Arkansas River Water Needs Assessment

Appendices

Arkansas River
Water Needs Assessment

Appendices

July 2000

Table of Contents

Appendix A.
Memorandum of Understanding

U.S.D.I. BUREAU OF LAND MANAGEMENT
U.S.D.I. BUREAU OF RECLAMATION
U.S.D.A. FOREST SERVICE
COLORADO DEPARTMENT OF NATURAL RESOURCES

CO-050-138-8350

BACKGROUND AND PURPOSE

The Arkansas River and its related reservoirs between Leadville and Pueblo are an important hydrological, biological, and recreational resource. Competing demands for water have made it necessary for management agencies to thoroughly understand and carefully weigh the tradeoffs associated with decisions that affect water uses, stream flows, and reservoir levels. Current and comprehensive information is essential to support sound decision making.

The study area for the Arkansas River Water Needs Assessment comprises Twin Lakes, Turquoise and Clear Creek Reservoirs; the mainstem of the Arkansas River downstream from Leadville to the dam at Pueblo Reservoir; and Pueblo Reservoir.

The Parties to this Memorandum of Understanding (MOU) affirm the need for cooperation and collaboration in developing an understanding of the water resource values, as identified herein, and related management objectives within the study area. The Parties, acknowledging their various authorities and management responsibilities, agree to design and conduct cooperative evaluations of water-dependent resource values within the study area.

The Parties affirm that the Colorado Constitution recognizes the doctrine of prior appropriation as the principle means of allocating the usage of the waters of the State. Around this doctrine a body of law has been developed to protect property rights in water usage, including the right to determine management practices that are in the best interests of water right holders. The Parties recognize that numerous water rights exist and are held by various entities whose interests lie within the study area and who rely upon these protections. The Parties agree that the Water Needs Assessment should not be used to justify actions that result in injury to water right owners.

PROJECT OBJECTIVES

The primary objective of the Water Needs Assessment is to provide useful information (a data base) about resource needs, water use constraints, and management opportunities to planners and decision makers. Specific objectives of the Assessment are:

1. Develop an understanding of the hydrology and geomorphology of the river, and the reservoir operations that affect the river flows.

2. Develop an understanding of the relationships between streamflows, reservoir levels, and the resource values they affect. The resource values to be considered include: fish and wildlife habitat; fishing recreation; boating recreation; water quality; riparian habitat; and aesthetics.

3. Identify and evaluate the management opportunities and strategies to provide water for maintaining and improving the resource values.

4. Determine the physical, legal, and institutional factors that influence the ability to implement the management opportunities and strategies.

RESPONSIBILITIES

1. In order to meet these objectives, the Parties agree to develop an Arkansas River Water Needs Assessment Project Statement of Work. The Statement will be a plan of study that includes the following investigations:

(a) preliminary assessment and detailed study design;

(b) hydrologic investigation of streamflow and reservoir levels;

(c) evaluation of flow- and reservoir level- dependent resource values and the flows and levels required to support those values;

(d) analysis of the legal and institutional framework for providing stream flows and maintaining reservoir levels; and

(e) presentation of opportunities for providing and maintaining desired flows and water levels, including scenarios that describe tradeoffs associated with a range of management options.

2. The Parties are to meet as necessary to develop the study design, coordinate work on the study, and evaluate progress. Each signer of this MOU will designate a person to act in their behalf. Exhibit 1 lists the persons responsible for coordinating the study activities included in this MOU.

3. The Parties will discuss and concur on specific work tasks to be performed under this MOU. The Parties will address other study-related matters, such as administration, subcontracting, and publications, in the Project Statement of Work.

4. The Parties agree to cooperate in supporting this project through funding, personnel, and other means; however, this MOU does not commit any Party to any specific commitment of funds, personnel, or other assistance. Participation by the Parties in the Water Needs Assessment will reflect their expertise and their ability to participate given the resources available to them through normal budget processes.

5. The Parties agree to consult with and keep informed the water users, recreational interests, local governments, and others during the development and implementation of the Water Needs Assessment.

GENERAL PROVISIONS

1. This memorandum shall be effective from the date of latest signature and shall continue in force for a period of five years unless mutually or unilaterally terminated.

2. Any party may withdraw from this MOU upon thirty (30) days notice to the other signatory agencies. Any separate Purchase Order or Contract entered into relating to this memorandum shall not affect this memorandum.

3. Changes or modifications of this memorandum may be initiated by any party. The changes or modification shall not be incorporated until all Parties agree, they are specified in an amendment to the memorandum, and signed by all Parties.

4. No member of or delegate to Congress, or resident commissioner, shall be admitted to any share or part of the MOU, or to any benefit that may arise therefrom; but this provision shall not be construed to extend to this MOU if made with a corporation for its general benefit.

5. During the performance of activities and projects initiated pursuant to this MOU, or any separate agreement entered into pursuant to this MOU, the Parties agree to abide by the terms of Executive Order 11246 on non-discrimination and will not discriminate against any person because of race, color, religion, sex, or national origin. The Parties will take affirmative action to ensure that applicants are employed without regard to their race, color, religion, sex, or national origin.

SIGNATURES

Bob Moore — 7/17/92

U.S.D.I. Bureau of Land Management
State Director, Colorado — Date

Neil Stessman — July 22, 1992

U.S.D.I. Bureau of Reclamation
Regional Director, Great Plains Region — Date

John Marrson Jr. — 8/13/92

U.S.D.A. Forest Service
Regional Forester, Rocky Mountain Region — Date

Ken Salazar — 7/17/92

Colorado Department of Natural Resources
Executive Director — Date

Appendix B.
Annual Flow Recommendation Letter to BOR

STATE OF COLORADO

OFFICE OF THE EXECUTIVE DIRECTOR
Department of Natural Resources
1313 Sherman Street, Room 718
Denver, Colorado 80203
Phone: (303) 866-3311
TDD: (303) 866-3543
Fax: (303) 866-2115

DEPARTMENT OF NATURAL RESOURCES

Bill Owens
Governor

Greg E. Walcher
Executive Director

April 7, 2000

Gerald Kelso
Eastern Colorado Area Office
U.S. Bureau of Reclamation
11056 West County Road 18E
Loveland, CO 80537-9711

Re: 2000-2001 Flow Recommendation for the Upper Arkansas

Dear Mr. Kelso:

The Colorado Department of Natural Resources (DNR) appreciates the Bureau of Reclamation's and the Southeastern Colorado Water Conservancy District's continued cooperation with the implementation of an annual flow program for fisheries and rafting in the Upper Arkansas River Basin, consistent with the operation of the Frying Pan-Arkansas Project. We are once again submitting this year's recommendations for the annual flow management program for the Upper Arkansas River. This request covers the period from May 2000 to May 2001. This request is supported by the managers of the Arkansas Headwaters Recreation Area.

These recommendations are intended to provide an annual flow regime that helps the state maintain the brown trout fishery, meet the demand for boating recreation, support the region's tourism industry, and allow the managers of the Arkansas Headwaters Recreation Area to meet their obligation to manage recreation and natural resources within the area's boundaries.

As always, the DNR recognizes that the implementation of these flow management recommendations will be subordinate to the rights of water owners and water users, and must not impair their associated diversions, storage, or exchanges of water. All flows recommended here should be measured at the Wellsville gauge.

The DNR is also aware that an Arkansas River Water Needs Assessment is being completed by the Bureau of Land Management and may be released later this year. Once this document is finished we may review our recommendations in light of its information. However, we do not believe that its completion alone will alleviate the need for the DNR to request continuation of the voluntary flow program.

Board of Land Commissioners • Division of Minerals & Geology/Geological Survey
Oil & Gas Conservation Commission • Colorado State Parks • Soil Conservation Board
Water Conservation Board • Division of Water Resources • Division of Wildlife

Gerald Kelso
April 7, 2000
Page 2

Specifically, with respect to the 2000-2001 flow program, we recommend that:

1. The highest priority is the maintenance of a minimum year-round flow of at least 250 cfs to protect the fishery. (This priority remains unchanged from those of previous years.)

2. Winter incubation flows (mid November through April) should be maintained at a level of not more than 5 inches below river height during the spawning period (October 15 to November 15). The optimum flow range is from 250 to 400 cfs, depending on spawning flows (this priority remains unchanged from those of previous years):

Minimum Incubation Flow		*Spawning Flow*
Nov. 16 - Apr. 30		*Oct. 15 - Nov. 15*
250 cfs	*IF*	*300 - 500 cfs*
325 cfs	*IF*	*500 - 600 cfs*
400 cfs	*IF*	*600 - 700 cfs*

3. To the extent possible, between April 1 and May 15, Reclamation should maintain flows within the range of 250 to 400 cfs in order to provide conditions favorable to egg hatching and fry emergence. (This priority remains unchanged from those of previous years.)

4. Deliveries in excess of 10,000 acre-feet should be subject to review and consideration, prior to such deliveries, by the Bureau and the District.

5. Subject to water and storage availability, Reclamation should augment flows during the July 1 to August 15 period at 700 cfs through releases from the Fry-Ark Project. The 700 cfs level is a target; when augmentation occurs, every effort should be made to ensure that flows are as little above, or as little below, 700 cfs as possible. The Division of Parks and Outdoor Recreation, using funds collected from commercial outfitters, shall be responsible for replacing evaporative losses caused by summer augmentation. (This priority remains unchanged from those of previous years.)

6. Reclamation should avoid dramatic fluctuations on the river as much as possible throughout the year. When it is necessary to alter flow rates, Reclamation should limit the daily change to 10-15 percent. (This priority remains unchanged from those of previous years.)

Gerald Kelso
April 7, 2000
Page 3

7. It may be possible to improve feeding conditions for brown trout by reducing flows between Labor Day and October 15 in years when flows would otherwise be higher than those recommended by the Division of Wildlife. If potential benefits warrant the effort, AHRA managers, the Division of Wildlife, Reclamation and the Division II Engineer should work with water users to seek opportunities for reducing flows after Labor Day. (This priority remains unchanged from those of previous years.)

Without the commitment and cooperation among the DNR, the Bureau of Reclamation, the SECWCD, local governments, water users, and the Bureau of Land Management, flow management for recreation and wildlife purposes in the Upper Arkansas River would not occur. We look forward to working with you, the District, and others to address issues related to resource management and recreation in this region.

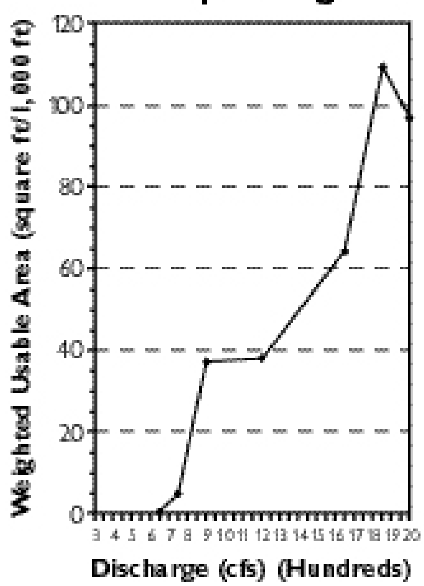
Very truly yours,

Greg Walcher
Executive Director

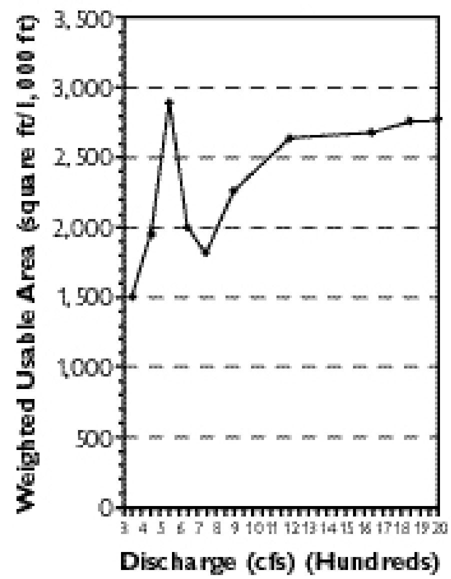
cc: Steve Arveschoug, Director, SECWCD
Laurie Mathews, Director, Colorado State Parks
John Mumma, Director, Division of Wildlife
Hal Simpson, Director, Water Resources
Peter Evans, Director, Water Conservation Board
Donnie Sparks, Field Office Manager, Bureau of Land Management
Tony Kay, Executive Director, Colorado Trout Unlimited
Bob Hamel, President, Arkansas River Outfitter Association

