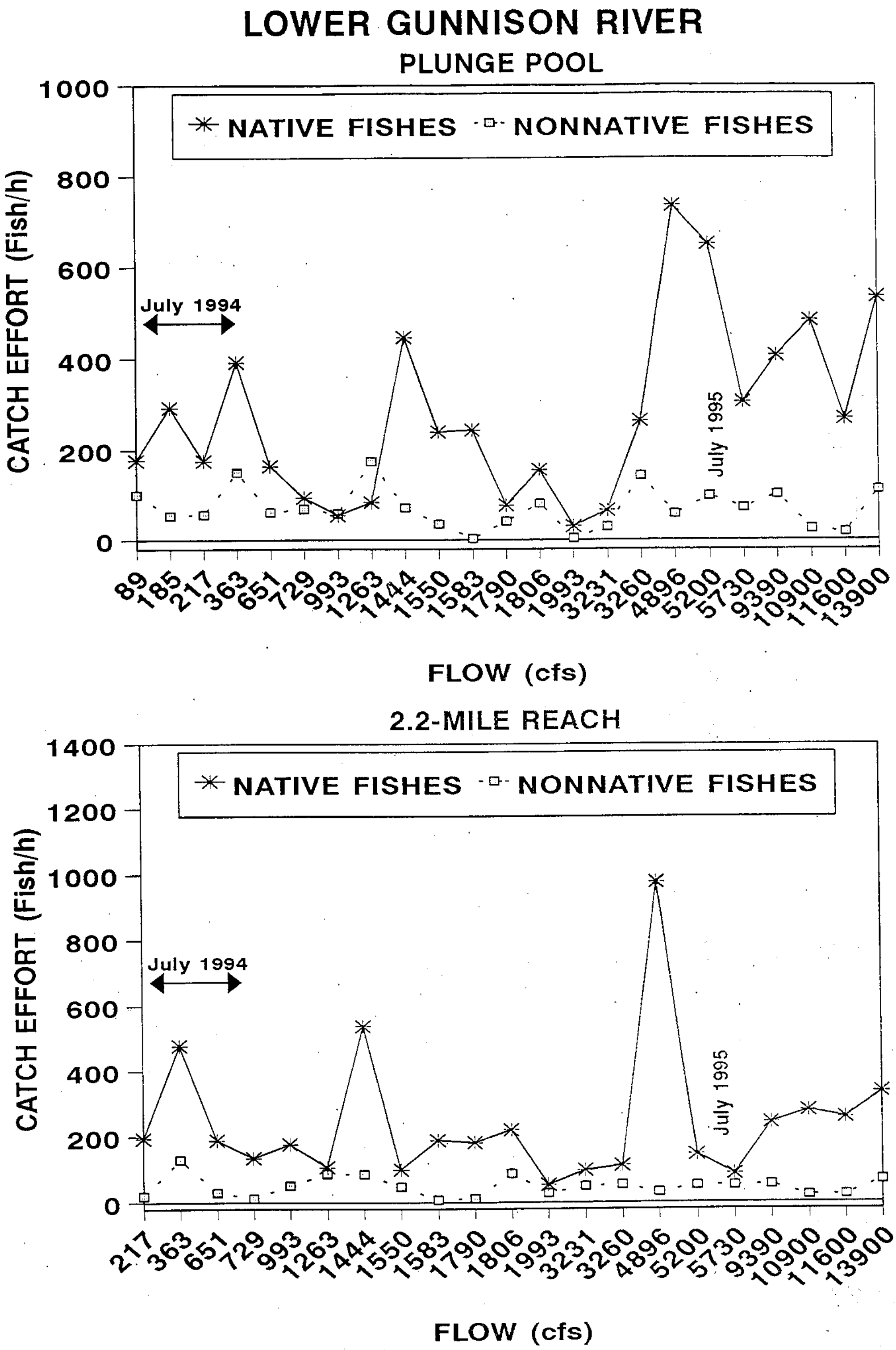


Figure 4. Combined catch per unit effort (Fish/h) versus flow (cfs) for four sub-adult and adult native fishes (BH, FM, RT, CS) and three sub-adult and adult nonnative fishes (CP, WS, CC) collected with electrofishing in the plunge pool and 2.2-mile reach of the Lower Gunnison River, 30 March 1994 to 7 November 1995. Note: refer to Appendix; Table A.1. for two-letter species code.

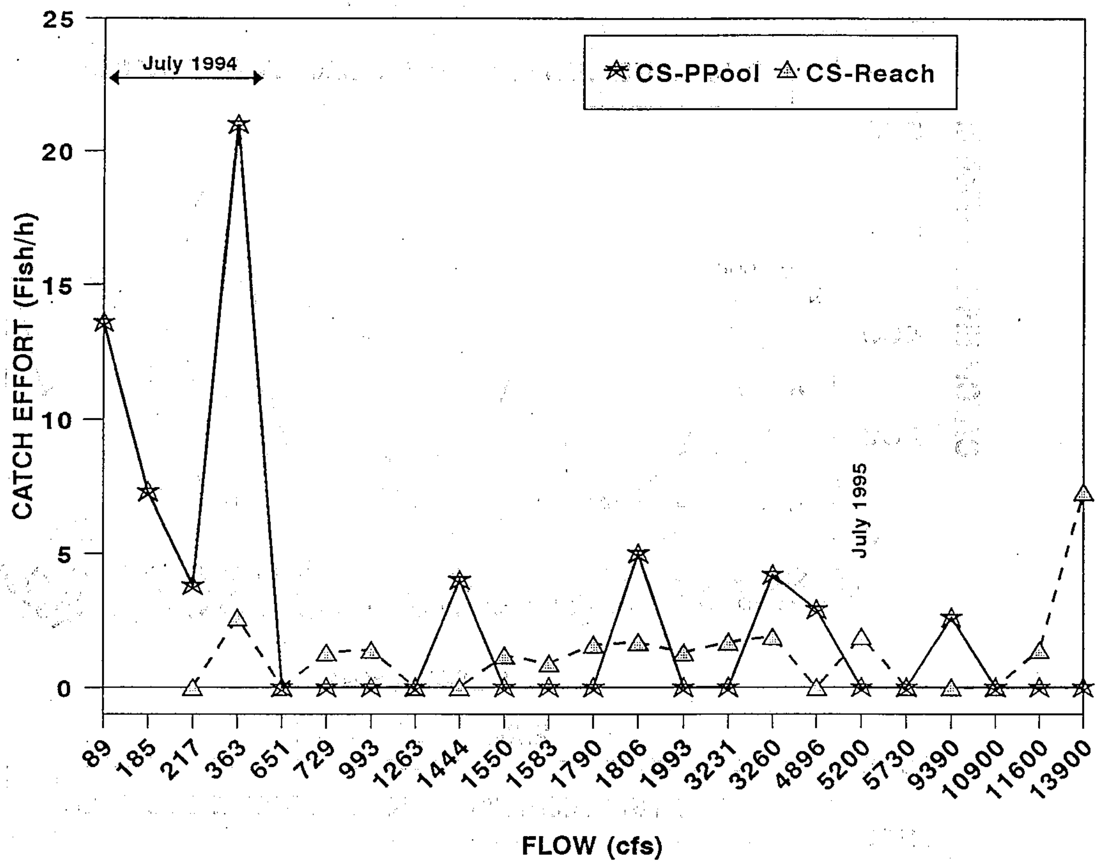


Figure 5. Comparison between total catch per unit effort (Fish/h) for sub-adult and adult Colorado squawfish collected by electrofishing in the plunge pool immediately downstream of the Redlands Diversion Dam and in the 2.2-mile reach of the Lower Gunnison River, Colorado, March 1994 to November 1995.

Hydrology

River Discharge

The maximum daily flow was about three times higher and the total annual discharge was about two times higher in the Gunnison River in 1995 than 1994. The total annual discharge for the Gunnison River at the USGS streamflow gage at Whitewater was 1,484,000 AF (784,395 cfs) in 1994 compared to 3,222,000 AF (1,624,310 cfs) in 1995. The maximum daily discharge was 6,040 cfs in 1994 compared to 17,300 cfs in 1995. The mean daily May and June flow in 1994 was 3,640 cfs compared to 11,196 cfs in 1995. The mean daily flow for July, August, and September in 1994 was 1,140 cfs versus 5,875 cfs for the same three months in 1995. In 1994 in the 2.3-mile reach, there were 86 days when the flow was less than 1,000 cfs and 14 days when the flow was less than 300 cfs during these three months. In 1995, there were only four days when the flow was less than 1,000 cfs in the reach during these three summer months--the lowest flow being 650 cfs on 6 September.

The actual streamflows calculated by subtracting the flow of the Redlands Canal from the USGS gage at Whitewater were always higher than the streamflow measured by the BR gage in the reach. During low flows, the instantaneous flow varied from 150-200 cfs in the 2.3-mile reach. The exact reason for this discrepancy was unknown. The Whitewater gage is located about 11 miles upstream. The difference between the two methods might be explained during runoff by the rapid hourly flow fluctuations and by the difficulty in determining the flow rate and "flow lag time" between the dam and upstream gage. However, the discrepancy is not explained during low-flow periods when the hourly and daily fluctuations are not great. The mean daily flow in the 2.3-mile reach for the two methods during study period is provided (Appendix F; Figure F.1.).

<u>BR Transects</u> (Figure 6; Appendix; Tables G.1-G.3)

Transect No. 1 (Appendix; Figure G.1.)

This transect was located at RM 3.0, the plunge pool of the Redlands Diversion Dam. The plunge pool offers deep-water habitat for Colorado squawfish when flow totally ceases in the reach. At 100 cfs, the mean and maximum water depth is 6.7 and 9.7 feet, respectively. At 300 cfs, the mean and maximum water depth is 7.6 and 10.4 feet, respectively (Appendix; Table G.1). In the 2.3-mile reach, Colorado squawfish and other native fishes have two options in coping with low-flow conditions. One is to travel downstream to the Colorado River and wait out the low-flow period in reaches below the confluence with the Colorado River where more water is available. The other strategy is to 'hole up' in habitats that provide adequate deep-water habitats, such as the plunge pool. Although the deep-water habitat of the plunge pool has been artificially created by the Redlands Diversion Dam, it does provide a temporary sanctuary for fish that might become stranded during low-flow periods.

Transect No. 2 (Appendix; Figure G.1.)

This transect was located at RM 3.0, immediately downstream of Transect 1. Two prominent thalwegs, one on river right and the other on river left, and a mid-channel sandbar appear in this transect profile. At 100 cfs, the mean and maximum water depth is 3.0 and 5.9 feet, respectively. The right thalweg, deepest of the two channels, is maintained by the flows released when the radial arm gates on river left are opened to sluice sediments from upstream of the dam. This area also provides deep-water habitat for Colorado squawfish during extreme low-flow conditions (e.g., 100 cfs or less). There is not an appreciable gain in habitat if flow is increased from 100 cfs to 300 cfs or from 300 to 600 cfs at this transect.

Transect No. 3 (Appendix; Figure G.2.)

This transect was located at RM 2.85 and was the widest of all transects (549 feet). Because of the wide nature of this section of the river, an increase

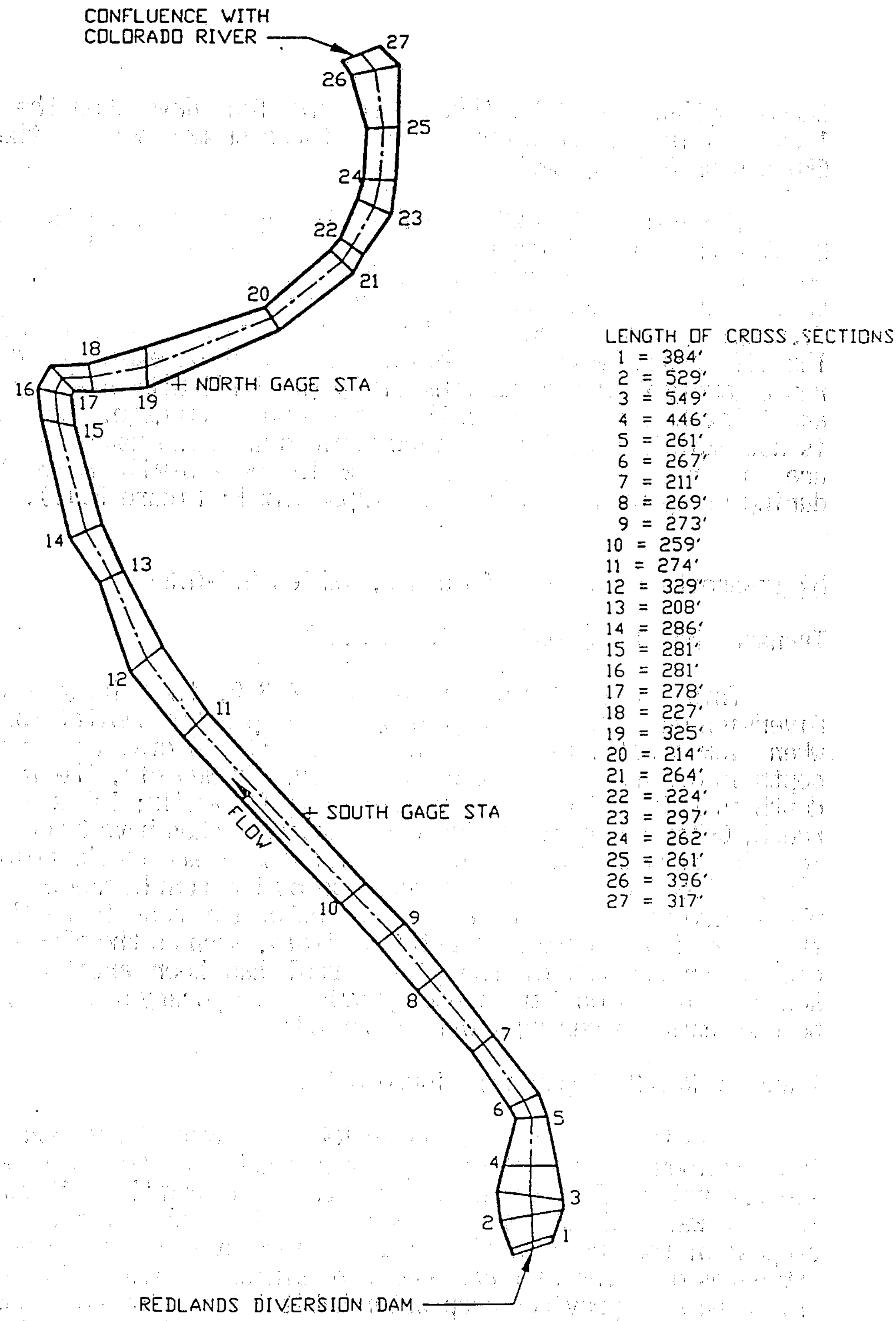


Figure 6. Plan view of the 2.3-mile reach of the lower Gunnison River and the location and widths of the 27 transects surveyed by the Bureau of Reclamation during April 1993. Note: Redlands Diversion Dam is river mile 3.0; the confluence with the Colorado River is river mile 0.7.

in flow does not translate to an proportional increase in water depth. The maximum depth at 100 cfs is 2.2 feet, compared to 2.5 feet at 300 cfs, and 3.0 feet at 600 cfs. The mean water depth at 100 cfs is 0.8 feet, compared to 1.1 feet at 300 cfs, and 1.3 at 600 cfs.

Transect No. 4 (Appendix; Figure G.2.)

This transect was located at RM 2.8 and was the third widest transect, 446 feet. At 300 cfs, the mean and maximum water depth was 0.5 and 1.1 feet, respectively. Although there were two defined thalwegs across this transect, a flow of 1,600 cfs would be required to maintain a mean water depth of 1 foot. A maximum water depth of 1 foot was exceeded only once each at 300, 400, 500, and 600 cfs. If a mean 1-foot water depth is to be maintained, this is a critically shallow cross section at 300 cfs.

Transect No. 5 (Appendix; Figure G.3.)

This transect was located at RM 2.8 where the river narrows and makes a 45° left-hand bend. A maximum water depth of 2 feet is achieved at 600 cfs. At 300 cfs, mean and maximum water depth was 1.0 and 1.6 feet, respectively. At 200 cfs 50% of the predicted water depths exceeded 1 foot.

Transect No. 8 (Appendix; Figure G.3.)

This transect was located at RM 2.75 and extended 269 feet. A 200 cfs flow maintains a 1-foot mean and 2-foot maximum water depth, respectively. Forty-three percent of predicted observations exceeded 1 foot at 200 cfs; 57% exceeded 1 foot at 300 cfs.

Transect No. 9 (Appendix; Figure G.4.)

This transect was located at RM 2.7 and extended 273 feet. This transect is slightly downstream of FWS Transect No. 9. At 300 cfs, the mean and maximum water depth was 0.5 and 1.2 feet, respectively. At 600 cfs, the mean and maximum water depth increased by only 0.2 and 0.4 foot. A mean water depth of 1 foot was maintained at 850 cfs. A 1,600 cfs flow would be required to maintain a 2-foot mean water depth at this transect. At 300 cfs, only one of 15 (7%) predicted observations exceeded 1 foot; at 400 cfs, only one of 21 (5%); at 500 cfs, only two of 21 (10%). There was not a well-defined thalweg across this transect. If at least a 1-foot water depth is to be maintained, this is also a critically shallow cross section at 300 cfs.

Transect No. 12 (Appendix; Figure G.4.)

This transect was located at RM 2.1 and extended 329 feet. A mean water depth of 1 foot is maintained at 400 cfs. However, at 300 cfs, approximately 38% of the predicted observations exceeded 1 foot. Doubling the flow from 300 cfs to 600 cfs only increases the maximum water depth from 2.6 to 3.2 feet. Therefore, the increased available habitat is disproportional to an increase in flow of this magnitude.

Transect No. 14 (Appendix; Figure G.5.)

This transect was located at RM 1.8 and extended 286 feet. A maximum water depth of 1 foot and 2 feet is achieved at 100 and 200 cfs, respectively. A mean water depth of 1 foot is maintained at approximately 225 cfs. At 200 cfs, 60% of the channel's water depth exceeded 1 foot.

Transect No. 19 (Appendix; Figure G.5.)

This transect was located at RM 1.4 and extended 325 feet. A mean water depth of 1 foot would be maintained at 600 cfs. However, 1,400 cfs would be required to maintain a mean water depth of 2 feet. At 300 cfs, the mean and maximum water depth was 0.7 and 1 foot, respectively, and only one predicted observation exceeded 1 foot. Doubling the flow from 300 to 600 cfs would not double the available habitat at this transect either--the mean depth would be increased by 0.3 foot, the maximum by 0.5 foot. This is considered a critically shallow cross section at 300 cfs.

Transect No. 26 (Appendix; Figure G.6.)

This transect was located at RM 0.8, 0.1 mile upstream of the confluence with the Colorado River and extended 396 feet. There is little change in available habitat at 100, 300, or 600 cfs. At 100 and 300 cfs, the mean and maximum water depth was similar, 2.2 and 4.1 feet, respectively. At 600 cfs, the mean water depth was 2.3 feet; the maximum water depth, 4.2 feet.

FWS Transects

The following contains a description of the transect placement relative to the stream channel, width of the wetted channel, channel width, habitat, and empirical water depths recorded in the 2.3-mile reach (Figure 7). A total of 818 individual water depth measurements was recorded.

Transect No. 4 (Appendix; Figure G.7.)

This transect was located at RM 2.9, 0.1 mile downstream of the Redlands Diversion Dam. The width of the wetted channel was only 160 feet, whereas the total channel width was 370 feet. This transect was at a 30° angle to the channel and spanned a primary channel on the east side, an island, and a secondary channel on the east, that was dewatered at the time. The mean and maximum water depth was 0.6 and 1.5 feet, respectively, on 8 August when the flow was 222 cfs; 14% of the wetted channel width exceeded 1 foot (Appendix; Table G.4.). One defined thalweg was evident at this flow. The habitat type at this transect was classified as a fast run.

Transect No. 9 (Appendix; Figure G.8.)

This transect was located at RM 2.7, 0.3 mile downstream of the Redlands Diversion Dam. This transect extended approximately 290 feet across the primary channel at a 45-60° angle to the channel. The mean and maximum water depth was 0.4 and 0.8 feet, respectively, when the flow was 245 cfs. There was not a

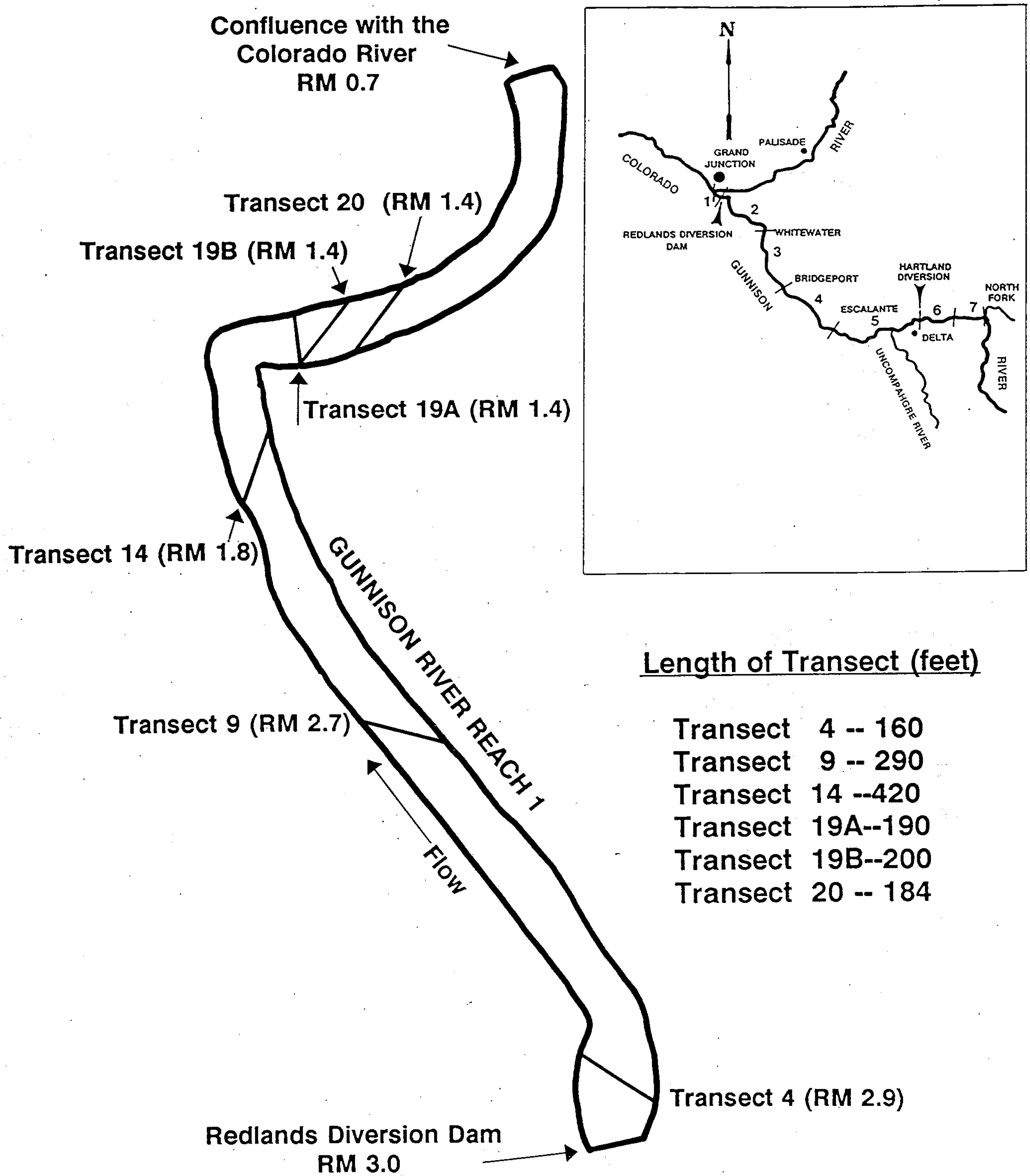


Figure 7. Plan view of the 2.3-mile study area of the lower Gunnison River between the Redlands Diversion Dam and the confluence with the Colorado River. Note: transects numbers correspond closely with those transects established by BR in the spring of 1993 to determine stage versus discharge relationships for this reach.

prominent thalweg across this transect which was a slow run across a riffle.

Transect No. 14 (Appendix; Figure G.9.)

This transect was located at RM 1.8, 1.2 miles downstream of the Redlands Diversion Dam. This transect extended approximately 420 feet across the primary channel at a 60° angle to the channel. The mean and maximum water depth was 0.6- and 1.2 feet, respectively, when the flow was 276 cfs. There was a slight thalweg near river left (west bank). Twenty-six of the 179 water depth observations (15%) exceeded 1 foot (Appendix; Table G.4.). Most of the habitat at this transect could be classified as a riffle; the thalweg portion being a slow run.

Transect No. 19A (Appendix; Figure G.10.)

This transect was located at RM 1.4, 1.6 miles downstream of the Redlands Diversion Dam, approximately 600 feet downstream of the former Black Bridge. The width of the wetted channel was 190 feet and the transect was perpendicular to the primary channel. The mean and maximum water depth was 0.7 and 1.1 feet, respectively, when the flow was 264 cfs and only 5% of the wetted channel width exceeded 1 foot (Appendix; Table G.4.). The habitat at this transect could be classified as a slow run. There was not a prominent thalweg across this transect.

Transect No. $19B_1$ & $19B_2$ (Appendix; Figures G.11. and G.12.)

This transect was located immediately downstream of Transect 19A at RM 1.4. Transects were conducted at this site on two different dates, 2 and 3 August. On both days, the transect extended 200 feet across the primary channel at a 45° angle. Flows on both days were similar--268 and 266 cfs; hence the mean and maximum water depth on both days were identical, 0.5 and 1.1 feet, respectively. However, the number of water depths that exceeded 1 foot were greater on 3 August (10 versus 4). The habitat at this transect at this flow was classified as a slow run/riffle.

Transect No. 20 (Appendix; Figure G.13.)

This transect was located at RM 1.4, immediately downstream of Transect 19B. This transect extended approximately 184 feet across the primary channel at a 45° angle. The mean and maximum water depth was 0.6 and 1.0 feet, respectively, when the flow was 266 cfs. No water depth exceeded 1 foot across this transect during this flow. The habitat at this transect was a slow run across a riffle.

Summary of Transect Data

Three of the seven FWS transects, 9, 19, and 20, within the 2.3-mile reach had critically shallow water depths less than 300 cfs. The most critical periods were during late-July and early-August 1994 when flows were 250-276 cfs. At these flows, the actual measured mean and maximum depth at transect 9 and 19 was 0.4 and 0.8 and 0.5 and 1.1 feet, respectively (Appendix; Table G.4.). At 300 cfs, the predicted mean and maximum depth at transect 9 and 19 was 0.5 and 1.2

and 0.7 and 1.1 feet, respectively (Appendix; Table G.1.). If Colorado squawfish require 2 feet for passage rather than 1 foot, a flow of 1,600 cfs would be required at transect 9 (Appendix; Figure G.4.). Similarly, 900-1,000 cfs would be required at transect 19 to provide a maximum water depth of 2 feet (Appendix; Figure G.5.). There was a discrepancy at transect 20 between the empirical and predicted water depths. Ninety-nine water depth observations were recorded at FWS transect 20 during July. The mean and maximum water depth was 0.6- and 1 foot, respectively, at 266 cfs. On the other hand, the BR transect predicted a mean and maximum water depth of 3.2 and 7.3 feet, respectively, at 300 cfs. One explanation is that the location and orientation of the BR and FWS transect to the channel did not exactly correspond.

Immediately up- and downstream of transect 9 and 19, the water column is deeper. At transect 8, immediately upstream of transect 9, the mean and maximum water depth was 1.3 and 2.3 feet, respectively, at 300 cfs (Appendix; Table G.1.). At transect 10, immediately downstream, the mean and maximum water depth was 1.9 and 2.8 feet, respectively, at 300 cfs. At transect 18, immediately upstream of transect 19, at 300 cfs the mean and maximum water depth was 6.9 and 11.0 feet, respectively. At transect 20, the predicted mean and maximum water depth was 3.2 and 7.3 feet, respectively.

These data indicate that adequate water depths for passage up- and downstream of these three critical shallow areas were available at 300 cfs. The HEC-2 model predicted that water depths greater than 1 foot were exceeded at only one location each at transects 4, 9, and 19. The model predicted that water depths greater than 1 foot up- and downstream of these three critical shallow areas were exceeded at least at three locations at each of the 24 other transects in the reach at 300 cfs; the predicted mean depth for the entire reach at 300 cfs was 2.7 feet (Appendix; Tables G.2. and G.1.). The high number of adult Colorado squawfish found in the reach during late July and early August 1994 indicates that sufficient habitat is available for "residency" at 300 cfs. The areas up- and downstream of these shallow-water areas are pools that provide suitable habitat for fish to "hole up" for short periods during low flows. Successive pool/riffle habitat combinations occur in the 2.3-mile reach during low flows. These pools are deeper than riffles and are maintained by cobble bars at the downstream end that serve as hydraulic controls to dam the water.

Water depths predicted by the HEC-2 model differed slightly from the empirical values. One possible explanation was that during the high runoff period in 1993, the stream bed may have scoured at cross sections surveyed. The BR field transect work was conducted in April prior to runoff, whereas the FWS field transects were conducted during July and August of the same year, following runoff. Consequently, the invert of the channel could have been altered following runoff. Also, the BR transects were surveyed in April when flows ranged from 2,700 to 4,100 cfs. Because the transect work was conducted during mid-flow conditions, the HEC-2 model predicted water depths greater than actually existed for low-flow periods; conversely the model predicted water depths less than actually existed during high flows. Ideally, the transects should have been conducted during a lower flow period to increase the accuracy of the model for the flows of interest (e.g, 300-1,000 cfs). Despite the slight differences between water depths for the two methods, water depths predicted by the HEC-2 model were comparable to the actual or empirical water depths for transects at the same location. The HEC-2 model provided an extensive database on the relationship of water depth versus flow at numerous other locations in the reach than those conducted by FWS. Corroboration between the two methods increased the available data base that could be used to make general conclusions about relationships between stage and water depth over a wide range of flows in the reach. No water depth data were collected on the relationship of low flow and Colorado squawfish use in 1995 because flows in the Gunnison River were much higher throughout 1995 compared to 1994 (Figure 1).

These results found that increasing flow does not translate to a proportional increase in water depth. Although the general habitat is distinctly dissimilar between the 2.3-mile reach of the Lower Gunnison River and the 15-mile reach of the Upper Colorado River, Osmundson et al. (1995) noted similar observations regarding availability of preferred habitats and flow.

