TROUT UNLIMITED

***David Nickum***
Regional Conservation Director
Southern Rockies

May 22, 1998

To: Dr. Bob Behnke
**Re: Colorado Flow Report**

Thank you for agreeing to review Dr. Elizabeth Strange's report on flow alteration in Colorado trout streams ("Flow Regime Limitations of Colorado Trout Populations: Perspectives for Watershed Management"). Your comments and suggestions will be invaluable as TU works to finalize the report for distribution. Please direct your responses to me at:

Trout Unlimited
190 E. Ninth Avenue, Suite 120
Denver, CO 80203

If you prefer, you can respond by email to TURockies@aol.com. I would appreciate receiving your comments by June 26 so that we can incorporate your suggestions into a final report.

While I encourage you to read the full report, the sections where your review will be most important are Chapter 5 (Flow Regimes and Trout Populations) and Chapter 6 (Findings and Recommendations).

Again, thank you for taking time from your busy schedule to review this report. If you have any questions, feel free to call me at (303) 837-9383.

***Trout Unlimited: America's Leading Coldwater Fisheries Conservation Organization***
Colorado Office: 190 E. Ninth Avenue, Suite 120, Denver, CO 80203
PHONE: (303) 837-9383 FAX: (303) 837-9382 EMAIL: TURockies@aol.com

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Dr. Bob Behnke
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# Flow Regime Limitations of Colorado Trout Populations: Perspectives for Watershed Management

**Elizabeth M. Strange, Ph.D.**
**Ecological Consultant**

**Report to Trout Unlimited**

**Review Draft**
**May 1998**

# CONTENTS

REFERENCES

# EXECUTIVE SUMMARY

Until now, water development impacts on trout fisheries have been described mostly in terms of the minimum instream flows needed to provide suitable habitat within stream reaches. Such approaches have met with mixed success, in large part because they do not contribute to the overall health of the river ecosystems on which trout and other species depend. By disrupting natural flow regimes and associated physical, chemical, and biological processes, land and water development fundamentally alter the ecology of riverine ecosystems. As a result, the future sustainability of fishery resources will require management at the watershed-scale.

Successful watershed-scale management of fishery resources will depend on improved understanding of the ways in which natural flow regimes have been altered by human activities. Human uses of water, such as reservoir storage and irrigation diversions, do more than reduce the quantity of water flowing in stream channels. They also change the magnitude, frequency, timing, duration, and rate of change of specific flow conditions needed for habitat development and trout growth, reproduction, and survival. Previous studies of Colorado's trout resources have not considered the potential importance of such biologically significant flow regime alterations.

This report analyzes the ways in which natural flow regimes of major trout rivers and streams in Colorado have been modified by decades of water development. The report also examines the current status of Colorado trout populations in relation to flow regime alterations. The purpose of the study is to provide information on biologically important flow regime characteristics of major trout rivers and streams to 1) assess current flow restoration efforts and 2) serve as a benchmark for assessing potential impacts of future water development.

Results indicate that flow regime alterations limit trout production in many of Colorado's mainstem rivers and threaten the future sustainability of existing trout fisheries and the river ecosystems on which they depend:

- ***The South Platte River*** is impounded by numerous reservoirs that store the river's natural flows. Storage of spring peaks results in a lack of flushing flows needed for channel maintenance and habitat-forming processes, including removal of accumulated sediments and building of gravel bars and pools. Sudden drops in daily flows due to reservoir operations can lead to stream dewatering. Overall reduction in flow quantity reduces the river's ability to dilute increased pollution from expanding land development. To meet projected growth in demand over the next 50 years, Front Range water providers are considering future development of another 121,000 A-ft of transbasin imports, an additional 44,000 A-ft of South Platte supply, and increased use of Denver Basin groundwater, greatly increasing potential fisheries impacts.

- ***The Cache La Poudre River*** is subject to numerous diversions for agriculture and municipal use that significantly reduce streamflows. During dry years, use of river water to supply downstream users leaves little water flowing in the channel. As water is diverted, flows can fall dramatically from one day to the next, increasing the likelihood of stream dewatering. A proposal for a large mainstem dam and reservoir at Grey Rock, just below the confluence of the Cache La Poudre with the North Fork, would further degrade the river's flow regime and its ability to sustain trout fisheries.