Appendix C.
Arkansas River Habitat Versus Discharge Relationships

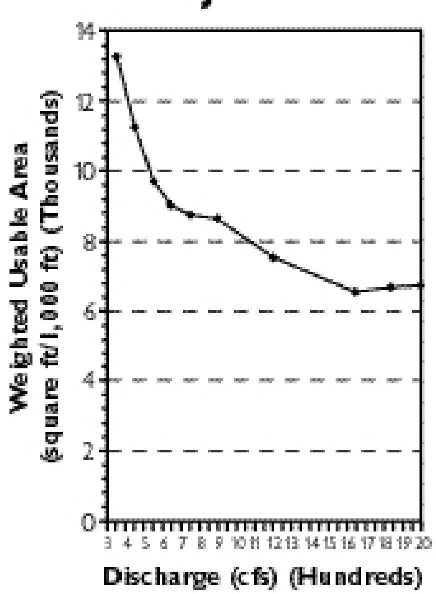
Floodplain - Brown Trout Spawning



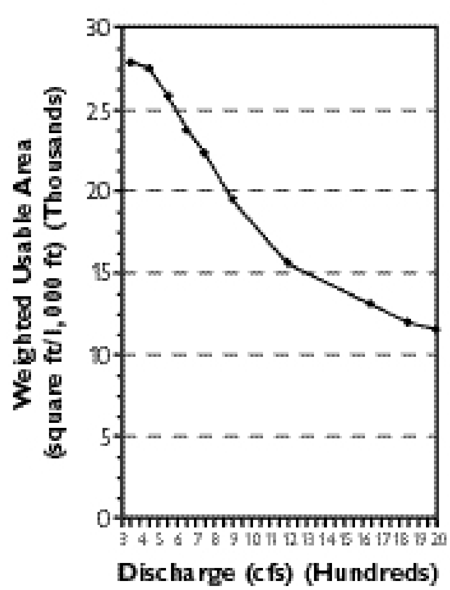
Floodplain - Brown Trout Fry



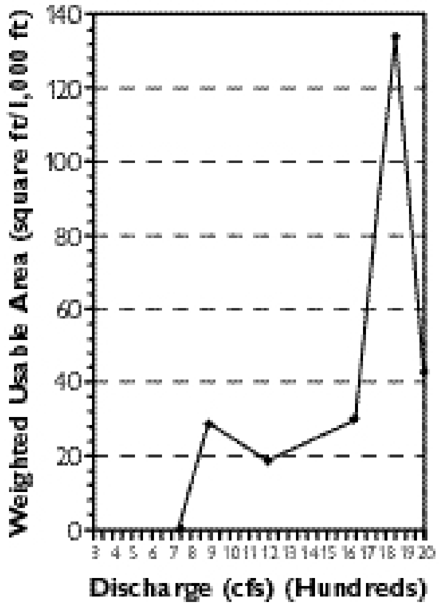
Floodplain - Brown Trout Juvenile



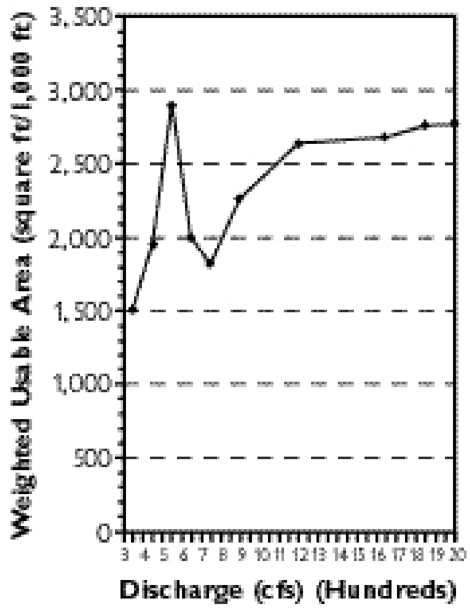
Floodplain - Brown Trout Adult



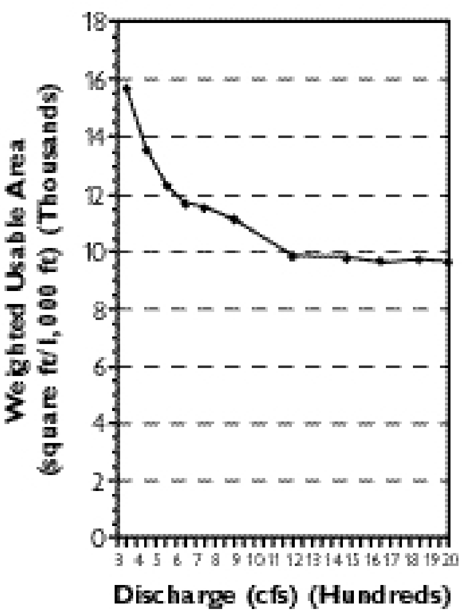
Floodplain - Rainbow Trout
Spawning



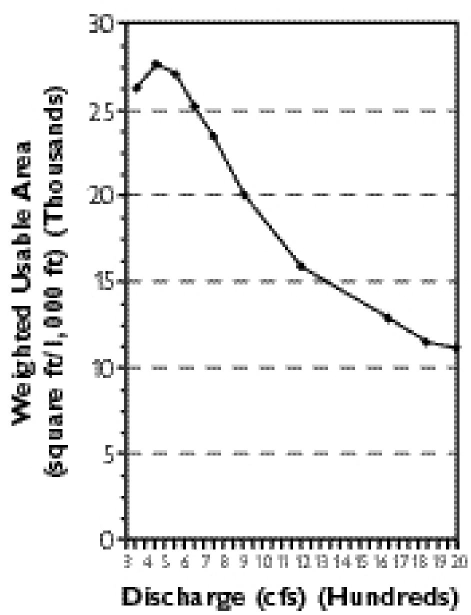
Floodplain - Rainbow Trout
Fry



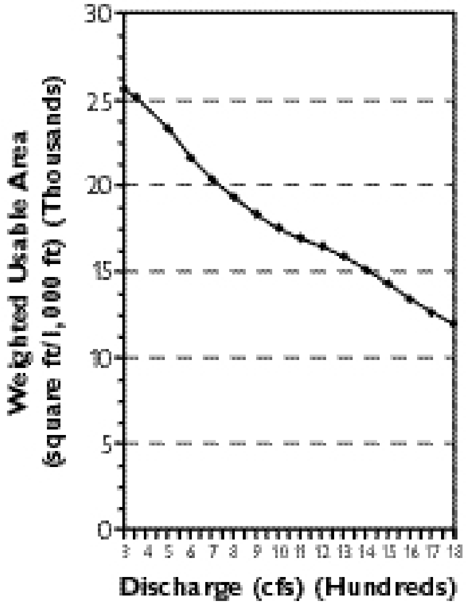
Floodplain - Rainbow Trout
Juvenile



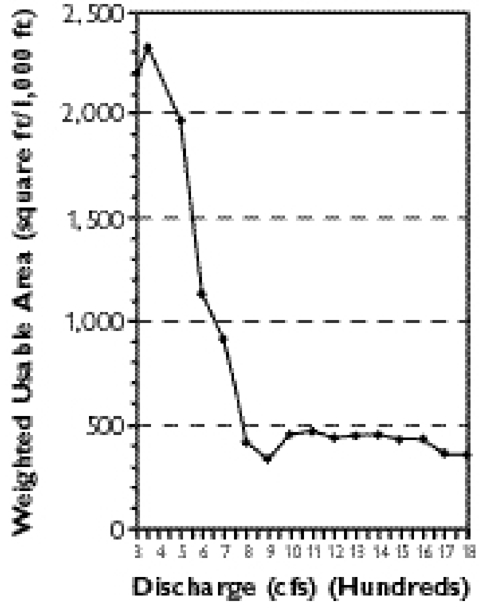
Floodplain - Rainbow Trout
Adult



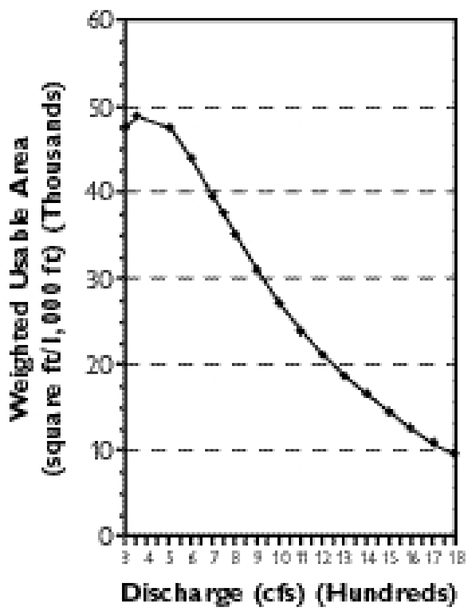
Stockyard - Brown Trout Spawning



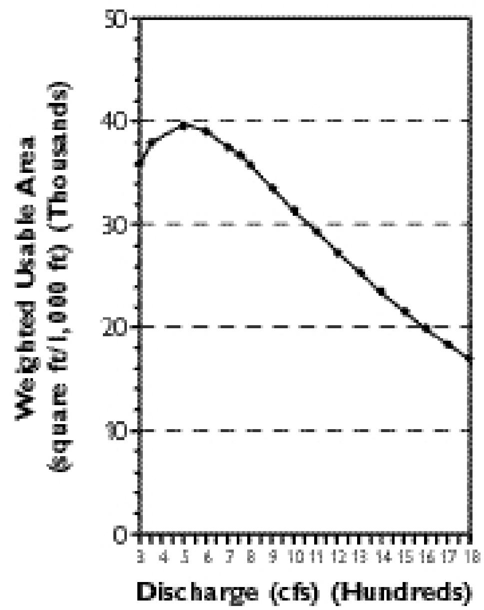
Stockyard - Brown Trout Fry



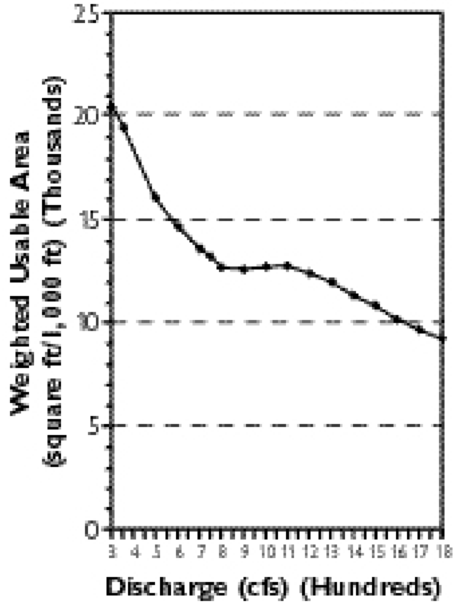
Stockyard - Brown Trout Juvenile



Stockyard - Brown Trout Adult



Stockyard - Rainbow Trout Spawning



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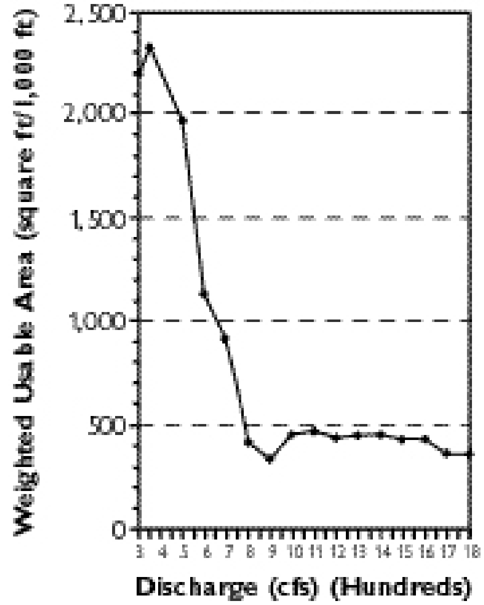
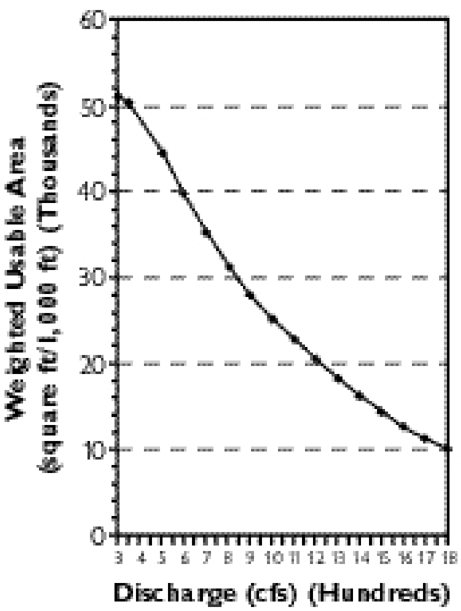
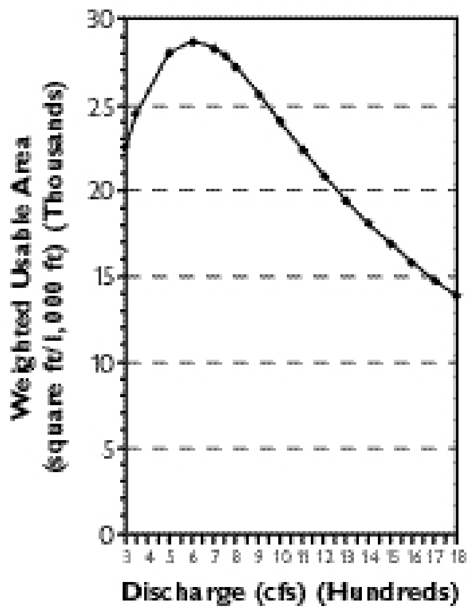


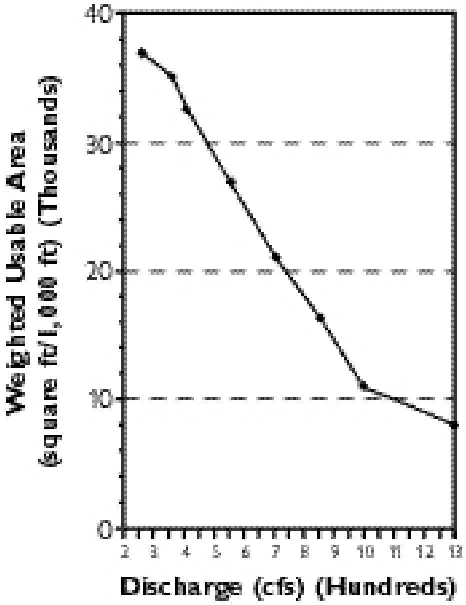
Stockyard - Rainbow Trout Juvenile



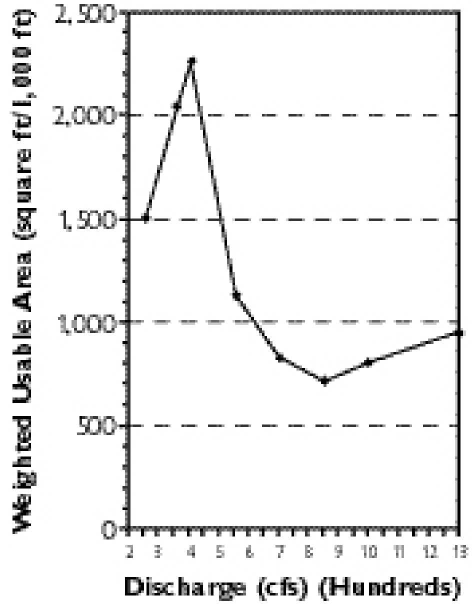
Stockyard - Rainbow Trout Adult



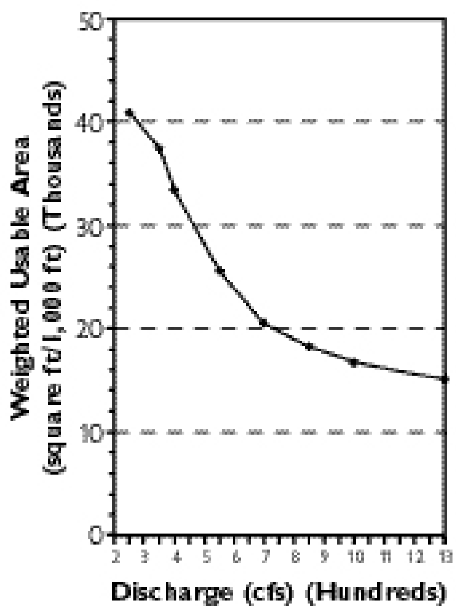
Independent WW - Brown Trout Spawning



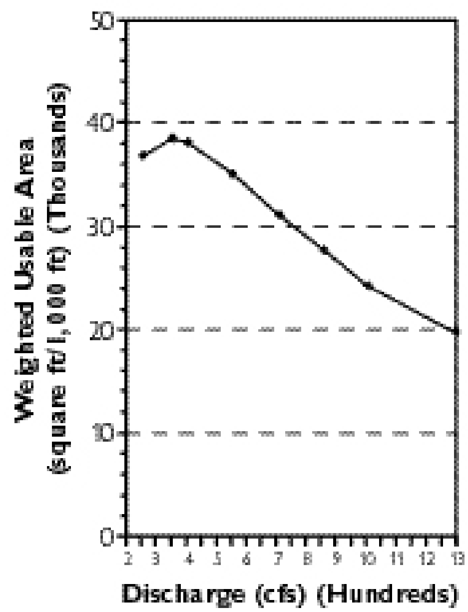
Independent WW - Brown Trout Fry



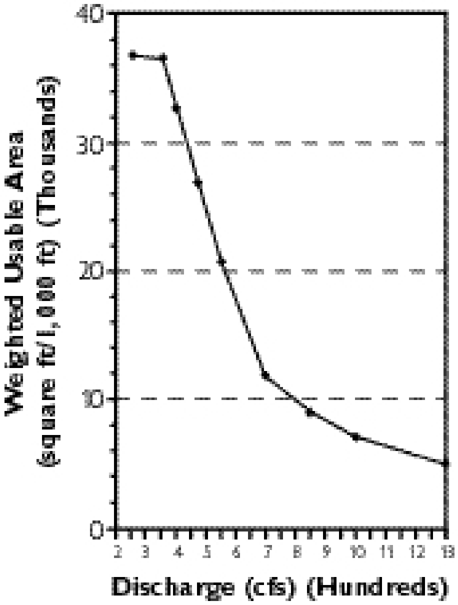
Independent WW - Brown Trout Juvenile



Independent WW - Brown Trout Adult



Independent WW - Rainbow Trout Spawning



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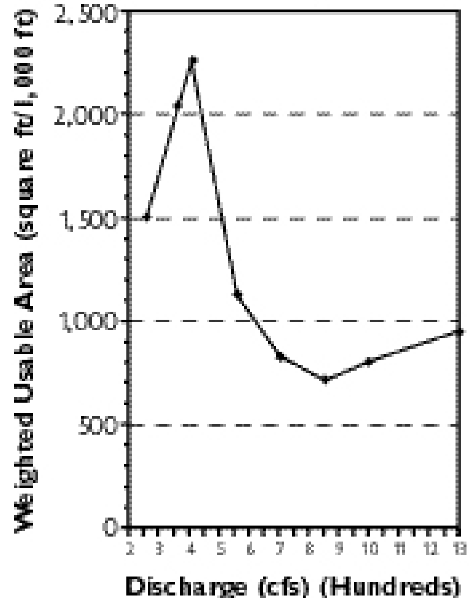
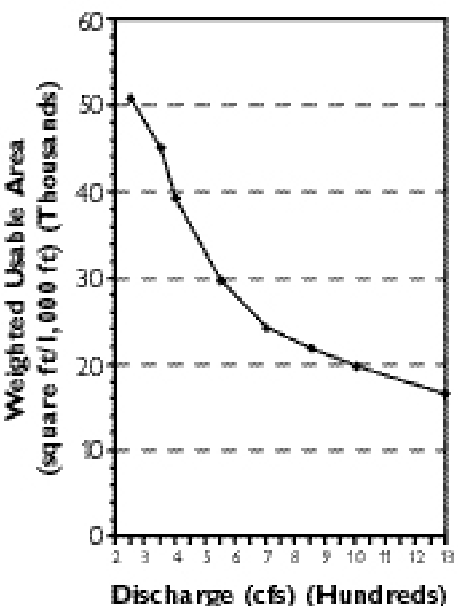
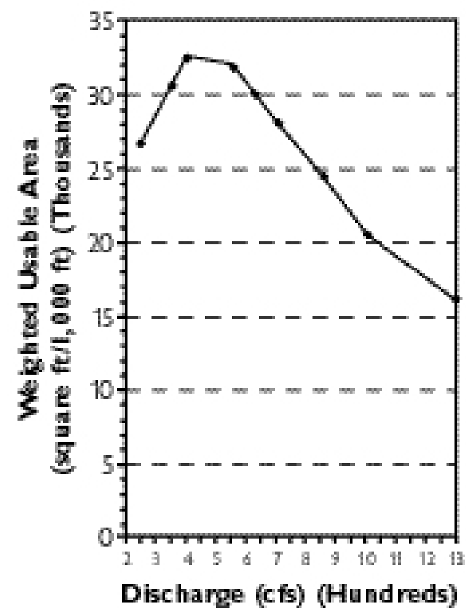