Habitat-use and water depth-preference data for sub-adult and adult squawfish that had occupied the 2.3-mile reach were not collected in this study. However, general statements could be made about habitats and water depths Colorado squawfish might prefer and need during summer low months in the 2.3-mile reach of the Lower Gunnison River using Colorado squawfish data from the 15-mile reach. Osmundson et al. (1995) found that during low summer flows in the 15-mile reach, Colorado squawfish preferred slow and fast runs. During summer low-flow months, they also reported that sub-adult and adult Colorado squawfish used slow runs with water depths of 1.4-7.6 ft (mean=3.6 ft) and fast runs 1.8-3.0 ft deep (mean=2.4 ft). The minimum water depth used by Colorado squawfish in the 15-mile reach meant that 550 cfs would be required in the 2.3-mile reach of the Lower Gunnison River to produce minimum depths of 1.4 ft at transects 9 and 19. Although it is acknowledged that these two stream reaches are different in habitat diversity and stream gradient, applying the water depth criteria for Colorado squawfish in the 15-mile reach to the 2.3-mile reach provides a reasonable estimate of minimum depth needed by Colorado squawfish. Furthermore, the water depths recorded from radiotagged Colorado squawfish in the 15-mile reach represent depth in preferred habitats and the corresponding flows recommended for that reach are intended to optimize habitat and to promote recovery. Therefore, recovery flows recommended for the 15-mile reach might be higher than needed to provide passage in the 2.3-mile reach.

Flow Exceedence

Snow pack and moisture content data allow water managers to predict whether a water year will be wet, above or below normal, or dry. Although flow duration curves do not provide water managers the ability to predict when low-flow conditions will occur, they do provide them with some probability of how frequent flows of interest may occur. A flow-duration curve predicts the likelihood of various flows based on regional climatological conditions (i.e. annual snow pack) and the amount of water available in the drainage based on current water management practices.

Flow exceedence for three water development periods, 1917-1938 (pre-), 1939-1964 (mid-), and 1967-1994 (post-Aspinall), in the Gunnison River drainage was analyzed. The mean daily flow exceedence for each month was computed for each of these three periods (Appendix; Table H.1.) and a flow-duration curve was developed for each month for the post-Aspinall period at the Whitewater gage (Appendix; Figures H.1-H.6.). The quantity of water delivered from upstream Federal reservoirs during nonrunoff months has increased and thus has increased water availability to downstream irrigation users. Dams and reservoirs on mainstem and tributary streams now allow water managers to allocate and redistribute water more evenly throughout the year for flood control and to accommodate downstream irrigation users. Since construction of the Aspinall Unit dams and reservoirs, flows can be delivered to downstream reaches during extreme low flows to sustain endangered fishes.

Since 1917, 300 cfs or less has occurred in the 2.3-mile reach less during 1967-1994 than the previous two water-development periods. During July, August, and September, months that have the lowest flow in the 2.3-mile reach, the number of days flows fell below 300 cfs was less following construction of Aspinall than during the previous water period (1939-1964; Appendix; Table H.1.). Based on current water availability, flows less than 300 cfs still occur in 3.5 out of every 10 years in July and in four out of every 10 years in August in the 2.3-mile reach. In September during the 1967-1994 period, flows fell below 300 cfs in two out of every 10 years compared to 7 of 10 years during two previous water development periods (Appendix; Table H.1.). During the 29-year period from 1967-1995, the number of days that the mean daily discharge was from 0 to 300 cfs in the 2.3-mile reach for July, August, September, and October was 604 days, or 33.6% of the time. During the same period, there were 226 days (about 12.8% of the time) that discharge was 0 cfs (Appendix; Table H.2.). The greatest number of days in which flows were 300 cfs of less occurred in 1977. Flows were less than 300 cfs for almost the entire four-month period (121 days) and 0 cfs occurred for 90 days.

Similarly, the frequency that flows fell below 300 cfs during the non-runoff months, October through March, occurred much less often following construction of the Aspinall Units. For example, during October, flows only fell below 300 cfs 18% of the time from 1967-1994, compared to 52% of the time from 1939-1964. A five-fold decrease was observed in December, 13% versus 69% comparing the same two periods. Surprisingly though, since 1965 flows less than 300 cfs still occur monthly in the 2.3-mile reach (Appendix; Table H.1.).

Flow in the Gunnison River is currently managed to store water during runoff months and augment natural flows during pre- and post-runoff months. For the runoff months of May and June, the frequency of flows below 300 cfs was 5- and 8%, respectively, during 1965-1994. For May, this was about 16 times greater than the 1939-1964 water development period and about 50 times greater than the 1917-1938 period (Appendix; Table H.1.).

SYNTHESIS

River Management

Low- and Moderate-Water Years

This study was to recommend a minimum flow for the 2.3-mile reach of the

Lower Gunnison River, targeting summer low-flow months when conditions are not suitable for Colorado squawfish passage. One approach to determine the minimum flow would be to identify which habitat types were preferred by sub-adult and adult Colorado squawfish and then determine the flow level those habitat types are maximized. To determine Colorado squawfish habitat preference, frequency of use by habitat type would be compared to their relative availability. The best means of obtaining habitat-use information is from radiotagged fish. This approach was used to identify and recommend year-round flows for Colorado squawfish in the 15-mile reach of the Upper Colorado River (Osmundson et al. 1995). However, this study did not collect or have past data on habitat use by sub-adult and adult Colorado squawfish and habitat availability to determine habitat preference during low summer flows in the 2.3-mile reach. Without such data, stage and stream channel water depths were used to determine the flow at which insufficient depth might become limiting to sub-adult and adult Colorado squawfish.

Peak runoff usually occurs earlier in the Gunnison than Colorado River. In the Gunnison River, runoff usually occurs in mid- to late-May compared to the Upper Colorado River which peaks usually in early- to mid-June. In the Upper Colorado River, July has always provided a transition from the high spring flows to the base flow of late summer and winter. In the Gunnison River, June is the transition month. The Gunnison River is not entirely regulated by upstream dams and reservoirs. Although its contribution is small during summer months, the North Fork influences the magnitude and duration of peak runoff in addition to the shape and timing of when flows decrease in summer.

Natural weather patterns determine the rate of snow melt and reservoir levels determine the amount of water delivered on individual days. The winter snow pack determines the magnitude and duration of the runoff. The level of precipitation in the drainage for the water year also influences the duration and abruptness of the descent of the hydrograph following runoff. For most rivers in the Upper Colorado River Basin, during high- and moderate-water years, flows decrease more gradually starting in early-June and taper off in mid-July. During low-water years, flows decrease more abruptly starting in early-June and usually decline to base flows by early-July.

Maintaining the shape of the 'natural' hydrograph is critical to benefiting endangered fishes, the associated native fish community, and the maintenance of the channel morphology and habitat characteristics important to native fishes (Stanford 1994; Tyus and Karp 1989; 1990). Flow recommendations that attempt to maintain the pattern of the 'natural' hydrograph benefit Colorado squawfish and razorback sucker recovery. Vanicek and Kramer (1969) first suggested that discharge and temperature influenced spawning in Colorado squawfish. Reproductive activities of Colorado squawfish and razorback sucker in the Upper Colorado River Basin are closely associated with spring runoff (Tyus and Karp 1989). High spring flows are necessary for the initiation of the spring migration. The greatest longitudinal stream movement by Colorado squawfish usually occurs with declining flows (following spring runoff) during spawning season. Spawning is cued by increasing water temperatures concomitant with declining flows in early to mid-summer.

Modde and Wick (1996) hypothesize that the shape of a natural hydrograph (both magnitude and duration of high flows) benefits the spawning success, growth, survival, and recruitment of razorback sucker. Furthermore, they add that spawning migrations of razorback sucker seem to be influenced both by rising discharge and temperature. Timing of spring flows seems to be an important cue to spawning, and the magnitude of flows may influence post-spawning razorback sucker movement. Additionally, the habitats provided by high flows provide important post-spawning habitat for larval and adult razorback sucker. High flows and the duration of flows which maintain connectivity of the river and floodplain are, thus, important attributes in defining quality and quantity of spring habitat for adult razorback sucker.

Osmundson et al. (1995) believed that a flow regime that eliminates the transition period placed native fish at risk because of the negative effects it may have on aquatic organisms long adapted to a naturally shaped hydrograph with daily and diurnal fluctuations. Abrupt decreases in flow might negatively effect Colorado squawfish spawning, which typically occurs in July, and strand benthic invertebrates and disrupt riverine food webs (Stanford 1994). For the Gunnison River, flows during June should gradually decline to provide a transition period between the spring high in late-May and base flow beginning in late-June to mid-July.

The general shape of the hydrograph for years with similar precipitation was determined. Total annual discharge recorded at the USGS gaging station at Whitewater was used as the criterion for establishing low- and moderate-water years (Appendix; Table H.2.). Usually by 1 April, snowpack and moisture content data are available for water managers to determine whether it will be a high, medium, or low-water year. For high and most moderate years, streamflows in the 2.3-mile reach should not be of concern. On the other hand, in low-water years, the hydrograph could be used as a guide to water managers for apportioning flows during summer low-flow periods.

The hydrographs for five low- (1972, 1977, 1981, 1989, and 1990) and five moderate water years (1969, 1973, 1975, 1982, 1992) in the Gunnison River drainage are given in Figures 8 and 9, respectively. The lowest water year from the low- (1990) and moderate- (1992) groups was graphed and compared to the Aspinall water development time period, 1967-1994. Four of the lowest water years (1931, 1934, 1935, and 1937) from the pre-water development period were also analyzed to compare the shape of the hydrograph with low-water years during the post-Aspinall water period. Because this study was concerned with low flows during the summer months following runoff, six months were used in the analyses, May through October.

For flows to be biologically beneficial, flow recommendations should be made for the shortest time step possible. Technical and institutional constraints make it impractical to administer flows on a daily or even weekly basis. BR hydrology personnel indicated that flows recommended by 10-day steps could be reasonably administered and practically implemented from Federal dams in the Gunnison River drainage during low-flow periods (Personal communication, Coll Stanton). Therefore, daily flows from each of the five years from the post-Aspinall and four from the pre-water development period were averaged by 10- and 11-day time steps.

For the low-water, post-Aspinall years, flows peaked during the first 10-day period in June. Flows abruptly decreased to the lowest level during the first 10-day period in July. Flows remained below 300 cfs from July to the second 10-day period in September. Flows during September and October usually increase in the 2.3-mile reach when irrigation demands decrease. The mean daily flow for each 10-day increment is provided in Figure 8 and Appendix; Table I.1.

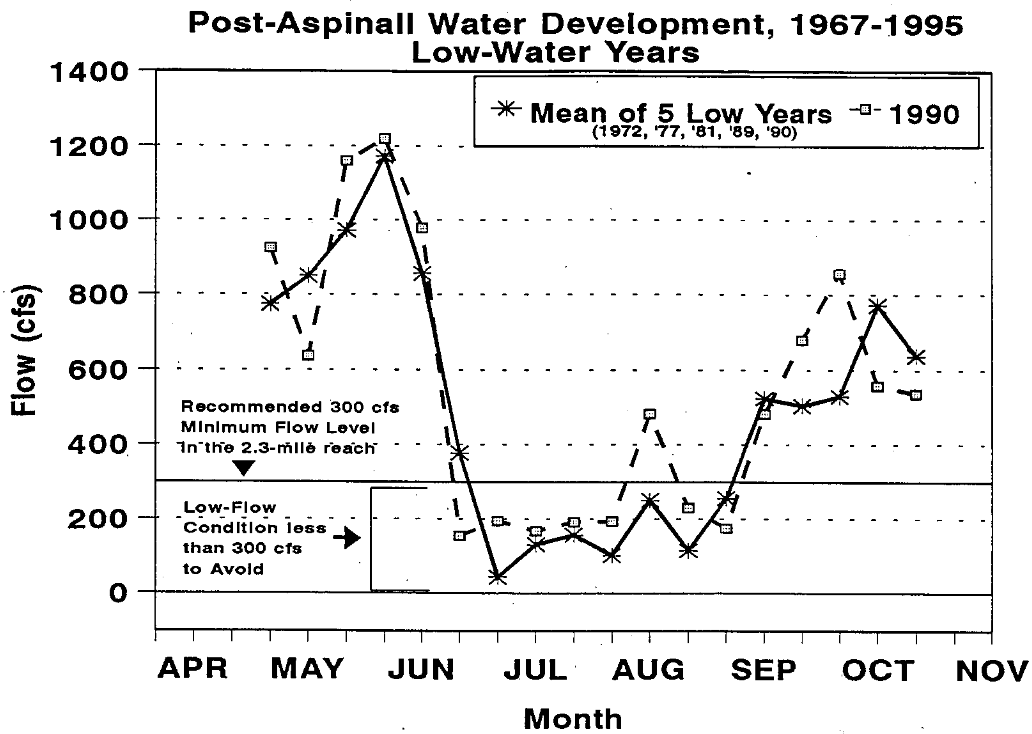
The low-flow years, 1917-1938, were climatologically wetter than either the 1939-1966 or 1967-1995 period. The lowest water years were 1931 and 1934 (Appendix; Table I.2.). Using the mean daily flow by 10-day time steps, a bi-modal peak occurred during the second 10-day period in May and the second 10-day period in June. The flow then abruptly declined to 0 cfs the first 10-day period in August. This descent of the hydrograph was similar for both pre-water development and post-Aspinall periods. However, from peak discharge to base discharge, flow duration was longer during the pre-development than post-Aspinall period (Appendix; Figure I.1.).

The low-flow period in July and August is a critical period biologically for Colorado squawfish. A minimum flow of 300 cfs in the 2.3-mile reach is necessary to maintain access for fish moving up- and downstream from the fish passageway. The presence of sub-adult and adult Colorado squawfish in the reach suggests that this has importance in addition to a passage corridor. The high use by squawfish during this period suggest that this reach might be a spawning or post-spawning feeding area. Therefore, to maintain 300 cfs for fish in the 2.3-mile reach, 70-75 days of augmenting the flow with releases from upstream Federal reservoirs is required during a low-water year.

For moderate-water years, flows peaked during the second 10-day period in May. The flow gradually decreased until the first 10-day period in August when mean daily flow was about 875 cfs. The lowest flow calculated was 860 cfs during the first 10-day period in September. Although the lowest mean daily flow calculated for a 10-day period was about 861 cfs during the first 10-day increment in September, there were days during moderate years when flows were less than 300 cfs in the 2.3-mile reach. In 1969, there were 9 days in July and August when flows were less than 300 cfs. Likewise, in 1975, there were 22 days in July and August when flows were less than 300 cfs and 9 days in September when flows were 0 cfs (Figure 9). For these reasons, it is important for water managers to be aware that even during moderate-water years, there can be instances when flows less than the recommended minimum flow might occur. Furthermore, it is disadvantageous to average flows for several days over several water years because there are occurrences that go undetected when flows may fall below the recommended minimum or a stream reach could be dewatered.

Minimum Flow Recommendation

The assumptions for establishing a minimum flow in the 2.3-mile reach of the Lower Gunnison River were discussed earlier. The most critical assumption was that Colorado squawfish need at least a water depth of 1 foot to move both up- and downstream within the reach that have critically shallow water depths. Three areas within the reach, transect 9, 19, and 20, were identified having maximum water depths at or slightly less than 1 foot at flows ranging from 245-



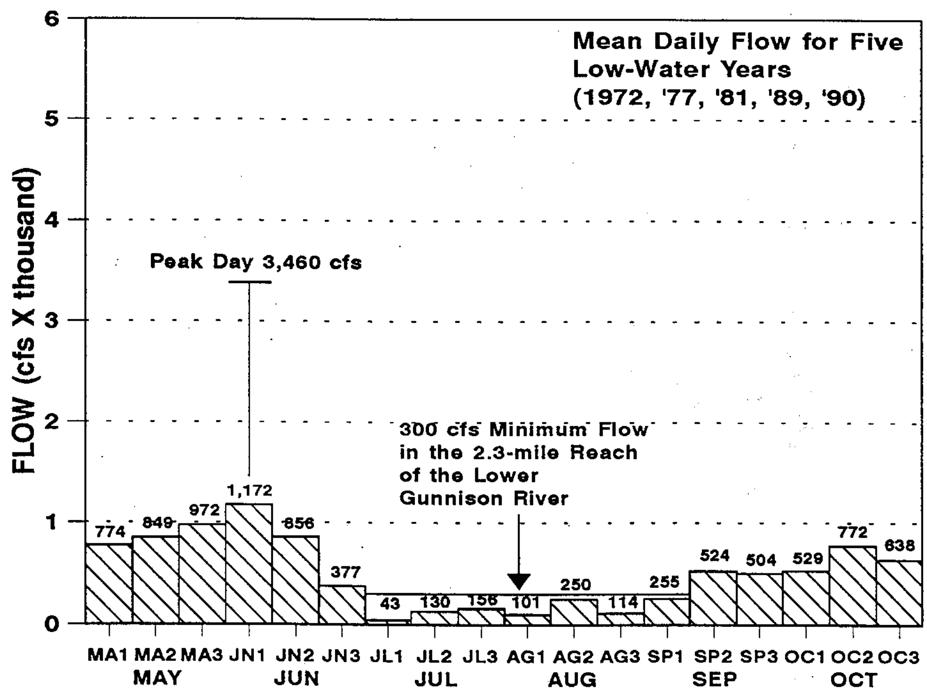
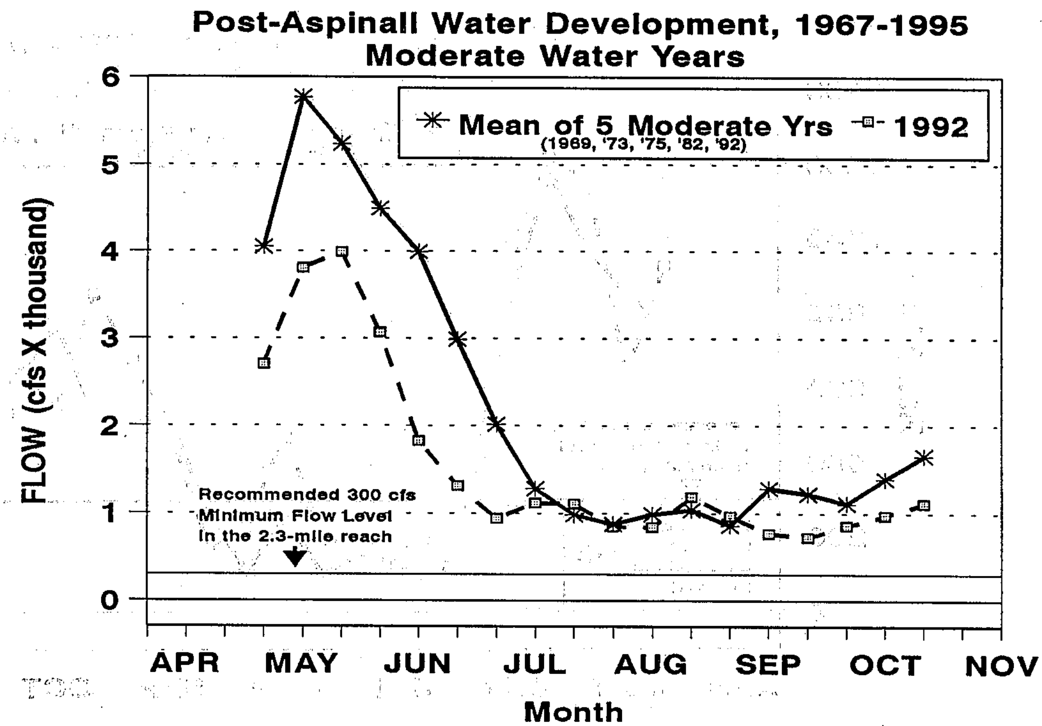


Figure 8. Mean daily flow (cfs) and shape of the hydrograph for five low-water years (1972, 1977, 1981, 1989, and 1990) compared to 1990, a low, low-water year from 1 May to 31 October in the 2.3-mile reach of the lower Gunnison River between the Redlands Diversion Dam and the confluence with the Colorado River (top). The bottom figure represents the mean daily flow for 1 May through 31 October for the 2.3-mile reach by 10- and 11-day step increments, e.g., May 1-10, May 11-20, May 21-31, etc.



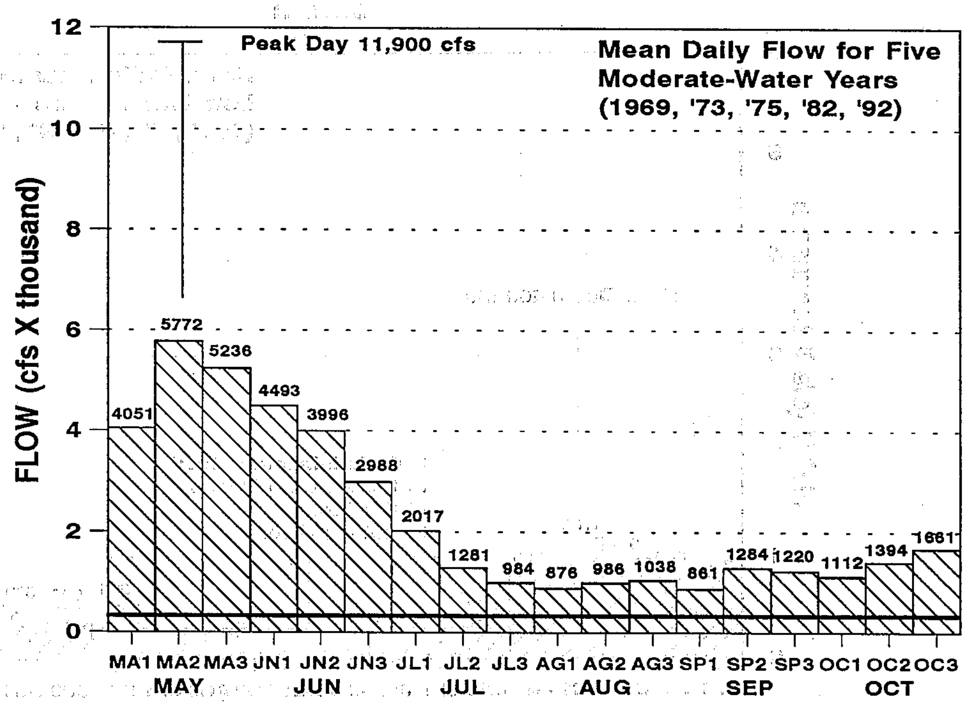


Figure 9. Mean daily flow (cfs) and shape of the hydrograph for five moderate-water years (1969, 1973, 1975, 1982, and 1992) compared to 1992, a low, moderate-water year from 1 May to 31 October in the 2.3-mile reach of the lower Gunnison River between the Redlands Diversion Dam and the confluence with the Colorado River. The bottom figure represents the mean daily flow for 1 May through 31 October for the 2.3-mile reach by 10- and 11-day step increments, e.g., May 1-10, May 11-20, May 21-31, etc. Solid line in the bottom figure represents the recommended 300 cfs minimum flow in the 2.3-mile reach.

276 cfs. A flow of 300 cfs provided at least a maximum 1-foot water depth at these three critical transects when sub-adult and adult Colorado squawfish occupied the reach up- and downstream of the three shallow water areas in late-July and early-August.

A minimum "threshold flow" could not be determined using catch rate and flows because a strong positive relationship between the two variables did not exist. Although flows were known on dates of capture, this method did not provide the resolution or accuracy to identify the minimum flow at which endangered and native fishes would leave the reach. For this study, water depth measured during known low flows was the best approach for determining a minimum passage flow.

The Oregon State Game Commission (Thompson 1972) suggested that the total width of stream having the specified passage depth should be at least 25% of the top width or that the longest continuous portion be at least 10% of the top width. These recommendations may be somewhat arbitrary but have been widely used and accepted by many fisheries agencies. If these guidelines are applied to the 2.3-mile reach and predicted water depths from the HEC-2 model are used, a 1-foot water depth would be maintained across 10% of channel width at 500 cfs at transect 9 (Appendix; Table G.2.). Similarly, 300-400 cfs would be required at transect 19. Until additional water depth data can be collected at transect 20 to clarify the discrepancy between the empirical and modeled water depths, it is difficult to estimate with certainty the flow necessary for passage using the Oregon guidelines. This study also recommended a minimum passage depth of 0.8 feet for Chinook salmon and 0.6 feet each for Coho, chum, steelhead, and large trout. Although these minimum water depths are recommended for salmonid species, they do provide some starting guidelines for what minimum water depths might be required to pass large, cyprinid fishes such as adult Colorado squawfish.

Based on the hydrological and biological data collected to date, a 300 cfs minimum flow is recommended. Furthermore, an instantaneous flow should be maintained rather than a mean daily flow of 300 cfs to eliminate possible daily fluctuations when flows may fall below the recommended minimum. During low-flow periods, a uniform, constant flow of 300 cfs should be reasonable to implement and should be more practical than attempting to implement flows during high-flow periods when flows are rapidly changing. A 300 cfs minimum flow, if required for the entire 123-day period of July through October, accounts for 73,191 AF of the 148,000 AF total set aside for endangered fish in the Aspinall Unit.

Ideally, minimum flows should be established using habitat preference during summer low flows. This requires obtaining habitat availability and habitat use from Colorado squawfish occupying the reach. As part of the fish passageway evaluation, Colorado squawfish will be radiotagged. Habitat types selected by these fish when occupying the 2.3-mile reach should further verify the water depth and minimum flow necessary for passage. As initial minimum flows are implemented, monitoring and evaluating the response of endangered and other native fishes to these flows is essential to the recovery process. Fine tuning passage flows will be determined from the response of native and endangered fish to various low flows and from other empirical biological data collected during the first few years of operating the fish passageway at Redlands Diversion Dam. Flow recommendations will no doubt continue to be refined as preliminary information is evaluated. Continued ongoing research and new information related to evaluation of the fish passageway will provide opportunity for refinement of the minimum streamflow recommendation for passage and year-round streamflows for habitat maintenance for all life stages of endangered fish in the 2.3-mile reach of the Lower Gunnison River. As additional studies related to evaluation of the fish passageway are completed, knowledge of the relationship between discharge and water depth versus fish habitat will continue to evolve. Channel morphology changes such as widening and aggradation of the channel may decrease the maximum water depth at present locations where water depth is now critical. If so, this may necessitate increasing the 300 cfs minimum flow recommendation.

Results of completed hydrology studies as well as ongoing habitat and geomorphology studies in the Gunnison River drainage and downstream reaches in the Colorado River will be used to write a biological opinion on operation of the Aspinall Unit, as well to identify recovery actions appropriate for the Gunnison River to assist in recovery of endangered fishes. Refinements to the minimum flow recommendation for passage in the 2.3-mile reach will be made as additional biological and hydrological data become available. Passage flows and comprehensive year-round flow recommendations that will optimize habitat and provide for recovery of Colorado squawfish in the Gunnison River will be incorporated into the final Aspinall Unit Biological Opinion.

RECOMMENDATIONS

Recommendations for the 2.3-mile reach of the Lower Gunnison River include,

1. Continue to implement a year-round, instantaneous 300 cfs minimum flow using water releases from upstream Federal Reservoirs. The 300 cfs minimum flow is especially important to maintain during the summer low-flow period (July-September) so that endangered fish will have access to the fish passageway.

2. Continue to obtain biological and hydrological data to evaluate the 300 cfs minimum flow for passage of sub-adult and adult Colorado squawfish. Continue to evaluate if a 1-foot water depth is sufficient for passing adult Colorado squawfish. During experimental low flows or during natural low-flow periods, measure water depths at critically shallow areas, correlate with known flows, and observe the response of both endangered and native fish in the reach. Based on these data, recommend a permanent minimum flow for passage.

   Utilize radiotagged Colorado squawfish to refine or validate the minimum passage flow recommendation. Delineate and quantify habitat-use data at various flows using aerial video and on-ground mapping. Compare above data to determine habitat preference for Colorado squawfish and identify and recommend year-round flows for maintaining and enhancing habitat for sub-adult and adult Colorado squawfish in the reach. These flows would be in addition to the minimum flow identified for passage and would be integrated into flow recommendations for the entire Gunnison River.

3. If Colorado squawfish spawning is documented in the reach, flows necessary for this aspect of their life history should also be identified.

4. The BR streamflow gage should be used in the future to monitor flows in the reach because a) it is a direct reading, b) it does not require subtracting withdrawal flows for irrigation from gages further upstream, and c) instantaneous data can be retrieved electronically via satellite downlink. The USGS gage at Whitewater that measures streamflow for the mainstem Gunnison River and CDWR gage that measures water withdrawn by the Redlands Canal should only be used to cross-check flows or used as a backup in the event that the BR gage is not operational.

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APPENDIX A

Scientific and Common Names of Fishes
Collected in the 2.3-Mile Reach of the
Lower Gunnison River During 1994 and 1995

and

Catch Statistics for Fishes Collected by
Electrofishing from the Plunge Pool
and 2.2-Mile Reach of the
Lower Gunnison River

Table A.1. Scientific and common names, status (native vs. nonnative), and two-letter code of fish collected from the 2.3-mile reach of the Lower Gunnison River between the Redlands Diversion Dam (river mile 3.0) and the Colorado River confluence (river mile 0.7), 1994 and 1995. Other fishes mentioned in the text but not collected in the Lower Gunnison River are denoted by an asterisk (☼).

Scientific Name	Common Name	Status	Code
Salmonidae			
Oncorhynchus tshawytscha	Chinook salmon☼	--	--
Oncorhynchus kisutch	chum salmon☼	--	--
Oncorhynchus mykiss	rainbow trout	nonnative	RB
	steelhead☼	--	--
Salmo trutta	brown trout	nonnative	BN
Cyprinidae			
Cyprinus carpio	common carp	nonnative	CP
Gila robusta	roundtail chub	native	RT
Ptychocheilus lucius	Colorado squawfish	native	CS[a]
Rhinichthys osculus	speckled dace	native	SD
Catostomidae			
Catostomus discobolus	bluehead sucker	native	BH
Catostomus latipinnis	flannelmouth sucker	native	FM
Catostomus commersoni	white sucker	nonnative	WS
Xyrauchen texanus	razorback sucker	native	RZ[a]
C. discobolus X C. latipinnis	bluehead X flannelmouth	native	FB
C. discobolus X C. commersoni	bluehead X white	nonnative	WB
C. commersoni X C. latipinnis	flannelmouth X white	nonnative	WF
Ictaluridae			
Ameiurus melas	black bullhead	nonnative	BB
Ictalurus punctatus	channel catfish	nonnative	CC
Centrarchidae			
Lepomis cyanellus	green sunfish	nonnative	GS
Micropterus salmoides	largemouth bass	nonnative	LG
Esocidae			
Esox lucius	northern pike	nonnative	NP

[a] Federally listed as "endangered".

Table A.2. Catch statistics for fishes collected by electrofishing from the plunge pool (river mile 3.0) immediately downstream of the Redlands Diversion Dam on the lower Gunnison River, Colorado, 30 March 1994 to 7 November 1995.

Common Name	Number of Fish	Catch Effort[a] (fish/h)	Percentage Composition
rainbow trout	5	0.74	0.20
brown trout	135	20.00	5.31
northern pike	0	--	--
common carp	432	64.00	17.01
roundtail chub	421	62.37	16.57
Colorado squawfish	22	3.26	0.87
speckled dace	4	0.59	0.16
white sucker	32	4.74	1.26
bluehead sucker	786	116.44	30.94
flannelmouth sucker	643	95.30	25.31
black bullhead	0	--	--
channel catfish	15	2.22	0.59
green sunfish	20	2.96	0.79
largemouth bass	11	1.63	0.43
Hybrids			
bluehead sucker X flannelmouth sucker	3	0.44	0.12
white sucker X bluehead sucker	3	0.44	0.12
white sucker X flannelmouth sucker	8	1.19	0.31
TOTALS	2,540	--	100.00

[a] Catch Effort=total catch per unit effort.
Total hours sampled: 6.75.