- ***The Arkansas River*** receives large quantities of West Slope water via the Frying Pan-Arkansas Project, increasing the volume of native flow by over 20%. Transfers of imported water from upper basin reservoirs to Pueblo Reservoir increase flows in the upper Arkansas in fall and winter and during the month of June. At present, these conditions appear to benefit the fall-spawning brown trout. Proposals for additional augmentations that may alter current conditions therefore need to be carefully evaluated.

- ***The Rio Grande River*** is impounded by the Rio Grande Reservoir 15 miles downstream from its headwaters. Below Del Norte much of the river's flow is diverted for irrigation. Monthly flow magnitudes near Del Norte have declined an average of 26%. Lack of flushing flows reduces both the quality and quantity of trout habitat. Flow and habitat conditions during the time of brown trout egg incubation may not be dependable or sufficient from year to year due to decreased magnitude and increased variability of winter flows.

- ***The Conejos River*** flow regime varies according to releases from Platoro Reservoir to supply downstream irrigators. Immediately below Platoro Dam, the flow regime often fails to meet minimum flow targets. Reservoir inflows are often less than releases required to meet downstream calls, and winter flows are below levels needed to sustain trout populations. There are also significant daily fluctuations in flow during November that can interfere with brown trout spawning and egg incubation. Near Mogote, the magnitude of fall flows has increased, while flows from April through June have declined an average of 20%, reducing the quantity of habitat available for rainbow trout.

- ***The Gunnison River*** is subject to 1,500 active water diversion structures, including projects that transfer Gunnison River water to other basins. Upstream reservoirs store May and June peak flows and increase winter baseflows. Natural variations in seasonal flows have been largely eliminated, while daily fluctuations have increased by over 60%. There are currently three new major water projects under consideration in the Gunnison drainage.

- ***The Taylor River*** is impounded by the Taylor Park Reservoir, resulting in flows below the reservoir from October through mid-December that can become excessively high due to releases to prepare for storage of spring runoff, followed by lower flows over winter as releases stop. Improvements to reservoir operations have decreased unnatural flow variability in fall and winter, but fall flows continue to be unnaturally high.

- ***The upper Colorado River*** is subject to substantial depletions of native flows as a result of water exports to other basins. An average of 230,000 A-ft of water is transported annually to the East Slope as part of the Colorado-Big Thompson (C-BT) Project. Annual mean flow near Hot Sulphur Springs has declined from an average of 709 cfs to 244 cfs as a result of upstream reservoir storage of Colorado River water for export to other basins. Peak flows in May and June have declined by an average of 70%, while minimum flows have declined by almost 75%. Such flow declines greatly reduce both the quality and quantity of trout habitat.

- ***The Blue River*** is impounded by Dillon Reservoir, and reservoir operations regulate the quantity of streamflow below the reservoir within a narrow range, reducing natural flow variation and habitat complexity. Currently, relatively little water is diverted in wet years, while significant quantities are diverted in dry years. The timing of annual minimum and maximum flows is highly irregular, disrupting the natural timing of environmental cues that are important for the timing of life cycle events of trout. Large daily fluctuations can lead to cycles of inundation and dewatering that are harmful for young trout and benthic insects that provide food for adult trout. Denver Water is currently working on a plan to develop another 30,000 acre-feet of junior water rights on the Blue River. The project is expected to reduce releases below Dillon Dam from the current 180 cfs to only 50 cfs year round, significantly impacting the trout fishery.

~40cfs = 30,000af/yr.
180-40=140

- ***The Eagle River*** is one of the only headwater tributaries of the Colorado River that still has no major dam, but many East Slope communities hold rights to further develop Eagle River water. In addition, ongoing development in the Eagle Valley threatens water quality. Peak and base flows have declined significantly from historic levels, limiting the river's capacity to dilute nonpoint pollution and sedimentation.

- ***The Fryingpan River*** supplies water to the Arkansas River drainage as a part of the Fryingpan-Arkansas Project. Fall and winter flows below Ruedi Reservoir have increased as a result of releases to increase storage capacity prior to spring runoff, improving habitat conditions for the fall-spawning brown trout. However, continued declines in spring peak flows will reduce trout habitat over time as channel conditions deteriorate due to lack of flushing flows.

- ***The Yampa River*** near Steamboat Springs continues to have a comparatively unmodified flow regime, and the Colorado Water Conservation Board has filed applications for water rights to protect Yampa River streamflows between the Williams Fork and Little Snake rivers. However, the water rights would also allow for a minimum of 52,000 A-ft of additional water development within the Yampa Basin, an increase of 50% over current water use. In addition, the Colorado River Water Conservation District continues to evaluate Yampa Basin sites for development of water rights associated with the Juniper Project.