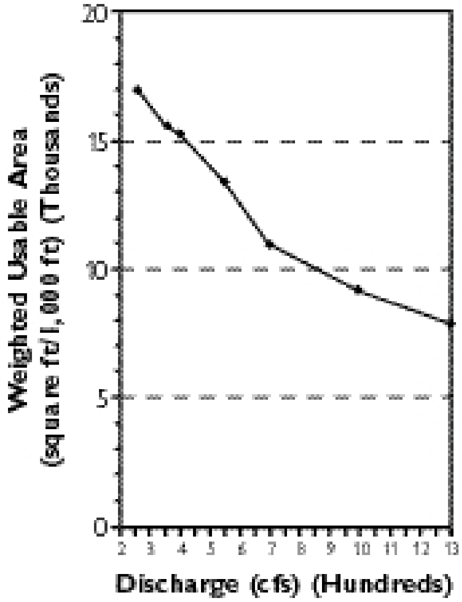
Independent WW - Rainbow Trout Juvenile



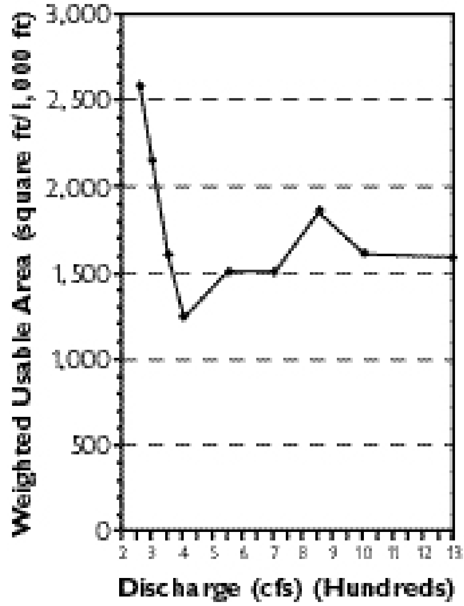
Independent WW - Rainbow Trout Adult



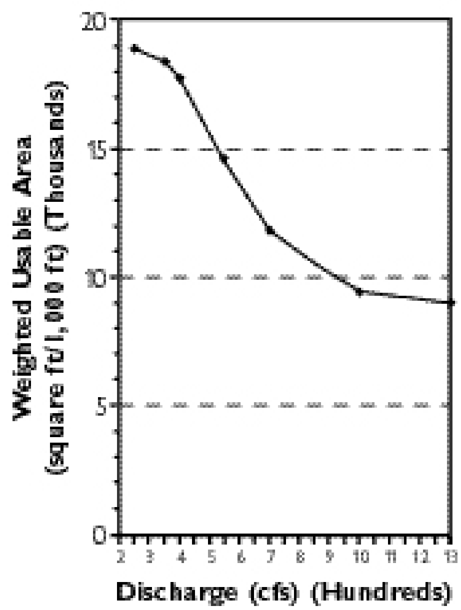
Browns Canyon - Brown Trout Spawning



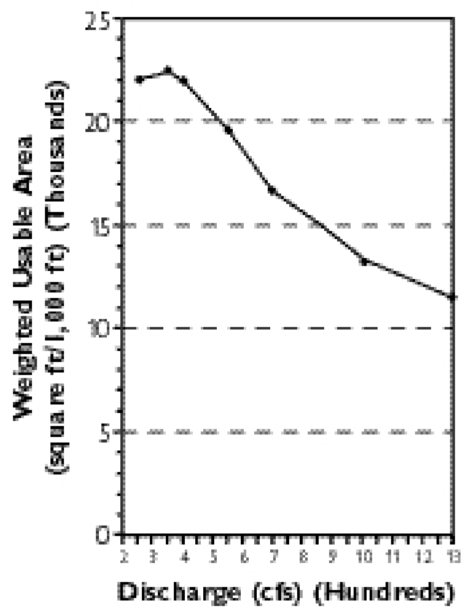
Browns Canyon - Brown Trout Fry



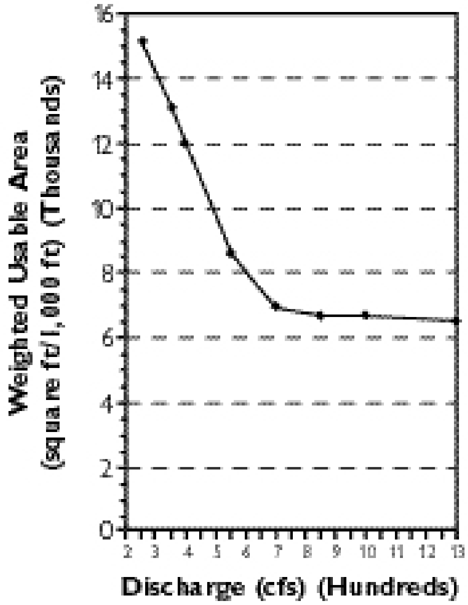
Browns Canyon - Brown Trout Juvenile



Browns Canyon - Brown Trout Adult



Browns Canyon - Rainbow Trout Spawning



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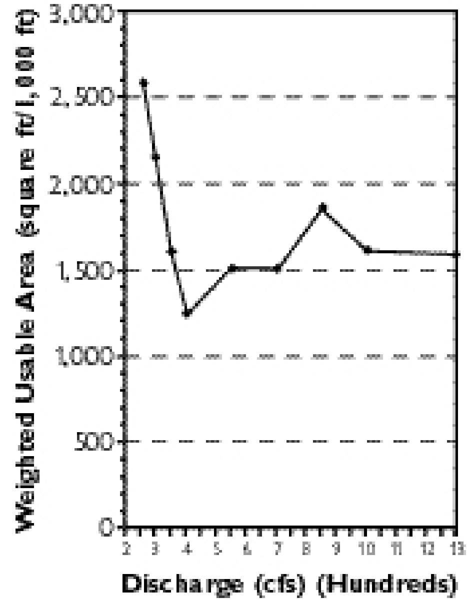
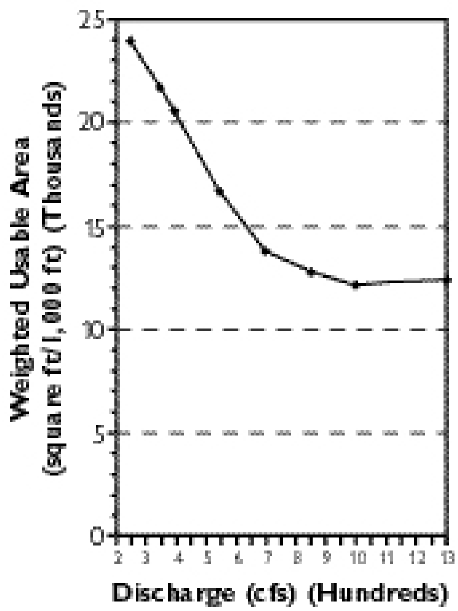
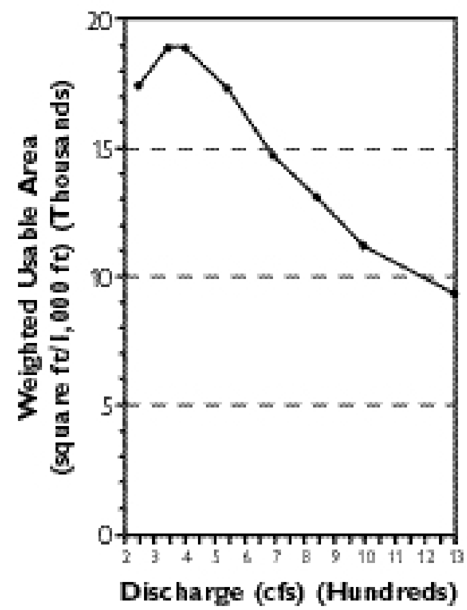


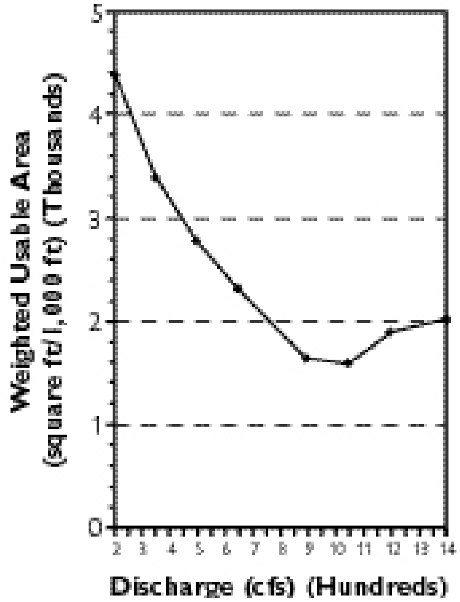
Browns Canyon - Rainbow Trout Juvenile



Browns Canyon - Rainbow Trout Adult



Numbers - Brown Trout Spawning



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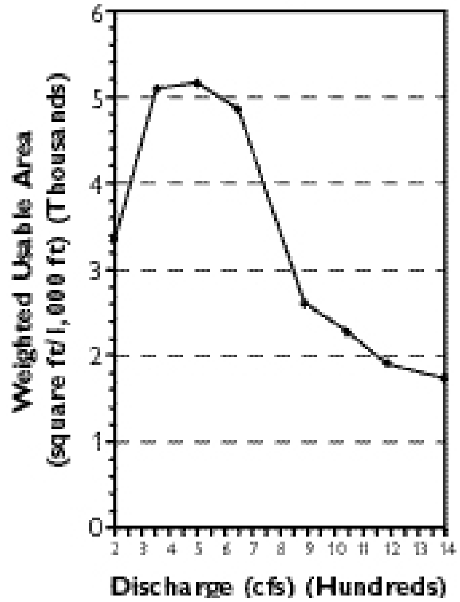
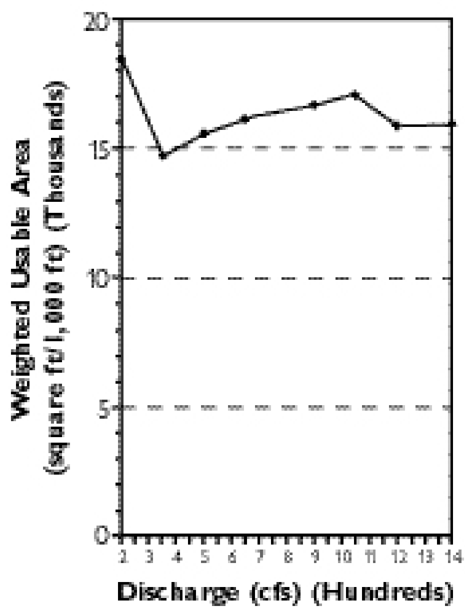
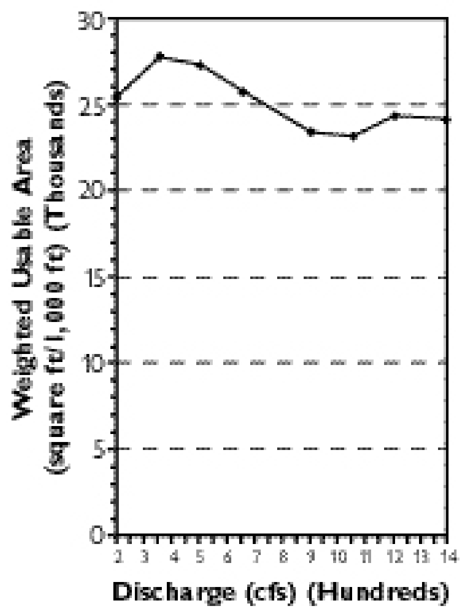


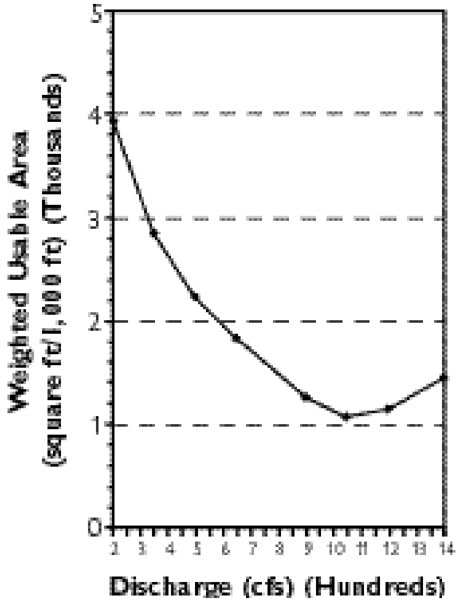
Numbers - Brown Trout Juvenile



Numbers - Brown Trout Adult



Numbers - Rainbow Trout Spawning



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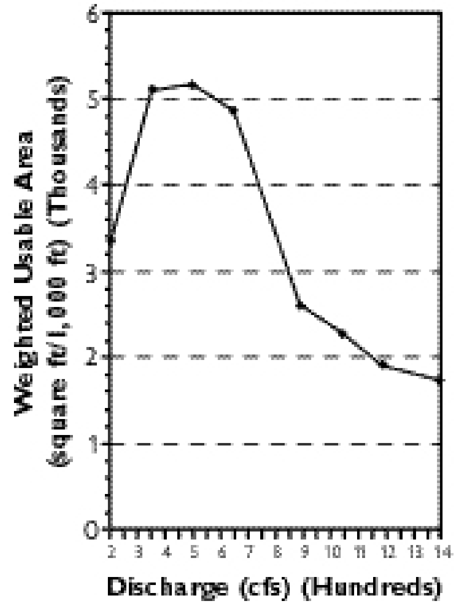
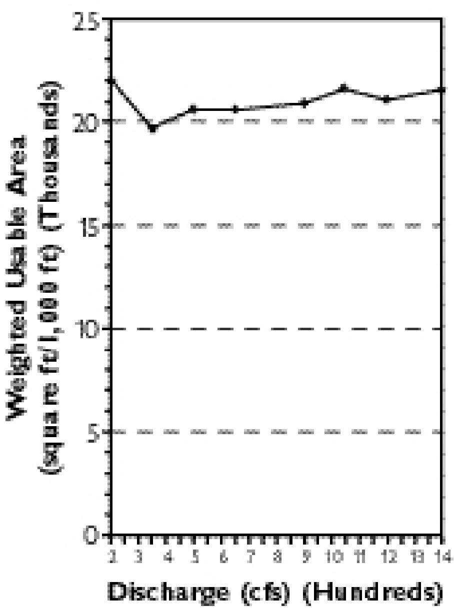
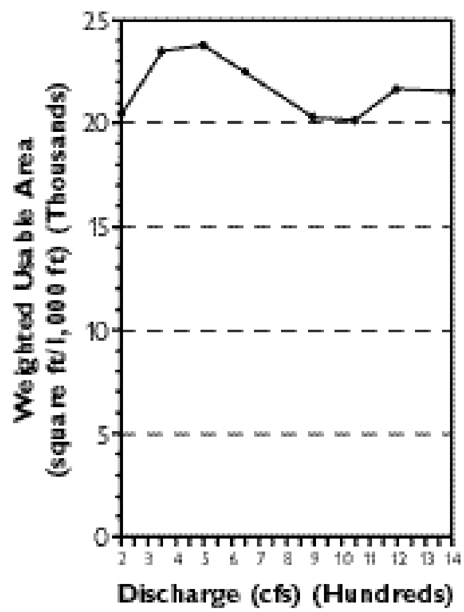