Table A.3. Catch statistics for fishes collected by electrofishing from the 2.2-mile reach downstream of the Redlands Diversion Dam on the Lower Gunnison River, Colorado, 30 March 1994 to 7 November 1995.

Common Name	Number of Fish	Catch Effort[a] (fish/h)	Percentage Composition
rainbow trout	3	0.20	0.07
brown trout	23	1.51	0.55
northern pike	1	0.07	0.02
common carp	478	31.30	11.35
roundtail chub	429	28.09	10.19
Colorado squawfish	20	1.31	0.47
speckled dace	13	0.85	0.31
white sucker	112	7.33	2.65
bluehead sucker	1,371	89.78	32.55
flannelmouth sucker	1,647	107.86	39.10
black bullhead	4	0.26	0.09
channel catfish	70	4.58	1.66
green sunfish	5	0.33	0.12
largemouth bass	3	0.20	0.07
Hybrids			
bluehead sucker X flannelmouth sucker	2	0.13	0.05
white sucker X bluehead sucker	19	1.24	0.45
white sucker X flannelmouth sucker	12	0.79	0.28
TOTALS	4,212	--	100.00

[a] Catch Effort=total catch per unit effort.
Total hours sampled: 15.27.

APPENDIX B
Size Groupings for Young-of-the-Year, Juvenile, and Adult Fishes Collected During 1994 and 1995 from the 2.3-mile Reach

Table B.1. Size groupings (total length, mm) by three age categories (YOY = young-of-the-year, JUV = juvenile, and adult) for fish species collected by electrofishing from the lower Gunnison River, Colorado, 1994-1995. See Appendix A; Table A.1. for the definition of the two-letter species fish code.

YOY	Total	JUV	Total	Adult	Total
BH<60		60-300		>300	
FM<60		60-410		>410	
RZ<60		60-400		>400	
WS<60		60-300		>300	
CP<70		70-250		>250	
CS<60		60-400		>400	
FH<20		20-35		>35	
HB<55		55-260		>260	
RS<20		20-30		>30	
RT<55		55-260		>260	
SS<20		20-30		>30	
SD<20		20-32		>32	
BB<50		52-250		>250	
CC<60		60-300		>300	
NP<100		100-500		>500	
RB<100		100-250		>250	
BN<100		100-250		>250	
GS<45		45-210		>210	
LG<50		50-250		>250	

APPENDIX C

Captures of Sub-adult and Adult Colorado Squawfish from the 2.3-Mile Reach During 1994 and 1995; Monthly Summary of Captures and Sightings of Colorado Squawfish from the 2.3-Mile Reach, 1979-1995

Table C.1. Sub-adult and adult Colorado squawfish collected from the Redlands Diversion Dam plunge pool (river mile [RM] 3.0) and from the 2.2-mile reach of the lower Gunnison River between the Redlands Diversion Dam plunge pool and Colorado River confluence during 1994 and 1995. Note: M=male; F=female, I=indeterminate.

Capture Date	Capture RM	PIT Tag ID	Total length (mm)	Weight (g)	Sex
1994 (MM/DD)					
04/28	2.8	7F7B081B65	763	4,375	F
05/18	3.0	7F7D1A3B3A	554	1,725	I
06/14	3.0	7F7D031559	571	1,950	I
06/23	3.0	1F204A3A3D	707	3,150	F
07/01	2.8	1F200B3501	485	780	I
07/01	2.8	1F203D3C48	595	1,580	I
07/01	2.8	7F7B106369	549	1,200	I
07/01	2.0	7F7D086422	801	---	F
07/01	2.8	1F1F7B5275	845	5,600	F
07/06	2.8	1F403C7174	548	1,275	F
07/06	2.8	1F204A3A3D	699	2,850	F
07/06	2.8	7F7D0F740C	510	2,150	M
07/06	2.8	1F43675463	627	2,350	F
07/06	3.0	1F1E316D25	488	850	M
07/06	2.8	1F73347446	680	2,450	F
07/06	2.8	1F407B475F[a]	633	2,200	M
07/06	2.7	1F407B475F[a]	630	2,350	M
07/22	3.0	1F4140015F	554	1,125	I
07/22	3.0	1F40504908	551	1,275	I
07/22	3.0	7F7B117D5F	554	1,175	I
07/22	3.0	7F7F145533	553	1,225	I
07/22	3.0	1F404F0A48	425	600	I
07/22	2.9	7F7B106369	548	1,250	I
07/22	3.0	1F73354970	402	475	I
07/22	2.0	1F74360631	809	4,800	F
07/22	3.0	1F743A2C07	503	900	I
07/22	3.0	1F743B664C	580	1,275	I
07/27	3.0	7F7D17310A	588	1,600	I
07/27	3.0	1F40341B52	592	1,500	I
07/29	3.0	1F41372544	497	800	I
07/29	3.0	1F200B3501	483	---	I
07/29	3.0	1F43557356	574	1,300	I
08/05	3.0	1F743E0827	510	900	M
08/05	3.0	1F731E5B75	575	1,450	M
08/05	3.0	1F4140015F	556	1,150	M
08/23	2.9	1F73244802	535	1,025	I

[a] This fish has a second PIT tag: 1F74357A3E

Table C.1. (cont'd). Sub-adult and adult Colorado squawfish collected from the Redlands Diversion Dam plunge pool (river mile [RM] 3.0) and from the 2.2-mile reach of the lower Gunnison River between the Redlands Diversion Dam plunge pool and Colorado River confluence during 1994 and 1995. Note: M=male; F=female, I=indeterminate.

Capture Date	RM	PIT Tag ID	Total length (mm)	Weight (g)	Sex
1994 (cont'd)					
08/23	2.9	1F404C480D	557	---	I
08/23	3.0	1F41457863	428	590	I
09/20	2.8	1F403B5F07	644	2,450	F
10/20	2.8	7F7D225B0C	628	2,100	F
1995 (MM/DD)					
04/13	3.0	7F7D17452A	677	2,900	I
04/13	2.8	7F7D073369	764	4,850	F
04/13	1.5	7F7D1D756E	697	3,500	I
05/31	3.0	1F74360631	809	5,140	F
06/21	2.1	7F7F146252	807	6,500	F
06/30	1.2	7F7B025618	570	1,875	M
07/13	2.7	1F40786F3A	824	7,100	F
07/13	2.0	7F7D030C31	804	5,600	F
07/13	2.0	7F7D162959	591	2,250	M
07/13	2.8	1F411C6E16	658	3,150	F
07/24	3.0	1F413A0066	858	9,000	F
07/27	1.3	1F412D4F24	603	2,200	M
08/25	2.8	1F74383A7B	848	5,900	F
09/08	2.7	1F402E2D46	860	6,600	F
09/29	3.0	1F46352442	521	1,250	I
09/29	2.8	7F7D164B62	722	3,300	F
09/29	3.0	7F7D1B7200	620	2,350	F
10/26	1.1	1F5E565558	604	2,400	I
11/07	2.7	7F7D1B7200	622	2,325	F

Table C.2. Capture/recapture data from Colorado squawfish collected in the plunge pool of the Redlands Diversion Dam and in the 2.2-mile reach of the lower Gunnison River downstream of the Redlands Diversion Dam, 1994 and 1995.

Recaptured Colorado squawfish in 1994

PIT TAG ID No.	Total Length[a] (mm)	Initial Capture Date	Initial Capture RM	1st Recapture Date	1st Recapture RM	2nd Recapture Date	2nd Recapture RM	3rd Recapture Date	3rd Recapture RM
1F200B3501	483	94/07/01	GU 2.8	94/07/29	GU 2.8				
7F7D17310A	588	92/04/17	CO163.9	94/07/27	GU 3.0				
7F7B117D5F	554	93/06/22	CO 63.9	94/07/22	GU 3.0				
7F7F145533	553	91/05/23	CO 58.3	91/06/12	CO 58.2	93/05/05	CO 58.2	94/07/22	GU 3.0
7F7B106369	549	93/05/05	CO 58.2	94/07/01	GU 2.8	94/07/22	GU 2.8		
1F204A3A3D	699	94/06/23	GU 3.0	94/07/06	GU 2.8				
7F7DOF740C	510	93/06/10	CO175.3	94/07/06	GU 2.0				
7F7D086422	801	91/06/25	CO175.3	94/05/27	CO174.4	94/07/01	GU 2.0		
7F7D031559	571	91/06/13	CO163.6	92/05/18	CO163.8	94/06/14	GU 3.0		
7F7D1A3B3A	554	92/05/29	CO161.2	94/05/18	GU 3.0				
1F4140015F	556	94/07/22	GU 3.0	94/08/05	GU 3.0				
1F404C480D	557	94/05/12	CO100.2	94/08/23	GU 2.9				
7F7D225B0C	628	92/04/20	CO 96.3	94/10/20	GU 2.8				

[a] Total length at last capture.

Table C.2. (cont'd). Capture/recapture data from Colorado squawfish fish collected in the plunge pool of the Redlands Diversion Dam and in the 2.2-mile reach of the lower Gunnison River downstream of the Redlands Diversion Dam, 1994 and 1995.

Recaptured Colorado squawfish in 1995

PIT TAG ID No.	Total Length[a] (mm)	Initial Capture Date	Initial Capture RM	1st Recapture Date	1st Recapture RM	2nd Recapture Date	2nd Recapture RM	3rd Recapture Date	3rd Recapture RM
7F7D073369	764	92/04/21	GU 3.0	95/04/13	GU 2.8	95/06/13	CO159.5		
7F7D1D756E	697	92/05/05	CO175.3	95/04/13	GU 1.5				
1F74360631	809	94/07/22	GU 2.0	95/05/31	GU 3.0				
7F7F146252	807	91/04/16	CO167.8	95/06/21	GU 2.1				
7F7D162959	591	93/04/26	CO176.1	93/05/10	CO175.5	95/07/13	GU 2.7		
7F7D030C31	804	91/08/20	GU 3.0	94/06/16	CO168.9	95/07/13	GU 2.0		
7F7D164B62	722	92/07/27	GU 2.8	95/09/29	GU 2.8				
7F7D1B7200	622	93/03/23	GU 3.0	95/09/29	GU 3.0	95/11/07	GU 2.7		

[a] Total length at last capture.

Table C.3. Monthly sampling summary of sub-adult and adult Colorado squawfish captured and positively sighted while electrofishing in the Redlands Diversion Dam plunge pool (RM 3.0) and in the 2.2-mile reach of the Gunnison River immediately downstream between the Redlands Diversion Dam plunge pool and Colorado River confluence, intermittently between 1979-1995. Note: ?=unknown as to whether sampling was conducted during these months; NS=not sampled.

Year	MONTH								
	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV
1979	?	?	?	?	?	?	7	?	?
1981	?	?	1	?	?	?	?	?	?
1982	?	?	3	?	?	?	?	?	?
1986	NS	NS	1	1	1	2	NS	1	0
1987	NS	NS	1	NS	4	8	0	NS	NS
1988	NS	NS	2	2	0	0	NS	0	NS
1991	NS	NS	2	1	NS	2	0	0	0
1992	0	1	2	1	1	NS	0	NS	NS
1993	4	2	2	0	NS	NS	0	0	NS
1994	0	1	1	8	34	7	1	1	0
1995	NS	3	1	3	8	2	1	4	1
Monthly Totals	4	7	16	16	48	21	9	6	1

APPENDIX D

Summary Statistics from Radiotagged and Captured
Sub-adult and Adult Colorado Squawfish
in the 2.3-mile Reach of the
Lower Gunnison River, 1979-1995

Table D.1. Daily summary data for captures and positive sightings of Colorado squawfish with electrofishing in the Gunnison River in the Redlands Diversion Dam plunge pool (river mile [RM] 3.0) and in the 2.3-mile reach immediately downstream of the Redlands Diversion Dam plunge pool to the Colorado River confluence. Note: CS=Colorado squawfish; cfs=cubic feet per second; NR=effort not recorded; catch effort is total effort (total fish divided by total effort).

Date	RM Sampled	Shocking Effort (hrs)	No. of CS Sighted	CS Caught No.	CS Caught TL(mm)	CS Caught Wt(g)	Catch effort fish/hr	Flow (cfs) below Redlands Diversion Dam
				1979				
79/09/05	3.0	NR	0	2	566	---	---	790
					483	---		
79/09/17	3.0	NR	0	1	622	2,100	---	1,200
79/09/18	3.0	NR	0	4	485	---	---	1,160
					668	2,400		
					521	---		
					480	---		
				1981				
81/05/20	3.0	NR	0	1	827	5,420	---	192
				1982				
82/05/19	3.0	NR	0	1	611	1,630	---	2,620
82/05/26	2.9.0.7	NR	0	2	749	3,680	---	3,850
					774	5,000		
				1986				
86/05/10	3.0	NR	0	1	566	1,452	---	6,790
86/06/22	3.0	NR	1	0	---	---	---	3,390
86/06/28	3.0	NR	0	0	---	---	---	3,830
86/07/20	3.0	NR	1	0	---	---	---	4,020
86/08/05	3.0	NR	0	0	---	---	---	1,790
86/08/11	3.0	NR	0	1	602	1,710	---	1,340
86/08/12	3.0	NR	0	1	582	1,300	---	1,410
86/10/14	3.0	1.40	1	0	---	---	0.00	3,670
86/10/20	3.0	NR	0	0	---	---	---	3,330
86/11/18	3.0	1.13	0	0	---	---	0.00	2,280
				1987				
87/05/19	3.0	0.80	1	0	---	---	0.00	6,940
87/07/16	3.0	NR	0	4	---	---	---	1,240

Table D.1. (cont'd). Daily summary data for captures and positive sightings of Colorado squawfish with electrofishing in the Gunnison River in the Redlands Diversion Dam plunge pool (river mile [RM] 3.0) and in the 2.3-mile reach immediately downstream of the Redlands Diversion Dam plunge pool to the Colorado River confluence. Note: CS=Colorado squawfish; cfs=cubic feet per second; NR=effort not recorded; catch effort is total effort (total fish divided by total effort).

				CS Caught				Flow (cfs)
Date	RM Sampled	Shocking Effort (hrs)	No. of CS Sighted	No.	TL(mm)	Wt(g)	Catch effort fish/hr	below Redlands Diversion Dam
				1987 (cont'd)				
87/08/12	3.0	1.20	0	1	750	3,975	0.83	1,340
87/08/13	3.0	1.52	0	5	608	1,875	3.29	1,240
					600	1,600		
					442	700		
					510	1,550		
					552	1,750		
87/08/25	3.0	0.87	1	1	431	635	1.15	2,030
87/09/24	3.0	1.04	0	0	---	---	0.00	1,180
87/09/25	3.0	2.58	0	0	---	---	0.00	1,180
87/09/28	3.0	1.42	0	0	---	---	0.00	1,180
				1988				
88/05/10	3.0	2.14	1	1	566	1,452	0.47	930
88/06/15	3.0	1.01	0	0	---	---	0.00	910
88/06/22	3.0	0.87	2	0	---	---	0.00	750
88/06/28	3.0	1.02	0	0	---	---	0.00	480
88/07/20	3.0	0.68	0	0	---	---	0.00	0
88/08/05	3.0	0.46	0	0	---	---	0.00	0
88/10/20	3.0	0.82	0	0	---	---	0.00	320
				1991				
91/05/08	3.0	NR	2	0	---	---	---	2,430
91/05/10	3.0	NR	0	0	---	---	---	4,260
91/06/04	2.9-0.7	NR	0	1	581	2,014	---	3,190
91/08/20	3.0	0.41	0	2	676	2,330	4.88	820
					772	3,508		
91/09/16	3.0	0.39	0	0	---	---	0.00	1,910
91/10/24	3.0	0.45	0	0	---	---	0.00	960
91/11/27	3.0	0.22	0	0	---	---	0.00	1,260

Table D.1. (cont'd). Daily summary data for captures and positive sightings of Colorado squawfish with electrofishing in the Gunnison River in the Redlands Diversion Dam plunge pool (river mile [RM] 3.0) and in the 2.3-mile reach immediately downstream of the Redlands Diversion Dam plunge pool to the Colorado River confluence. Note: CS=Colorado squawfish; cfs=cubic feet per second; NR=effort not recorded; catch effort is total effort (total fish divided by total effort).

Date	RM Sampled	Shocking Effort (hrs)	No. of CS Sighted	CS Caught				Flow (cfs) below Redlands Diversion Dam
				No.	TL(mm)	Wt(g)	Catch effort fish/hr	
				1992				
92/03/20	3.0	0.53	0	0	---	---	0.00	570
92/04/21	3.0	0.38	0	1	712	3,050	2.63	2,210
92/04/21	2.9-0.7	0.64	0	0	---	---	0.00	2,210
92/05/06	3.0	NR	0	1	628	2,518	---	2,070
92/05/08	3.0	0.48	1	0	---	---	0.00	2,690
92/06/01	3.0	0.24	0	0	---	---	0.00	3,830
92/06/01	2.9-0.7	0.89	0	1	762	5,230	1.12	3,830
92/06/19	3.0	0.40	0	0	---	---	0.00	1,310
92/07/27	3.0	0.29	0	0	---	---	0.00	1,440
92/07/27	2.9-0.7	0.79	0	1	652	2,240	1.27	1,440
92/09/21	3.0	0.32	0	0	---	---	0.00	840
				1993				
93/03/23	3.0	0.19	0	1	597	2,092	5.26	2,600
93/03/23	2.9-0.7	1.36	1	0	---	---	0.00	2,600
93/03/24	3.0	0.40	0	0	---	---	0.00	2,790
93/03/24	2.9-0.7	0.96	0	0	---	---	0.00	2,790
93/03/29	3.0	0.42	0	0	---	---	0.00	3,460
93/03/29	2.9-0.7	0.85	1	0	---	---	0.00	3,460
93/03/31	3.0	0.44	0	0	---	---	0.00	3,100
93/03/31	2.9-0.7	0.96	0	1	700	3,068	1.04	3,100
93/04/02	3.0	0.33	0	0	---	---	0.00	2,920
93/04/02	2.9-0.7	0.89	0	0	---	---	0.00	2,920
93/04/05	3.0	0.47	0	0	---	---	0.00	2,960
93/04/09	3.0	0.47	0	0	---	---	0.00	2,890
93/04/09	2.9-0.7	0.86	0	1	597	1,892	1.16	2,890
93/04/19	3.0	0.43	0	0	---	---	0.00	3,690
93/04/19	2.9-0.7	0.90	0	1	901	6,560	1.11	3,690
93/04/20	3.0	0.39	0	0	---	---	0.00	3,550
93/04/20	2.9-0.7	0.95	0	0	---	---	0.00	3,550
93/04/30	3.0	1.02	0	0	---	---	0.00	9,150

Table D.1. (cont'd). Daily summary data for captures and positive sightings of Colorado squawfish with electrofishing in the Gunnison River in the Redlands Diversion Dam plunge pool (river mile [RM] 3.0) and in the 2.3-mile reach immediately downstream of the Redlands Diversion Dam plunge pool to the Colorado River confluence. Note: CS=Colorado squawfish; cfs=cubic feet per second; NR=effort not recorded; catch effort is total effort (total fish divided by total effort).

Date	RM Sampled	Shocking Effort (hrs)	No. of CS Sighted	CS Caught No.	CS Caught TL(mm)	CS Caught Wt(g)	Catch effort fish/hr	Flow (cfs) below Redlands Diversion Dam U.S.G.S.	Flow (cfs) below Redlands Diversion Dam BR[a]
				1993 (cont'd)					
93/05/07	3.0	0.19	0	0	---	---	0.00	6,220	
93/05/10	2.9-0.7	0.55	1	0	---	---	0.00	5,350	
93/05/26	3.0	0.42	0	0	---	---	0.00	14,140	
93/05/07	2.9-0.7	0.87	0	1	705	3,670	1.15	6,220	
93/05/10	3.0	0.42	0	0	---	---	0.00	5,350	
93/05/26	2.9-0.7	0.40	0	0	---	---	0.00	14,140	
93/06/29	3.0	0.23	0	0	---	---	0.00	5,290	
93/06/29	2.9-0.7	0.95	0	0	---	---	0.00	5,290	
93/09/30	3.0	0.42	0	0	---	---	0.00	1,060	
93/09/30	2.9-0.7	0.79	0	0	---	---	0.00	1,060	
93/10/29	3.0	0.30	0	0	---	---	0.00	1,660	
				1994					
94/03/30	3.0	0.36	0	0	---	---	0.00	611	652
94/03/30	2.9-0.7	0.92	0	0	---	---	0.00	611	652
94/04/28	3.0	0.30	0	0	---	---	0.00	1,349	1,582
94/04/28	2.9-0.7	0.92	0	1	763	4,375	1.09	1,349	1,582
94/05/18	3.0	0.35	0	1	554	1,725	2.86	5,276	4,899
94/05/18	2.9-0.7	0.64	0	0	---	---	0.00	5,276	4,899
94/06/14	3.0	0.28	1	1	571	1,950	3.57	1,521	1,442
94/06/14	2.9-0.7	0.52	2	0	---	---	0.00	1,521	1,442

[a] The USGS gage at Whitewater, Colorado was used to calculate flows downstream from Redlands Diversion Dam. Flow data for Redlands Canal were obtained from the State of Colorado, Division of Water Resources. Additional data were available to determine streamflows in the 2.3-mile reach immediately downstream from Redlands Diversion Dam from a gage installed by the Bureau of Reclamation (BR) March 1994 at Gunnison River RM 2.6. The BR discharge was the daily mean of 24 hourly discharge values.

Table D.1. (cont'd). Daily summary data for captures and positive sightings of Colorado squawfish with electrofishing in the Gunnison River in the Redlands Diversion Dam plunge pool (river mile [RM] 3.0) and in the 2.3-mile reach immediately downstream of the Redlands Diversion Dam plunge pool to the Colorado River confluence. Note: CS=Colorado squawfish; cfs=cubic feet per second; NR=effort not recorded; catch effort is total effort (total fish divided by total effort).

Date	RM Sampled	Shocking Effort (hrs)	No. of CS Sighted	CS Caught No.	CS Caught TL(mm)	CS Caught Wt(g)	Catch effort fish/hr	Flow (cfs) below Redlands Diversion Dam U.S.G.S.	Flow (cfs) below Redlands Diversion Dam BR[a]
1994 (cont'd)									
94/06/16	3.0	0.33	0	0	---	---	0.00	1,267	1,207
94/06/16	2.9-0.7	0.83	0	0	---	---	0.00	1,267	1,207
94/06/23	3.0	0.30	1	1	707	3,150	3.33	1,726	1,583
94/06/23	2.9-0.7	0.91	1	0	---	---	0.00	1,726	1,583
94/07/01	3.0	0.30	2	4	845	5,600	13.33	916	789
					549	1,200			
					595	1,580			
					485	780			
94/07/01	2.9-0.7	0.87	0	1	801	---	1.15	916	789
94/07/06	3.0	0.24	0	1	488	850	4.17	698	602
94/07/06	2.9-0.7	1.17	1	7	548	1,275	5.98	698	602
					627	2,350			
					699	2,850			
					633	2,200			
					680	2,450			
					630	2,350			
					510	2,150			
94/07/22	3.0	0.38	2	8	551	1,275	21.05	476	361
					554	1,125			
					503	900			
					554	1,175			
					553	1,225			
					425	600			

[a] The USGS gage at Whitewater, Colorado was used to calculate flows downstream from Redlands Diversion Dam. Flow data for Redlands Canal were obtained from the State of Colorado, Division of Water Resources. Additional data were available to determine streamflows in the 2.3-mile reach immediately downstream from Redlands Diversion Dam from a gage installed by the Bureau of Reclamation (BR) March 1994 at Gunnison River RM 2.6. The BR discharge was the daily mean of 24 hourly discharge values.

Table D.1. (cont'd). Daily summary data for captures and positive sightings of Colorado squawfish with electrofishing in the Gunnison River in the Redlands Diversion Dam plunge pool (river mile [RM] 3.0) and in the 2.3-mile reach immediately downstream of the Redlands Diversion Dam plunge pool to the Colorado River confluence. Note: CS=Colorado squawfish; cfs=cubic feet per second; NR=effort not recorded; catch effort is total effort (total fish divided by total effort).

				CS Caught				Flow (cfs) below Redlands Diversion Dam	
Date	RM Sampled	Shocking Effort (hrs)	No. of CS Sighted	No.	TL(mm)	Wt(g)	Catch effort fish/hr	U.S.G.S.	BR[a]
				1994 (cont'd)					
					402	475			
					580	1,275			
94/07/22	2.9-1.5	0.77	0	2	548	1,250	2.60	476	361
					809	4,800			
94/07/27	3.0	0.52	1	2	592	1,500	3.85	289	221
					588	1,600			
94/07/29	3.0	0.22	1	3	574	1,300	13.64	95	91
					497	800			
					483	---			
94/08/05	3.0	0.41	0	3	556	1,150	7.32	301	185
94/08/05	2.9-1.5	1.00	0	0	---	---	0.00	301	185
94/08/23	3.0	0.27	1	1	428	590	3.72	728	605
94/08/23	2.9-1.5	0.62	0	2	557	---	3.21	728	605
					535	1,025			
94/09/20	3.0	0.28	0	0	---	---	0.00	899	729
94/09/20	2.9-1.5	0.76	0	1	644	2,450	1.32	899	729
94/10/20	3.0	0.24	0	0	---	---	0.00	1,062	993
94/10/20	2.9-1.5	0.70	0	1	628	2,100	1.43	1,062	993

[a] The USGS gage at Whitewater, Colorado was used to calculate flows downstream from Redlands Diversion Dam. Flow data for Redlands Canal were obtained from the State of Colorado, Division of Water Resources. Additional data were available to determine streamflows in the 2.3-mile reach mmediately downstream from Redlands Diversion Dam from a gage installed by the Bureau of Reclamation (BR) March 1994 at Gunnison River RM 2.6. The BR discharge was the daily mean of 24 hourly discharge values.

Table D.1. (cont'd). Daily summary data for captures and positive sightings of Colorado squawfish with electrofishing in the Gunnison River in the Redlands Diversion Dam plunge pool (river mile [RM] 3.0) and in the 2.3-mile reach immediately downstream of the Redlands Diversion Dam plunge pool to the Colorado River confluence. Note: CS=Colorado squawfish; cfs=cubic feet per second; NR=effort not recorded; catch effort is total effort (total fish divided by total effort).

Date	RM Sampled	Shocking Effort (hrs)	No. of CS Sighted	CS Caught No.	CS Caught TL(mm)	CS Caught Wt(g)	CS Caught Catch effort fish/hr	Flow (cfs) below Redlands Diversion Dam U.S.G.S.	Flow (cfs) below Redlands Diversion Dam BR[a]
				1994 (cont'd)					
94/11/14	3.0	0.23	0	0	---	---	0.00	1,340	1,263
94/11/14	2.9-1.5	0.64	0	0	---	---	0.00	1,340	1,263
				1995					
95/04/13	3.0	0.24	0	1	677	2,900	4.17	3,290	3,160
95/04/13	2.9-0.7	1.04	0	2	764	4,850	0.96	3,290	3,160
					697	3,500			
95/05/10	3.0	0.24	0	0	---	---	0.00	5,842	5,730
95/05/10	2.9-0.7	0.77	0	0	---	---	0.00	5,842	5,730
95/05/31	3.0	0.39	0	1	809	5,140	2.54	9,390	---
95/05/31	2.9-0.7	0.68	0	0	---	---	0.00	9,390	---
95/06/21	3.0	0.18	0	0	---	---	0.00	12,706	11,600
95/06/21	2.9-0.7	0.71	0	1	807	6,500	5.67	12,706	11,600
95/06/30	3.0	0.17	0	0	---	---	0.00	11,212	10,900
95/06/30	2.9-0.7	0.53	1	1	570	1,875	1.89	11,212	10,900

[a] The USGS gage at Whitewater, Colorado was used to calculate flows downstream from Redlands Diversion Dam. Flow data for Redlands Canal were obtained from the State of Colorado, Division of Water Resources. Additional data were available to determine streamflows in the 2.3-mile reach immediately downstream from Redlands Diversion Dam from a gage installed by the Bureau of Reclamation (BR) starting in March 1994 at Gunnison River RM 2.6. The BR discharge was the daily mean of 24 hourly discharge values.

Table D.1. (cont'd). Daily summary data for captures and positive sightings of Colorado squawfish with electrofishing in the Gunnison River in the Redlands Diversion Dam plunge pool (river mile [RM] 3.0) and in the 2.3-mile reach immediately downstream of the Redlands Diversion Dam plunge pool to the Colorado River confluence. Note: CS=Colorado squawfish; cfs=cubic feet per second; NR=effort not recorded; catch effort is total effort (total fish divided by total effort).

Date	RM Sampled	Shocking Effort (hrs)	No. of CS Sighted	CS Caught No.	CS Caught TL(mm)	CS Caught Wt(g)	Catch effort fish/hr	Flow (cfs) below Redlands Diversion Dam U.S.G.S.	Flow (cfs) below Redlands Diversion Dam BR[a]
				1995 (cont'd)					
95/07/13	3.0	0.21	0	0	---	---	0.00	14,400	13,700
95/07/13	2.9-0.7	0.55	0	4	658	3,150	7.27	14,400	13,700
					824	7,100			
					591	2,250			
					804	5,600			
95/07/24	3.0	---	1	1	858	9,000	---	8,448	8,560
95/07/27	3.0	0.35	0	0	---	---	0.00	5,363	5,200
95/07/27	2.9-0.7	0.53	1	1	603	2,200	1.89	5,363	5,200
95/08/03	3.0	0.43	1	0	---	---	0.00	3,583	3,350
95/08/03	2.9-0.7	0.72	0	0	---	---	0.00	3,583	3,350
95/08/25	3.0	0.31	0	0	---	---	0.00	1,666	1,550
95/08/25	2.9-0.7	0.83	0	1	848	5,900	1.20	1,666	1,550
95/09/08	3.0	0.29	0	0	---	---	0.00	1,715	1,800
95/09/08	2.9-0.7	0.63	0	1	860	6,600	1.59	1,715	1,800
95/09/27	3.0	0.40	0	2	521	1,250	5.00	1,289	1,215
					620	2,350			
95/09/27	2.9-0.7	0.60	0	1	722	3,300	1.67	1,289	1,215

[a] The USGS gage at Whitewater, Colorado was used to calculate flows downstream from Redlands Diversion Dam. Flow data for Redlands Canal were obtained from the State of Colorado, Division of Water Resources. Additional data were available to determine streamflows in the 2.3-mile reach immediately downstream from Redlands Diversion Dam from a gage installed by the Bureau of Reclamation (BR) March 1994 at Gunnison River RM 2.6. The BR discharge was the daily mean of 24 hourly discharge values.