- ***The Dolores River*** below McPhee Reservoir has failed to develop self-sustaining trout populations, and there are ongoing efforts to improve reservoir operations to benefit the fishery. Reservoir spill periods from April to June can result in flows reaching as high as 5000 cfs and then dropping rapidly to as low as 20 cfs, leading to stream dewatering and loss of incubating trout eggs and pre-emergent larvae. During dry years, thermal stress can result from low minimum flows and elevated water temperatures in summer. Lack of adequate flushing flows leads to silt accumulation and reduced production of insects that provide food for adult trout.

Results indicate significant changes in the magnitude, frequency, timing, duration and rate of change of flow conditions needed for the development of trout habitat and the completion of critical life cycle events in Colorado's major rivers. In most cases, multiple projects have had interacting and cumulative effects. Moreover, flow-related reductions in habitat and nutritional resources can contribute to declines in fish health, increasing susceptibility to disease and accelerating population losses. This may be the case in Colorado, where trout infection with whirling disease is greatest in the state's most heavily modified rivers.

These findings make clear that the streamflow conditions necessary for the long-term health of Colorado's river ecosystems and the fisheries they support are highly degraded or absent. As a result, trout production is limited in many Colorado river basins, and the future sustainability of Colorado's trout resources is no longer assured. This points to the importance of closely monitoring ongoing changes to Colorado flow regimes and the critical need for new management approaches. Recommendations include:

- ***manage resources at the watershed-scale*** to sustain the health of the larger ecosystems upon which trout depend
- ***expand management efforts beyond a sole focus on minimum instream flows*** to include the many other biologically significant components of flow regimes
- ***protect against further water development*** in basins that already experience chronic dewatering and other disruptions to flow regime characteristics needed to support trout fisheries and watershed health
- ***review water management activities on a regular basis*** in specific watersheds to determine if changes are needed to maintain or restore biologically significant flow regime characteristics
- ***monitor flow regimes and fishery resources on an ongoing basis*** to establish benchmarks for evaluating any trends as well as potential impacts of proposed land or water development
- ***manipulate regulated flow regimes to the extent possible*** to restore biologically significant flow regime characteristics needed to support fishery resources and watershed processes
- ***adjust management programs on an ongoing basis*** in response to improved science-based understanding of flow-dependent watershed dynamics and trout responses to flow regime alterations

# ACKNOWLEDGMENTS

Thanks are due to Dr. Brian Richter, Michael Mendelson, and Ruth Matthews of The Nature Conservancy's Biohydrology Program for sharing their time and expertise as we learned to use the flow analysis software, Indicators of Hydrologic Alteration (IHA, copyright 1997 The Nature Conservancy). Thanks also to The Nature Conservancy for donating a copy of the IHA program. Smythe Scientific Software in Boulder, Colorado produces the IHA software and manual.

Numerous biologists and other staff with the Colorado Division of Wildlife (CDOW) also provided helpful information. CDOW biologist Barry Nehring generously shared his time to discuss his trout research and provided both published and unpublished survey data. Other population data and research reports were provided by CDOW biologists John Alves, Jake Bennett, John Woodling, and Greg Policky. Harry Vermillion, Scientific Programmer/Analyst with the Aquatic Section at the Wildlife Research Center in Fort Collins, provided copies of computer databases with current data on trout stocking and sampling. Other inquiries were addressed by CDOW biologists Mike Japhet, Robin Knox, Tom Powell, and Sherm Hebein.

Finally, special thanks to Dave Nickum of Trout Unlimited, who provided numerous helpful suggestions throughout the development of this report and contributed substantially to the section on Colorado's instream flow program.