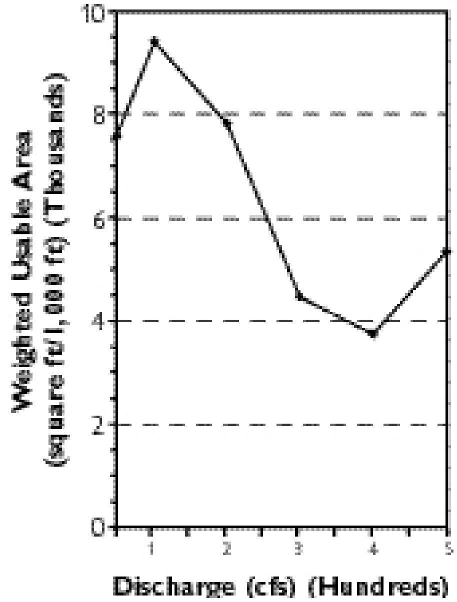
Numbers - Rainbow Trout Juvenile



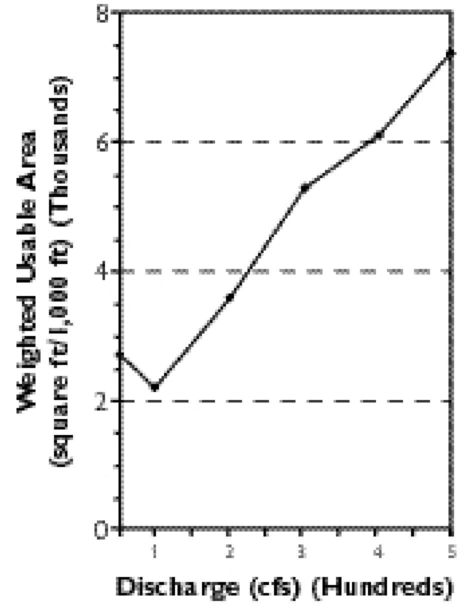
Numbers - Rainbow Trout Adult



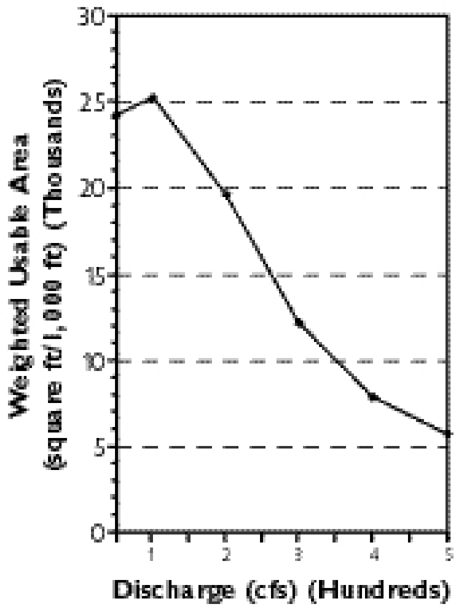
Leadville - Brown Trout Spawning



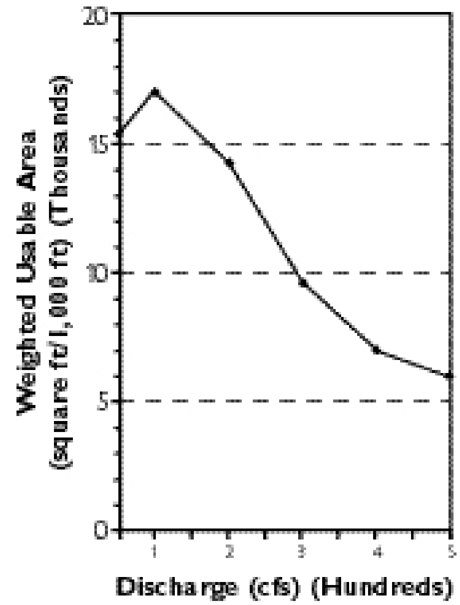
Leadville - Brown Trout Fry



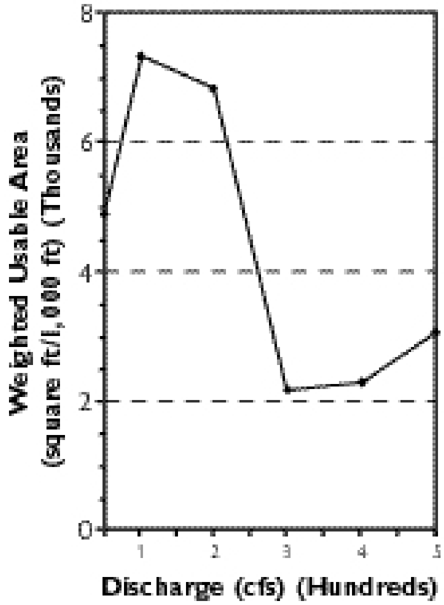
Leadville - Brown Trout Juvenile



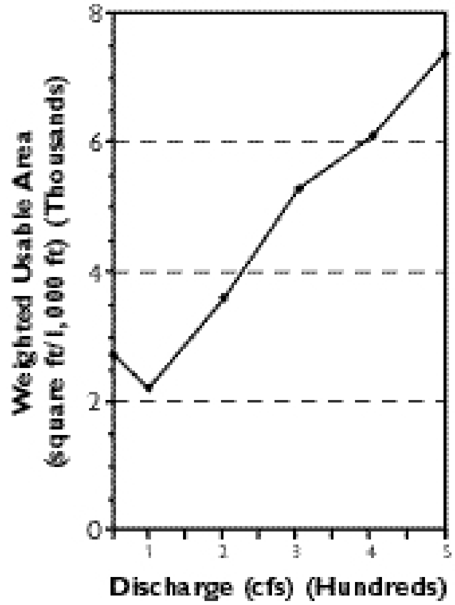
Leadville - Brown Trout Adult



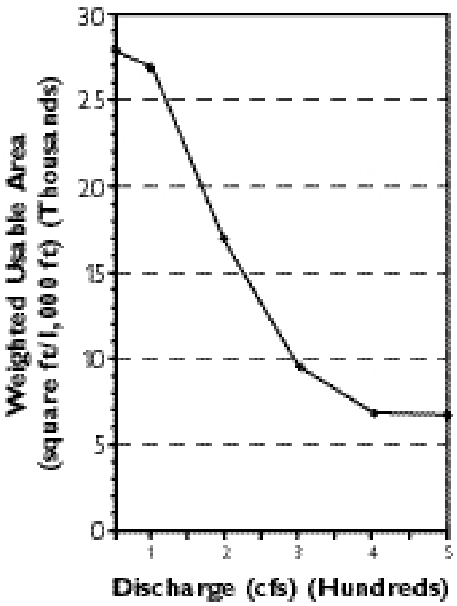
Leadville - Rainbow Trout
Spawning



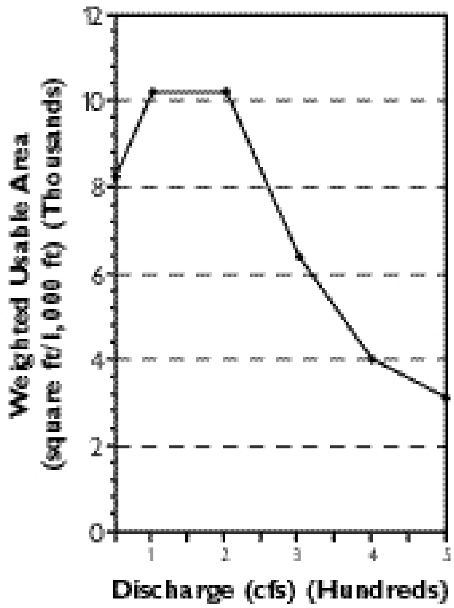
Leadville - Rainbow Trout
Fry



Leadville - Rainbow Trout
Juvenile



Leadville - Rainbow Trout
Adult



Appendix D.
Summary of Weighted Usable Area at the Six Cross Section Locations

Floodplain
Brown Trout

WUA (square ft/1,000 ft)

Discharge (cfs)	Spawning	Fry	Juvenile	Adult
350	0	1,517	13,251	27,890
450	0	1,954	11,254	27,474
540	0	2,909	9,677	25,816
630	0	1,995	8,981	23,808
730	5	1,808	8,728	22,352
900	37	2,251	8,613	19,517
1,200	38	2,621	7,496	15,578
1,630	64	2,670	6,512	13,130
1,850	109	2,744	6,621	11,973
2,000	96	2,760	6,690	11,598

Rainbow Trout

Discharge (cfs)	Spawning	Fry	Juvenile	Adult
350	0	1,517	15,670	26,254
450	0	1,954	13,571	27,694
540	0	2,909	12,286	27,074
630	0	1,995	11,678	25,165
730	0	1,808	11,571	23,419
900	29	2,251	11,114	20,083
1,200	19	2,621	9,843	15,821
1,630	30	2,670	9,667	12,842
1,850	134	2,744	9,706	11,414
2,000	43	2,760	9,581	11,096

Stockyard

Brown Trout

WUA (square ft/1,000 ft)

Discharge (cfs)	Spawning	Fry	Juvenile	Adult
300	25,621	2,190	47,533	36,049
356	25,218	2,326	48,923	37,915
500	23,318	1,968	47,558	39,678
600	21,683	1,135	44,099	39,031
700	20,421	918	39,677	37,518
744	19,915	689	37,722	36,733
800	19,384	414	35,270	35,646
900	18,388	334	31,094	33,497
1,000	17,605	449	27,292	31,368
1,100	16,992	468	24,015	29,305
1,200	16,501	438	21,219	27,276
1,300	15,928	448	18,737	25,299
1,400	15,157	447	16,484	23,385
1,500	14,336	427	14,422	21,514
1,600	13,406	423	12,512	19,802
1,700	12,602	356	10,826	18,180
1,797	11,924	352	9,417	16,730

Rainbow Trout

300	20,476	2,190	50,932	22,058
356	19,526	2,326	50,248	24,467
500	16,086	1,968	44,574	28,026
600	14,711	1,135	39,782	28,590
700	13,625	918	35,258	28,250
744	13,214	689	33,427	27,844
800	12,721	414	31,375	27,115
900	12,607	334	28,005	25,585
1,000	12,747	449	25,241	23,955
1,100	12,756	468	22,810	22,334
1,200	12,395	438	20,490	20,783
1,300	11,979	448	18,346	19,401
1,400	11,345	447	16,283	18,108
1,500	10,843	427	14,400	16,895
1,600	10,160	423	12,692	15,772
1,700	9,695	356	11,294	14,730
1,797	9,274	352	10,194	13,823

Independent Whitewater
Brown Trout

WUA (square ft/1,000 ft)

Discharge (cfs)	Spawning	Fry	Juvenile	Adult
250	36,979	1,505	40,880	36,970
327	35,182	2,034	37,422	38,520
400	32,660	2,260	33,350	38,241
550	26,892	1,132	25,587	35,244
700	21,217	824	20,444	31,320
830	16,404	711	18,127	27,979
1,000	11,062	808	16,661	24,425
1,300	8,007	954	15,028	19,734

Rainbow Trout

Discharge (cfs)	Spawning	Fry	Juvenile	Adult
250	36,695	1,505	50,690	26,581
327	36,474	2,034	44,988	30,602
400	32,573	2,260	39,277	32,502
550	20,793	1,132	29,679	31,865
700	11,744	824	24,172	28,093
830	8,945	711	21,796	24,437
1,000	6,995	808	19,779	20,452
1,300	4,938	954	16,353	15,928

Brown's Canyon
Brown Trout

WUA (square ft/1,000 ft)

Discharge (cfs)	Spawning	Fry	Juvenile	Adult
250	16,930	2,590	18,845	22,069
357	15,560	1,604	18,375	22,438
400	15,229	1,241	17,717	22,012
550	13,409	1,500	14,629	19,583
715	10,959	1,506	11,838	16,692
830	10,055	1,855	10,547	15,101
1,000	9,195	1,608	9,449	13,344
1,325	7,839	1,584	9,026	11,505

Rainbow Trout

250	15,163	2,590	23,873	17,409
357	13,140	1,604	21,635	18,825
400	11,998	1,241	20,475	18,805
550	8,644	1,500	16,622	17,191
715	6,969	1,506	13,746	14,664
830	6,672	1,855	12,744	13,029
1,000	6,686	1,608	12,111	11,156
1,325	6,514	1,584	12,290	9,333

Numbers

Brown Trout

WUA (square ft/1,000 ft)

Discharge (cfs)	Spawning	Fry	Juvenile	Adult
210	4,396	3,206	18,383	25,295
350	3,390	5,108	14,726	27,640
500	2,781	5,147	15,566	27,159
650	2,320	4,839	16,128	25,642
890	1,646	2,594	16,675	23,362
1,050	1,594	2,275	17,078	23,143
1,200	1,914	1,904	15,877	24,287
1,420	2,024	1,739	15,925	24,048

Rainbow Trout

210	3,928	3,206	21,994	20,438
350	2,849	5,108	19,634	23,542
500	2,240	5,147	20,555	23,806
650	1,823	4,839	20,573	22,556
890	1,250	2,594	20,864	20,341
1,050	1,064	2,275	21,548	20,209
1,200	1,145	1,904	21,047	21,691
1,420	1,437	1,739	21,517	21,486

Leadville
Brown Trout

WUA (square ft/1,000 ft)

Discharge (cfs)	Spawning	Fry	Juvenile	Adult
70	7,588	2,739	24,140	15,334
86	8,611	2,452	24,968	16,434
97	9,285	2,272	25,172	16,868
100	9,444	2,195	25,190	16,944
200	7,843	3,613	19,642	14,212
300	4,488	5,280	12,227	9,587
400	3,747	6,089	7,875	6,968
500	5,360	7,406	5,695	5,951

Rainbow Trout

Discharge (cfs)	Spawning	Fry	Juvenile	Adult
70	4,909	2,739	27,820	8,288
86	6,202	2,452	27,624	9,432
97	7,086	2,272	27,149	10,048
100	7,336	2,195	26,963	10,192
200	6,847	3,613	16,996	10,176
300	2,150	5,280	9,496	6,410
400	2,265	6,089	6,814	4,003
500	3,041	7,406	6,635	3,106

Appendix E.
Summary of Arkansas River Water Quality Issues

Introduction

The purpose of this appendix is to present an overview of water quality in the upper Arkansas River from its headwaters to Pueblo Reservoir. Water quality in the upper Arkansas River has been heavily impacted by hard-rock mining that has occurred in the basin for over 100 years. Water flowing through abandoned mines and tailings piles has contributed high concentrations of cadmium, copper, lead, zinc, and other metals to the upper Arkansas River (Lewis and Clark 1996). Therefore, this discussion of water quality is primarily concerned with the occurrence and concentration of metals in the upper Arkansas Basin and their effects on designated uses.

The upper Arkansas River supports a number of designated uses, including recreation, aquatic life, domestic water supply, and agriculture (Colorado Department of Public Health and Environment, Water Quality Control Commission 1996). Recreation and aquatic life are most sensitive to water quality, because water in the upper Arkansas is rarely unsuitable for agriculture, and waters classified for domestic water supply must be treated prior to use (Colorado Department of Public Health and Environment, Water Quality Control Commission 1996). The Arkansas River between Buena Vista and Pueblo Reservoir is the most extensively used recreational river in Colorado (Colorado Department of Public Health and Environment, Water Quality Control Commission 1996). Recreational activities include, but are not limited to, fishing, swimming, rafting, and kayaking (Colorado Department of Public Health and Environment, Water Quality Control Commission 1996). Aquatic life is directly related to recreation activities such as fishing because a healthy aquatic food chain is necessary to support healthy fish populations.