Table D.1. (cont'd). Daily summary data for captures and positive sightings of Colorado squawfish with electrofishing in the Gunnison River in the Redlands Diversion Dam plunge pool (river mile [RM] 3.0) and in the 2.3-mile reach immediately downstream of the Redlands Diversion Dam plunge pool to the Colorado River confluence. Note: CS=Colorado squawfish; cfs=cubic feet per second; NR=effort not recorded; catch effort is total effort (total fish divided by total effort).

				CS Caught				Flow (cfs) below Redlands Diversion Dam	
Date	RM Sampled	Shocking Effort (hrs)	No. of CS Sighted	No.	TL(mm)	Wt(g)	Catch effort fish/hr	U.S.G.S.	BR[a]
				1995 (cont'd)					
95/10/26	3.0	0.23	0	0	---	---	0.00	1,847	1,740
95/10/26	2.9-0.7	0.80	0	1	604	2,400	1.25	1,847	1,740
95/11/07	3.0	0.17	0	0	---	---	0.00	3,430	3,490
95/11/07	2.9-0.7	0.59	0	1	622	2,325	1.69	3,430	3,490

[a] The USGS gage at Whitewater, Colorado was used to calculate flows downstream from Redlands Diversion Dam. Flow data for Redlands Canal were obtained from the State of Colorado, Division of Water Resources. Additional data were available to determine streamflows in the 2.3-mile reach immediately downstream from Redlands Diversion Dam from a gage installed by the Bureau of Reclamation (BR) March 1994 at Gunnison River RM 2.6. The BR discharge was the daily mean of 24 hourly discharge values.

Table D.2. Monthly sampling summary of sub-adult and adult Colorado squawfish captured and positively sighted while electrofishing in the Redlands Diversion Dam plunge pool (river mile [RM] 3.0) and in the 2.2-mile reach of the Gunnison River immediately downstream between the Redlands Diversion Dam plunge pool and Colorado River confluence, 1979-1995. Note: catch effort is total catch per unit effort (total fish divided by total effort); ?=unknown as to whether sampling was conducted during these months; NS=not sampled; NR=effort was not recorded, thus unable to calculate total catch per unit of effort.

	Month																	
	MAR		APR		MAY		JUN		JUL		AUG		SEP		OCT		NOV	
Year Locale	No. of fish	Catch effort (fish/h)	No. of fish	Catch effort (fish/h)	No. of fish	Catch effort (fish/h)	No. of fish	Catch effort (fish/h)	No. of fish	Catch effort (fish/h)	No. of fish	Catch effort (fish/h)	No. of fish	Catch effort (fish/h)	No. of fish	Catch effort (fish/h)	No. of fish	Catch effort (fish/h)
1979																		
Pl. Pool	?		?		?		?		?		?		7	NR	?		?	
2.2-mi	?		?		?		?		?		?		?		?		?	
1981																		
Pl. Pool	?		?		1	NR	?		?		?		?		?		?	
2.2-mi	?		?		?		?		?		?		?		?		?	
1982																		
Pl. Pool	?		?		1	NR	?		?		?		?		?		?	
2.2-mi	?		?		2	NR	?		?		?		?		?		?	
1986																		
Pl. Pool	NS		NS		1	NR	1	NR	1	NR	2	NR	NS		1	0.71	0	0.00
2.2-mi	NS		NS		NS		NS		NS		NS		NS		NS		NS	
1987																		
Pl. Pool	NS		NS		1	1.25	NS		4	NR	8	2.23	0	0.00	NS		NS	
2.2-mi	NS		NS		NS		NS		NS		NS		NS		NS		NS	
1988																		
Pl. Pool	NS		NS		2	0.93	2	0.69	0	0.00	0	0.00	NS		0	0.00	NS	
2.2-mi	NS		NS		NS		NS		NS		NS		NS		NS		NS	
1991																		
Pl. Pool	NS		NS		2	NR	NS		NS		2	4.88	0	0.00	0	0.00	0	0.00
2.2-mi	NS		NS		NS		1	NR	NS		NS		NS		NS		NS	
1992																		
Pl. Pool	0	0.00	1	2.63	2	2.08	0	0.00	0	0.00	NS		0	0.00	NS		NS	
2.2-mi	NS		0	0.00	NS		1	1.12	1	1.27	NS		NS		NS		NS	

Table D.2. (cont'd). Monthly sampling summary of sub-adult and adult Colorado squawfish captured and positively sighted while electrofishing in the Redlands Diversion Dam plunge pool (river mile [RM] 3.0) and in the 2.2-mile reach of the Gunnison River immediately downstream between the Redlands Diversion Dam plunge pool and Colorado River confluence, 1979-1995. Note: catch effort is total catch per unit effort (total fish divided by total effort); ?=unknown as to whether sampling was conducted during these months; NS=not sampled; NR=effort was not recorded, thus unable to calculate total catch per unit of effort.

	Month																	
	MAR		APR		MAY		JUN		JUL		AUG		SEP		OCT		NOV	
Year Locale	No. of fish	Catch effort (fish/h)	No. of fish	Catch effort (fish/h)	No. of fish	Catch effort (fish/h)	No. of fish	Catch effort (fish/h)	No. of fish	Catch effort (fish/h)	No. of fish	Catch effort (fish/h)	No. of fish	Catch effort (fish/h)	No. of fish	Catch effort (fish/h)	No. of fish	Catch effort (fish/h)
1993																		
Pl. Pool	1	1.69	0	0.00	0	0.00	0	0.00	NS		NS		0	0.00	0	0.00	NS	
2.2-mi	3	0.73	2	0.56	2	1.10	0	0.00	NS		NS		0	0.00	NS		NS	
1994																		
Pl. Pool	0	0.00	0	0.00	1	2.87	4	4.40	24	14.45	5	7.35	0	0.00	0	0.00	0	0.00
2.2-mi	0	0.00	1	0.94	0	0.00	3	2.24	10	3.56	2	1.23	1	1.32	1	1.43	0	0.00
1995																		
Pl. Pool	NS		1	4.17	1	2.54	0	0.00	1	1.79	1	1.35	2	2.90	0	0.00	0	0.00
2.2-mi	NS		2	0.96	0	0.00	2	5.74	7	6.48	1	0.65	3	2.44	1	1.25	1	1.69

Table D.2. (cont'd). Monthly sampling summary of sub-adult and adult Colorado squawfish captured and positively sighted while electrofishing in the Redlands Diversion Dam plunge pool (river mile [RM] 3.0) and in the 2.2-mile reach of the Gunnison River immediately downstream between the Redlands Diversion Dam plunge pool and Colorado River confluence, 1979-1995. Note: catch effort is total catch per unit effort (total fish divided by total effort); ?=unknown as to whether sampling was conducted during these months; NS=not sampled; NR=effort was not recorded, thus unable to calculate total catch per unit of effort.

Year / Locale	MAR: No. of fish / Catch effort (fish/h)	APR: No. of fish / Catch effort (fish/h)	MAY: No. of fish / Catch effort (fish/h)	JUN: No. of fish / Catch effort (fish/h)	JUL: No. of fish / Catch effort (fish/h)	AUG: No. of fish / Catch effort (fish/h)	SEP: No. of fish / Catch effort (fish/h)	OCT: No. of fish / Catch effort (fish/h)	NOV: No. of fish / Catch effort (fish/h)
Monthly Totals (1979-1995)									
Pl. Pool									
No. of fish	1 (1)[a]	2 (2)	7 (12)	6 (7)	24 (30)	16 (21)	2 (9)	1 (1)	0 (0)
Effort (h)	2.34	4.03	5.43	5.03	3.40	6.72	7.56	3.44	1.75
Catch effort (fish/h)	0.43	0.50	1.29	1.19	7.06	2.38	0.26	0.29	0.00
No. of trips	6	9	15	12	12	12	12	7	4
Fish/trip	0.17	0.22	0.80	0.58	2.50	1.75	0.75	0.14	0
2.2-mi									
No. of fish	3 (3)	5 (5)	2 (4)	6 (7)	17 (18)	3 (3)	3 (3)	2 (2)	1 (1)
Effort (h)	5.05	6.34	3.91	4.52	5.23	4.89	2.78	1.50	1.23
Catch effort (fish/h)	0.59	0.79	0.51	1.33	3.25	0.61	1.08	1.33	0.81
No. of trips	5	7	6	8	7	4	4	2	1
Fish/trip	0.60	0.71	0.67	0.88	2.57	0.75	0.75	1.00	1.00

[a] Value in parenthesis represents the total number of all fish sighted and captured when the effort was not recorded and was used to calculate fish/trip; value not in parenthesis represents the total number of fish sighted and captured only when effort was recorded and was used to calculate total catch effort.

Table D.3. Summary data for Colorado squawfish implanted with radiotransmitters and later contacted in the lower 2.3-mile reach of the Gunnison River between the Redlands Diversion Dam and Colorado River confluence. Note: RM=river mile; cfs=cubic feet per second. Prior to the flood years of 1983 and 1984, the confluence of the Gunnison and Colorado rivers was 0.0. During these flood years, the Colorado River claimed 0.7 mile of a former side channel of the Gunnison River. Therefore, after 1984, the new confluence designation was 0.7 rather than 0.0.

Date YY/MM/DD	Frequency	TL (mm)	Wt (g)	RM	No. of Radio Contacts in the Gunnison	Flow (cfs) below Redlands Div. Dam
82/05/26	.662	523	1,400	0.0	13	3,860
82/06/02				2.7		3,820
82/06/04				3.0		3,660
82/06/10				3.0		3,350
82/06/14				2.2		3,320
82/06/22				2.2		3,360
82/06/30				1.0		2,900
82/07/08				1.8		1,370
82/07/14				1.8		1,040
82/08/04				2.0		1,130
82/08/05				2.5		990
82/08/13				2.6		900
82/08/27				2.3		2,170
82/05/21	.684	749	3,600	1.8	14	2,810
82/05/19				2.0		2,620
82/05/26				1.9		3,850
82/05/28				2.0		4,680
82/06/02				1.8		3,820
82/06/04				1.9		3,660
82/06/10				3.0		3,350
82/06/14				1.3		3,320
82/06/22				1.6		3,350
82/06/25				1.3		3,250
82/06/30				0.8		2,910
82/07/12				0.3		1,230
82/07/21				0.2		710
82/07/27				0.5		700
83/07/12	.687	502	1,000	0.7	3	8,220
83/07/18				0.8		5,190
83/07/27				0.7		5,780

Table D.3. (cont'd). Summary data for Colorado squawfish implanted with radiotransmitters found in the lower 2.3-mile reach of the Gunnison River between the Redlands Diversion Dam and Colorado River confluence. Note: RM=river mile; cfs=cubic feet per second.

Date YY/MM/DD	Frequency	TL (mm)	Wt (g)	RM	No. of Radio Contacts in the Gunnison	Flow (cfs) below Redlands Div. Dam
85/06/21	.042	726	3,800	2.6	6	6,890
85/06/24				3.0		6,160
85/07/08				3.0		2,820
85/07/23				3.0		2,660
85/07/30				0.7		2,320
85/08/14				3.0		850
85/06/19	.790	896	5,800	3.0	8	6,480
85/06/21				2.4		6,890
85/06/24				3.0		6,160
85/06/27				2.1		5,920
85/07/01				2.4		2,690
85/07/08				2.4		2,830
85/07/12				2.4		1,790
85/07/23				2.2		2,660
86/06/24	.432	693	3,350	2.0	2	3,010
87/08/13				3.0		1,240
86/06/24	.491	541	1,180	3.0	4	3,010
86/07/03				1.2		3,720
86/07/08				1.2		4,860
86/07/17				1.3		4,470
87/08/13	.431	600	1,600	3.0	1	1,240
87/08/12	.470	750	3,975	3.0	3	1,250
87/08/13				1.0		1,240
88/08/12				1.2		23
87/07/28	.516	486	1,050	3.0	7	1,240
87/08/06				3.0		1,270
87/08/13				3.0		1,240
87/08/18				3.0		1,030
87/08/27				3.0		1,720
87/09/10				3.0		1,340
87/10/06				2.6		1,070

Table D.3. (cont'd). Summary data for Colorado squawfish implanted with radiotransmitters found in the lower 2.3-mile reach of the Gunnison River between the Redlands Diversion Dam and Colorado River confluence. Note: RM=river mile; cfs=cubic feet per second.

Date YY/MM/DD	Frequency	TL (mm)	Wt (g)	RM	No. of Radio Contacts in the Gunnison	Flow (cfs) below Redlands Div. Dam
87/07/28	.536	468	900	3.0	6	1,240
87/08/06				3.0		1,270
87/08/13				3.0		1,240
87/08/18				3.0		1,030
87/08/27				3.0		1,720
87/09/10				3.0		1,340
87/07/10	.541	585	1,925	3.0	2	1,370
87/07/14				3.0		1,340
87/08/13	.780	608	1,875	3.0	1	1,240
88/06/08	.340	629	2,800	1.3	1	1,530
88/05/10	.360	566	1,452	3.0	1	930
88/06/08	.290	556	1,650	2.6	4	1,530
88/06/16				2.7		910
88/09/19				1.0		870
89/05/17				1.7		910
89/03/22	.310	679	3,120	1.5	2	570
89/04/19				1.5		2,250

APPENDIX E

Total CPUE versus Flow for Four Native and Three Nonnative Fishes Collected by Electrofishing from the Plunge Pool and 2.2-Mile Reach of the Lower Gunnison River, 1994 and 1995

Table E.1. Total catch per unit effort (Fish/h) for four sub-adult and adult native fishes and three sub-adult and adult nonnative fishes collected with electrofishing at various flows from the plunge pool (RM 3.0) of the Redlands Diversion Dam in the Lower Gunnison River, 30 March 1994 to 7 November 1995. Refer to Appendix; A.1. for two-letter species code.

	Total Catch Effort (Fish/h)								
	Native Fishes					Nonnative Fishes			
Flow (cfs)	BH	FM	RT	CS	Combined	CP	WS	CC	Combined
89	86	13.6	63.6	13.6	177	95.5	0	4.5	100
185	163	68.3	2.4	7.3	293	43.9	2.4	7.3	54
217	110	35	27	3.8	175	48.1	1.9	5.8	56
363	168	108	95	21	392	137	0	13	150
651	25	83	56	0	164	56	5.6	0	61
729	46.4	32.1	14.3	0	93	64.3	3.6	0	68
993	20.8	29.2	4.2	0	54	58.3	0	0	58
1,263	13.0	69.6	0	0	83	174	0	0	174
1,444	139	118	186	4	446	53	14.3	4	71
1,550	25.8	142	71	0	239	25.8	9.7	0	11
1,583	77	107	60	0	243	0	3.3	0	3
1,790	6.9	34.5	34.5	0	76	37.9	3.4	0	41
1,806	82.5	45	22.5	5	155	75	5	0	80
1,993	8.7	13	8.7	0	30	0	4.3	0	4
3,231	0	64.7	0	0	65	23.5	5.9	0	29
3,260	79	117	63	4.2	263	142	0	0	142
4,896	411	194	126	2.9	734	42.9	11.4	2.9	57
5,200	226	291	131	0	649	83	14.3	0	97
5,730	92	158	54	0	304	62.5	8.3	0	71
9,390	174	185	43.6	2.6	405	92	7.7	0	100
10,900	165	153	165	0	482	17.6	0	5.9	24
11,600	211	56	0	0	267	0	16.7	0	17
13,900	210	162	162	0	533	105	4.8	0	110

Correlation coefficient ("r") for Catch effort versus flow

Range of Flows (cfs) Analyzed	BH	FM	RT	CS	Combined	CP	WS	CC	Combined
89- 1,000	-0.74	-0.05	-0.33	-0.62	0.40	-0.21	0.21	-0.65	0.40
89- 2,000	-0.53	-0.03	0.04	-0.57	0.55	-0.36	0.45	-0.50	0.55
89-13,900	0.50	0.49	0.38	-0.33	0.35	-0.09	0.35	-0.36	0.35

Table E.2. Total catch per unit effort (Fish/h) for four sub-adult and adult native fishes and three sub-adult and adult nonnative fishes collected with electrofishing at various flows from the 2.2-mile reach of the Lower Gunnison River, 30 March 1994 to 7 November 1995. Refer to Appendix; Table A.1. for two-letter species code.

	Total Catch Effort (Fish/h)								
	Native Fishes					Nonnative Fishes			
Flow (cfs)	BH	FM	RT	CS	Combined	CP	WS	CC	Combined
217	133	59	2	0	194	11	4	5	20
363	252	168	42.9	2.6	478	49.4	75.3	3.9	129
651	69.6	112	6.5	0	188	0	2.2	28.2	30
729	75	54	3.9	1.3	134	0	10.5	1.3	12
993	107	64.3	2.9	1.4	176	34.3	0	17.1	51
1,263	46.9	57.8	1.6	0	106	78	7.8	0	86
1,444	127	156	65	0	538	80.8	1.9	1.9	85
1,550	48.2	41	8.4	1.2	99	27.7	10.8	8.4	47
1,583	70.8	109	6.6	0.9	188	5.7	1.9	0	7.5
1,790	82.5	84.1	12.7	1.6	181	0	9.5	1.6	11
1,806	127	78	13.3	1.7	220	83.3	3.3	0	87
1,993	37.5	53.8	8.8	1.3	53	20	7.5	0	28
3,231	49.2	42.4	3.4	1.7	97	32.2	16.9	0	49
3,260	22.1	65.4	22.1	1.9	112	49	2.9	1.0	53
4,896	444	369	164	0	977	31	0	0	31
5,200	41.5	71.7	30.2	1.9	145	30.2	20.8	0	51
5,730	31	49	5	0	86	42	9	0	51
9,390	32	171	40	0	243	38	12	4	54
10,900	18.9	189	71.7	0	279	7.5	13.2	0	21
11,600	53.5	159	43.7	1.4	258	12.7	9.9	0	23
13,900	42	167	120	7.3	336	38	10.9	18.2	67

Correlation coefficient ("r") for Catch effort versus flow

Range of Flows (cfs) Analyzed	BH	FM	RT	CS	Combined	CP	WS	CC	Combined
217- 1,000	-0.54	0.34	-0.39	0.11	0.41	-0.06	-0.43	0.43	0.54
217- 2,000	-0.53	-0.22	0.01	0.13	0.39	0.21	-0.40	-0.41	0.60
217-13,900	-0.22	0.43	-0.56	0.13	0.24	-0.09	-0.04	0.01	0.29

LOWER GUNNISON RIVER

Plunge Pool

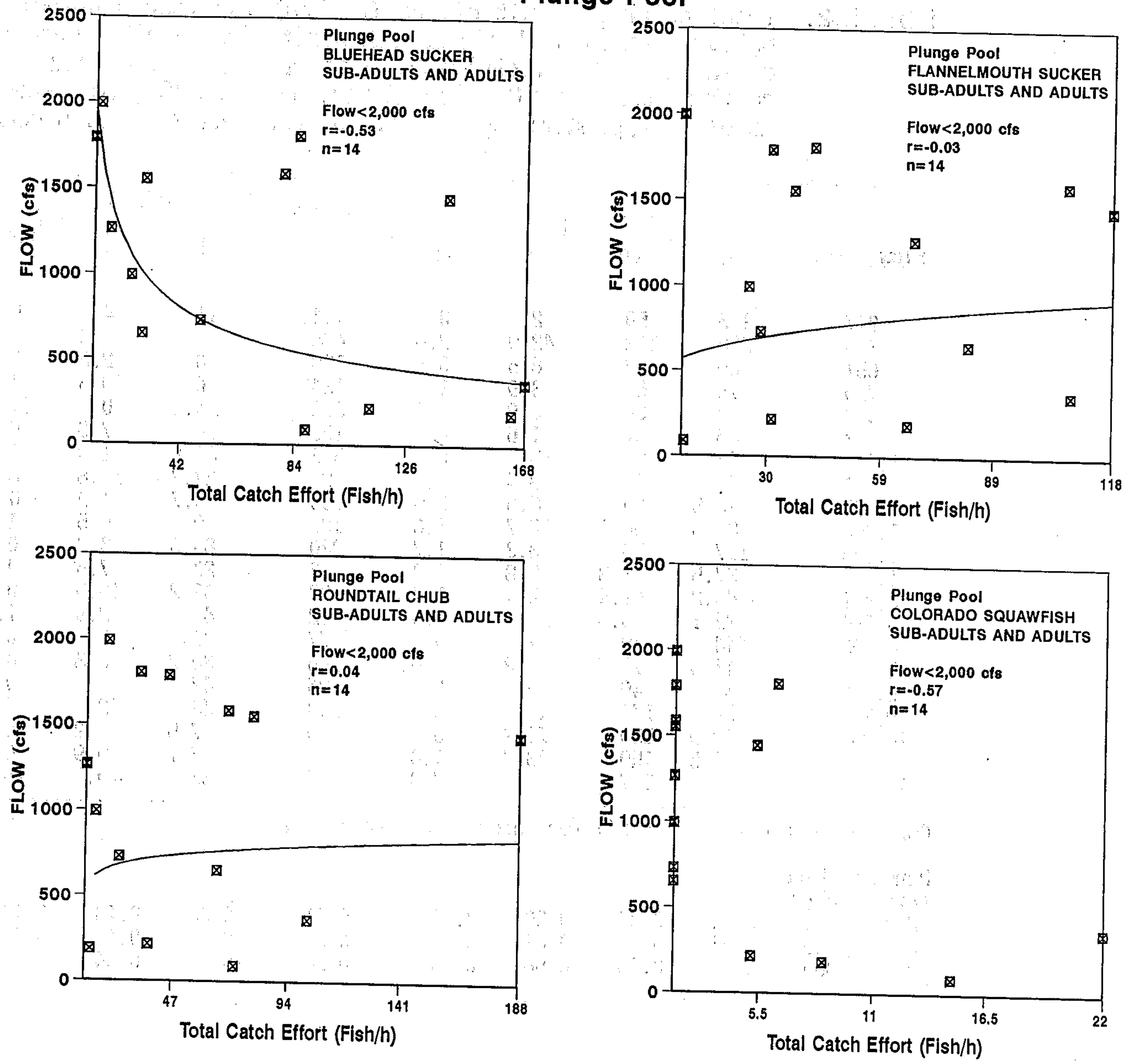


Figure E.1. Plot of total catch per unit effort (Fish/h) versus mean daily discharge for sub-adult and adult bluehead sucker, flannelmouth sucker, roundtail chub, and Colorado squawfish collected in the plunge pool (RM 3.0) of the Redlands Diversion Dam in the Lower Gunnison River, Colorado, March 1994 to November 1995. Note: 89-2,000 cfs was the range of flows analyzed; goodness-of-fit line fitted by computer.

LOWER GUNNISON RIVER
Plunge Pool

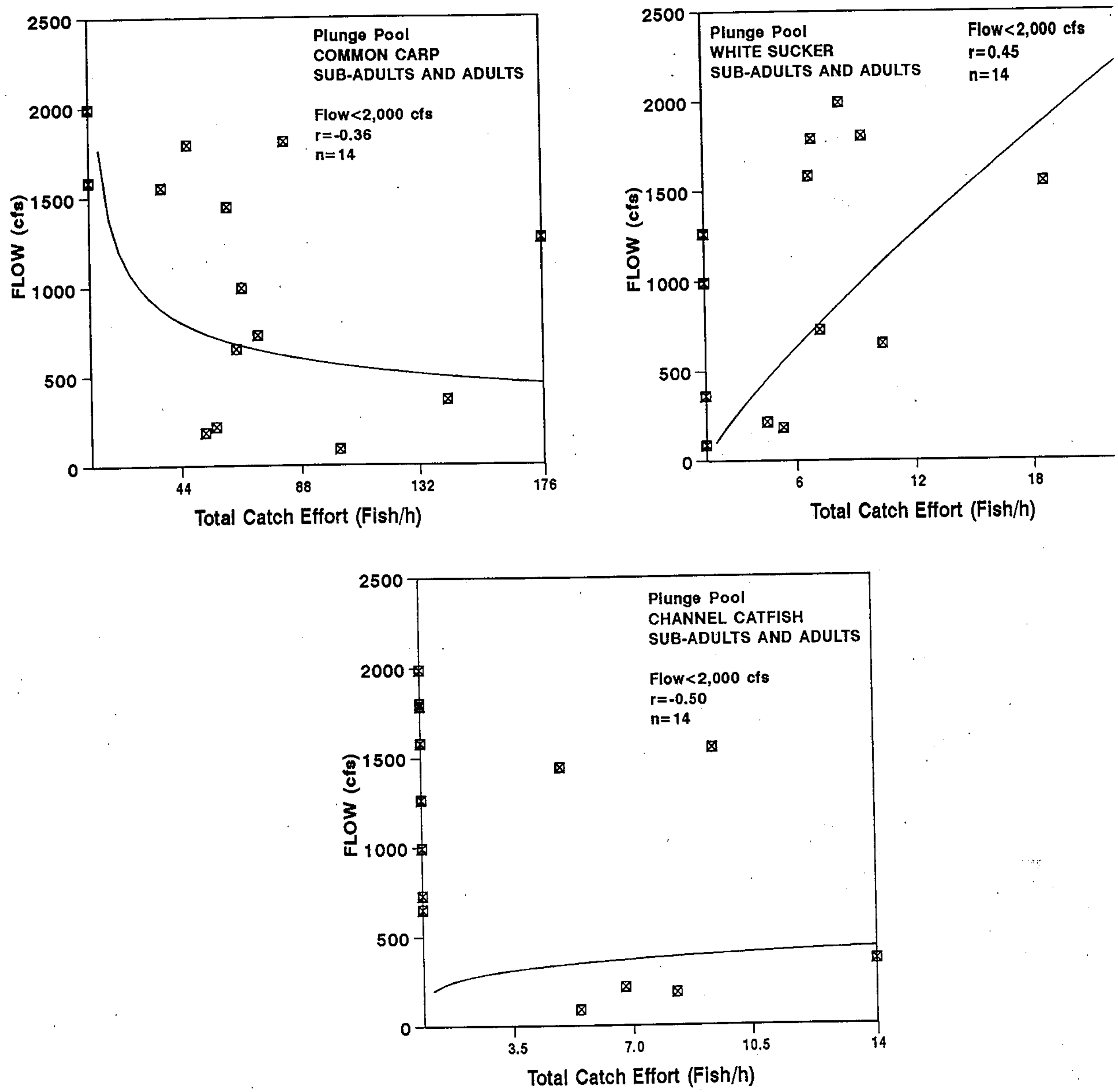


Figure E.2. Plot of total catch per unit effort (Fish/h) versus mean daily discharge for sub-adult and adult common carp, white sucker, and channel catfish collected in the plunge pool (RM 3.0) of the Redlands Diversion Dam in the Lower Gunnison River, Colorado, March 1994 to November 1995. Note: 89-2,000 cfs was the range of flows analyzed; goodness-of-fit line fitted by computer.

LOWER GUNNISON RIVER
2.2-Mile Reach

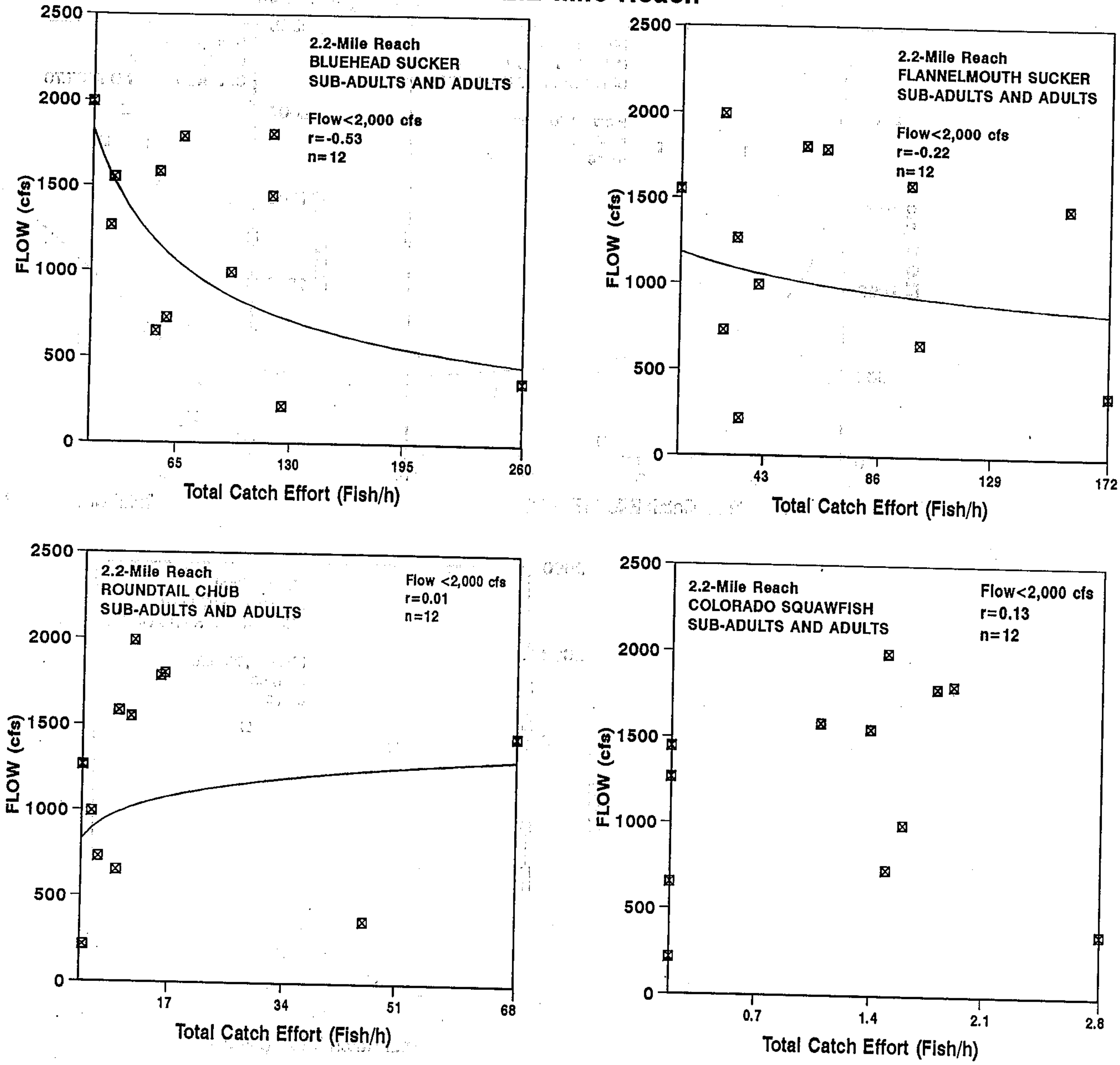


Figure E.3. Plot of total catch per unit effort (Fish/h) versus mean daily discharge for sub-adult and adult bluehead sucker, flannelmouth sucker, roundtail chub, and Colorado squawfish collected in the 2.2-mile reach of the Lower Gunnison River, Colorado, March 1994 to November 1995. Note: 217-2,000 cfs was the range of flows analyzed; goodness-of-fit line fitted by computer.