## ABBREVIATIONS

A-ft = acre feet
cfs = cubic feet per second
Mgal/d = million gallons per day
WY = water year (October 1 through September 30)

## WATER RELATIONS

1 A-ft = 325,851 gallons
= 43,560 cubic feet

1 million gallons = 3.07 A-ft

1 cubic foot = 7.48 gallons

## CONVERSION FACTORS

| *Multiply* | *By* | *To obtain* |
|---|---|---|
| | **Length** | |
| inch | 25.4 | millimeter (mm) |
| foot | 0.3048 | meter (m) |
| mile | 1.609 | kilometer (km) |
| | **Area** | |
| square mile | 2.59 | square kilometer ($km^2$) |
| | **Volume** | |
| acre-foot | 1,233 | cubic meter ($m^3$) |
| | **Flow** | |
| cubic foot per second | 0.02832 | cubic meter per second ($m^3/s$) |
| million gallons per day | 0.04381 | |

# GLOSSARY OF WATER TERMS

**acre-foot,** the volume of water need to cover 1 acre of land (about the size of a football field) to a depth of 1 foot

**baseflow,** refers to river flow during times of little or no precipitation as a result of groundwater entering the stream channel; in this report, baseflow is measured as the 7-day minimum flow/mean annual flow

**consumptive use,** the water consumed during use that does not return to the stream system; of the water withdrawn, the amount that is evaporated, transpired, taken up by crops or other products, consumed by humans or livestock, or otherwise removed from the water supply

**delivery/releases,** the amount of water delivered to a point of use and the amount released after use

**flow,** the volume of water passing a fixed point per unit time; in this report flow is measured in cubic feet per second (cfs), the rate of water flow at a given point amounting to one cubic foot per second (equal to 7.48 gallons per second)

**flow regime,** patterns of flow quantity and variation over space and time

**instream use**, all environmental and human uses of water taking place within the stream channel; e.g., hydroelectric power generation is an instream use of water by humans

**offstream use,** water diverted or withdrawn from a surface or groundwater source and conveyed to a place of use; offstream water-use categories typically include public supply, domestic, commercial, irrigation, livestock, mining and thermoelectric power

**pulses of flow,** are defined in this report as periods within the year in which the daily mean water conditions either rise above or below a given threshold

**recharge,** the addition of water to groundwater

**return flow,** water that reaches a ground or subsurface water source after release from the point of use; such water is again available for additional use

**reversals in flow,** are positive or negative changes in flow from one day to the next

**transbasin diversion,** water removed from one river basin and artificially conveyed to another basin

**water use**, the water used for a specific purpose (e.g., domestic, irrigation, etc.), including self-supplied withdrawals and public-supply deliveries

**withdrawal**, water removed from the ground or diverted from a surface water source for use

# CHAPTER 1 INTRODUCTION

Until now, impacts of water development on trout fisheries have been described mostly in terms of the minimum instream flows needed to provide suitable habitat within stream reaches. However, reservoir operations, irrigation diversions, and other human uses of water do much more than reduce the quantity of water flowing within the stream channel. By disrupting natural hydrology and associated processes, water development fundamentally alters the ecology of the riverine ecosystems upon which trout depend (National Research Council 1992; Doppelt et al. 1993; Naiman et al. 1995; Poff et al. 1997).

## River Ecosystems

A river is nested within and intimately connected to its surrounding drainage basin or watershed (Gordon et al. 1992; Allan 1995). Numerous physical, chemical, and biological processes structure the watershed as a whole. These processes occur at three spatial dimensions, including *longitudinal* (upstream-downstream), *lateral* (stream channel-riparian zone/floodplain), and *vertical* (streambed-groundwater zone) dimensions, and are integrated across the fourth dimension of *time* (Karr and Schlosser 1978; Vannote et al. 1980; Stanford and Ward 1988; Ward 1989; Gregory et al. 1991). A river's characteristics depend on how the various processes operating across these four dimensions transfer water, sediment, nutrients, and organic matter from the larger watershed to the stream channel. In turn, river and streamside biota depend on this movement of resources.

## Management at the Watershed Scale

Recognition that rivers are components of larger ecosystems has shifted the focus in fisheries management from the scale of the stream reach to the surrounding watershed that helps create and maintain the river environment (Doppelt et al. 1993; Naiman et al. 1995; Stanford et al. 1996; Williams et al. 1997; Poff et al. 1997; Trout Unlimited 1997). Lack of a watershed perspective has resulted in a general inability of existing management and restoration programs to sustain riverine productivity and to recover declining species (Roper et al. 1997). For example, despite numerous efforts to improve conditions for Northwest salmon, populations continue to decline because of continued degradation of the ecosystem processes upon which instream habitat and biological production depend (National Research Council 1996).

## Loss of Watershed Health

Implementation of a watershed approach to fisheries management will require improved understanding of the factors that impair the watershed-scale structures and functions that support and maintain riverine habitats and biological production. As human uses of water have increased, the structures and functions that define healthy riverine ecosystems have been degraded or lost. In natural river ecosystems of the Western U.S.