Most of the information contained in this appendix was taken directly from existing publications. No new water quality data collection or analysis was done as a result of this project. In particular, this appendix relies heavily on a comprehensive water quality study performed by the U.S. Geological Survey from 1990 to 1993 (Ortiz et al. 1998; Clark and Lewis 1997; Lewis and Clark 1996; Dash and Ortiz 1996). The primary reason for emphasizing this study is that two water treatment plants, one at the Leadville Mine Drainage Tunnel on the East Fork of the Arkansas River above Leadville and the other at the Yak Tunnel on California Gulch, began operation in 1992. The purpose of both of these plants is to remove heavy metals from tunnel discharge water. Because these two tunnels have been identified as major contributors of metals to the Arkansas River, any assessment of current water quality conditions must be made using data collected after the plants began operations. The USGS study is the most comprehensive published study that contains data collected after the plants began operating.

General Water Quality Characteristics

Water quality samples were collected and analyzed for dissolved and total recoverable metals, major ions, and nutrients at eight sites on the Arkansas River between Leadville and Portland from April 1990 through March 1993 (Ortiz et al. 1998). For these eight sites, pH generally ranged from 7.5 to 8.5 and tended to increase downstream (Clark and Lewis 1997). This range of pH is within the range of 6.5 to 9.0 contained in the water quality standards for the upper Arkansas River (Colorado Department of Public Health and Environment, Water Quality Control Commission 1995). Alkalinity ranged from as low as 20 to 30 mg/L as $CaCO_3$ at Granite to about 170 mg/L near Portland (Clark and Lewis 1997). The lowest alkalinity values at Granite were the result of low alkalinity inflow from Lake Creek (Clark and Lewis 1997). Dissolved oxygen concentrations generally were near saturation throughout the basin (Clark and Lewis 1997). Ammonia, nitrate, and total-phosphorus concentrations were low in comparison to State and Federal criteria (Ortiz et al. 1998).

Major solutes in the upper Arkansas River reflect the weathering of various rock types in the basin. Inflows affected by acid mine drainage in the Leadville area reflect the oxidation of metal-sulfide deposits, producing acidic, sulfate-rich water (Kimball et al. 1995). The igneous and metamorphic rocks of the Leadville area also contribute calcium, sodium, and bicarbonate to the river (Kimball et al. 1995). The proportion of sedimentary rock increases downstream of Granite (Clark and Lewis 1997). The chemistry of inflows downstream of Salida is strongly influenced by the weathering of shale that contributes calcium, sodium, and sulfate (Kimball et al. 1995). Dissolved solids concentrations are lowest at Granite due to dilution by inflow from Lake Creek, and increase downstream as the less resistant sedimentary rocks contribute more solutes to the river. Dissolved metals are discussed in detail in the following sections.

Metals Toxicity in the Aquatic Environment

Although some metals, in trace amounts, are essential for life, most metals become toxic in high concentrations (Lewis and Clark 1996). Cadmium, copper, lead, and zinc are the metals of particular concern in the upper Arkansas River because of their toxicity to aquatic life (Lewis and Clark 1997). Metals in the aquatic environment can occur in the dissolved or particulate phase, or they can become sorbed to particulates (Lewis and Clark 1996). The toxicity of metals is related not only to their concentration, but also to their phase (Lewis and Clark 1996). The uptake of metals from the dissolved phase generally is the pathway that is most toxic to aquatic life (Lewis and Clark 1996).

The dissolved phase of a water sample is traditionally defined by passing the sample through a 0.45 μm filter (Kimball et al. 1995). For metal-rich streams affected by mining, 0.45 μm is not an effective breakpoint for measurement of dissolved and particulate concentrations (Kimball et al. 1995). This is because metals coming out of solution form a continuum of particulate sizes from about 0.001 to about 1.0 μm (Kimball et al. 1995). Particles in this size range are called colloids. Aggregation of individual colloids is primarily responsible for the larger particulate sizes in this continuum (Kimball et al. 1995). Metals that are toxic to aquatic life, such as cadmium, copper, lead, and zinc, may form colloids or they may be sorbed to other colloids such as iron colloids (Kimball et al. 1995). The actual mechanism of colloid formation was shown by Witters et al. (1996) to be toxic. Witters et al. (1996) found that the toxicity to brown trout was greater during the formation of aluminum colloids than the toxicity when mature, developed aluminum colloids were present. The direct implication of the Witters et al. (1996) study is that any change in chemistry that induces colloid formation in a metal-rich stream could create an area of increased toxicity to fish. Changes in chemistry can result from any inflow with sufficiently different chemistry than the receiving stream. In addition to the toxic effects of colloids, metal toxicity varies depending on what chemical association the dissolved metal is in.

Dissolved metals can exist by themselves as free-metal ions, or they can form complexes with other constituents in the water, such as carbonates, chlorides, and sulfates (Lewis and Clark 1996). These different complexes, including the free, uncomplexed metal ion, are referred to as different "species" of the dissolved metal. Most studies of metal toxicity have indicated that the free-metal ion is the more toxic dissolved metal species (Lewis and Clark 1996). Low alkalinity and pH are more conducive to the existence of free-metal ions in solution (Lewis and Clark 1996). In the upper Arkansas River, the high streamflow during snowmelt runoff typically has a lower alkalinity and pH than the flows that occur throughout the remainder of the year.

Another factor affecting alkalinity and pH is that water imported from the Colorado River Basin generally has lower alkalinity and pH than native water (Lewis and Clark 1996). Since most of the imported water is routed through Twin Lakes Reservoir and Lake Creek, the reach immediately downstream from the confluence of Lake Creek is most susceptible to being affected by the chemistry of the imported water (Lewis and Clark 1996).

Water Quality Criteria for Metals

Water quality criteria for metals in the upper Arkansas consist of acute and chronic numerical values. A violation of an acute criterion can be established based on one sample, whereas a violation of a chronic criterion is usually based on an average of several samples taken within a specified time period (Colorado Department of Public Health and Environment, Water Quality Control Commission 1996). Metals concentrations for the 1992-1993 samples can only be compared to acute standards because sampling occurred too infrequently for them to be compared with chronic standards.

Water quality criteria for metals are based on a computation that involves hardness because the toxicity of metals to aquatic life is affected by the hardness of the water. Most metals are less toxic in water with hardness exceeding 100mg/L as calcium carbonate (Gerhardt 1993).

Impairment from Dissolved Metals Before and After 1992

The impairment of beneficial uses due to dissolved metals concentrations prior to 1992 is described in the 1989 Colorado Nonpoint Source Assessment Report (Colorado Department of Public Health and Environment, Water Quality Control Division, 1989) for the upper Arkansas River:

> "One of the most impacted segments of the Arkansas River lies immediately below California Gulch near Leadville, and upstream of the confluence with the Lake Fork. Concentrations of zinc, cadmium, copper, lead, manganese, and iron are the metals of concern in this segment. Concentrations of metals appear to decrease in the segment of the Arkansas below the Lake Fork and above Lake Creek. Basic standards for aquatic life are exceeded for cadmium, copper, zinc, iron, and lead, though at somewhat reduced levels from those immediately upstream. Chronic toxicity is evident by the greatly reduced trout populations in this reach of the river. The reach of the Arkansas River between Browns Canyon (about six miles north of Salida) and Cañon City exceeds basic standards for aquatic life for cadmium, zinc, nickel, lead, and copper. The source of the metals appears to be drainage from the many mining districts upstream. In this reach of river few trout are found over three years of age."

Table E-1 compares the use-support status of the upper Arkansas River as reported in the 1992 and 1996 305(b) reports (Colorado Department of Public Health and Environment, Water Quality Control Division, 1992, 1996). This comparison shows a distinct improvement in water-quality conditions in the 4-year period after the two treatment plants began operation. The remaining sources of metals upstream of Lake Creek are St. Kevin Gulch and nonpoint sources, including placer deposits along the river alluvium (Clark and Lewis 1997).

TABLE E-1

Use-Support Status for the Upper Arkansas River as Reported in the 1992 and 1996 305(b) Reports

Segment	1992 Status	Cause	1996 Status	Cause
Leadville Drain to California Gulch	Not Supporting	Metals	Fully Supporting	
California Gulch to Lake Fork	Not Supporting	Metals	Partially Supporting	Cadmium & Zinc
Lake Fork to Lake Creek	Partially Supporting	Metals	Partially Supporting	Zinc
Lake Creek to Cañon City	Not Supporting	Metals	Fully Supporting	
Cañon City to Pueblo Reservoir	Water Quality Limited	Metals	Fully Supporting	

According to Table E-1, cadmium and zinc continue to cause some use impairment in the California Gulch to Lake Creek reach. For data collected after the treatment plants began operating, Ortiz et al. (1998) found no exceedances of the acute criterion for cadmium and one exceedance of the acute criterion for zinc. Sufficient data were not collected to determine exceedances of the chronic criteria.

Cadmium and Zinc

Lewis and Clark (1996) reported that dissolved cadmium and zinc exhibited similar spatial patterns even though their concentrations were different. The highest concentrations of dissolved cadmium and zinc were found at the Empire Gulch site, which is the only sampling station in the California Gulch to Lake Creek reach (Lewis and Clark 1996). Concentrations decreased more than 50 percent between Empire Gulch and Granite, largely because of dilution by Lake Creek (Lewis and Clark 1996).

The free-metal ions (Cd^{+2} and Zn^{+2}) dominated the speciation from Leadville to Nathrop, whereas cadmium and zinc complexes dominated the speciation from Wellsville to Portland (Lewis and Clark 1996). More than 60 percent of the dissolved species occurred as free-metal ions at Granite and Buena Vista (Lewis and Clark 1996). The low alkalinity and low dissolved solids concentration of the inflow from Lake Creek results in low metal-complexing potential and, compared to upstream sites, a higher percentage of free-metal ions at Granite and Buena Vista (Lewis and Clark 1996).

The highest concentrations of dissolved cadmium and zinc occurred during early snowmelt runoff (Lewis and Clark 1996). During early snowmelt runoff, streamflow begins to increase as snow at lower elevations melts and flushes the abandoned mines, mine dumps, and tailings piles of metal enriched water (Lewis and Clark 1996). The volume of water that actually flows into the river during this time is relatively small, but because the flow of the river is low, the effect on metal concentrations can be substantial (Lewis and Clark 1996). Dissolved metal concentrations become diluted by large volumes of snowmelt during peak snowmelt runoff in May and June (Lewis and Clark 1996).

Although dissolved cadmium and zinc concentrations decreased during peak snowmelt runoff, the percentage of free-metal ions increased to about 70 percent (Lewis and Clark 1996). The lower alkalinity and lower pH of snowmelt water tend to favor the speciation of free metal ions compared to metal complexes (Lewis and Clark 1996). In contrast, less than 50 percent of the dissolved cadmium and zinc exists as free-metal ions during the post snowmelt and low-flow periods, when alkalinity and pH generally are higher (Lewis and Clark 1996).

For the 1990-1993 study, the dissolved phase was defined by filtering water samples through a 0.45µm filter (Lewis and Clark 1996; Clark and Lewis 1997; Dash and Ortiz 1996). However, Kimball et al. (1995) found that iron concentrations were consistently higher in the colloidal fraction (>0.001 µm) than in the truly dissolved phase as defined by ultrafiltration (<0.001 µm). Partitioning of ferric iron (Fe^{3+}) to the colloidal fraction between pH 7 and 8 is by precipitation of amorphous ferrihydrite ($Fe(OH)_{3(s)}$) (Kimball et al.1995). The amorphous structure of ferrihydrite creates a large surface area that strongly influences the partitioning of toxic metals through sorption and coprecipitation (Clark and Lewis 1997; Kimball et al. 1995). To determine the effect of adsorption on concentrations calculated for species of cadmium and zinc, Clark and Lewis (1997) used an adsorption model for reactions involving colloidal ferrihydrite.

A range of dissolved iron concentrations from 25-700 µg/L was modeled to determine the adsorption effects on concentrations calculated for species of cadmium and zinc (Clark and Lewis 1997). For high concentrations of dissolved iron (700 µg/L), the model indicated that about 12 percent of available zinc and about 2 percent of available cadmium became bound to the ferrihydrite surfaces (Clark and Lewis 1997). About 5 percent of the zinc was contributed from the Zn^{+2} species and about 7 percent was contributed from complexed species (Clark and Lewis 1997). About 1 percent of the cadmium was contributed from the Cd^{+2} species and about 1 percent was contributed from complexed species (Clark and Lewis 1997). For low concentrations of dissolved iron (25 µg/L), the adsorption effect was negligible (Clark and Lewis 1997).

Summary and Flow Options

Water quality in the upper Arkansas River Basin is dominated by high concentrations of metals that result from historic mining activity. Water treatment plants on two major mine drainage tunnels have significantly decreased metals concentrations since the plants began operating in 1992. The remaining sources of metals upstream of Lake Creek are St. Kevin Gulch and nonpoint sources, including placer deposits along the river alluvium (Clark and Lewis 1997). Contributions of these metals to the Arkansas occur mostly during snowmelt runoff, with highest concentrations occurring during the early snowmelt period (Clark and Lewis 1997).

Although metals concentrations have decreased since the treatment plants began operating, cadmium and zinc continue to cause some use impairment in the California Gulch to Lake Creek reach (Colorado Department of Public Health and Environment, Water Quality Control Division 1996). The free-metal ions (Cd^{+2} and Zn^{+2}) dominate the speciation in this reach (Clark and Lewis 1997). Most studies of metal toxicity have indicated that the free-metal ion is the more toxic dissolved metal species (Lewis and Clark 1996). The inflow from Lake Creek dilutes metals concentrations, but the lower alkalinity, pH, and dissolved solids concentrations of Lake Creek water tend to increase the percentage of free-metal ions in solution (Clark and Lewis 1997). The highest concentrations of dissolved cadmium and zinc occurred during early snowmelt runoff.

An adsorption model indicated that adsorption to ferrihydrite colloids had a small to negligible effect on dissolved concentrations of Cd^{+2} and Zn^{+2} (Clark and Lewis 1997). For high concentrations of dissolved iron (700 µg/L), the model indicated that about 12 percent of available zinc and about 2 percent of available cadmium became bound to the ferrihydrite surfaces (Clark and Lewis 1997). About 5 percent of the zinc was contributed from the Zn^{+2} species and about 1 percent of the cadmium was contributed from the Cd^{+2} species (Clark and Lewis 1997). For low concentrations of dissolved iron (25 µg/L), the adsorption effect was negligible (Clark and Lewis 1997).

Little can be done with respect to flow scenarios that would benefit water quality in the California Gulch to Lake Fork reach, because there are no storage facilities upstream of Lake Fork. The most beneficial flow scenario for water quality would be to provide dilution flows from Turquoise Reservoir during early snowmelt. Although the Turquoise Lake water would probably increase the percentage of free-metal ions in solution, it would also reduce concentrations of dissolved metals in the Lake Fork to Lake Creek reach.

References

Clark, M.L., and Lewis, M.E., 1997, Metal speciation in the upper Arkansas River, Colorado, 1990 93: U.S. Geological Survey Water-Resources Investigations Report 96-4282, 24 p.

Colorado Department of Public Health and Environment, Water Quality Control Commission, 1996, The Basic Standards and Methodologies for Surface Water 3.1.0: 5 CCR 1002-8, 141 p.

Colorado Department of Public Health and Environment, Water Quality Control Commission, 1995, Classifications and numeric standards for the Arkansas River Basin 3.2.0: 37 p.

Colorado Department of Public Health and Environment, Water Quality Control Division, 1989, Colorado nonpoint source assessment report: 189 p.

Colorado Department of Public Health and Environment, Water Quality Control Division, 1992, Colorado water quality: 103 p.