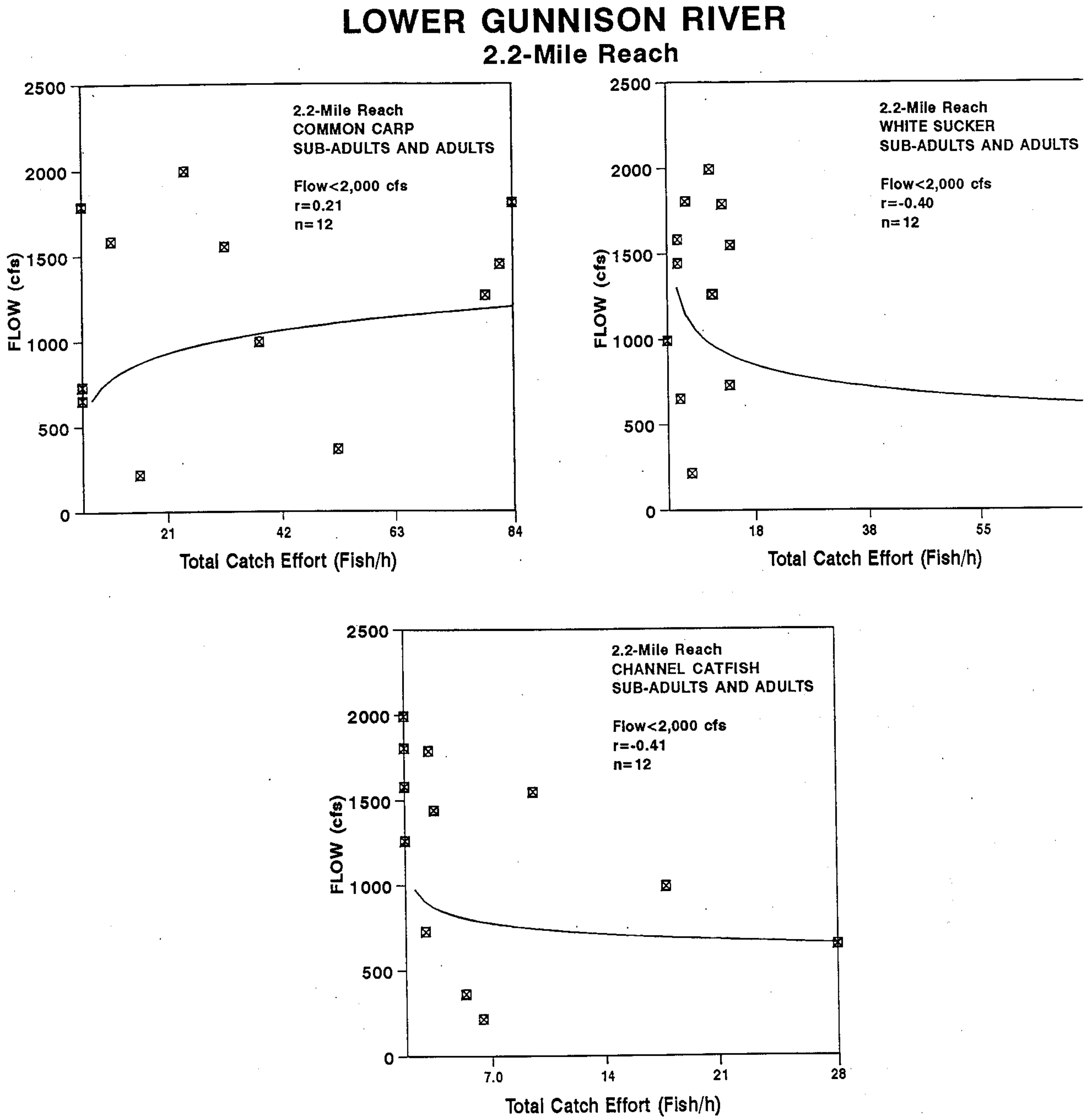


Figure E.4. Plot of total catch per unit effort (Fish/h) versus mean daily discharge for sub-adult and adult common carp, white sucker, and channel catfish collected in the 2.2-mile reach of the Lower Gunnison River, Colorado, March 1994 to November 1995. Note: 217-2,000 cfs was the range of flows analyzed; goodness-of-fit line fitted by computer.

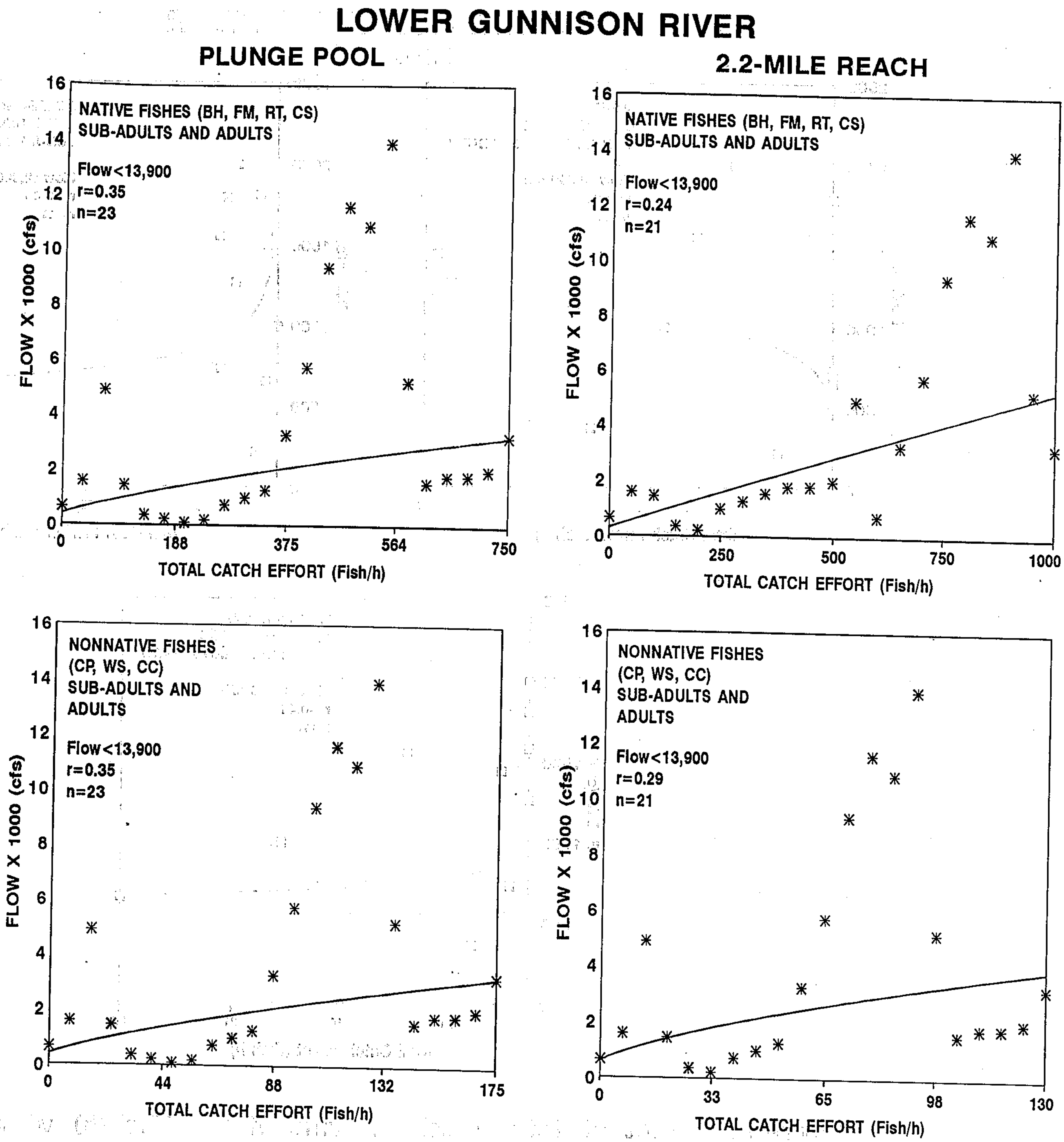


Figure E.5. Plot of combined total catch per unit effort (Fish/h) versus mean daily discharge for four sub-adult and adult native fishes (bluehead sucker, flannelmouth sucker, roundtail chub, and Colorado squawfish) and three sub-adult and adult nonnative fishes collected from the plunge pool (RM 3.0) and 2.2-mile reach of the Lower Gunnison River, Colorado, March 1994 to November 1995. Note: 89-13,900 cfs and 217-13,900 cfs was the range of flows analyzed for the plunge pool and reach, respectively; goodness-of-fit line fitted by computer.

APPENDIX F
Comparison of Two Methods of
Determining Flow in the 2.3-Mile Reach
of the Lower Gunnison River

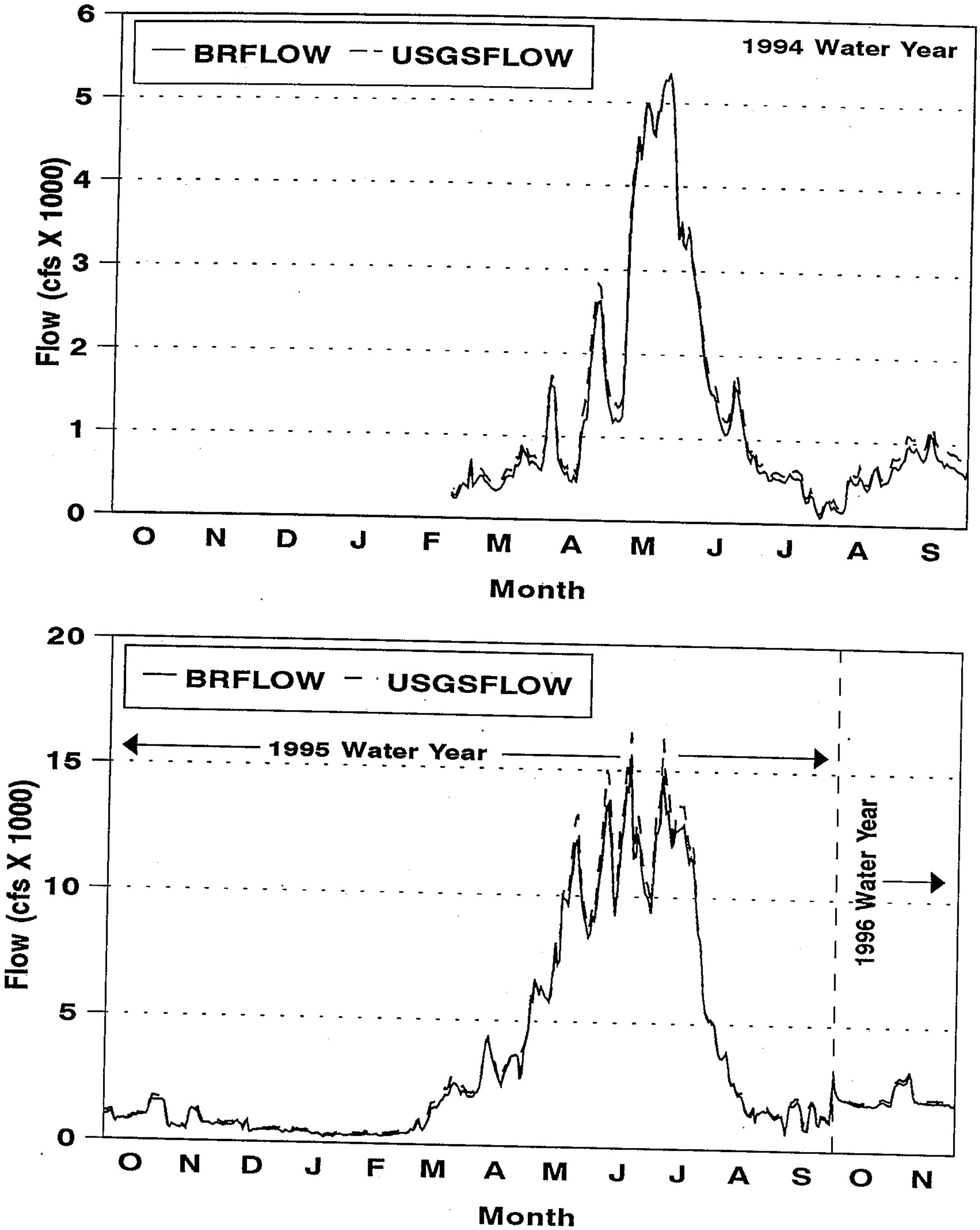


Figure F.1. Comparison of the mean daily streamflow of the USGS gage at Whitewater minus the Redlands Canal versus the mean daily streamflow of the Bureau of Reclamation (BR) gage in the 2.3-mile reach of the lower Gunnison River between the Redlands Diversion Dam and the confluence with the Colorado River during the study period, 1994 (top) and 1995 (bottom).

APPENDIX G

Tabular and Graphic Statistics of Water Depths at Various Low Flows in the 2.3-Mile Reach of the Lower Gunnison River

Table G.1. Predicted mean and maximum water depths for six discharges (100-600 cfs) determined from 27 transects conducted during March and April 1993 in the 2.3-mile reach of the lower Gunnison River between the Redlands Diversion Dam (river mile 3.0) and the confluence with the Colorado River (river mile 0.7). Bureau of Reclamation (BR) personnel conducted the transects; mean and maximum water depths were predicted by the HEC-2 computer model. Note: "n" denotes the number of observations; ☼ denotes a critically shallow transect @ 300 cfs.

BR Transect No.	DISCHARGE																	
	100 cfs			200 cfs			300 cfs			400 cfs			500 cfs			600 cfs		
		Water Depth (ft)			Water Depth (ft)			Water Depth (ft)			Water Depth (ft)			Water Depth (ft)			Water Depth (ft)	
	n	Mean	Max	n	Mean	Max	n	Mean	Max	n	Mean	Max	n	Mean	Max	n	Mean	Max
1	28	6.67	9.66	28	7.07	10.06	28	7.58	10.40	28	7.69	10.68	28	7.86	10.85	28	8.02	11.01
2	38	2.97	5.94	41	3.07	6.33	57	2.59	6.67	61	2.66	6.95	62	2.78	7.12	62	2.92	7.27
3	7	0.86	1.82	8	1.09	2.19	10	1.14	2.49	14	1.05	2.75	15	1.13	2.90	15	1.31	3.03
4☼	3	0.38	0.71	5	0.35	0.91	5	0.50	1.06	7	0.48	1.19	7	0.59	1.30	7	0.68	1.39
5☼	2	0.67	0.67	4	0.82	1.27	5	0.95	1.59	6	0.98	1.81	6	1.16	1.99	6	1.33	2.16
6	5	1.13	2.03	7	1.27	2.54	11	1.07	2.88	11	1.29	3.10	11	1.50	3.31	12	1.54	3.48
7	9	2.58	5.64	9	3.03	6.09	9	3.30	6.36	9	3.52	6.58	9	3.72	6.78	9	3.89	6.95
8	18	0.78	1.61	23	1.01	2.05	23	1.27	2.31	23	1.47	2.51	23	1.66	2.70	23	1.82	2.86
9☼	8	0.37	0.77	11	0.47	0.99	15	0.49	1.16	21	0.52	1.35	21	0.54	1.38	23	0.70	1.62
10	14	1.01	1.75	15	1.46	2.30	15	1.94	2.82	15	2.30	3.14	15	2.58	3.42	16	2.66	3.67
11	17	1.15	1.70	19	1.51	2.20	19	2.10	2.79	19	2.36	3.05	19	2.59	3.28	19	2.79	3.48
12☼	6	0.59	1.37	10	0.75	1.84	24	0.86	2.60	25	1.04	2.82	26	1.19	3.02	26	1.36	3.19
13	13	1.59	2.49	13	2.04	2.94	13	2.63	3.53	13	2.94	3.84	14	2.99	4.10	14	3.23	4.34
14	19	0.64	1.03	20	0.94	1.43	23	1.42	2.02	23	1.71	2.31	23	1.96	2.56	24	2.11	2.79
15	11	1.27	2.30	12	1.40	2.55	13	1.59	2.87	14	1.66	3.06	14	1.83	3.23	14	2.01	3.41
16	7	4.60	7.79	7	4.83	8.02	7	5.13	8.32	7	5.30	8.49	7	5.46	8.65	7	5.62	8.81
17	14	6.13	11.57	14	7.67	11.79	14	7.98	12.10	14	8.14	12.27	14	8.31	12.43	14	8.47	12.59
18	12	6.92	10.51	12	7.14	10.73	13	6.89	11.04	13	7.06	11.21	13	7.21	11.36	13	7.37	11.52
19☼	12	0.28	0.49	16	0.35	0.64	19	0.68	1.06	20	0.78	1.21	20	0.93	1.35	20	1.06	1.50

Table G.1. (cont'd). Predicted mean and maximum water depths for six discharges (100-600 cfs) determined from 27 transects conducted during March and April 1993 in the 2.3-mile reach of the lower Gunnison River between the Redlands Diversion Dam (river mile 3.0) and the confluence with the Colorado River (river mile 0.7). Bureau of Reclamation (BR) personnel conducted the transects; mean and maximum water depths were predicted by the HEC-2 computer model. Note: "n" denotes the number of observations.

BR Transect No.	DISCHARGE																	
	100 cfs			200 cfs			300 cfs			400 cfs			500 cfs			600 cfs		
		Water Depth (ft)			Water Depth (ft)			Water Depth (ft)			Water Depth (ft)			Water Depth (ft)			Water Depth (ft)	
	n	Mean	Max	n	Mean	Max	n	Mean	Max	n	Mean	Max	n	Mean	Max	n	Mean	Max
20	9	2.97	7.03	9	3.08	7.14	9	3.23	7.29	9	3.40	7.46	10	3.25	7.65	10	3.43	7.83
21	18	2.25	4.14	19	2.19	4.21	20	2.18	4.31	20	2.30	4.43	20	2.43	4.56	20	2.56	4.69
22	15	3.75	4.74	15	3.82	4.81	15	3.91	4.90	15	4.02	5.01	15	4.15	5.14	15	4.27	5.26
23	23	1.98	2.95	23	2.03	2.28	23	2.10	3.07	23	2.18	3.15	23	2.03	3.25	23	2.37	3.34
24	19	2.35	3.56	19	2.39	3.60	19	2.45	3.66	19	2.53	3.74	19	2.61	3.82	19	2.69	3.90
25	20	2.78	4.29	20	2.91	4.32	20	2.86	4.37	20	2.92	4.43	20	2.99	4.50	20	3.05	4.56
26	28	2.20	4.06	28	2.23	4.09	29	2.18	4.12	29	2.21	4.15	29	2.25	4.19	29	2.28	4.22
27	23	2.36	4.63	23	2.38	4.65	23	2.40	4.67	23	2.44	4.69	23	2.45	4.72	23	2.47	4.74
Totals	398	---	---	430	---	---	481	---	---	501	---	---	506	---	---	511	---	---
Grand Mean	---	2.58	3.90	---	2.68	4.17	---	2.68	4.46	---	2.73	4.64	---	2.85	4.80	---	2.97	4.95
Maximum	---	---	11.57	---	---	11.79	---	---	12.10	---	---	12.27	---	---	12.43	---	---	12.59

Table G.2. Total number and percentage of predicted depths that exceed 1 foot for each of the 27 transects conducted during March and April 1993 in the 2.3-mile reach of the lower Gunnison River between the Redlands Diversion Dam (river mile 3.0) and the confluence with the Colorado River (river mile 0.7). Note: ☼ denotes a critically shallow transect @ 300 cfs.

	DISCHARGE											
	100 cfs		200 cfs		300 cfs		400 cfs		500 cfs		600 cfs	
BR Transect No.	n	Number of Observations That Exceed 1 foot (%)	n	Number of Observations That Exceed 1-foot (%)	n	Number of Observations That Exceed 1-foot (%)	n	Number of Observations That Exceed 1-foot (%)	n	Number of Observations That Exceed 1-foot (%)	n	Number of Observations That Exceed 1-foot (%)
1	28	28 (100%)	28	28 (100%)	28	28 (100%)	28	28 (100%)	28	28 (100%)	28	28 (100%)
2	38	32 (84%)	41	36 (87%)	57	38 (67%)	61	38 (62%)	62	38 (61%)	62	40 (64%)
3	7	3 (43%)	8	5 (63%)	10	6 (60%)	14	6 (43%)	15	7 (47%)	15	7 (47%)
4☼	3	0 (0%)	5	0 (0%)	5	1 (20%)	7	1 (14%)	7	1 (14%)	7	1 (14%)
5	2	0 (0%)	4	2 (50%)	5	3 (60%)	6	3 (50%)	6	3 (50%)	6	4 (67%)
6	5	2 (40%)	7	4 (57%)	11	4 (36%)	11	5 (45%)	11	4 (36%)	12	7 (58%)
7	9	6 (67%)	9	7 (78%)	9	8 (89%)	9	9 (100%)	9	9 (100%)	9	9 (100%)
8	18	7 (39%)	23	10 (43%)	23	13 (57%)	23	16 (70%)	23	19 (83%)	23	19 (83%)
9☼	8	0 (0%)	11	0 (0%)	15	1 (7%)	21	1 (5%)	21	2 (10%)	23	6 (26%)
10	14	6 (43%)	15	13 (86%)	15	14 (93%)	15	14 (43%)	15	15 (100%)	16	15 (94%)
11	17	13 (76%)	19	14 (74%)	19	18 (95%)	19	19 (100%)	19	19 (100%)	19	19 (100%)
12	6	2 (33%)	10	2 (20%)	24	9 (38%)	25	9 (36%)	26	15 (58%)	26	16 (61%)
13	13	8 (62%)	13	11 (85%)	13	13 (100%)	13	13 (100%)	14	13 (93%)	14	13 (93%)
14	19	2 (11%)	20	12 (60%)	23	19 (83%)	23	20 (87%)	23	21 (91%)	24	22 (92%)
15	11	8 (73%)	12	8 (67%)	13	9 (69%)	14	10 (71%)	14	11 (79%)	14	11 (79%)
16	7	6 (86%)	7	6 (86%)	7	6 (86%)	7	7 (100%)	7	7 (100%)	7	7 (100%)
17	14	14 (100%)	14	14 (100%)	14	14 (100%)	14	14 (100%)	14	14 (100%)	14	14 (100%)
18	12	12 (100%)	12	12 (100%)	13	12 (92%)	13	12 (92%)	13	12 (92%)	13	12 (92%)
19☼	12	0 (0%)	16	0 (0%)	19	1 (5%)	20	6 (30%)	20	11 (55%)	20	14 (70%)
20	9	7 (78%)	9	7 (78%)	9	7 (78%)	9	8 (89%)	10	9 (90%)	10	9 (90%)

Table G.2. (cont'd). Total number and percentage of predicted depths that exceed 1 foot for each of the 27 transects conducted during March and April 1993 in the 2.3-mile reach of the lower Gunnison River between the Redlands Diversion Dam (river mile 3.0) and the confluence with the Colorado River (river mile 0.7).

	DISCHARGE											
	100 cfs		200 cfs		300 cfs		400 cfs		500 cfs		600 cfs	
BR Transect No.	n	Number of Observations That Exceed 1 foot (%)	n	Number of Observations That Exceed 1-foot (%)	n	Number of Observations That Exceed 1-foot (%)	n	Number of Observations That Exceed 1-foot (%)	n	Number of Observations That Exceed 1-foot (%)	n	Number of Observations That Exceed 1-foot (%)
21	18	13 (72%)	19	13 (68%)	20	14 (70%)	20	15 (75%)	20	15 (75%)	20	15 (75%)
22	15	15 (100%)	15	15 (100%)	15	15 (100%)	15	15 (100%)	15	15 (100%)	15	15 (100%)
23	23	23 (100%)	23	23 (100%)	23	23 (100%)	23	23 (100%)	23	23 (100%)	23	23 (100%)
24	19	19 (100%)	19	19 (100%)	19	19 (100%)	19	19 (100%)	19	19 (100%)	19	19 (100%)
25	20	20 (100%)	20	20 (100%)	20	20 (100%)	20	20 (100%)	20	20 (100%)	20	20 (100%)
26	28	22 (79%)	28	22 (79%)	29	22 (76%)	29	22 (76%)	29	22 (76%)	29	22 (76%)
27	23	20 (87%)	23	21 (91%)	23	21 (91%)	23	20 (87%)	23	20 (87%)	23	20 (87%)
Totals	398	288	430	296	451	357	501	381	506	394	511	408
Mean		(72%)		(69%)		(79%)		(76%)		(78%)		(80%)

Table G.3. Total number and percentage of predicted depths that exceed 2 feet for each of the 27 transects conducted during March and April 1993 in the 2.3-mile reach of the lower Gunnison River between the Redlands Diversion Dam (river mile 3.0) and the confluence with the Colorado River (river mile 0.7). Note: ☼ denotes a critically shallow transect @ 300 cfs.

	DISCHARGE											
	100 cfs		200 cfs		300 cfs		400 cfs		500 cfs		600 cfs	
BR Transect No.	n	Number of Observations That Exceed 2 feet (%)	n	Number of Observations That Exceed 2-feet (%)	n	Number of Observations That Exceed 2-feet (%)	n	Number of Observations That Exceed 2-feet (%)	n	Number of Observations That Exceed 2-feet (%)	n	Number of Observations That Exceed 2-feet (%)
1	28	28 (100%)	28	28 (100%)	28	28 (100%)	28	28 (100%)	28	28 (100%)	28	28 (100%)
2	38	21 (55%)	41	29 (70%)	57	30 (53%)	61	32 (52%)	62	35 (56%)	62	35 (56%)
3	7	0 (0%)	8	1 (13%)	10	1 (10%)	14	3 (21%)	15	3 (20%)	15	3 (20%)
4☼	3	0 (0%)	5	0 (0%)	5	0 (0%)	7	0 (0%)	7	0 (0%)	7	0 (0%)
5	2	0 (0%)	4	0 (0%)	5	0 (0%)	6	0 (0%)	6	0 (0%)	6	2 (33%)
6	5	1 (20%)	7	2 (29%)	11	2 (18%)	11	3 (27%)	11	4 (36%)	12	4 (33%)
7	9	5 (56%)	9	5 (56%)	9	6 (67%)	9	6 (67%)	9	6 (67%)	9	7 (78%)
8	18	0 (0%)	23	4 (17%)	23	5 (22%)	23	6 (26%)	23	8 (35%)	23	9 (39%)
9☼	8	0 (0%)	11	0 (0%)	15	0 (0%)	21	0 (0%)	21	0 (0%)	23	0 (0%)
10	14	0 (0%)	15	5 (33%)	16	5 (40%)	15	12 (75%)	15	13 (87%)	16	13 (81%)
11	17	0 (0%)	19	6 (32%)	19	13 (68%)	19	13 (68%)	19	14 (74%)	19	15 (79%)
12	6	0 (0%)	10	0 (10%)	24	2 (8%)	25	2 (8%)	26	3 (12%)	26	4 (15%)
13	13	6 (46%)	13	7 (54%)	13	10 (77%)	13	10 (77%)	14	11 (79%)	14	13 (93%)
14	19	0 (0%)	20	0 (0%)	23	2 (9%)	23	10 (43%)	23	15 (65%)	24	17 (71%)
15	11	2 (18%)	12	3 (25%)	13	4 (31%)	14	6 (43%)	14	6 (43%)	14	8 (57%)
16	7	6 (86%)	7	6 (86%)	7	6 (86%)	7	6 (86%)	7	6 (86%)	7	6 (86%)
17	14	12 (86%)	14	12 (86%)	14	12 (86%)	14	12 (86%)	14	13 (93%)	14	14 (100%)
18	12	11 (92%)	12	11 (92%)	13	11 (85%)	13	11 (85%)	13	12 (92%)	13	12 (92%)
19☼	12	0 (0%)	16	0 (0%)	19	0 (0%)	20	0 (0%)	20	0 (0%)	20	0 (0%)
20	9	3 (33%)	9	3 (33%)	9	3 (33%)	9	3 (33%)	10	4 (40%)	10	6 (60%)

Table G.3. (cont'd). Total number and percentage of predicted depths that exceed 2 feet for each of the 27 transects conducted during March and April 1993 in the 2.3-mile reach of the lower Gunnison River between the Redlands Diversion Dam (river mile 3.0) and the confluence with the Colorado River (river mile 0.7).

	DISCHARGE											
	100 cfs		200 cfs		300 cfs		400 cfs		500 cfs		600 cfs	
BR Transect No.	n	Number of Observations That Exceed 2 feet (%)	n	Number of Observations That Exceed 2-feet (%)	n	Number of Observations That Exceed 2-feet (%)	n	Number of Observations That Exceed 2-feet (%)	n	Number of Observations That Exceed 2-feet (%)	n	Number of Observations That Exceed 2-feet (%)
21	18	12 (67%)	19	12 (63%)	20	12 (60%)	20	12 (60%)	20	12 (60%)	20	12 (60%)
22	15	14 (93%)	15	14 (93%)	15	14 (93%)	15	14 (93%)	15	14 (93%)	15	14 (93%)
23	23	10 (43%)	23	13 (57%)	23	13 (57%)	23	14 (61%)	23	16 (70%)	23	21 (91%)
24	19	12 (63%)	19	13 (68%)	19	13 (68%)	19	15 (79%)	19	16 (84%)	19	16 (84%)
25	20	15 (75%)	20	16 (80%)	20	15 (75%)	20	16 (80%)	20	17 (85%)	20	17 (85%)
26	28	15 (54%)	28	15 (54%)	29	15 (52%)	29	15 (52%)	29	15 (52%)	29	16 (55%)
27	23	15 (65%)	23	15 (65%)	23	15 (65%)	23	15 (65%)	23	16 (70%)	23	16 (70%)
Totals	398	288	430	298	451	358	501	373	506	392	511	407
Mean		(72%)		(69%)		(74%)		(74%)		(77%)		(80%)

Table G.4. Summary of water depths recorded at seven separate transects during low flows between 2 and 4 August 1994 in the 2.3-mile reach of the lower Gunnison River between the Redlands Diversion Dam and the confluence with the Colorado River. Transects conducted by FWS.

Transect No.	Number of Observations	Depth (ft)		Number of Observations Greater Than 1-foot (%)	Date	Time	Flow (cfs)[a]	
		Mean	Max				USGS[b] Gage	BR Gage
4	81	0.6	1.5	11 (14%)	94/08/03	1520	222	168
9	99	0.4	0.8	0 ---	94/08/03	1400	245	180
14	179	0.6	1.2	26 (15%)	94/08/04	1455	276	218
19A	127	0.7	1.1	6 (5%)	94/08/03	1105	264	201
$19B_1$	113	0.5	1.1	4 (4%)	94/08/02	1530	268	202
$19B_2$	120	0.5	1.1	10 (8%)	94/08/03	1130	266	201
20	99	0.6	1.0	0 ---	94/08/03	1200	266	192
Totals	818	---	---	---	---	---	---	---

[a] Hourly flows were used.

[b] Whitewater USGS stream gage minus Redlands Diversion Dam Canal. At these low flows, it was assumed that it would have taken about 5 hours for flows to reach the 2.2-mile stream reach between Redlands Diversion Dam and the Colorado River confluence from the Whitewater USGS gaging station.