> *...Runoff flowed slowly from undisturbed watersheds with a larger proportion passing underground. Groundwater filled porous valley soils, assuring more reliable flow. Channels were complex and only locally eroded; pools were common, scoured near boulders and fallen logs; bottoms were of diverse particle sizes; and beaver, common then, added structure through damming and other activities. Riparian vegetation was extensive, from forest to shrub and marshlands. Summer water temperatures were moderate due to shading by plants and in summer and winter alike by extensive ground and surface water exchange. Damaging floods and droughts were actually less frequent and violent, buffered by vegetated slopes, spongy flood plains, and complex, current-retarding channels. In short, there was more permanent water, habitats were more complex, and extreme conditions were less frequent* (Minckley et al. 1997, p. 67).

As water development has modified natural watershed hydrology and habitat-forming processes, many of these characteristics of natural watersheds and free-flowing rivers have been fundamentally altered (National Research Council 1992; Doppelt et al. 1993; Naiman et al. 1995; Poff et al. 1997; Williams et al. 1997).

Dams and other water supply structures not only reduce the volume of water flowing in stream channels, but they also alter natural temporal and spatial patterns in the distribution of flow (Collier et al. 1996). As a result, essential ecological processes are impaired. For example, when a dam blocks the natural flow of a river, oxygen is depleted and nutrient and temperature regimes are altered. Salts are also concentrated in river water due to high rates of evaporation from reservoirs. In addition, impoundment often eliminates seasonal peak flows that are important in the life cycles of many species. Lack of natural flooding has also been shown to disrupt food webs in waters below dams (Wootton et al. 1996).

Dams also change the river channel and streambed (Ligon et al. 1995; Collier et al. 1996). Sediments are trapped by dams instead of being transported as water flows downstream. As a result, downstream habitat is eroded when waters free of sediment are released from the dam. Unnatural pulses of flow from dam releases can also erode streambanks, increasing the input of sediments in downstream reaches. If no high flows are released from the dam, silt accumulates over time in stream gravel, eliminating interstitial spaces that are occupied by bottom-dwelling organisms or early life stages of some species.

Water-supply reservoirs that manage water for irrigation or municipal needs also dramatically alter natural flow regimes (National Research Council 1992; Doppelt et al. 1993; Naiman et al. 1995; Poff et al. 1997; Williams et al. 1997). Peak flows in spring are substantially reduced or even eliminated, while water deliveries augment natural flows over summer. Water releases in fall and winter to increase storage capacity to capture spring runoff increase the magnitude and variation of base flow conditions. Such releases are often followed by a complete lack of flow release over winter.

The overall stabilization of flows in regulated rivers also has important ecological consequences. Flow stabilization creates an unnaturally constant environment downstream and alters aquatic and riparian communities that are adapted to complex and changing flow regimes. For example, loss of high, overbank flows increases streamside vegetation that would otherwise be controlled by periodic flooding. Algae become more abundant in stream channels, depleting dissolved oxygen. Top predators that are favored by more stable flows can eliminate other species, reducing overall river productivity and biodiversity.

The timing and spatial location of withdrawals of river water for irrigation and other offstream uses alter natural flow patterns upon which the life cycles of river and riparian species depend. Below water-supply reservoirs the timing of high and low flows is often the opposite of the normal seasonal pattern, with minimal flow during wet months due to storage of runoff, and higher flows during base flow periods due to irrigation return flows. In addition, extreme daily changes in flow conditions can occur during summer, ranging from inundation to dewatering, depending on the timing, location, and frequency of water deliveries and “calls” for irrigation water.

Even small water projects are seldom benign. Effects of multiple projects interact and accumulate over time, resulting in what has been called “slow death by a thousand wounds” (Doppelt et al. 1993). Colorado’s Gunnison River, for example, is subject to 1,500 active water diversions that profoundly alter the river’s natural flow regime and overall ecology.

Land development and other human activities in the surrounding watershed also alter natural hydrology and ecosystem functions (National Research Council 1992; Doppelt et al. 1993; Naiman et al. 1995; Poff et al. 1997;

Williams et al. 1997). Agriculture, logging, road building, and grazing reduce streamside vegetation needed to regulate water temperature and supply nutrients and organic matter, increase erosion, and reduce water storage in floodplains, artificially increasing overland flow to streams and rivers. Mining and urbanization have been major factors in increased water pollution, and withdrawals of water for offstream uses greatly reduce the river's capacity to dilute pollutants.