Colorado Department of Public Health and Environment, Water Quality Control Division, 1996, Status of water quality in Colorado: 178 p.

Dash, R.G., and Ortiz, R.F., 1996, Water-quality data for the Arkansas River Basin, Southeastern Colorado, 1990-1993: U.S. Geological Survey Open-File Report 95-464, 137 p.

Gerhardt, A., 1993, Review of impact of heavy metals on stream invertebrates with special emphasis on acid conditions: Water, Air, and Soil Pollution, v. 66, pp. 289-314.

Kimball, B.A., Callender, E., and Axtmann, E.V., 1995, Effects of colloids on metal transport in a river receiving acid mine drainage, upper Arkansas River, Colorado, U.S.A.: Applied geochemistry, v. 10, pp. 285-306.

Lewis, M.E., and Clark, M.L., 1996, How does streamflow affect metals in the upper Arkansas River?: U.S. Geological Survey Fact Sheet, FS-226-96.

Ortiz, R.F., Lewis, M.E., and Radell, M.J., 1998, Water-quality assessment of the Arkansas River Basin, Southeastern Colorado, 1990-1993: U.S. Geological Survey Water-Resources Investigations Report 97-4111, 69 p.

Witters, H.E., Van Puymbroeck, S., Stouthart, A.J.H.X., and Bonga, S.E.W., 1996, Physiochemical changes of aluminum in mixing zones: mortality and physiological disturbances in brown trout (*Salmo Trutta* L.): Environmental Toxicology and Chemistry, v. 15, n. 6, pp. 986-996.

Appendix F.
Analysis of Natural Resource Tradeoffs Associated with Arkansas River Flows

Arkansas River Water Management Scenarios

Assumptions Used in Scenarios

The water management scenarios outlined in this section incorporate one critical assumption. The scenarios were established for analysis purposes only to help resource managers see the natural resource implications of various flow regimes. They are designed to provide objective information that may be later utilized in a variety of circumstances by river managers and the public. As such, the scenarios do not constitute any sort of recommendation by the study group that flows be managed in the manner outlined in the scenario. In addition, the scenarios were not developed to serve as a preset number of alternatives for any future decisionmaking process that will involve public participation.

To focus on these natural resource tradeoffs, the study group made a hypothetical assumption that each of the scenarios could be implemented without injury to established water rights, water storage/delivery contracts, and other legal obligations. When river managers use the information contained in the scenarios to make decisions about specific flow management practices, a specific analysis would have to be conducted to test the above assumption. Any flow management practices that are considered during a public decisionmaking process will have to be altered and tailored to fit legal, storage, and operational requirements. None of the scenarios have been put through a modeling process to determine if these requirements can be met.

Rationale for Using Water Management Scenarios for Natural Resource Analysis

As noted in the previous section, flow preferences for biological and recreational values on the Arkansas River are very similar and mutually reinforcing during 10 months of the year. However, during the period from July 24 through September 7, these preferences diverge. This divergence occurs for two reasons:

~ This period has warmer stream water temperatures, presenting an opportunity for good growth among all trout life stages if suitable habitat is present. Higher flows during this period reduce the amount of usable habitat for the trout and can decrease the carrying capacity of the river for trout populations. Reduced growth and weight loss in fish is indicative of this reduction in habitat.

~ Demand for recreational boating increases during this period. This period presents an opportunity for satisfying the public's demand for boating opportunities and for recreation oriented businesses to attract customers. Lower flows during this period equate to river conditions that may present marginal riverflows for rafting.

~ Demand for recreational angling is high during this period. This period presents an opportunity for satisfying public demand for float fishing, spin fishing, and fly fishing. However, the three different types of angling activities all have different flow preferences.

When river managers make decisions about what flow conditions to provide during this period, it is not sufficient to know just the generalities outlined above and what the preferred flows are for each resource value. It is essential to know exactly how well the preferences for each resource value are met under different flow regimes. For that reason, this analysis will utilize flow scenarios to illustrate the tradeoffs between various resource values.

The Relationship of Water Management Scenarios to the Arkansas River Baseline Hydrograph

Flow scenarios are simply different combinations of flow rates and timing during the July 24 to September 7 timeframe. Each scenario is only a point along a spectrum. The spectrum ranges from flows that strongly favor biological values in the river to flows that strongly favor recreational values on the river. As such, the study group does not recommend that any of the scenarios be directly adopted by river managers as a river management plan.

To facilitate the process of identifying how different flow regimes might fit into legal water delivery requirements, the analysis of tradeoffs began by using the baseline hydrograph for the Arkansas River.

~ First, the volume of flow releases and/or storage space required to implement each scenario was calculated. Then the baseline flow rate that is typically seen in the Arkansas River during each day of the July 24 to September 7 period was identified, as was the amount of water that would either need to be stored or released to meet the target flow rate in the scenario. The hydrologic analysis that was conducted in cooperation with the U.S. Geological Survey and that is part of this volume was used to calculate volumes of flow releases and storage space required.

~ Second, the required storage volumes and flow rates to implement each scenario were then either added to or subtracted from the typical flow rates and storage volumes seen in the Arkansas River baseline hydrograph. The increase/decrease in storage and flow levels is noted in the description of each scenario.

It should be noted that the predictions of increase/decrease in flow and storage levels assumes that all other water management factors on the river are held constant. In reality, implementation of these scenarios would not automatically produce the predicted results because there are so many other factors that influence river and storage levels. Again, the scenarios have not been run through a modeling effort that incorporates these other factors.

Descriptions of Water Management Scenarios

Scenario 1 - 1,000 cfs from July 24 to September 7

This scenario represents flows that most strongly favor recreational boating values. Because surveys indicated that experienced boating users preferred a flow of at least 1,000 cfs for their river experiences, this scenario analyzes a flow maintained at 1,000 cfs through Labor Day, a date after which boating use falls off sharply. After September 7, the Frypingan-Arkansas Project baseline flow patterns would resume. Slightly lower flows from October to March would be required to offset the additional water released from upper basin reservoirs.

Implementation of this scenario would require the following water management considerations.

Average Water Supply Year

Augmentation of baseline hydrograph would need to begin: August 7
Required augmentation volume: 12,600 acre-feet
Decrease in October through March riverflows: 35 cfs/day

Effects of this scenario:

1. Maximum decrease in upper basin reservoir elevation during augmentation period (assumes needed water releases are evenly divided between the two reservoirs):

   Turquoise: - 3.7 feet
   Twin: - 2.5 feet

2. Historical mean water surface elevation at Pueblo Reservoir on July 24: 4,858.0 feet

3. Increase in Pueblo Reservoir elevation by September 7 due to augmentation: +2.5 feet

Wet Water Supply Year

Augmentation of baseline hydrograph would need to begin: September 5
Required augmentation volume: 500 acre-feet
Decrease in October through March riverflows: insignificant

Effects of this scenario:

1. Maximum decrease in upper basin reservoir elevation during augmentation period (assumes needed water releases are evenly divided between the two reservoirs):

   Turquoise: less than 0.5 foot
   Twin: less than 0.5 foot

2. Historical mean water surface elevation at Pueblo Reservoir on July 24: 4,880.0 feet

3. Increase in Pueblo Reservoir elevation by September 7 due to augmentation: less than 0.5 feet

Dry Water Supply Year

Augmentation of baseline hydrograph would need to begin: July 24
Required augmentation volume: 53,000 acre-feet
Decrease in October through March riverflows: 150 cfs/day

Effects of this scenario:

1. Maximum decrease in upper basin reservoir elevation during augmentation period (assumes needed water releases are evenly divided between the two reservoirs):

   Turquoise: - 16.0 feet
   Twin: - 12.25 feet

2. Historical mean water surface elevation at Pueblo Reservoir on July 24: 4,845.0 feet

3. Increase in Pueblo Reservoir elevation by September 7 due to augmentation: +14.0 feet

Scenario 2 - 700 cfs from July 24 to September 7

This scenario represents flows that are designed to support boating throughout the high usage season, while using the minimum amount of augmentation water possible. Even though the river may be technically navigable at lower flows, user surveys indicated that the minimum acceptable flow for rafting users is approximately 750 cfs. Therefore, under this scenario, flows are provided at 700 cfs through September 7. After September 7, the baseline flow patterns would resume. Slightly lower flows from October to March would be required to offset the additional water released from upper basin reservoirs.

Implementation of this scenario would require the following water management considerations:

Average Water Supply Year

Augmentation of baseline hydrograph would need to begin: August 29
Required augmentation volume: 1,000 acre-feet
Decrease in October through March riverflows: insignificant

Effects of this scenario:

1. Maximum decrease in upper basin reservoir elevation during augmentation period (assumes needed water releases are evenly divided between the two reservoirs):

   Turquoise: less than 0.5 foot
   Twin: less than 0.5 foot

2. Historic mean water surface elevation at Pueblo Reservoir on July 24: 4,858.0 feet

3. Increase in Pueblo Reservoir elevation by September 7 due to augmentation: less than 1.0 foot

Wet Water Supply Year

Augmentation of baseline hydrograph would need to begin: not required
Required augmentation volume: not required
Decrease in October through March riverflows: not applicable

Effects of this scenario:

None.

Dry Water Supply Year

Augmentation of baseline hydrograph would need to begin: July 24
Required augmentation volume: 25,000 acre-feet
Decrease in October through March riverflows: 70 cfs/day

Effects of this scenario:

1. Maximum decrease in upper basin reservoir elevation during augmentation period (assumes needed water releases are evenly divided between the two reservoirs):

   Turquoise: - 7.5 feet
   Twin: - 5.25 feet

2. Historic mean water surface elevation at Pueblo Reservoir on July 24: 4,845.0 feet

3. Increase in Pueblo Reservoir elevation due to augmentation: + 5.0 feet

Scenario 3 - 550 cfs from July 24 to September 7

Fisheries studies indicate that usable habitat starts to be lost most rapidly as riverflows exceed 550 cfs. Therefore, this scenario provides a flow of 550 cfs from July 24 to September 7. After September 7, flows would return to baseline levels. Under this scenario, BOR would have to ensure that it had adequate storage space for supplemental storage during the July 24 to September 7 period. Creating this storage space may require higher releases during runoff prior to July 24 in some water years, a practice that might not be possible if the channel below Twin Lakes is already at capacity. The required supplemental storage would result in full reservoirs being maintained through September 7 in many water years.

Higher flow releases during the **following** October to March would be required to offset the additional water held at upper basin reservoirs during the July 24 to September 7 period. These higher releases would be required to make sure that the reservoirs are drawn down sufficiently to accommodate the following year's spring runoff.

Higher flow releases during the **preceding** October to March period may be required to offset the additional water held at upper basin reservoirs during the July 24 to September 7 period. These higher releases may be required to ensure that BOR has sufficient water available for delivery to water users from Pueblo Reservoir during the late summer period. Because there are so many factors that go into water delivery decisions, it is impossible to predict the frequency or magnitude of this possible event.

In addition to the flow management considerations outlined above, BOR would have to work with the Colorado Division of Water Resources to address multiple institutional and legal concerns that would be created by increased storage in late summer. For example, downstream water rights that rely upon flows from the upper basin during the July 24 to September 7 time period would have to be protected. If BOR had to store water out of priority to implement this scenario, those flows would have to be replaced by releases from another storage structure.

Implementation of this scenario would require the following water management considerations:

Average Water Supply Year

Supplemental storage would need to occur from July 24 to: September 7
Required storage volume: 33,000 acre-feet

Effects of this scenario:

1. Approximate increase in May 15 to July 15 flows to create storage space for July 24 to September 7 period = 300 cfs

2. Upper reservoir drawdown required by July 24 to accommodate storage during July 24 to September 7 period:

   Turquoise: 9.5 feet
   Twin: 7.0 feet

3. Increase in October through March riverflows: 100 cfs/day

4. Historic mean water surface elevation at Pueblo Reservoir on July 24: 4,858.0 feet

5. Foregone storage elevation at Pueblo Reservoir by September 7 due to upper basin storage and reduced releases July 24 to September 7: - 11.0 feet

Wet Water Supply Year

Supplemental storage would need to occur from July 24 to: September 7
Required storage volume: 98,000 acre-feet

Effects of this scenario:

1. Approximate increase in May 15 to July 15

flows to create storage space for July 24 to September 7 period = 825 cfs

2. Upper Reservoir drawdown required by July 24 to accommodate storage for July 24 to September 7 period:

   Turquoise: 33.0 feet
   Twin: 27.0 feet

3. Increase in October through March riverflows: 275 cfs/day

4. Historic mean water surface elevation at Pueblo Reservoir on July 24: 4,880.0 feet

5. Foregone storage elevation at Pueblo Reservoir by September 7 due to upper basin storage and reduced releases July 24 to September: - 34.0 feet

Dry Water Supply Year

Supplemental storage would need to occur from July 24 to: not required
Required storage volume: not required
Increase in October through March river flows: not applicable

Effects of this scenario:

None.

Scenario 4 - 400 cfs from July 24 to September 7

This scenario represents flows that most strongly favor biological values during the July 24 to September 7 period. Studies indicate that the maximization of usable fishery habitat occurs between flows of 300 cfs and 400 cfs. Therefore, this scenario provides flows at 400 cfs from July 24 to September 7. After that point, flows would return to baseline levels. Under this scenario, BOR would have to ensure that it had adequate storage space for supplemental storage during the July 24 to September 7 period. Creating this storage space may require higher releases during runoff prior to July 24 in some water years, a practice that might not be possible if the channel below Twin Lakes is already at capacity. The required supplemental storage would result in full reservoirs being maintained through September 7 in many water years.

Higher flow releases during the **following** October to March would be required to offset the additional water held at upper basin reservoirs during the July 24 to September 7 period. These higher releases would be required to make sure that the reservoirs are drawn down sufficiently to accommodate the following year's spring runoff.

Higher flow releases during the **preceding** October to March period may be required to offset the additional water held at upper basin reservoirs during the July 24 to September 7 period. These higher releases may be required to ensure that BOR has sufficient water available for delivery to water users from Pueblo Reservoir during the late summer period. Because there are so many factors that go into water delivery decisions, it impossible to predict the frequency or magnitude of this possible event.

In addition to the flow management considerations outlined above, BOR would have to work with the Colorado Division of Water Resources to address multiple institutional and legal concerns that would be created by increased storage in late summer. For example, downstream water rights that rely upon flows from the upper basin during the July 24 to September 7 time period would have to be protected. If BOR had to store water out of priority to implement this scenario, those flows would have to be replaced by releases from another storage structure.

Implementation of this scenario would require the following water management considerations:

Average Water Supply Year

Supplemental storage would need to occur from July 24 to: September 7
Required storage volume: 47,000 acre-feet

Effects of this scenario:

1. Approximate increase in May 15 to July 15 flows to create storage space for July 24 to September 7 period = 390 cfs

2. Upper reservoir drawdown required by July 24 to accommodate supplemental storage during July 24 to September 7 period:

   Turquoise: 14.0 feet
   Twin: 11.75 feet

3. Increase in October through March riverflows: 130 cfs/day

4. Historic mean water surface elevation at Pueblo Reservoir on July 24: 4,858.0 feet

5. Foregone storage elevation at Pueblo Reservoir by September 7 due to upper basin storage and reduced releases July 24 to September 7: -16.0 feet

Wet Water Supply Year

Supplemental storage would need to occur from July 24 to: September 7
Required storage volume: 112,000 acre-feet

Effects of this scenario:

1. Approximate increase in May 15 to July 15 flows to create storage space for July 24 to September 7 period = 930 cfs

2. Upper reservoir drawdown required by July 24 to accommodate supplemental storage during July 24 to September 7 period:

   Turquoise: 35.0 feet
   Twin: 33.0 feet

3. Increase in October through March riverflows: 310 cfs/day

4. Historic mean water surface elevation at Pueblo Reservoir on July 24: 4,880.0 feet

5. Foregone storage elevation at Pueblo Reservoir by September 7 due to upper basin storage and reduced releases July 24 to September 7: - 42.0 feet

Dry Water Supply Year

Supplemental storage would need to occur from July 24 to: August 20
Required storage volume: 4,000 acre-feet

Effects of this scenario:

1. Approximate increase in May 15 to July 15 flows to create storage space for July 24 to September 7 period = 30 cfs

2. Upper Reservoir drawdown required by July 24 to accommodate storage during July 24 to September 7 period:

   Turquoise: 1.5 feet
   Twin: 2.0 feet

3. Increase in October through March riverflows: 10 cfs/day

4. Historic mean water surface elevation at Pueblo Reservoir on July 24: 4,845.0 feet

5. Foregone storage elevation at Pueblo Reservoir by September due to supplemental storage and reduced releases July 24 to September 7: 1.0 feet

Discussion of Natural Resource Tradeoffs for Water Management Scenarios

Procedures and Assumptions Used in Analyzing Tradeoffs Between Resource Values

In the previous sections of this study, a relationship has been identified between flow levels (or reservoir levels) and how well a resource value is supported. For each resource value, a given flow or reservoir level will lie somewhere in a spectrum ranging from "does not support this resource value" to "optimally supports this resource value." Tradeoffs simply illustrate how resource values are affected by various flows. To derive the full picture of all the tradeoffs associated with a given scenario, a resource manager would look at each resource value (rafting, angling, fish habitat, etc.) at each water management location (Arkansas River, Turquoise Reservoir, Twin Lakes, and Pueblo Reservoir.) When taking this overall view, it becomes readily apparent that flows which are excellent for supporting some resource values are very negative for other resource values.