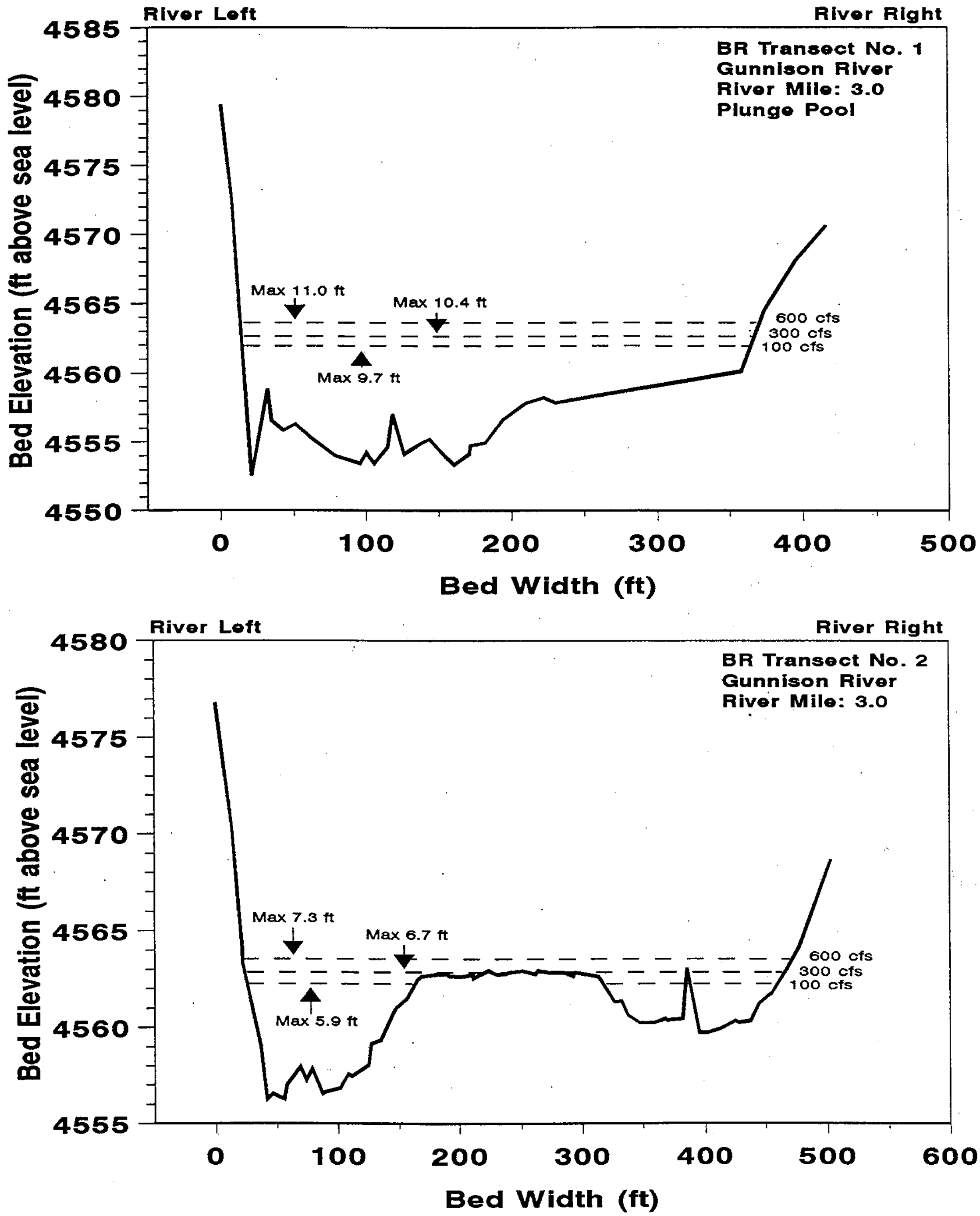


Figure G.1. River profile and variation in stage and maximum depth at various flow levels (100, 300, and 600 cfs) at Transects 1 (top) and 2 (bottom). Transects conducted by BR personnel.

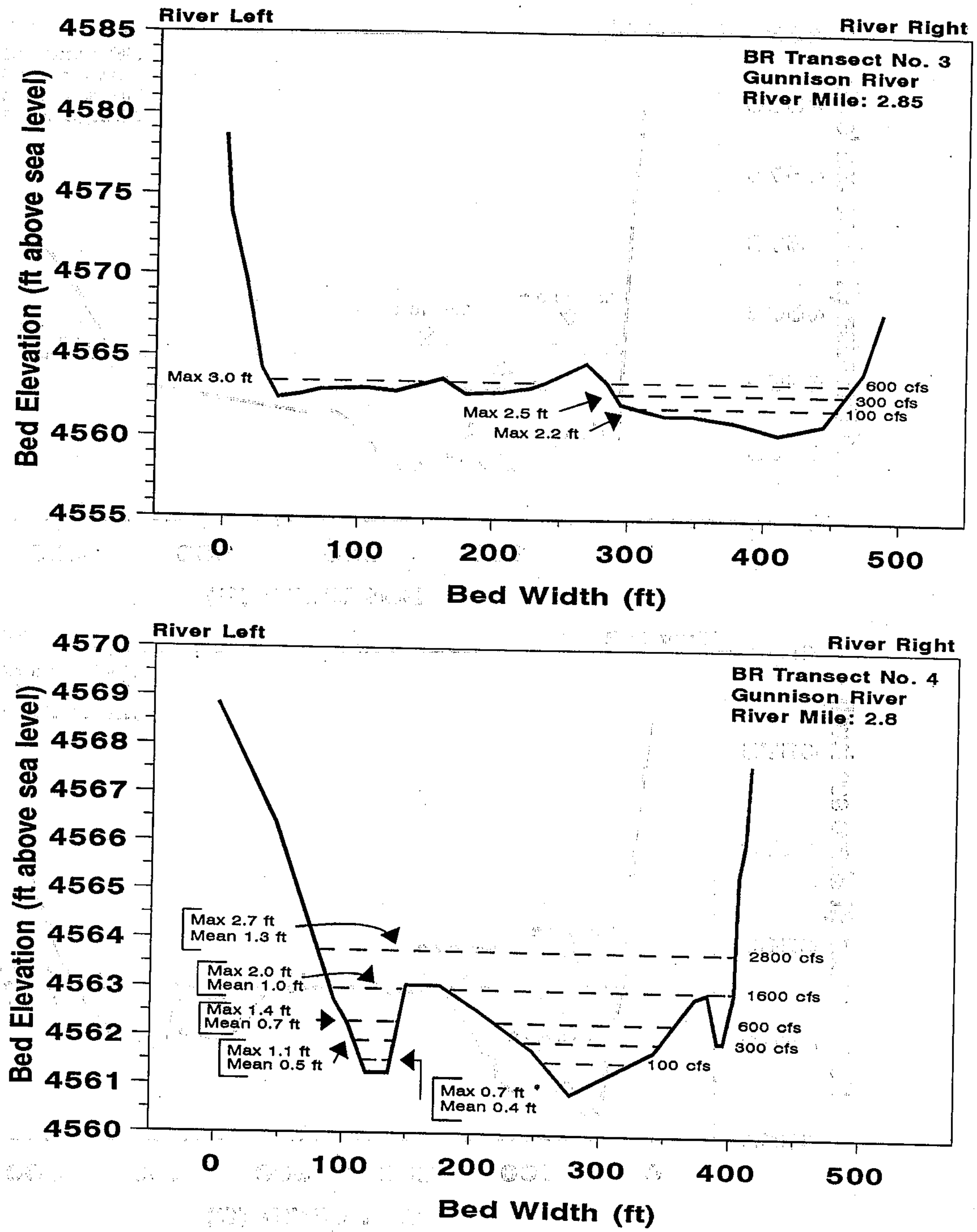


Figure G.2. River profile and variation in stage and maximum depth at various flow levels at Transect 3 (100, 300, and 600 cfs; top) and Transect 4 (100, 300, 600, 1,600, and 2,800 cfs; bottom). Transects conducted by BR personnel.

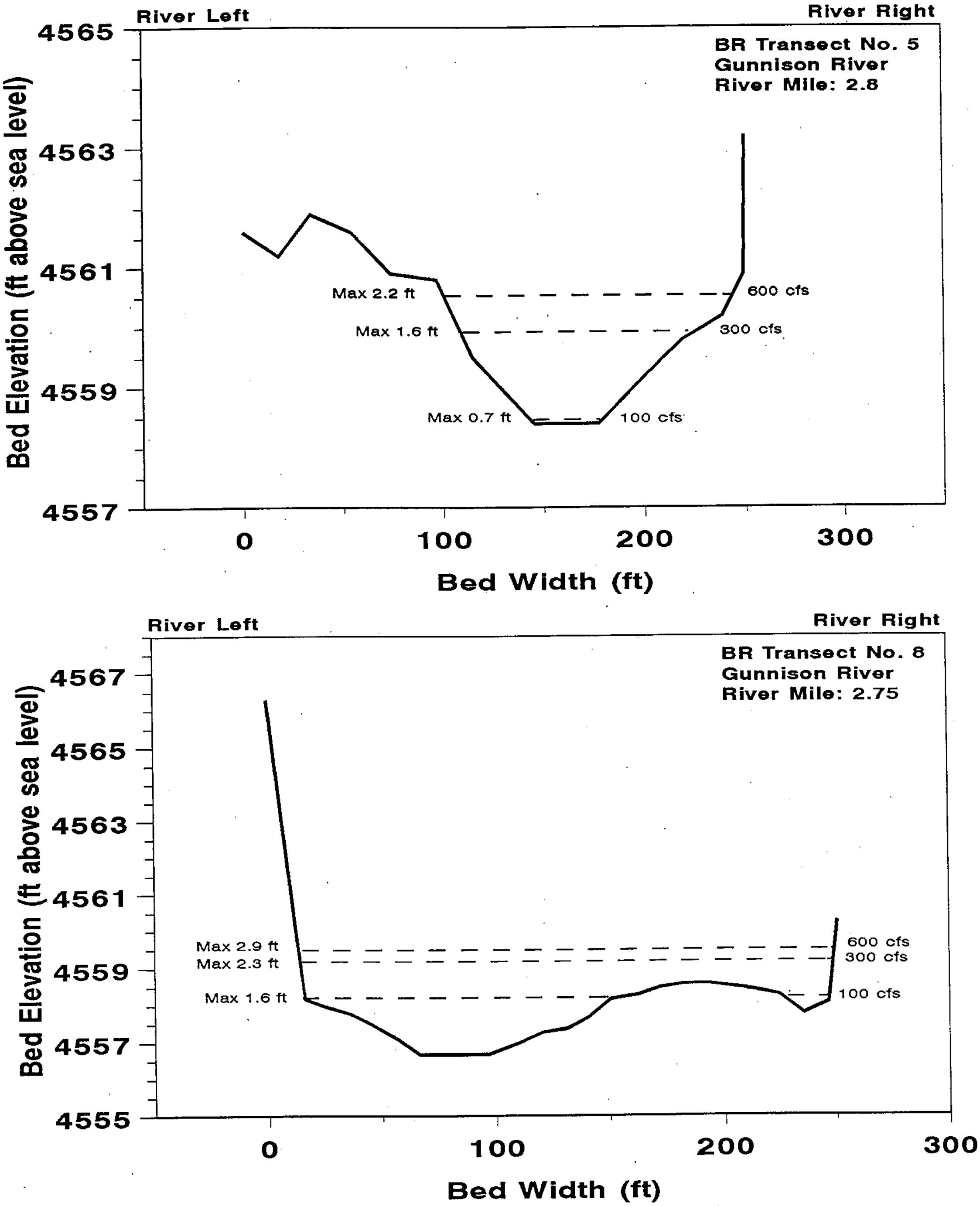
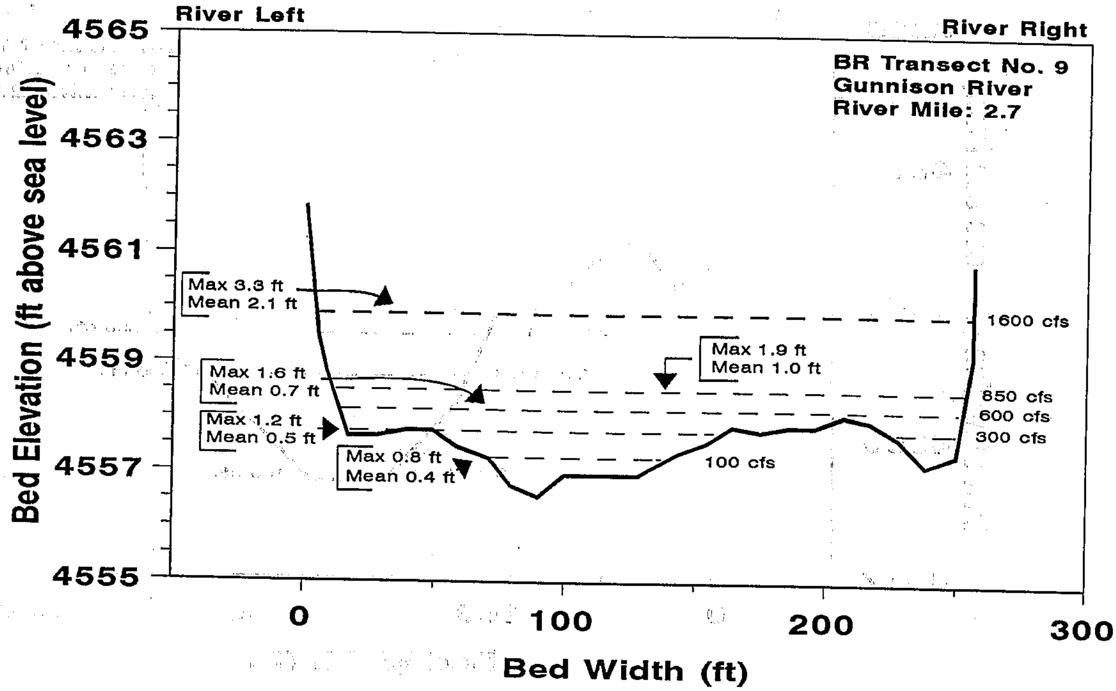


Figure G.3. River profile and variation in stage and maximum depth at various flow levels (100, 300, and 600 cfs) at Transects 5 (top) and 8 (bottom). Transects conducted by BR personnel.



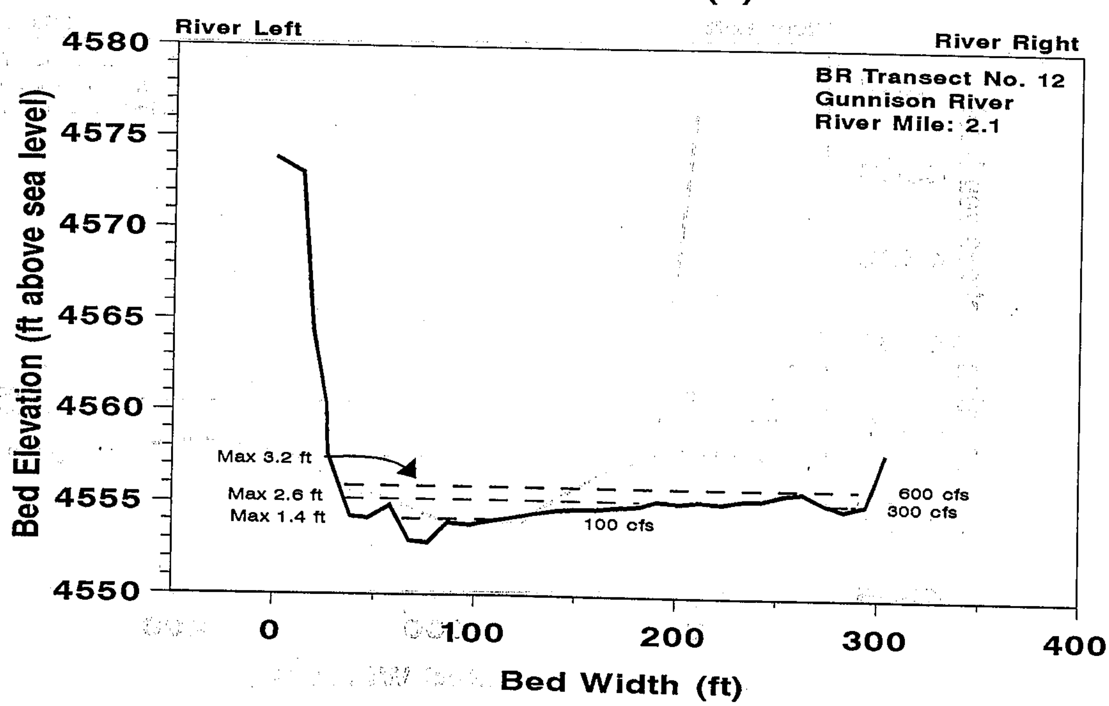


Figure G.4. River profile and variation in stage and maximum depth at various flow levels at Transect 9 (100, 300, 600, 850, and 1,600 cfs; top) and Transect 12 (100, 300, 600 cfs; bottom). Transects conducted by BR personnel.

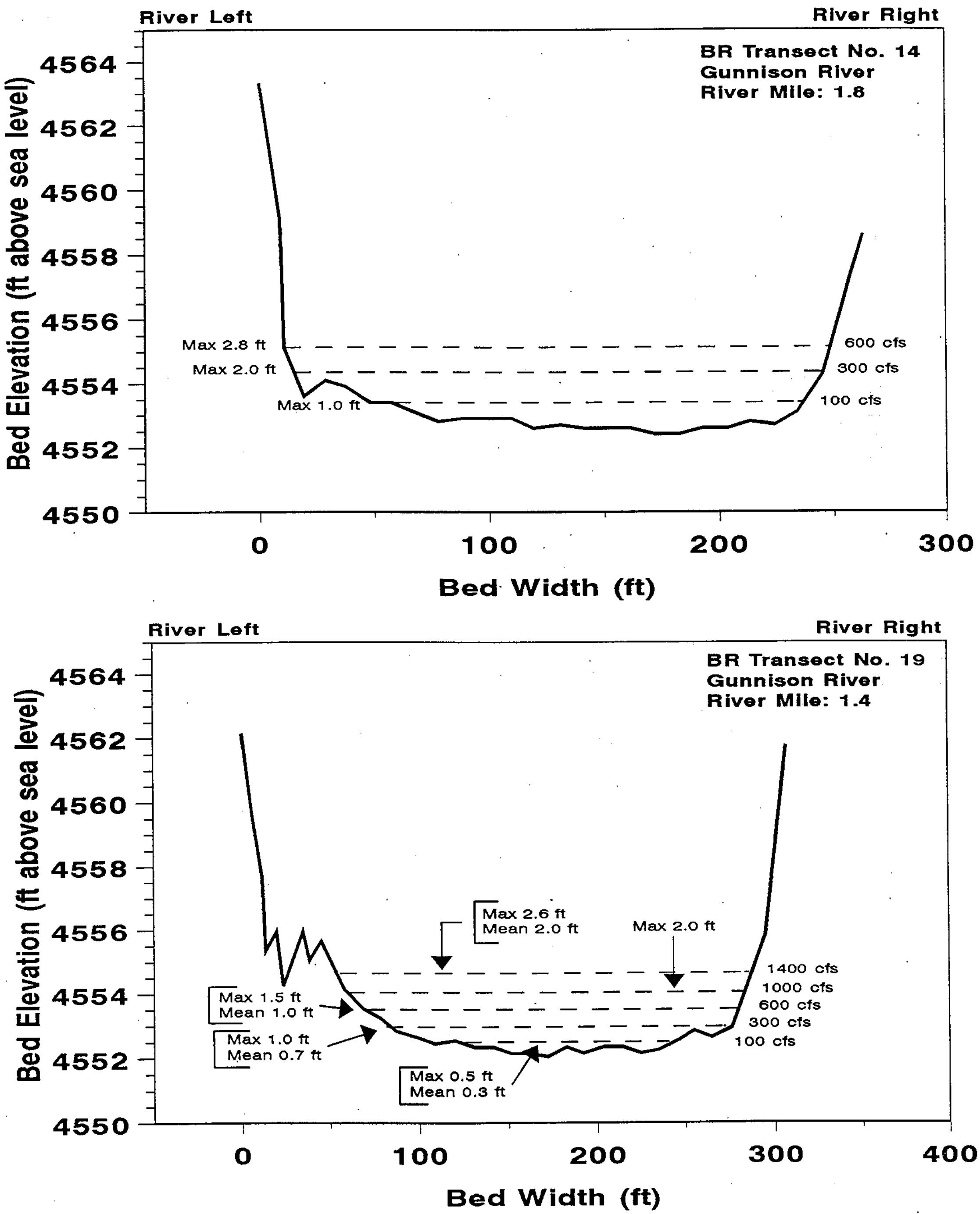


Figure G.5. River profile and variation in stage and maximum depth at various flow levels at Transect 14 (100, 300, and 600 cfs; top) and Transect 19 (100, 300, 600, 1,000, and 1,400 cfs; bottom). Transects conducted by BR personnel.

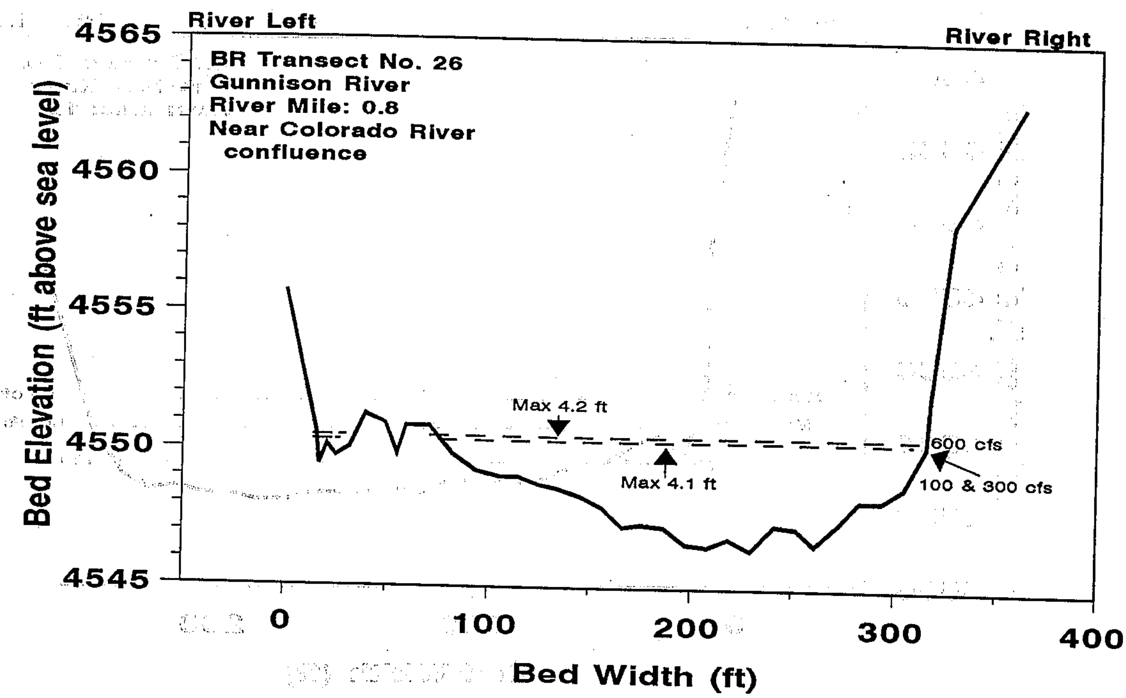
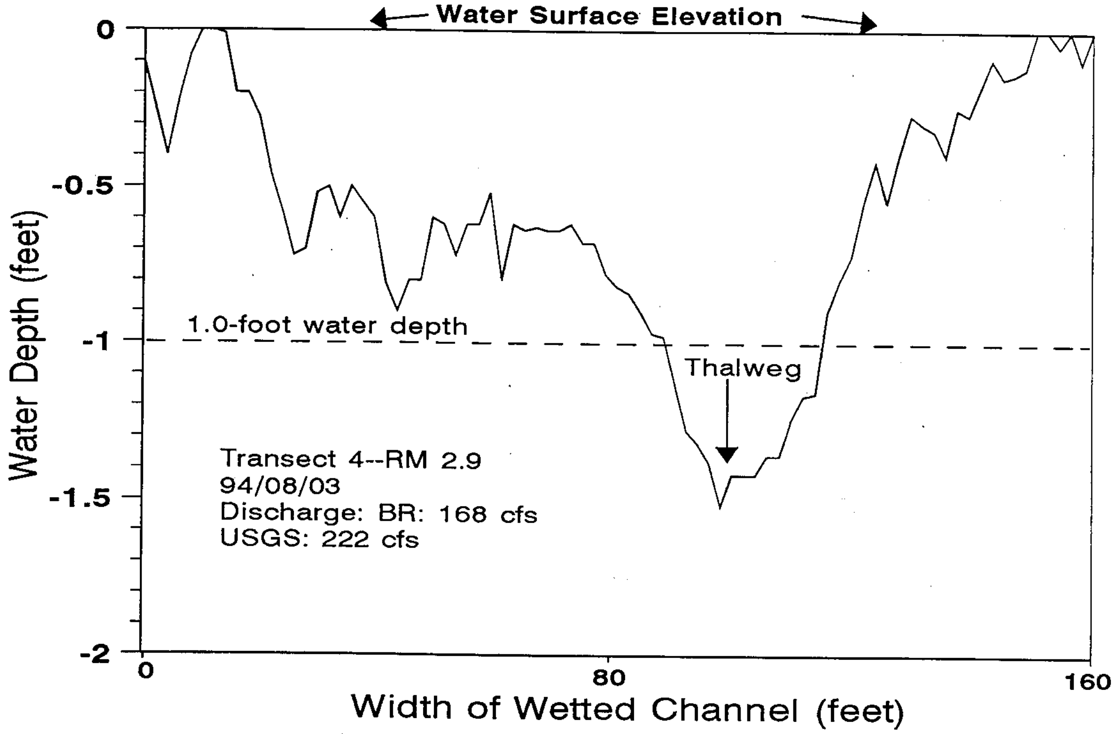


Figure G.6. River profile and variation in stage and maximum depth at various flow levels (100, 300, and 600 cfs) at Transect 26. Transect conducted by BR personnel.



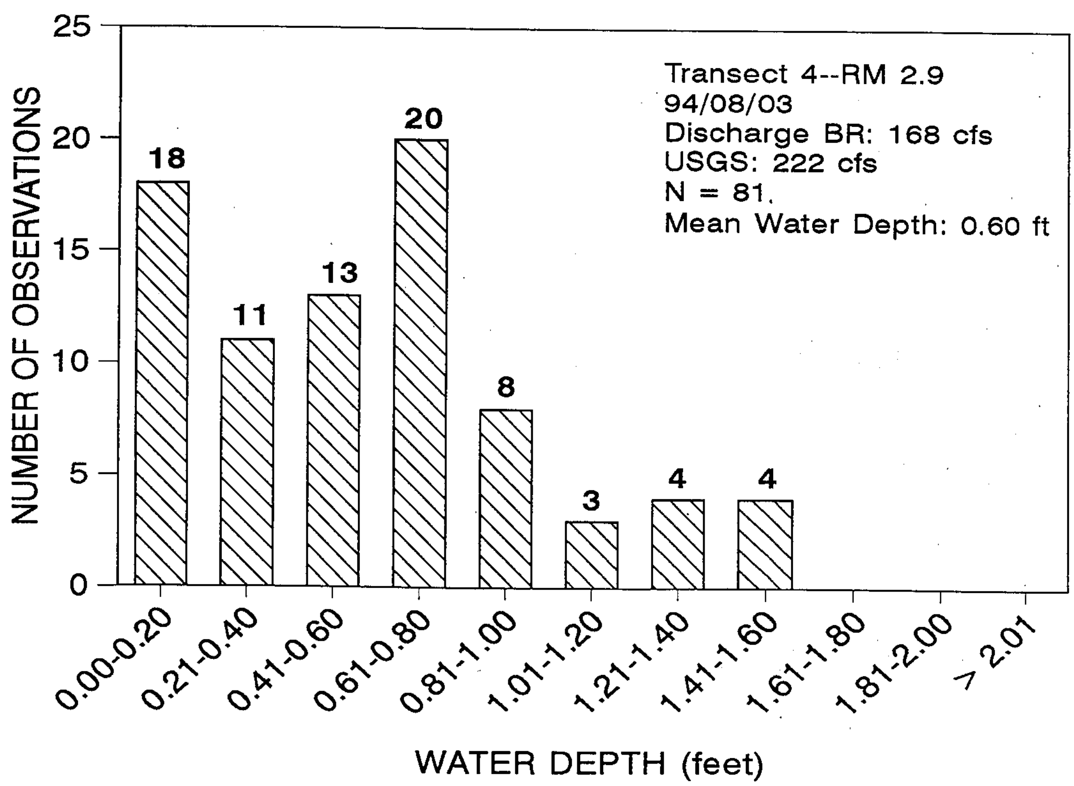


Figure G.7. River profile (top) and the distribution of water depths (feet) observed by 0.2-foot increments (bottom) for transect 4, river mile 2.9, Gunnison River, Colorado, 3 August 1994.