## Organization of Report

The combined effect of these many changes to natural flow regimes has been the loss of watershed conditions needed to sustain aquatic and riparian species throughout the U.S. In this report, we focus on consequences of flow regime alterations for trout in Colorado's major rivers and streams. Our emphasis is on general trends for several key mainstem rivers for which streamflow and trout population data are available. Because of a lack of stream gages on smaller tributaries, we were unable to analyze flow conditions of these waters using the methodology applied in this report. However, it is important to bear in mind that smaller tributaries can be critical for the survival of trout species because they provide spawning habitat, thermal refuges, and other necessary habitat conditions. If an historically important spawning tributary has been dewatered or otherwise altered by land and water development, it may have ramifications for the fishery far in excess of reduced flow in the mainstem.

The information presented in this report is organized as follows:

- **Chapter 2** summarizes existing information on flow regime needs of trout.
- **Chapter 3** describes Colorado's surface water supplies and uses.
- **Chapter 4** outlines Colorado water law, Colorado's Instream Flow Program, and emerging instream flow issues.
- **Chapter 5** presents information on water development in each of Colorado's seven administrative water divisions, analyzes current flow regimes of key mainstem rivers in relation to historic conditions, and discusses potential consequences of flow regime alterations for Colorado's trout populations.
- **Chapter 6** discusses findings and recommendations.

# CHAPTER 2 WATER DEVELOPMENT IMPACTS ON TROUT

Trout reproduction, growth, and survival depend on factors such as the volume of available habitat, current velocity, temperature, and food (Marcus et al. 1990; Stolz and Schnell 1991; Behnke 1992; Trout Unlimited 1997). All of these factors are strongly influenced by watershed hydrology and streamflow (Poff et al. 1997). As a result, the flow regime is the single most important environmental variable affecting trout populations, and alterations to natural flow regimes can play a major role in trout population declines (Trout Unlimited 1997).

Water development in Colorado has changed the magnitude, timing, frequency, duration, and rate of change of specific flow conditions that are necessary for trout growth, reproduction, and survival, and the maintenance of instream and out-of-channel physical conditions that determine overall habitat. For example, water-supply reservoirs store spring peak flows for release in summer when flows are low under natural conditions. As a result, natural spring peaks are greatly reduced, while summer flows are often substantially increased. Large "spills" of stored water to increase a reservoir's storage capacity create unnaturally high and variable discharges. Such spill periods are followed by sudden reductions in flow releases. Interbasin water transfers greatly reduce instream flows in the basin of origin, while substantially augmenting natural flows in receiving streams. Irrigation diversions not only reduce the amount of water flowing in the stream channel, but also produce wide fluctuations in daily flows and spatially discontinuous flow depending on points of diversion. The cumulative and interacting effects of multiple projects in individual river basins not only alter natural flow regimes, but also result in overall ecosystem deterioration.

Changes to natural flow regimes can reduce trout production if flow conditions are unsuitable during critical life stages or alter watershed processes needed for habitat formation (Trout Unlimited 1997). For example, reservoir storage of spring peaks reduces the occurrence of high flows needed to flush accumulated sediments and to maintain river channels, reducing the quality and quantity of habitat. Flow stabilization reduces habitat complexity, resulting in loss of important habitat features such as side channels and backwater habitat needed for different life stages of trout. Interconnections among habitat elements that are maintained by natural hydrology and related processes are often lost as water development alters flow regimes.

Changes in flow patterns can also interfere with different life stages of trout that require very specific and often contrasting flow conditions at different times of the year depending on the timing of particular life history stages (Marcus et al. 1990; Stolz and Schnell 1991; Behnke 1992; Trout Unlimited 1997). Sudden drying of the stream channel can dewater redds and strand fish. Low flow periods also reduce intragravel flow and lower dissolved oxygen levels (Ward and Stanford 1979; Petts 1984). This can cause high mortality of incubating trout eggs and reduce the production of invertebrate food supplies needed by adult trout (Sear 1995). High flow releases and sudden inundation can displace or kill early life stages (Nehring 1988). Erratic base flows below reservoirs can produce rapid cycles of inundation and drying of shallow, near-shore habitat needed by young fish and benthic insects that provide food for adult trout (Stanford et al. 1996). Deep water with low velocity promotes overwintering survival (Behnke 1992), but reservoir releases in fall and winter to increase storage capacity can alter such conditions.