For this analysis, it is helpful to review the flow preferences and baseline Arkansas River hydrograph presented in the Executive Summary (Section 1).

Resource Tradeoffs - Arkansas River

Table F-1 indicates how each water management scenario affects various resource values. The type of analysis used in this section is a "departure" analysis, which simply means that the flow provided under each scenario has been compared with the preferred flow for each resource value. Specifically, the preferred flow is subtracted from the flow provided in the scenario to determine how much change there is, in terms of cubic feet per second, from the preferred flow. The amount of change from the preferred flow is expressed in terms of a percentage difference.

Table F-1 shows the departure ratings for each resource value under each of the flow scenarios. It is followed by text that summarizes and highlights the resource tradeoffs.

Key to Table of Arkansas River Tradeoffs

Rating of the Streamflow Provided in Scenario	Percentage Departure from Preferred Flow
extremely negative	71 or more
very negative	61 - 70
somewhat negative	51 - 60
slightly negative	41 - 50
slightly positive	31 - 40
somewhat positive	21 - 30
very positive	11 - 20
extremely positive	0 - 10

Departure Analysis Example: The juvenile fish population prefers a flow of 350 cfs. Under Scenario 1, the flow rate of 1,000 cfs would be a difference of 650 cfs from the preferred flow rate of 350 cfs. The 650 cfs change divided by 350 cfs preference reveals that the 1,000 cfs flow rate would be departure (change) of 185 percent from the preferred flow rate. A change of 185 percent would receive a rating of "extremely negative."

When using Table F-1, the following important limitations and background information should be considered:

1. Even though all resource values are given equal space on the table, there are dramatically different levels of river usage during the July 24 to September 7 timeframe:

   ~ Juveniles of the fish population are more affected by flow manipulations than adults during the July 24 to September 7 period. Fry have recruited to the juvenile life stage by this date, and spawning does not occur during this time. The row in the table that illustrates effects on juveniles has been shaded to indicate their susceptibility to changes in flow during this time period.

TABLE F-1

Arkansas River Tradeoffs.
(Shading indicates the recreational activities and biological life stages that have the highest river usage rates during the July 24 to September 7 period.)

Resource Value	Scenario 1 - 1,000 cfs	Scenario 2 - 700 cfs	Scenario 3 - 550 cfs	Scenario 4 - 400 cfs
Fish population - juvenile (median preference = 350 cfs)	Extremely negative (185% departure)	Extremely negative (100% departure)	Somewhat negative (57% departure)	Somewhat positive (30% departure)
Fish population - adult (median preference = 500 cfs)	Extremely negative (185% departure)	Slightly positive (40% departure)	Extremely positive (10% departure)	Very positive (20% departure)
Rafting (median preference = 1,750 cfs)	Slightly negative (42% departure)	Somewhat negative (60% departure)	Very negative (69% departure)	Extremely negative (71% departure)
Kayaking (median preference = 1,400 cfs)	Somewhat positive (29% departure)	Slightly negative (50% departure)	Very negative (61% departure)	Extremely negative (71% departure)
Fly fishing (median preference = 450 cfs)	Extremely negative (122% departure)	Somewhat negative (56% departure)	Somewhat positive (22% departure)	Very positive (11% departure)
Spin fishing (median preference = 950 cfs)	Extremely positive (5% departure)	Somewhat positive (26% departure)	Slightly negative (42% departure)	Somewhat negative (58% departure)
Float fishing (median preference = 1,050 cfs)	Extremely positive (5% departure)	Slightly positive (33% departure)	Slightly negative (48% departure)	Very negative (62% departure)

- Of total boating use, 90 percent is use by rafters, while the other 10 percent is use by kayakers. The row in the table that illustrates effects on rafting has been shaded to indicate the large overall effect.

- Of total angling use, 54 percent is fly fishing, 41 percent is spin fishing, and 5 percent is float fishing. The row in the table that illustrates effects on fly fishing has been shaded to indicate the higher level of use.

2. Fish population preferences were calculated by using brown trout as an indicator species. This does not mean that other fish species, such as rainbow trout, were ignored. Rather, rainbow trout preferences are close to brown trout preferences, and one species had to be selected in order to avoid an overly complicated analysis and presentation of data.

3. All preferences are expressed as flow preferences at the Wellsville streamflow gage. Because inflow from tributaries upstream and downstream from the gage, a given flow at Wellsville will translate to a lower flow upstream and a higher flow downstream. For a discussion of how to calculate the typical flow differences between different reaches of the river, please see the Hydrologic Analysis (Section 4) in this report.

4. By using scenarios that provide a constant flow rate over the 45-day period from July 24 to September 7, the resource implications of changes in flows that naturally occur during this period are not illustrated. For example, the current flow augmentation program to support rafting uses typically starts operation when natural flows come down to 700 cfs, rather than automatically providing an exact flow rate of 700 cfs starting on July 24. Natural riverflows may not recede to 700 cfs until well into the July 24 to September 7 period. Therefore, the analysis of the scenarios does not take into account any flows that might have been much higher than 700 cfs before the augmentation program begins.

Discussion of Arkansas River Tradeoffs

In this section, flow preferences for each resource value are discussed. The flow preferences in relation to the four river management scenarios presented previously are also discussed.

Fish Habitat Tradeoffs

Fish habitat tradeoffs in relation to discharge at the Wellsville gage can be easily discerned by referring to the flow preference curves from the Executive Summary (Section 1, Figure 1-7). Flow preference for brown trout was the focus of this analysis because they are prevalent in the river, the population is self sustaining, and any given operational program will influence rainbow trout in a similar manner. Figure 1-7 displays all life stages of brown trout so tradeoffs can be determined year-round. However, the focus of this analysis is from July 24 to September 7, when juveniles and adults are prevalent in the river. Growth of juvenile fish (fish that are approximately 2 to 8 inches in length) is the primary lifestage of concern during this period. This is because fish growth can be particularly affected by flows above 550 cfs, as demonstrated by the sharp loss in usable habitat in the juvenile trout flow preference curve.

The Stockyard station was selected to illustrate flow preferences for fish populations because fish populations throughout the remainder of the river are generally protected when a preferred flow is delivered at the Wellsville gage, which is close to the Stockyard study site. However, caution should be exercised when extrapolating flows to other reaches. The Stockyard reach has a wider channel than much of the river, and therefore, a flow that provides preferred habitat at Stockyard may produce depths and velocities that are either above or below the preferred range at other sites.

Habitat consistently improves with lower discharge down to 300 cfs (flows were not modeled below 300 cfs). The amount of habitat available at various flow levels can be determined by referring to the Instream Flow Incremental Methodology (IFIM) data in Appendices C and D. Preferred flows are obtained most often in dry water years, as illustrated by the hydrographs in the Executive Summary (Section 1).

In addition, Figures 1-4, 1-5, and 1-6 from Section 1 provide an idea of typical flow rates for average, wet, and dry water years. From this, frequency of preferred flows can be determined. The following discussion describes tradeoffs for brown trout juveniles under the various flow scenarios outlined previously. It should be noted that the water levels needed for reservoir fisheries are discussed later, and that water needs for river fisheries do not always produce reservoir conditions that are favorable to reservoir fisheries.

Scenario 1 (1,000 cfs) provides the least amount of habitat and is furthest from the flow preference for fish populations. Although Scenario 2 (700 cfs) provides more habitat than Scenario 1, it is still almost double the preferred flows for fish habitat.

IFIM research demonstrated that the amount of usable habitat rapidly declines as flows exceed 550 cfs, so Scenario 3 (550 cfs) delivers significantly more available habitat than Scenario 2. However, it is still more than 50 percent higher than the preferred flow for juvenile fish populations. Scenario 4 delivers a flow that is within the optimum range for habitat preference.

Under many of the flow scenarios, Arkansas River flows may need to be manipulated at other times of the year outside of the July 24 to September 7 period. In general, when the winter flows remain inside the 300 to 500 cfs range, there would be no major impact on the fishery. In two cases, winter flows would fall outside this range. Scenarios 3 and 4 would require a mean discharge of 770 cfs and 805 cfs respectively from October through March in wet years, and would require a mean discharge of 595 cfs and 625 cfs during an average year. This would result in a reduction of available habitat, but it occurs during a period that is much less critical to fish growth and recruitment than summer months. Winter flow adjustments (December through March) have the least impact on fish populations. Reservoir releases could be ramped up during this period to minimize impacts during October and November. Alternatively, if the total volume that needs to be sent downstream is small enough, the least impact on habitat occurs if releases are evenly spread out from October through March to attempt to keep flows at 500 cfs or below. As mentioned previously, spawning (mid-October to mid-November) and hatching/emergence flows (April to mid-May) that are similar tend to maximize survival rates.

Riparian Tradeoffs

The exact magnitude, extent, and acreage of riparian change under the four scenarios is impossible to calculate because there is continuous change along the river corridor in terms of channel type, soil parent materials, streambank porosity, and local water table depths. However, principles from the scientific literature are well-established. The present-day riparian community is a direct result of the baseline hydrograph presented previously. Any effects to the riparian communities along the river due to a different flow regime during the growing season will occur slowly and can only be quantified via long-term studies.

Consistently lower growing season flows could cause encroachment on the channel by riparian vegetation, while higher elevation riparian plants could be lost if lower groundwater tables occur as a result of lower growing season flows. The overall result may be approximately the same amount of riparian acreage, but at different locations relative to the river channel.

Consistently higher growing season flows could cause long-term flooding and extermination of some riparian sites. In some locations, higher flows could also cause erosion of soils and substrates that support riparian resources. However, higher groundwater levels and newly deposited soils could create riparian communities in locations that were either previously unvegetated or vegetated by upland species. The overall result may be approximately the same amount of riparian acreage, but at different locations relative to the channel.

Scenario 1 would not increase flows over those typically experienced during wet water years. However, flows would increase during average and dry water years. Under Scenario 1, the river would experience flows of 1,000 cfs much more frequently after August 8 than under present management, so the increase in water level would be likely to prolong inundation of some riparian communities and raise water table levels. Although there is no certainty that change would occur, principles of riparian ecology would suggest that the composition and placement of riparian vegetation could change based on the tolerance individual species have for duration of flooding and groundwater levels. Similarly, longer periods of shear stress on unvegetated banks at higher flows could erode streambanks. Because of the solid rock substrate underlying much of the river corridor, it is difficult to determine if elevated flows would create wetland/riparian potential in new locations.

Scenario 2 would not increase flows over those typically experienced during wet and average water years, but there would be an increase over typical dry year flows. Implementation of Scenario 2 would not be expected to significantly change the riparian community, since flows are increased over baseline flows only during dry years.

Scenarios 3 and 4 could significantly decrease flows for a 6-week period of the growing season. Consistent implementation of these scenarios could cause wetland species encroachment into the channel during the growing season. This encroaching vegetation may be successful in establishing itself, or it could then subsequently be removed by the sheer stress associated with spring runoff. In addition, vegetation at the upper margin of the band of riparian vegetation could experience dieback. Loss of this vegetation may make these soil surfaces more prone to erosion during high flow events. October through March flows in Scenarios 3 and 4 increase a maximum of 310 cfs, which translates to a mean October through March flow of 805 cfs. These flow levels would not be expected to significantly affect the riparian community because they are still significantly below the rooting zone of most riparian communities along the river.

Wildlife Tradeoffs

As stated previously, flow regimes that support a stable and diverse riparian community will also support the most stable and diverse assemblage of terrestrial wildlife. The negative and positive effects of the scenarios outlined in the riparian section above would also translate into negative and positive indirect effects for wildlife. However, the effects of the scenarios on wildlife are even more difficult to predict than the effects on riparian vegetation because many of the wildlife species of concern are mobile and have some ability to adapt to gradual changes in the riparian community that would occur as the result of a changed growing season flow regime. As noted in the riparian discussion, it is also difficult to predict whether suitable replacement habitat would emerge after a new flow regime is implemented.

Under Scenario 1, the river would experience flows of 1,000 cfs much more frequently and for a longer duration than under present management. This increase in water level would be likely to create a situation where some breeding, nesting, feeding, and prey areas are inundated for longer periods than under the baseline flow. Backwater and side channel areas could remain connected to the main channel for a longer period, possibly producing depths and water temperatures that are not usable by some wildlife species. Implementation of Scenario 2 would not be expected to significantly impact wildlife species since flows are increased over baseline flows only during dry years.

Consistently lower flows occur during 6 weeks of the growing season in Scenarios 3 and 4. Some breeding, nesting, feeding, and prey areas would not be inundated for a sufficient period of time to produce usable substrate conditions, plant composition, cover, and prey populations. Backwater and side channels may not flood or may not remain connected to the main channel. Therefore, water depth, inundated area, and water quality may not be sufficient for terrestrial wildlife use. The increase in October through March flows in Scenarios 3 and 4, which is a maximum of 310 cfs, would not be a large enough increase to significantly impact the amount and quality of habitat available to terrestrial wildlife.

If the flows provided in Scenarios 1 and 2 result in higher numbers of recreational users floating the river, then additional impacts related to disturbance of wildlife would be expected. Presence of humans can flush wildlife out of breeding, feeding, resting, and cover areas. The additional disturbance can cause wildlife to utilize metabolic reserves that would normally be used for completing important life stages. In addition, the disturbance can result in the loss of usable habitat, creating greater competition for wildlife resources in undisturbed areas.

Recreation Tradeoffs

Scenarios 1 and 2 illustrate that augmentation of baseline flows is most beneficial to spin fishing, float fishing, kayaking, and rafting in dry water years. During dry water years, augmentation of flows in Scenario 1 (up to the 1,000 cfs level) creates significant additional periods of time when flows are within the preferred ranges for float fishing and spin fishing. In addition, augmentation to 1,000 cfs brings flows to within the acceptable range for kayaking and rafting.

Scenario 2 (700 cfs) provides similar benefits to these activities, with two exceptions. At 700 cfs, flows for float fishing are within the acceptable range rather than the preferred range. At 700 cfs, flows are 50 cfs outside of the acceptable range for kayaking. However, reducing the augmentation target to the 700 cfs level in Scenario 2 brings flows to within the range of preferred flows for fly fishing.

In average to wet water years, implementation of Scenarios 1 and 2 would not dramatically improve recreation managers' ability to provide the ranges of preferred flows because in wet years the baseline flows are typically above 700 cfs and frequently above 1,000 cfs.

Implementation of Scenario 3 (550 cfs) and Scenario 4 (400 cfs) would reduce flows that rafters, kayakers, spin fishers, and float fishers have enjoyed from 1982 to 1995 in average and wet years. Under Scenario 3, flows would be outside of the preferred range of flows for spin fishing and float fishing, significantly diminishing the quality of the experience that is available to those users. However, fly fishing users would be expected to have a higher quality experience, as flows are brought to within the range of preferred flows for that activity. During a wet year, implementation of Scenarios 3 and 4 would be positive for spin fishing and fly fishing because the baseline flows in wet years were above the range of acceptable flows for those activities.