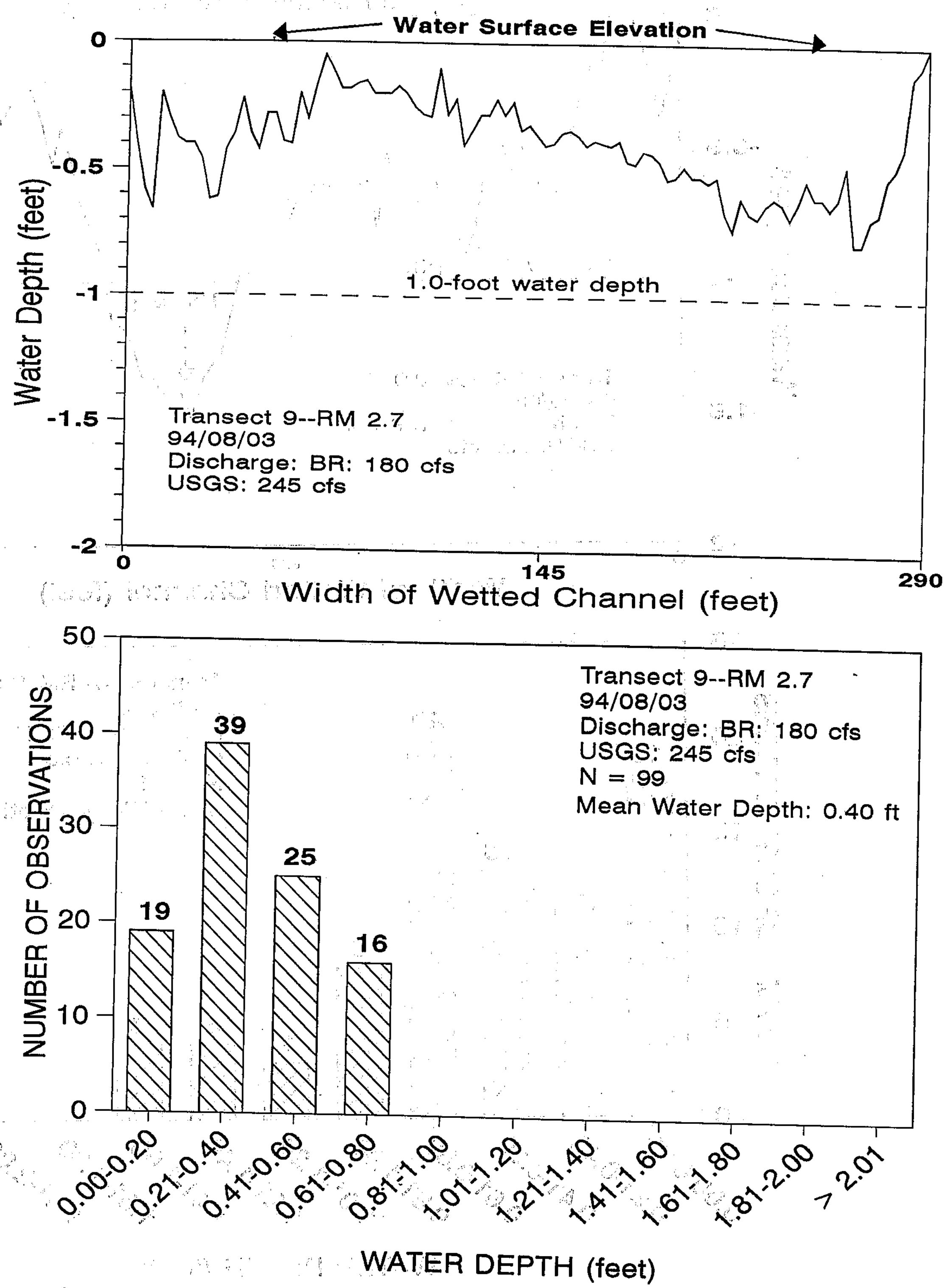
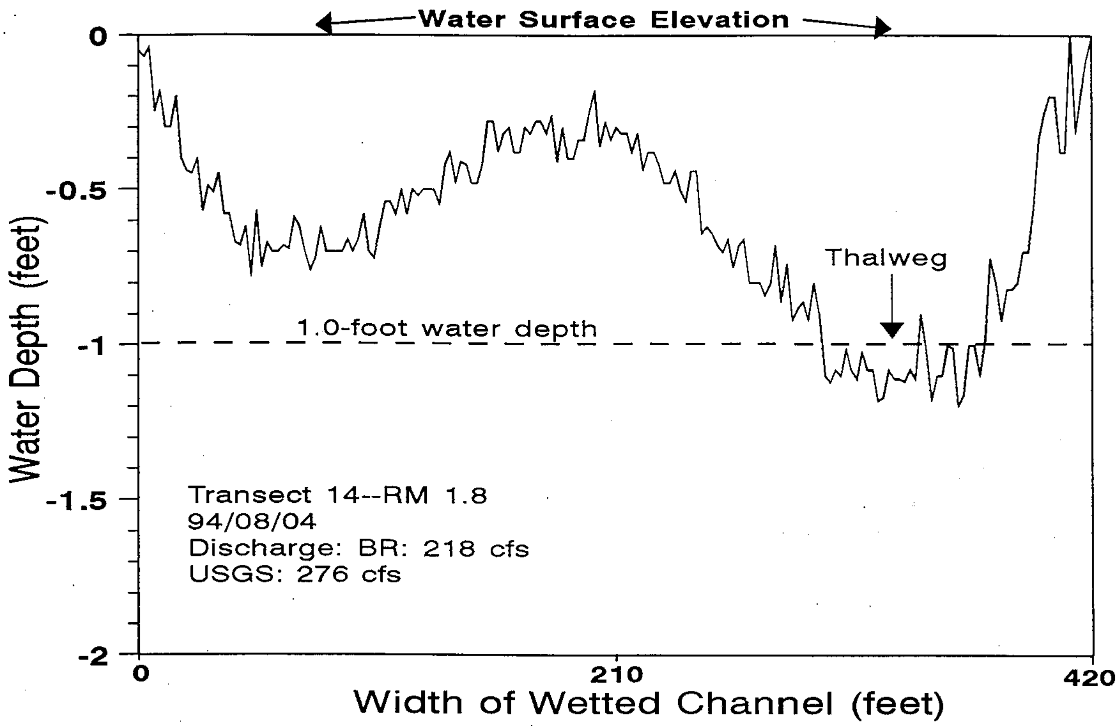


Figure G.8. River profile (top) and the distribution of water depths (feet) observed by 0.2-foot increments (bottom) for transect 9, river mile 2.4, Gunnison River, Colorado, 3 August 1994.



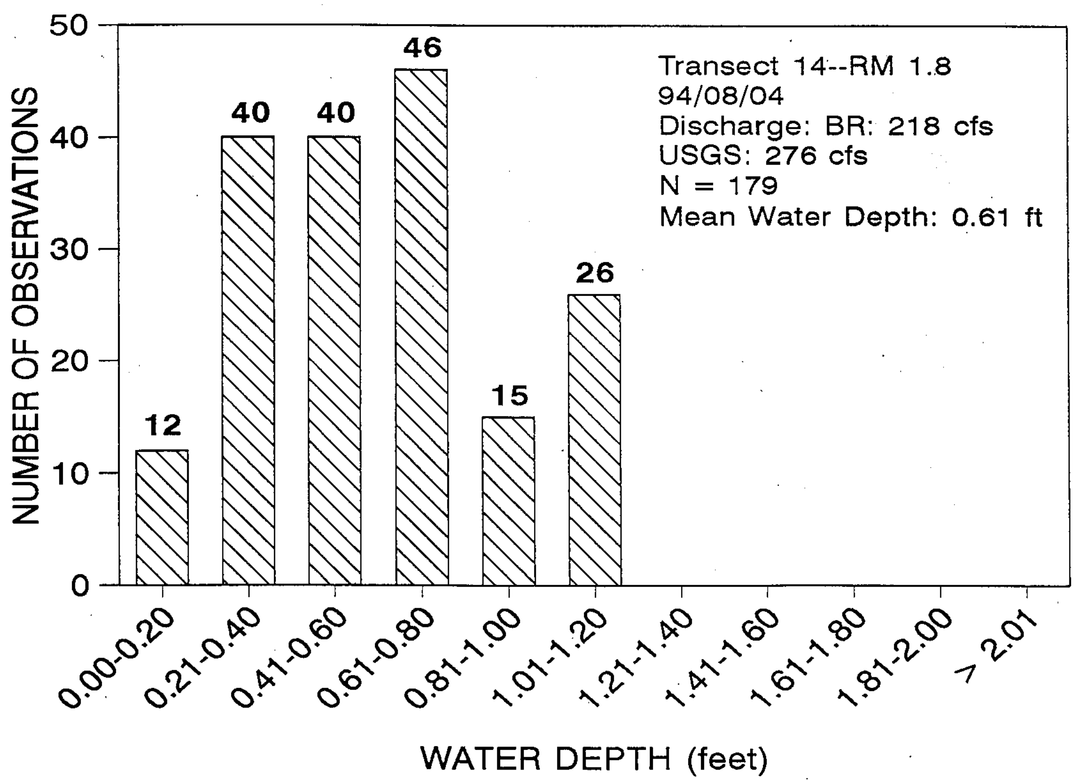


Figure G.9. River profile (top) and the distribution of water depths (feet) observed by 0.2-foot increments (bottom) for transect 14, river mile 1.8, Gunnison River, Colorado, 4 August 1994.

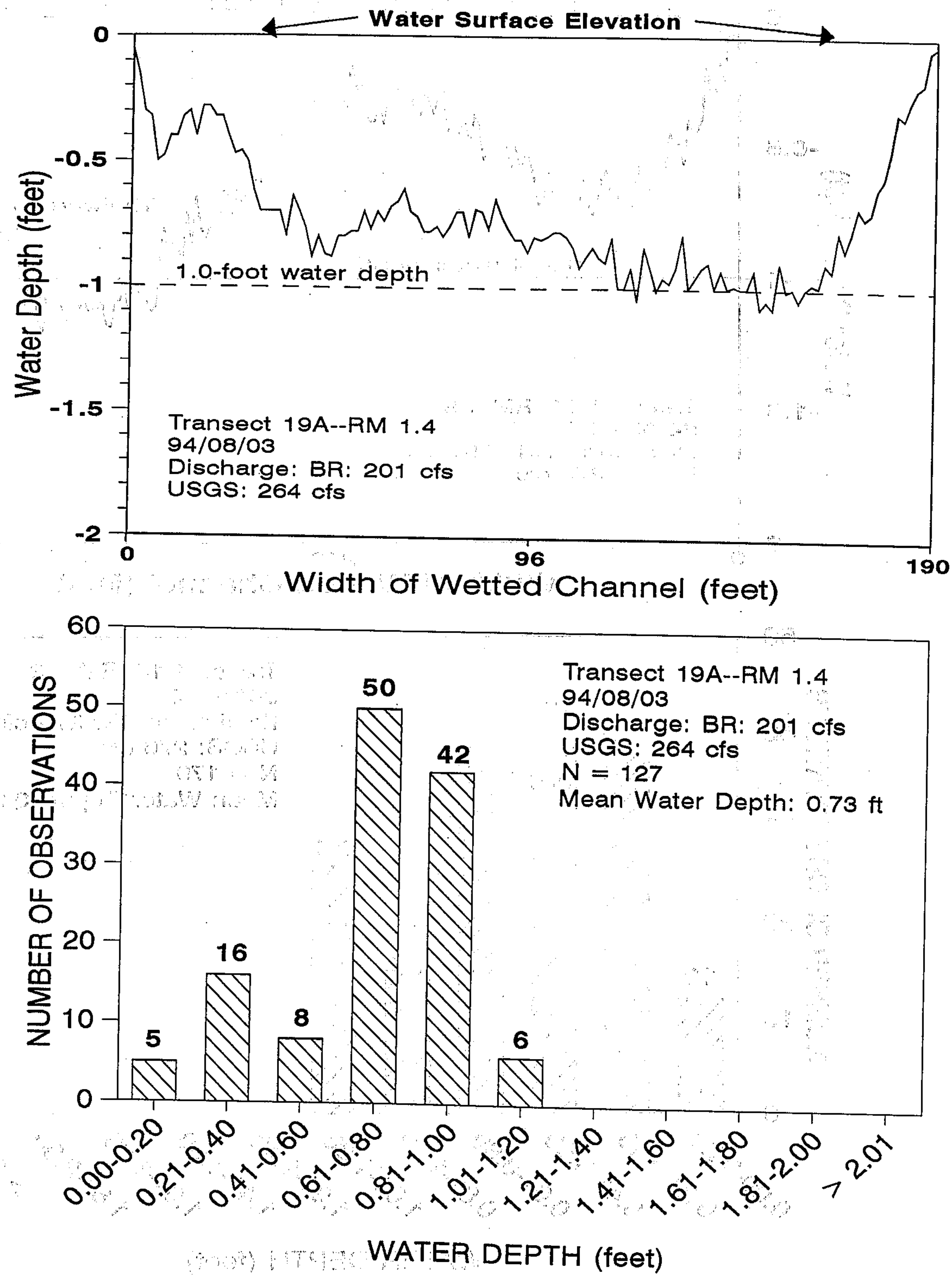


Figure G.10. River profile (top) and the distribution of water depths (feet) observed by 0.2-foot increments (bottom) for transect 19A, river mile 1.4, Gunnison River, Colorado, 3 August 1994.

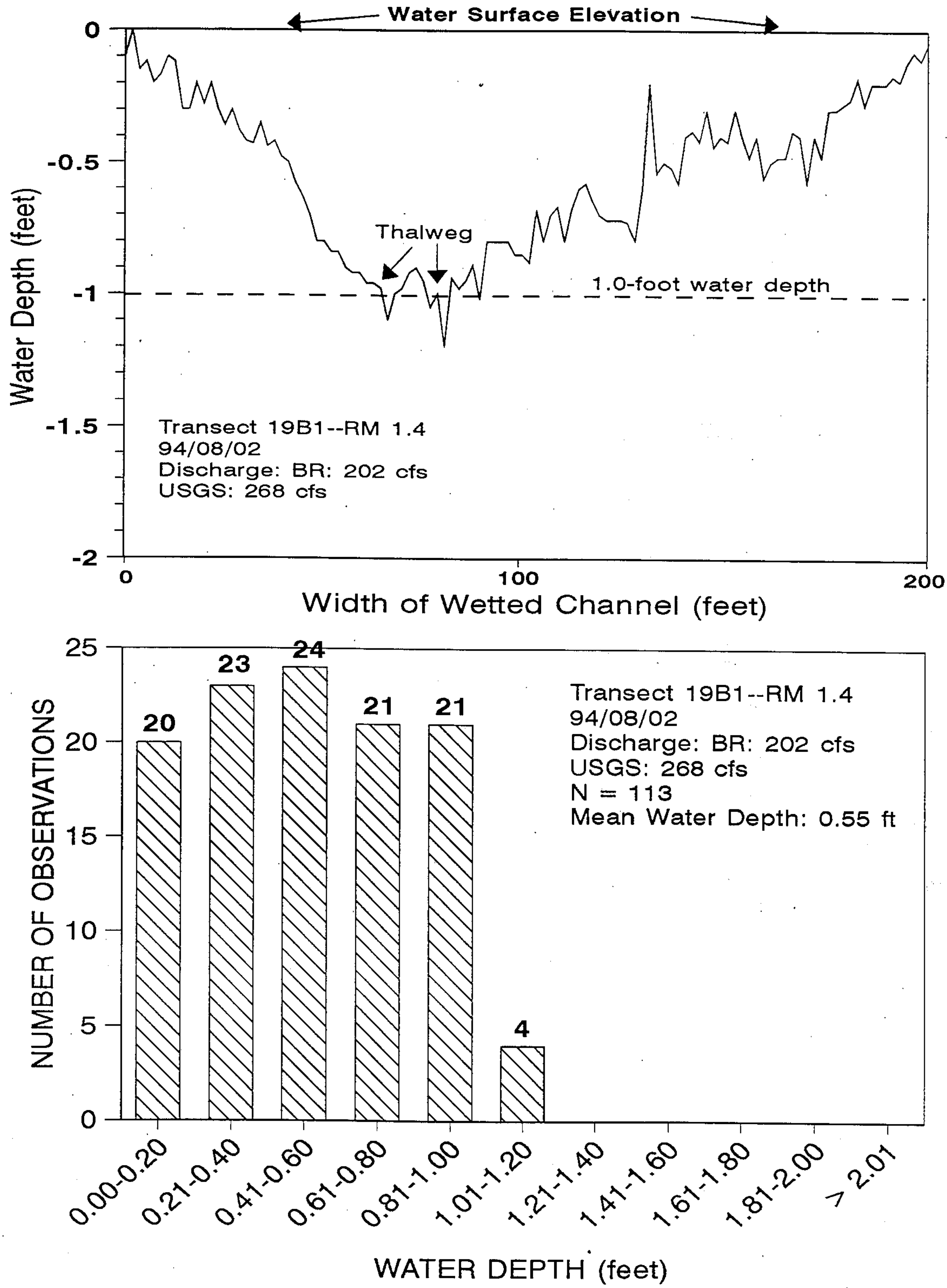


Figure G.11. River profile (top) and the distribution of water depths (feet) observed by 0.2-foot increments (bottom) for transect 19B1, river mile 1.4, Gunnison River, Colorado, 2 August 1994.

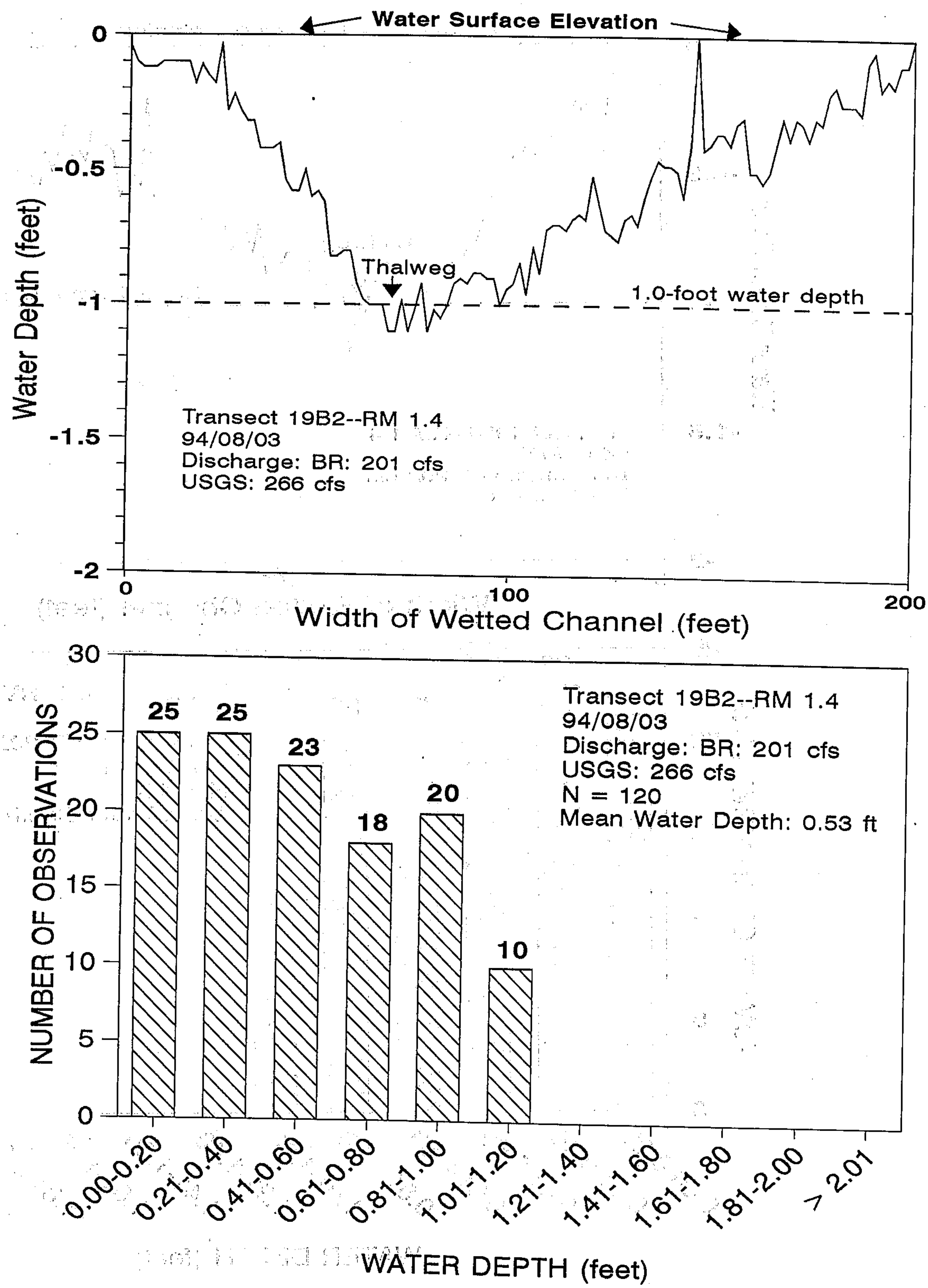


Figure G.12. River profile (top) and the distribution of water depths (feet) observed by 0.2-foot increments (bottom) for transect 19B2, river mile 1.4, Gunnison River, Colorado, 3 August 1994.

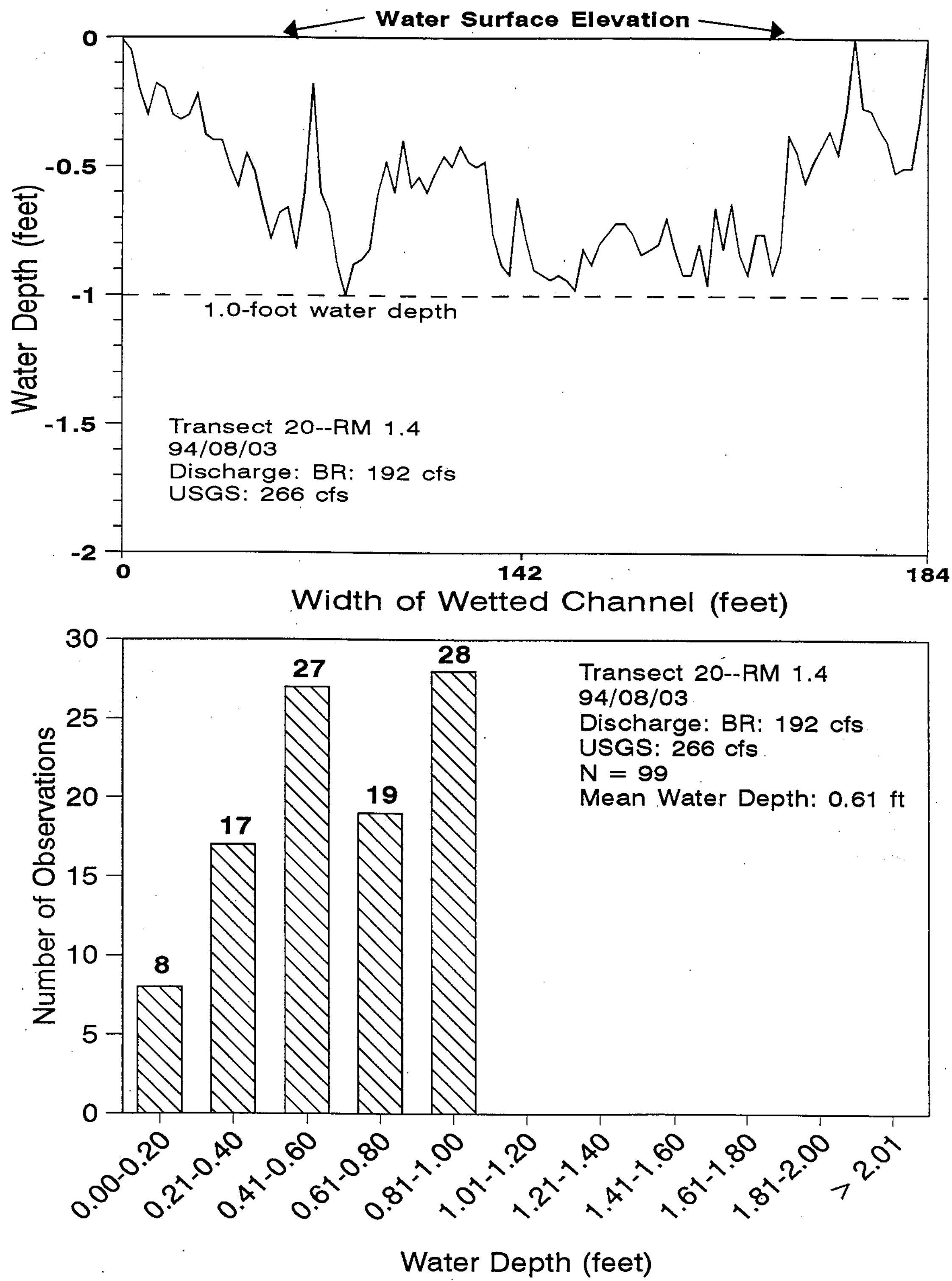


Figure G.13. River profile (top) and the distribution of water depths (feet) observed by 0.2-foot increments (bottom) for transect 20, river mile 1.4, Gunnison River, Colorado, 3 August 1994.

APPENDIX H

Mean Daily Flow Exceedences By Month
for the Gunnison River at the USGS Whitewater Gage
for the Water Development Period, 1967-1994

Table H.1. Frequency of time 300 cfs or less has occurred in the 2.3-mile reach of the lower Gunnison River between Redlands Diversion Dam and the confluence with the Colorado River during three water development periods, 1917-1994. For the 1965-1994 period, refer to Appendix; Figures H.1.-H.6. for monthly exceedences.

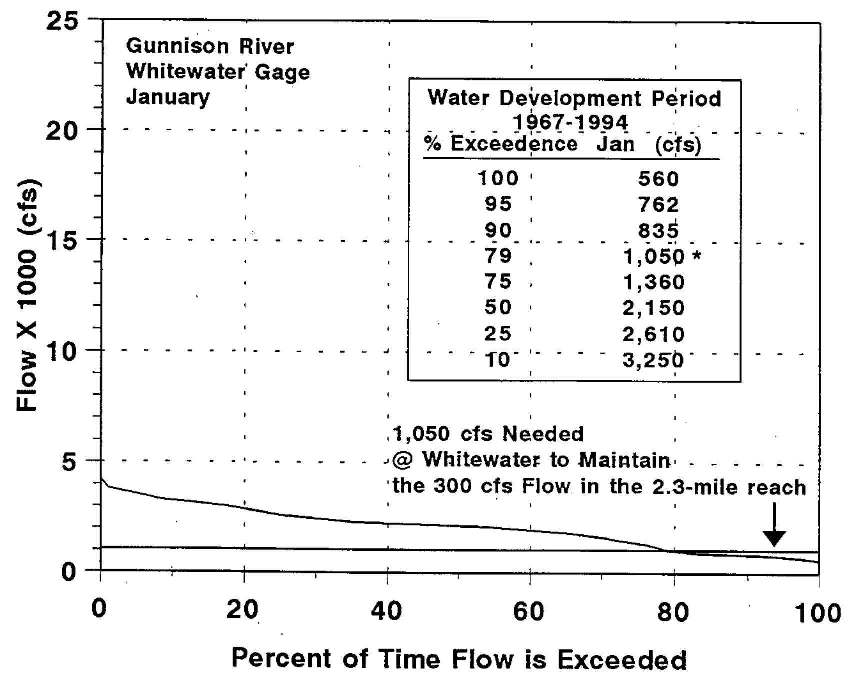
Month	Water Development Period 1917-1938	1939-1964	1965-1994
October	42 %	52 %	18 %
November	25 %	32 %	18 %
December	59 %	69 %	13 %
January	81 %	85 %	21 %
February	67 %	81 %	23 %
March	39 %	70 %	20 %
April	10 %	19 %	12 %
May	0.1%	0.3%	5 %
June	5 %	5 %	8 %
July	27 %	42 %	35 %
August	58 %	62 %	40 %
September	67 %	67 %	19 %

Table H.2. Summary of total annual discharge, mean daily discharge for June, July, August, September, and October, and the frequency and duration streamflows were 0 cfs or less than or equal to 300 cfs in the 2.3-mile reach of the lower Gunnison River between the Redlands Diversion Dam and the confluence with the Colorado River. Data were analyzed for the post-Aspinall water development period, 1967-1995; the USGS stream gage at Whitewater was used. Note: the total annual discharge is for the Gunnison River at the Whitewater USGS gage; mean daily discharge for the 2.3-mile reach was determined by substracting 750 cfs, the flow diverted for the Redlands Canal, from the discharge at the Whitewater gage.

Water Year	Gunnison River @ Whitewater Total Annual Discharge (cfs)	Mean Daily Discharge (cfs) for 4 months combined JUN JUL AUG SEP	2.3-Mile Reach: Mean Daily Discharge (cfs) JUL & AUG	SEP & OCT	No. of Days Discharge was ≤ 300 cfs JUL & AUG	SEP & OCT	Duration Which Discharge Was ≤ 300 cfs	No. of Days Discharge was 0 cfs JUL & AUG	SEP & OCT	Duration Which Discharge Was 0 cfs
1967	446,961	658	216	369	47	30	1 JUL-31 AUG 1 SEP-20 OCT	24	6	5 JUL-31 AUG 1 SEP- 8 SEP
1968	727,993	1,284	604	524	35	19	4 JUL-31 AUG 1 SEP-30 OCT	0	0	...
1969	945,294	1,334	803	1,516	9	0	10 JUL-28 AUG	0	0	...
1970	1,136,067	2,906	1,487	2,421	0	0	...	0	0	...
1971	1,121,461	1,618	1,104	1,338	5	0	14 JUL-16 AUG	0	0	...
1972	604,732	391	0	806	60	6	1 JUL-31 AUG 15 SEP- 6 SEP	61	1	30 JUN-31 AUG 1 SEP
1973	1,050,126	2,702	1,784	1,188	0	0	...	0	0	...
1974	856,674	406	13	482	59	14	1 JUL-31 AUG 1 SEP-14 SEP	41	0	3 JUL-31 AUG
1975	915,612	1,609	1,101	784	22	9	6 AUG-30 AUG 1 SEP- 9 SEP	0	0	...
1976	662,538	509	97	604	58	6	4 AUG-31 AUG 1 SEP- 9 SEP	17	0	1 JUL-31 AUG
1977	389,599	0	0	707	60	61	1 JUL-31 AUG 1 SEP-31 OCT	56	34	1 JUL-31 AUG 1 SEP-10 OCT
1978	663,794	1,736	890	517	25	21	2 AUG-31 AUG 1 SEP-20 OCT	2	10	8 AUG- 9 AUG 5 OCT-14 OCT
1979	1,181,170	2,471	1,517	1,049	0	0	...	0	0	...
1980	1,134,037	2,104	947	1,130	6	29	1 SEP-29 OCT 12 AUG-31 AUG	0	0	...
1981	535,059	335	131	729	45	6	1 JUL-31 AUG 27 SEP- 2 SEP	23	0	1 JUL-29 AUG
1982	859,292	958	1,258	1,913	0	0	...	0	0	...
1983	1,586,820	6,022	4,938	1,583	0	0	...	0	0	...

Table H.2. (cont'd). Summary of total annual discharge, mean daily discharge for June, July, August, September, and October, and the frequency and duration streamflows were 0 cfs or less than or equal to 300 cfs in the 2.3-mile reach of the lower Gunnison River between the Redlands Diversion Dam and the confluence with the Colorado River. Data were analyzed for the post-Aspinall water development period, 1967-1995; the USGS stream gage at Whitewater was used. Note: the total annual discharge is for the Gunnison River at the Whitewater USGS gage; mean daily discharge for the 2.3-mile reach was determined by substracting 750 cfs, the flow diverted for the Redlands Canal, from the discharge at the Whitewater gage.