Under Scenario 4 (400 cfs), the quality of all recreation activities, except for fly fishing, would suffer significant negative impacts in average and wet water years. This flow is outside of the preferred flow range for all activities except fly fishing. The constant flow of 400 cfs in Scenario 4 is similar to what already occurs in dry water years. During dry years, baseline flows are low enough to be outside of the range of preferred flows for most recreational activities.

Resource Tradeoffs - Reservoirs

Resource tradeoffs for reservoirs were also evaluated by using preferences that were identified in the biological and recreational studies. Ratings of each scenario are based upon how much water levels would increase or decrease relative to the preferred reservoir level. Under Scenarios 1 and 2, an assumption is made that the reservoirs would be full on July 24. Under Scenarios 3 and 4, an assumption is made that reservoirs would have to be drawn down by July 24 to accommodate additional storage during the July 24 to September 7 period.

Key to Table of Turquoise Reservoir and Twin Lakes Tradeoffs

Biological studies revealed that fish populations at Turquoise and Twin Lakes Reservoirs prefer full reservoirs in which the water level does not fluctuate dramatically during critical growth periods. Recreational studies revealed that users also prefer full reservoirs in which the water level does not fluctuate dramatically. Implementation of the scenarios occurs between July 24 to September 7, which is a period critical for both fish growth and recreation usage.

The ratings used in Table F-2 can be interpreted as follows:

Rating of Reservoir Level in Scenario	Change in Reservoir Elevation
very negative	8-foot or more loss
somewhat negative	4- to 8-foot loss
no change	changes between -4 feet and +4 feet
somewhat positive	4- to 8-foot gain
very positive	8-foot or more gain

Key to Table of Pueblo Reservoir Tradeoffs

Biological studies revealed that fish populations at Pueblo Reservoir prefer stable to gradually dropping water levels during the July 24 to September 7 period. Some warmwater species benefit from a quick drop in reservoirs levels between July 15 and August 15. Recreational studies revealed that the user preference for boating during this period is for stable or gradually increasing water levels. Anglers prefer stable to increasing water levels for access and safety reasons, but satisfactory angling success rates are also critical, so the fish population needs must be strongly considered.

Ratings are based upon how much water levels would change under each of the scenarios during the July 24 to September 7 period. The table assumes the following historic mean surface elevations at Pueblo Reservoir on July 24:

Average year - 4,858.0 feet
Wet year - 4,880 0 feet
Dry year - 4,845.0 feet

TABLE F-2

Turquoise Reservoir and Twin Lakes Tradeoffs
During Implementation of Scenarios July 24-September 7

	Scenario 1 - 1,000 cfs			Scenario 2 - 700 cfs			Scenario 3 - 550 cfs			Scenario 4 - 400 cfs		
	Water Level	Fish Habitat Rating	Recreation Rating	Water Level	Fish Habitat Rating	Recreation Rating	Water Level	Fish Habitat Rating	Recreation Rating	Water Level	Fish Habitat Rating	Recreation Rating
Average Year	no change	no change	no change	no change	no change	no change	7- to 9.5-foot drawdown as of 7/24	somewhat negative to very negative	somewhat negative to very negative	12- to 14-foot drawdown as of 7/24	very negative	very negative
Wet Year	no change	no change	no change	no change	no change	no change	27- to 33-foot drawdown as of 7/24	very negative	very negative	33- to 35-foot drawdown as of 7/24	very negative	very negative
Dry Year	12- to 16-foot drawdown 7/24-9/7	very negative	very negative	5- to 7-foot drawdown 7/24-9/7	somewhat negative	somewhat negative	no change	no change	no change	no change	no change	no change

Given that *fisheries* prefer stable to declining water levels, the ratings used in Table F-3 can be interpreted as follows:

Rating of Reservoir Level in Scenario	Change in Reservoir Elevation
very negative	8-foot or more gain
somewhat negative	4- to 8-foot gain
no change	changes between -4 feet and +4 feet
somewhat positive	4- to 8-foot loss
very positive	8-foot or more loss

Given that *recreationists* prefer stable to increasing water levels, the ratings used in Table F-3 can be interpreted as follows:

Rating of Reservoir Level in Scenario	Change in Reservoir Elevation
very negative	8-foot or more loss
somewhat negative	4- to 8-foot loss
no change	changes between -4 feet and +4feet
somewhat positive	4- to 8-foot gain
very positive	8-foot or more gain

TABLE F-3

Pueblo Reservoir Tradeoffs

During Implementation of Scenarios July 24-September 7

	Scenario 1 - 1,000 cfs			Scenario 2 - 700 cfs			Scenario 3 - 550 cfs			Scenario 4 - 400 cfs		
	Water Level	Fish Habitat Rating	Recreation Rating	Water Level	Fish Habitat Rating	Recreation Rating	Water Level	Fish Habitat Rating	Recreation Rating	Water Level	Fish Habitat Rating	Recreation Rating
Average Year	no change	no change	Boating - no change Angling*	no change	no change	Boating - no change Angling*	11-foot foregone elevation 7/24-9/7	very positive	Boating - very negative Angling*	16-foot foregone elevation 7/24-9/7	very positive	Boating - very negative Angling*
Wet Year	no change	no change	Boating - no change Angling*	no change	no change	Boating - no change Angling*	34-foot foregone elevation 7/24-9/7	very positive	Boating - very negative Angling*	42-foot foregone elevation 7/24-9/7	very positive	Boating - very negative Angling*
Dry Year	14-foot gain 7/24-9/7	very negative	Boating - very positive Angling*	5-foot gain 7/24-9/7	somewhat negative	Boating - somewhat positive Angling*	no change	no change	Boating - no change Angling*	no change	no change	Boating - no change Angling*

* Angling preference parallels boating preference, but angling use is also affected by fish habitat preference

Discussion of Tradeoffs - Reservoirs

Fish Habitat Tradeoffs

The first part of this discussion focuses on primary and secondary production impacts related to water level manipulations at Twin Lakes and Turquoise Reservoirs. July 24 to September 7 manipulations that result in drafts of more than 10 feet from the top of the conservation pool, the elevation where the greatest impacts on primary productivity occur, are of highest concern. Impacts on the fishery at other times of the year are also briefly discussed.

Typical reservoir elevations and the corresponding drawdown with typical Fryingpan-Arkansas operations from 1982 to 1995 were used to create a baseline to begin tradeoff analysis. Typical 1982-1995 drawdowns were used to calculate reservoir level increases and decreases for each of the scenarios. Mean elevation with Fryingpan-Arkansas operations at Twin Lakes in July, August, and September is 9,193, 9,190, and 9,190 feet, respectively, representing drawdowns of 7, 10, and 10 feet. Turquoise Reservoir is typically at 2 feet below the top of the conservation pool for all 3 months. In the scenarios, it is assumed that one-half of the total acre-feet of water needed to accommodate a scenario would come from each reservoir. However, the drawdowns in the scenarios could be adjusted to optimize levels within each reservoir.

Clear Creek Reservoir is not part of the Fryingpan-Arkansas Project and, therefore, is not discussed. However, natural resource values are best maintained when the reservoir is maintained as close to full pool as possible year-round.

Scenario 1 - Impacts to primary productivity would occur at Twin Lakes and Turquoise Reservoirs for all 3 months in dry and average years. This is of particular concern in dry water years where the surface elevation in this scenario could be 22 feet below the top of the conservation pool at Twin Lakes and 18 feet below at Turquoise Reservoir. Drawdowns of 12.5 feet could occur in average water years at Twin Lakes in this scenario. However, this drawdown could possibly be kept to less than 10 feet by drafting more water from Turquoise Reservoir. Drafts of over 10 feet would not occur in either impoundment during wet years. Drawdowns to achieve this scenario would take place from July 24 to September 7, the most critical time of year concerning productivity.

Scenario 2 - Impacts to productivity would occur at Twin Lakes and Turquoise Reservoirs for all 3 months in a dry water year. The resulting surface elevation in this scenario could be 15 feet below the top of the conservation pool at Twin Lakes and 10 feet below at Turquoise Reservoir. Drafts of over 10 feet would not occur in either impoundment in wet or average years in this scenario. Drawdowns to achieve this scenario would take place from July 24 to September 7, the most critical time of year concerning productivity.

Scenario 3 - Impacts to productivity at Twin Lakes and Turquoise Reservoirs would occur for all 3 months in wet and average years in this scenario. This scenario is of particular concern in wet water years where the surface elevation could be 31 feet below the top of the conservation pool at both Twin Lakes and Turquoise Reservoirs. In an average water year, this scenario could produce a surface elevation 16 feet below the top of the conservation pool at Twin Lakes and 11 feet below at Turquoise Reservoir. Drafts of over 10 feet would not occur in either impoundment in dry years in this scenario. Although these drawdowns are undesirable, any winter or spring drawdown effects on productivity are of less concern compared to late summer. However, during a wet year, possible reduction of spawning habitat in October and dewatering of redds in the winter could impact lake trout reproduction.

Scenario 4 - Impacts to productivity at Twin Lakes and Turquoise Reservoirs would occur for all 3 months in wet and average years in this scenario. This scenario is of particular concern in wet water years where the surface elevation could be 34 feet below the top of the conservation pool at Twin Lakes and 36 feet below at Turquoise Reservoir. In an average water year, this scenario could produce a surface elevation 20 feet below the top of the conservation pool at Twin Lakes and 16 feet below at Turquoise Reservoir. Drafts of over 10 feet would not occur in either impoundment in dry years. Although these drawdowns are undesirable, any winter or spring drawdown effects on productivity are of less concern compared to late summer. However, during a wet year, possible reduction of spawning habitat in October and dewatering of redds in the winter could impact lake trout reproduction.

The following tradeoffs would be expected at Pueblo Reservoir:

Scenario 1 - In a dry year, Pueblo Reservoir water levels would be expected to increase by approximately 14 feet. This increase would occur at a time when declining water levels are preferred for revitalization of shorelines and increasing predation of forage fish.

Scenario 2 - In wet or average years, there would be minimal or no increases to water levels in Pueblo Reservoir. Although the historic, baseline water levels are not preferred levels, they would not be significantly detrimental to fish populations. In dry years, the 5-foot increase in water levels would be a negative factor for increasing the productivity of the warmwater fishery.

Scenario 3 - In wet or average years, this scenario would result in foregone elevations of 11 and 34 feet, respectively, at Pueblo Reservoir. This would provide excellent benefits to the primary productivity of the reservoir and to prey foraging by bass and crappie.

Scenario 4 - At Pueblo Reservoir, the fishery would only be marginally affected in a dry year. In wet and average years, this scenario creates foregone elevations of 16 and 42 feet, respectively. This would provide midseason benefits to the warmwater fishery by allowing shoreline areas to rejuvenate and by providing maximum efficiency of prey foraging by sport fish.

Riparian/Wildlife Tradeoffs

All five scenarios require reservoir operational changes that could affect riparian and wetland resources. Scenario 1 would require the release of more water from upper reservoirs than has historically occurred during average and dry years. Scenario 2 would require the release of more water from upper reservoirs than historically occurred during dry years. The amount released varies greatly depending on the water supply situation, but it is the most significant in dry water years. Any accelerated lowering of reservoir levels beyond the long-term elevation trends will separate groundwater from the rooting zones of some riparian/wetland plants.

At Pueblo Reservoir, the historic water elevation during late summer is typically far removed from the rooting zone of riparian/wetland plants. The water elevations gained under implementation of Scenarios 1 and 2 would be insufficient to bring the water level back up to the rooting zone of riparian/wetland plants.

Implementation of Scenarios 3 and 4 would mean that Turquoise and Twin Lakes Reservoirs would be filling or remain full during the July 24 to September 7 period in most water years. An increasing water level during the late growing season would mean that many plants that established themselves earlier in the growing season (when reservoirs had to be kept at lower elevations to accommodate July 24 to September 7 storage) could be flooded out late in the growing season. In turn, flooded riparian areas may mean less available habitat for wildlife species. During wet water years, the supplemental storage in upper basin reservoirs during this period would mean that between 34 and 42 feet of storage would be foregone at Pueblo Reservoir during the July 24 to September 7 period. Although Pueblo Reservoir water levels are typically below the rooting zone during this period, a significant and infrequent opportunity to increase the vigor and extent of the riparian/wetland community would be foregone.

Recreation Tradeoffs

Although recreation users express a preference for full reservoirs with a stable water level, actual recreation use at reservoirs is not extremely sensitive to water levels. Decreases in water elevation of 10 feet or less at Turquoise Reservoir, 10 feet or less at Twin Lakes, and 15 feet or less at Pueblo Reservoir would not be expected to dramatically change recreation use patterns. Fishing usage under all scenarios would be expected to track with the impact of water on fish populations, which is discussed in the previous section.

Under Scenario 1 during a *dry* water year, water levels would drop 16.0 feet at Turquoise Reservoir and 12.25 feet at Twin Lakes. The quality of user experiences would be diminished significantly, and it would be anticipated that some unquantified drop in usage would occur. During *average* and *wet* years, no significant changes to water levels would be expected to occur at Turquoise and Twin Lakes Reservoirs. At Pueblo Reservoir, water levels would increase by 14 feet during the July 24 to September 7 period, assuming that other operational variables remain constant. Accordingly, unquantified increases in recreational boating use would be expected, along with enhanced shoreline access, visual quality, and safety.

Under Scenario 2, changes in reservoir levels would be modest. Turquoise Reservoir would lose 7.5 feet during a *dry* year, while Twin Lakes would lose 5.25 feet. This would be expected to slightly decrease the quality of the recreational experience for users, but the change may not be of sufficient magnitude to discourage users from visiting.

Under Scenario 3 during a *wet* water year, approximately 34 feet of water elevation would be foregone at Pueblo Reservoir during the July 24 to September 7 period, assuming all other operational variables remain constant. Pueblo Reservoir is typically filled to the top of the conservation pool on July 24 of a *wet* year, and would likely remain full if water were not held back in upper basin storage. Therefore, under this scenario, water levels would likely decline because there would be less inflow to replace deliveries of water made to water users. If the reservoir forgoes the entire 34 feet of storage and large water demands significantly lower the reservoir, boating uses could be almost entirely eliminated. Shoreline access, visual quality, and safety would be very seriously affected.

Under Scenario 3, Turquoise and Twin Lakes Reservoirs would have to be drawn down significantly by July 24 to provide the storage space needed to hold back flows during the July 24 to September 7 period. In an *average* year, Turquoise Reservoir would be drawn down 9.5 feet, while Twin Lakes would be drawn down 7.0 feet. In a *wet* year, these effects would be even more pronounced, requiring Turquoise Reservoir to be draw down by 33.0 feet, and Twin Lakes to be drawn down by 27.0 feet to accommodate the supplement storage required to implement the scenario. At the peak season of recreational use, reservoir levels could be more than 30 feet below capacity, severely affecting the quality of recreation use. While reservoir levels would be rising during the July 24 to September 7 period, the reservoir may not fill until early September, just when recreational demand is starting to taper off.

If Scenario 4 were implemented, the effects at Pueblo Reservoir, Turquoise Reservoir, and Twin Lakes would be similar to Scenario 3, but more pronounced. During a *wet* water supply year, 42 feet of water elevation would be foregone at Pueblo Reservoir during the July 24 to September 7 period. In a *wet* year, up to 35 feet of drawdown may be required at the upper reservoir by July 24 to provide the storage space needed to implement the scenario. An *average* year would see 16.0 feet of foregone storage at Pueblo Reservoir during the July 24 to September 7 period, while the upper reservoirs would need to be lowered from 11.75 to 14.0 feet by July 24 to provide the storage space needed to implement the scenario. The *dry* year effects of implementing this scenario would be minimal because only 4,000 acre-feet of additional storage would be required in upper basin reservoirs to keep riverflows at 400 cfs from July 24 to September 7.