	Gunnison River @ Whitewater	2.3-Mile Reach								
Water Year	Total Annual Discharge (cfs)	Mean Daily Discharge (cfs) for 4 months combined JUN JUL AUG SEP	Mean Daily Discharge (cfs) JUL & AUG	Mean Daily Discharge (cfs) SEP & OCT	No. of Days Discharge was ≤ 300 cfs JUL & AUG	No. of Days Discharge was ≤ 300 cfs SEP & OCT	Duration Which Discharge Was ≤ 300 cfs	No. of Days Discharge was 0 cfs JUL & AUG	No. of Days Discharge was 0 cfs SEP & OCT	Duration Which Discharge Was 0 cfs
1984	1,898,500	5,918	1,045	2,164	0	0	---	0	0	---
1985	1,592,410	2,956	1,646	2,036	0	0	---	0	0	---
1986	1,457,810	3,175	2,763	2,548	0	0	---	0	0	---
1987	1,248,920	1,672	1,404	1,255	0	0	---	0	0	---
1988	693,102	504	118	588	52	5	8 JUL-31 AUG 5 OCT-31 OCT	15	0	16 JUL-23 AUG
1989	456,030	343	154	546	50	6	1 JUL-31 AUG 1 SEP- 8 SEP	21	0	30 JUN-10 AUG
1990	386,049	365	122	561	57	11	1 JUL-31 AUG 1 SEP-13 SEP	16	0	28 JUN-31 AUG
1991	726,850	1,897	1,062	1,329	0	3	10 OCT-12 OCT	0	0	---
1992	770,910	1,225	1,011	904	0	0	---	0	0	---
1993	1,359,561	3,442	1,968	1,583	0	0	---	0	0	---
1994	784,395	945	519	979	14	0	27 JUL- 9 AUG	0	0	---
1995	1,624,310	6,888	6,806	1,875	0	0	---	0	0	---
Totals Frequency	---	---	---	---	604 33.6%	226 12.8%	---	276 15.4%	51 2.9%	---



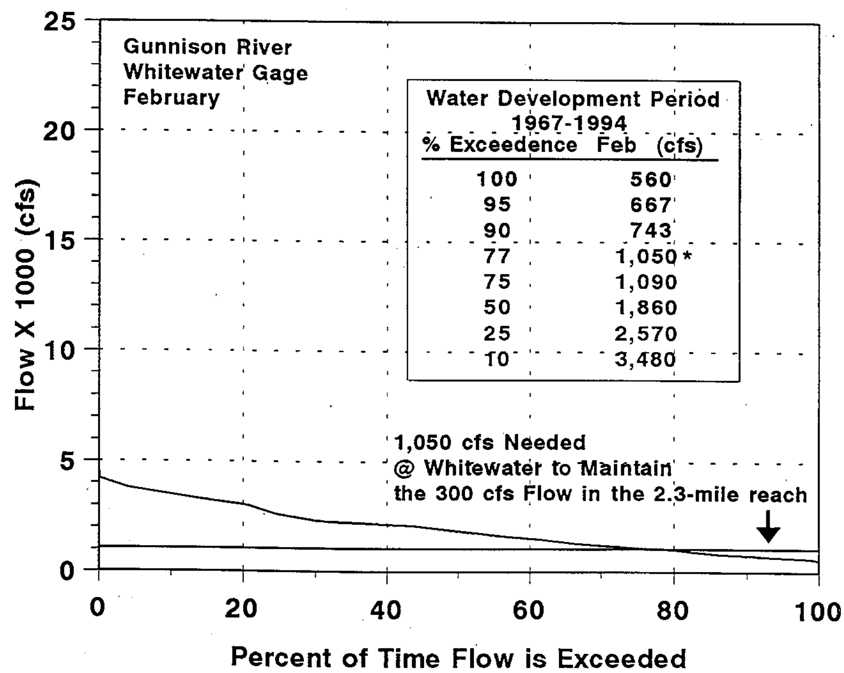
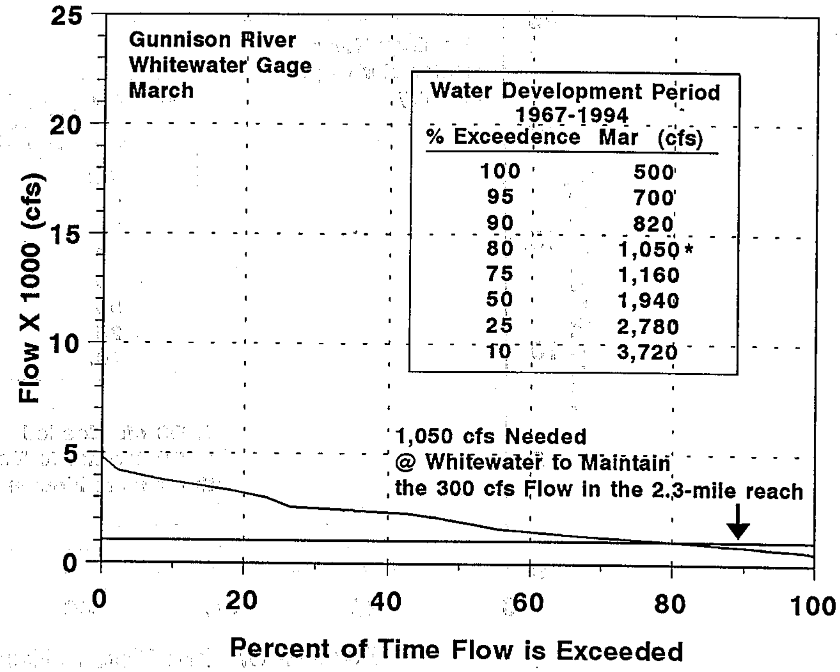


Figure H.1. Mean daily flow exceedences for January (top) and February (bottom) for the Gunnison River at the Whitewater USGS stream gage during the post-water development period, 1967-1994. The horizontal line at 1,050 represents the minimum amount of water (cfs) needed at the USGS stream gage at Whitewater to provide a minimum of 300 cfs in the 2.3-mile reach of the lower Gunnison River immediately downstream of Redlands Diversion Dam. This assumes that Redlands Canal withdraws at least 750 cfs from the river, thus 750+300=1,050.



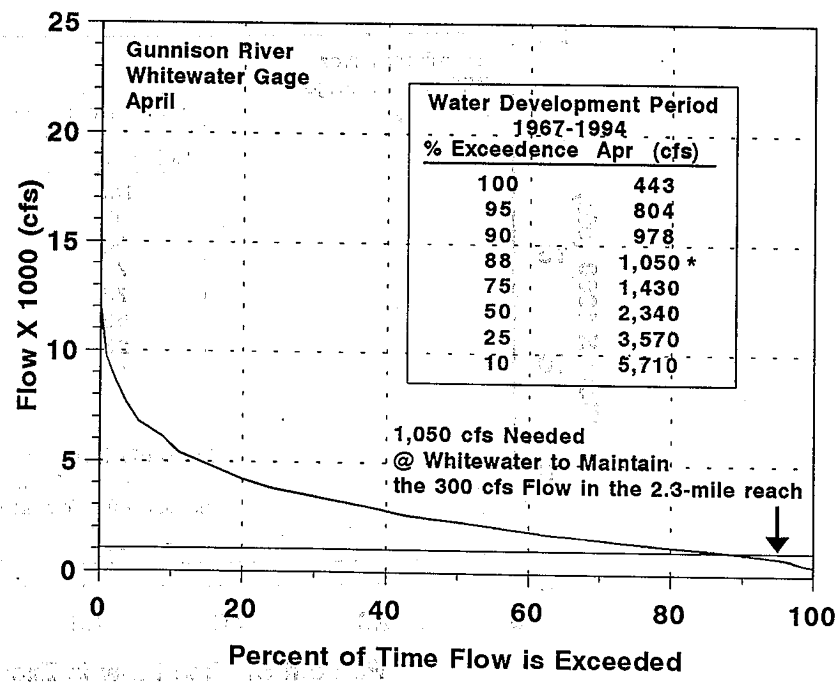


Figure H.2. Mean daily flow exceedences for March (top) and April (bottom) for the Gunnison River at the Whitewater USGS stream gage during the post-water development period, 1967-1994. The horizontal line at 1,050 represents the minimum amount of water (cfs) needed at the USGS stream gage at Whitewater to provide a minimum of 300 cfs in the 2.3-mile reach of the lower Gunnison River immediately downstream of Redlands Diversion Dam. This assumes that Redlands Canal withdraws at least 750 cfs from the river, thus 750+300=1,050.

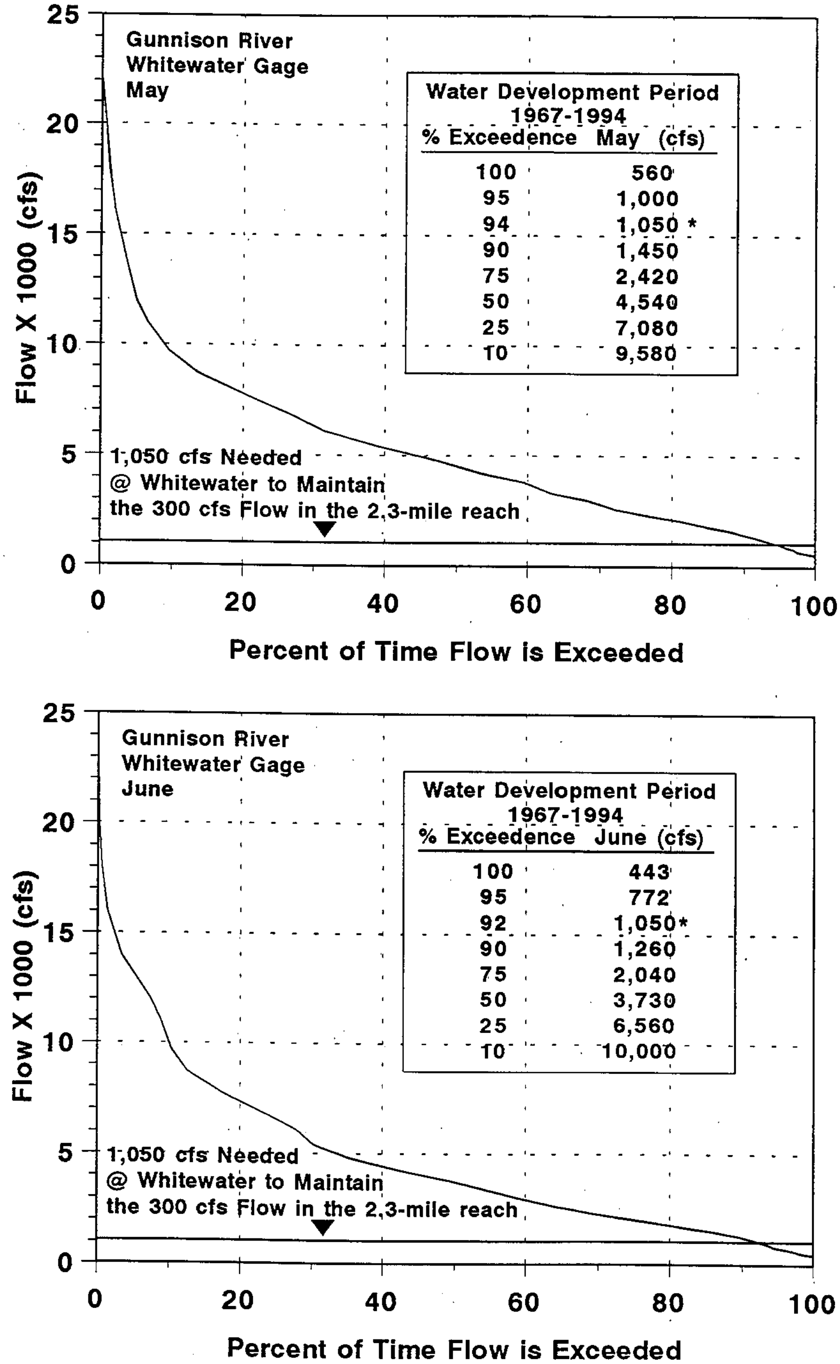
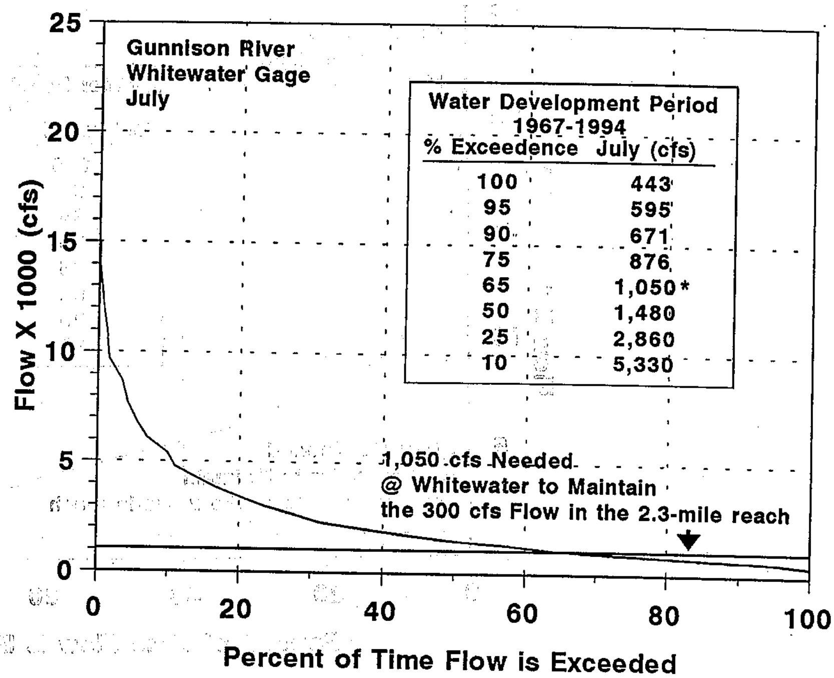


Figure H.3. Mean daily flow exceedences for May (top) and June (bottom) for the Gunnison River at the Whitewater USGS stream gage during the post-water development period, 1967-1994. The horizontal line at 1,050 represents the minimum amount of water (cfs) needed at the USGS stream gage at Whitewater to provide a minimum of 300 cfs in the 2.3-mile reach of the lower Gunnison River immediately downstream of Redlands Diversion Dam. This assumes that Redlands Canal withdraws at least 750 cfs from the river, thus 750+300=1,050.



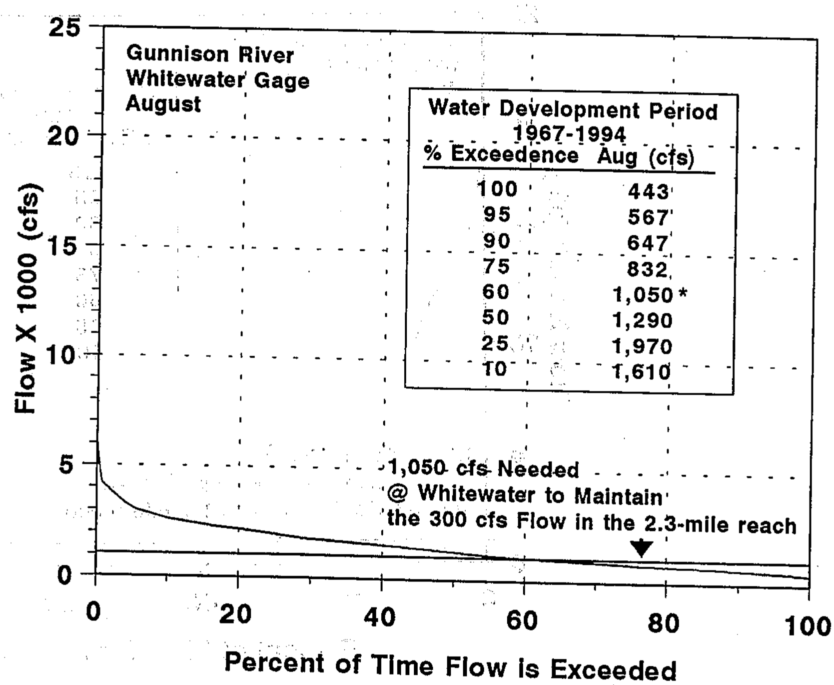
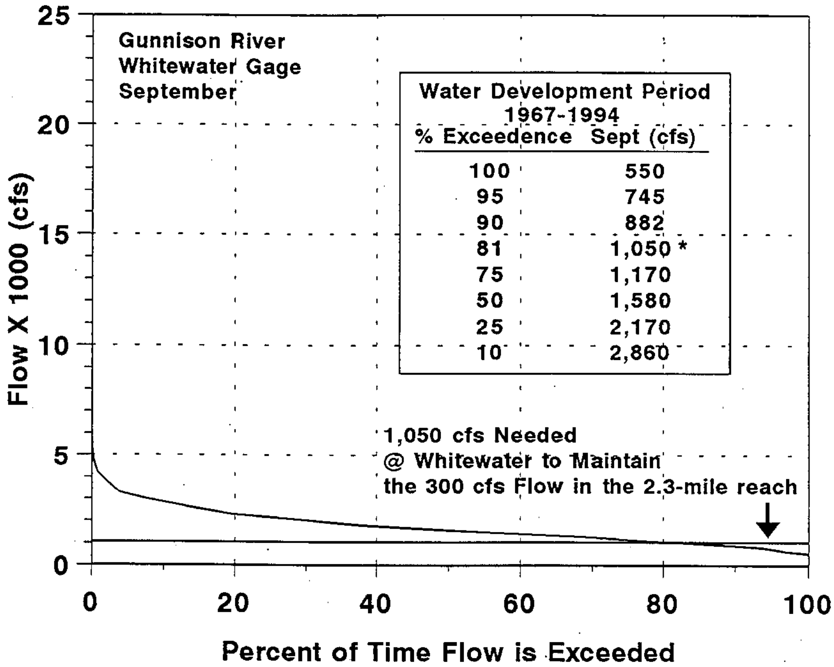


Figure H.4. Mean daily flow exceedences for July (top) and August (bottom) for the Gunnison River at the Whitewater USGS stream gage during the post-water development period, 1967-1994. The horizontal line at 1,050 represents the minimum amount of water (cfs) needed at the USGS stream gage at Whitewater to provide a minimum of 300 cfs in the 2.3-mile reach of the lower Gunnison River immediately downstream of Redlands Diversion Dam. This assumes that Redlands Canal withdraws at least 750 cfs from the river, thus 750+300=1,050.



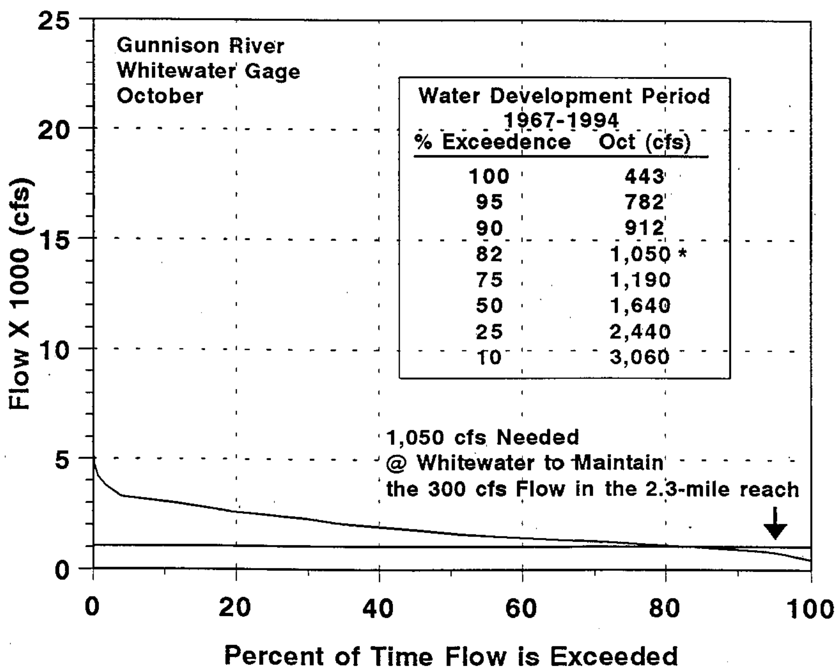


Figure H.5. Mean daily flow exceedences for September (top) and October (bottom) for the Gunnison River at the Whitewater USGS stream gage during the post-water development period, 1967-1994. The horizontal line at 1,050 represents the minimum amount of water (cfs) needed at the USGS stream gage at Whitewater to provide a minimum of 300 cfs in the 2.3-mile reach of the lower Gunnison River immediately downstream of Redlands Diversion Dam. This assumes that Redlands Canal withdraws at least 750 cfs from the river, thus 750+300=1,050.

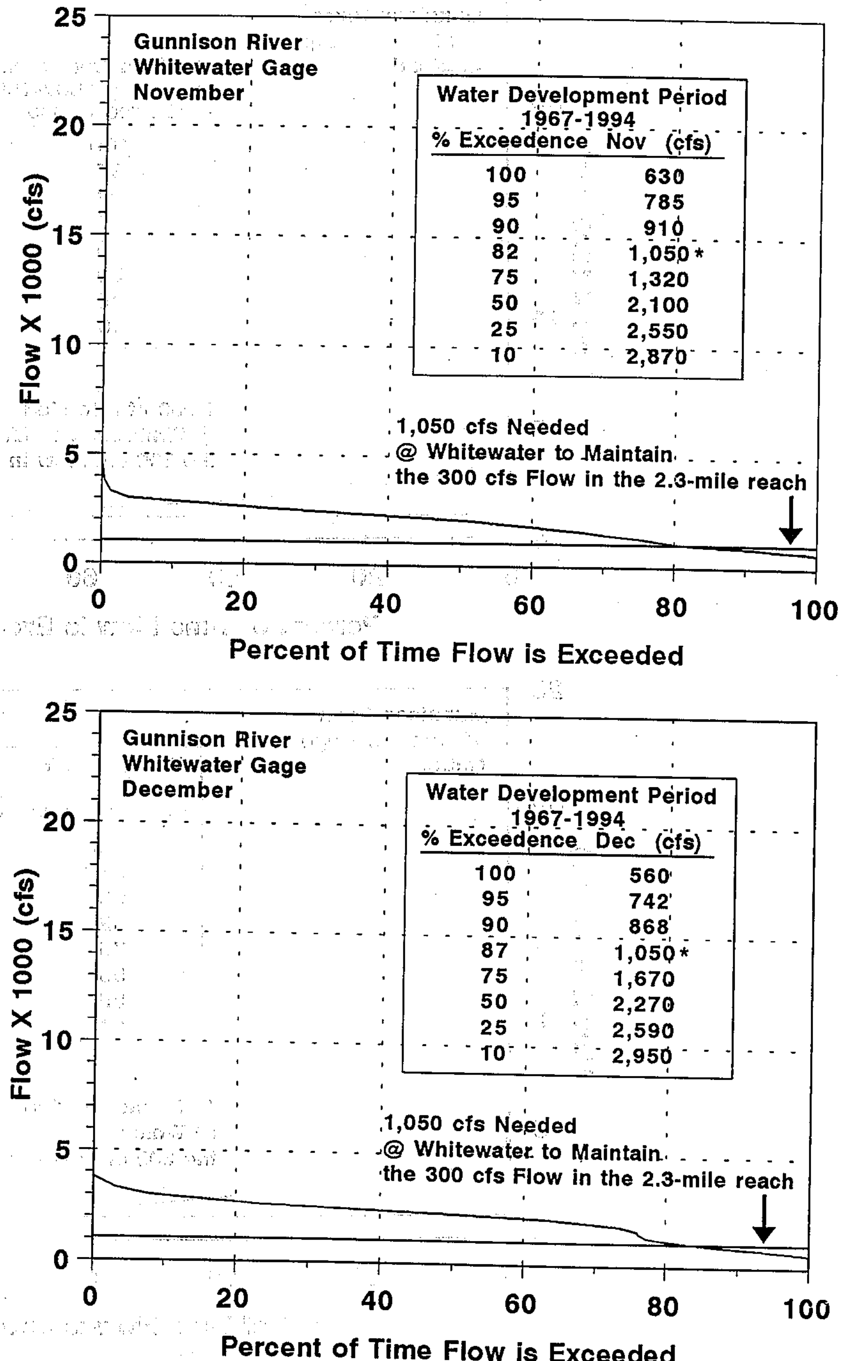


Figure H.6. Mean daily flow exceedences for November (top) and December (bottom) for the Gunnison River at the Whitewater USGS stream gage during the post-water development period, 1967-1994. The horizontal line at 1,050 represents the minimum amount of water (cfs) needed at the USGS stream gage at Whitewater to provide a minimum of 300 cfs in the 2.3-mile reach of the lower Gunnison River immediately downstream of Redlands Diversion Dam. This assumes that Redlands Canal withdraws at least 750 cfs from the river, thus 750+300=1,050.

APPENDIX I

Comparison of Mean Daily Flow by 10-Day Increments for Four Low Water Years, 1917-1938, and Five Low and Five Moderate Water Years, 1967-1995

Table I.1. Comparison of the mean daily flow (cfs) by 10- and 11-day increments from 1 May to 31 October during low- and moderate-water years in the 2.3-mile reach of the lower Gunnison River between Redlands Diversion Dam and the confluence with the Colorado River. The post-Aspinall water development period, 1967-1995, was analyzed. Refer to Figures 8 and 9 for graphic display of these flows.

Time Period	Low-Water Years: Mean of 5 Years 1972, '77, '81, '89, '90	Low-Water Years: 1990[a]	Moderate-Water Years: Mean of 5 Years 1969, '73, '75, '82, '92	Moderate-Water Years: 1992[b]
MAY 1-10	774	925	4,051	2,701
11-20	849	637	5,772	3,808
21-31	972	1,160	5,236	3,995
JUN 1-10	1,172	1,220	4,493	3,067
11-20	856	979	3,996	1,828
21-30	377	154	2,988	1,314
JUL 1-10	43	194	2,017	942
11-20	130	167	1,281	1,116
21-31	156	191	984	1,106
AUG 1-10	101	193	876	846
11-20	250	482	986	842
21-31	114	229	1,038	1,188
SEP 1-10	255	174	861	966
11-20	524	482	1,284	770
21-30	504	680	1,220	725
OCT 1-10	529	856	1,112	860
11-20	772	558	1,394	974
21-31	638	536	1,661	1,111

[a] Considered a low, low-water year on the Gunnison River following construction of the Aspinall Unit based on total annual discharge at the USGS streamflow gage at Whitewater.

[b] Considered a low, moderate-water year on the Gunnison River following construction of the Aspinall Unit based on total annual discharge at the USGS streamflow gage at Whitewater.

Table I.2. Comparison of the mean daily flow (cfs) by 10- and 11-day increments from 1 May to 31 October during four of the lowest water years in the pre-water development period, 1917-1938, in the 2.3-mile reach of the lower Gunnison River between Redlands Diversion Dam and the confluence with the Colorado River. Refer to Appendix; Figure I.1. for graphic display of these flows.

	2.3-Mile Reach	
	Low-Water Years	
	Mean of 4 Years	
Time Period	1931, '34, '35, '37[a]	1934[b]
MAY 1-10	3,235	2,725
11-20	5,106	2,602
21-31	4,019	1,193
JUN 1-10	3,801	491
11-20	4,179	0
21-30	3,149	0
JUL 1-10	1,023	0
11-20	413	0
21-31	233	0
AUG 1-10	58	0
11-20	33	0
21-31	25	0
SEP 1-10	41	0
11-20	4	0
21-30	57	0
OCT 1-10	277	0
11-20	242	0
21-31	315	0

[a] Total annual discharge (cfs) for the Gunnison River at the Whitewater USGS gage: 1931=396,683; 1934=305,987; 1935=699,169; 1937=754,188.

[b] Considered a low, low-water year on the Gunnison River during the pre-water development period based on total annual discharge at the USGS streamflow gage at Whitewater.

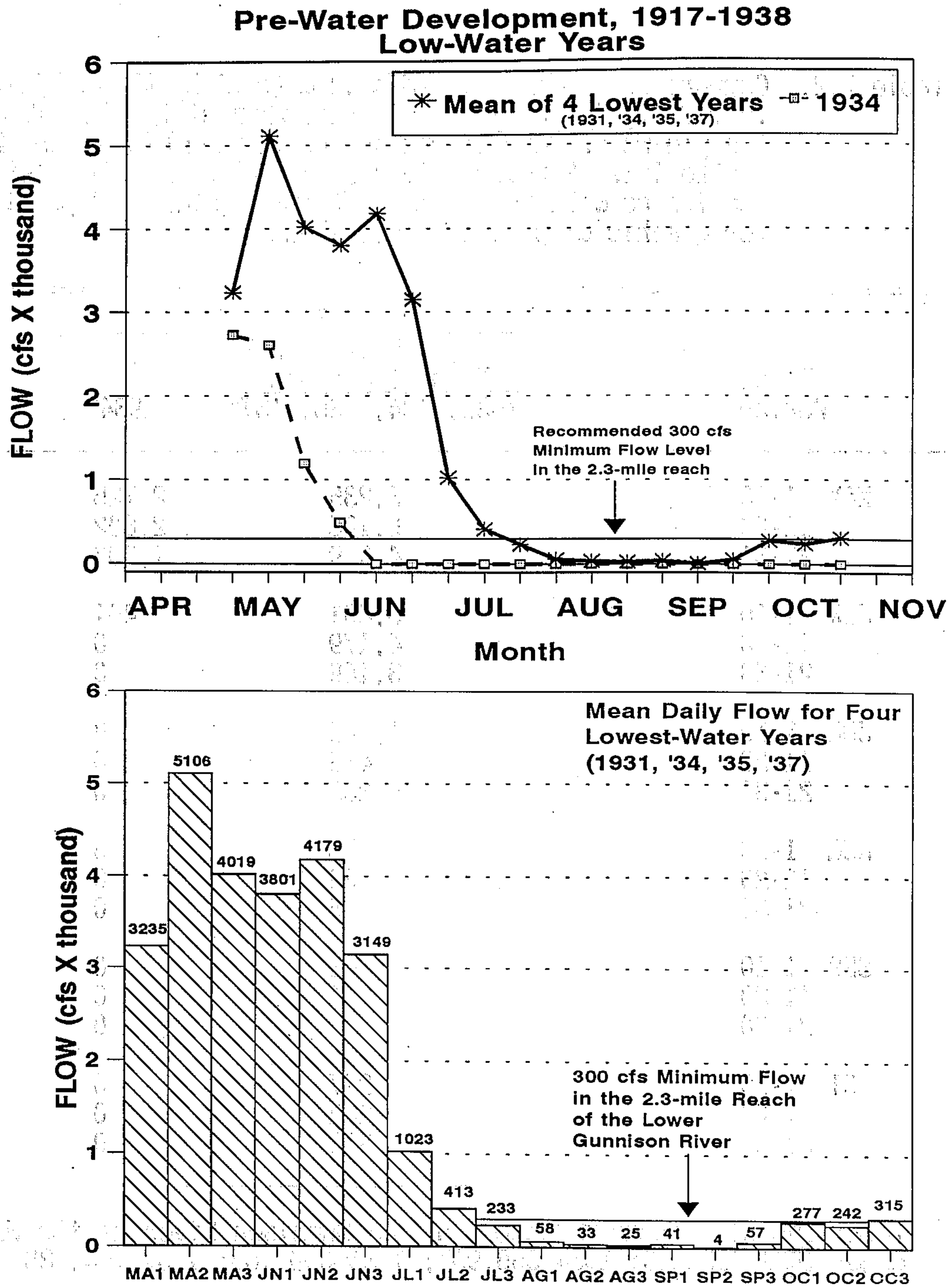


Figure I.1. Mean daily flow (cfs) and shape of the hydrograph for four lowest-water years (1931, 1934, 1935, and 1937) compared to 1934, a low, low-water year from 1 May to 31 October in the 2.3-mile reach of the lower Gunnison River between the Redlands Diversion Dam and the confluence with the Colorado River. The bottom figure represents the mean daily flow for 1 May through 31 October for the 2.3-mile reach by 10- and 11-day step increments, e.g., May 1-10, May 11-20, May 21-31, etc.

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