Altered flow regimes also have indirect effects on trout populations due to flow-related reductions in habitat and nutritional resources that reduce overall fish health. As a result, susceptibility to disease may increase. For example, recruitment of trout populations throughout Colorado has declined in recent years due to whirling disease, and losses are greatest in the state's most highly degraded rivers (Nehring and Walker 1996; Bennett et al. 1996).

The extent of such ecologically significant flow regime alterations is poorly documented for most of Colorado's rivers and streams. In part, this is because most current management programs focus almost exclusively on minimum instream flows. Yet there is increasing awareness that a range of different flow conditions are needed for healthy riverine ecosystems and not simply minimum instream flows (Poff et al. 1997). In this report, we examine this broader range of flow conditions in major trout streams and rivers in Colorado to provide a basis for management of trout fisheries at the watershed scale.

# CHAPTER 3 COLORADO'S WATER RESOURCES

*Here is a land where life is written in water*……Thomas Hornsby Ferril

Colorado and other western states are defined by a lack of water and by human attempts to capture and distribute limited supplies to promote human settlement (Stegner 1953). We are now shifting from an era of building large water supply structures to one that will increasingly focus on ways to manage existing supplies more efficiently and equitably (Western Water Policy Review Advisory Commission 1997). Understanding the changing context of water management will be necessary to promote efforts to leave more water for instream uses, including the support of trout fisheries.

## Colorado's Major River Basins

Four major river basins drain Colorado: the Upper Colorado, Missouri, Arkansas, and Rio Grande river basins (Colorado Office of Water Conservation 1996; League of Women Voters of Colorado 1992). All have their headwaters in the Rocky Mountains along the Continental Divide. Rivers to the east of the Divide flow towards the Gulf of Mexico, while rivers to the west ultimately flow into the Gulf of California and the Pacific Ocean. Although most surface water occurs west of the Divide, most ground water is found to the east. The highest-yielding aquifers are in the High Plains of the Arkansas and South Platte river basins and in the San Luis Valley.

Over a third of Colorado is drained by the Upper Colorado River Basin. In addition to the Upper Colorado mainstem, the basin includes the Green, White, Yampa, Gunnison, San Miguel, San Juan and Dolores rivers. The Upper Colorado mainstem flows southwest from the north-central mountains to the Gunnison River at Grand Junction and then west into Utah. The Yampa and White rivers flow west to join the Green River near the Utah border. The San Miguel and Dolores rivers originate in southwest Colorado and flow north along the western border. The San Juan River flows to New Mexico.

The Missouri River Basin includes the South Platte, North Platte, and Republican river sub-basins. The South Platte River originates in the Front Range of the Eastern Slope and drains the most populated area of the state. The mainstem flows northeast to join the North Platte River in Nebraska.

The Arkansas River Basin drains parts of southeastern Colorado. The Arkansas River flows southeast from the central mountains near Leadville to southern Colorado and the Kansas border.

The Rio Grand basin is relatively isolated between two mountain ranges, the San Juan and Sangre de Cristo, in south-central Colorado. The main river of the basin, the Rio Grande, flows south to New Mexico.

## Wild Trout and Gold Medal Rivers and Streams

A recent statewide survey by the Colorado Division of Wildlife (CDOW) estimated that about 9,300 coldwater stream miles in Colorado have average to excellent trout habitat (Nehring 1990). However, the CDOW officially designates only about 254 miles of this total as Wild Trout and Gold Medal waters, mostly in headwater streams along the Western Slope (Bennett et al. 1996). These fisheries are primarily introduced populations of rainbow and brown trout that are managed with little or no stocking and with catch-and-release and limited harvest regulations. Gold Medal waters make up 157.8 miles of the officially designated high quality trout waters, including portions of the Blue, Colorado, Frying Pan, Roaring Fork, Rio Grande, and South Platte rivers. Designated Wild Trout waters total 96.2 miles, including portions of the Cache La Poudre, South Platte, Roaring Fork, and Gunnison rivers. Another 595 stream miles currently provide habitat for native cutthroat trout species, including Greenback cutthroat trout (35 stream miles), Rio Grande cutthroat trout (210 stream miles), and Colorado River cutthroat trout (350 stream miles) (Bennett et al. 1996).

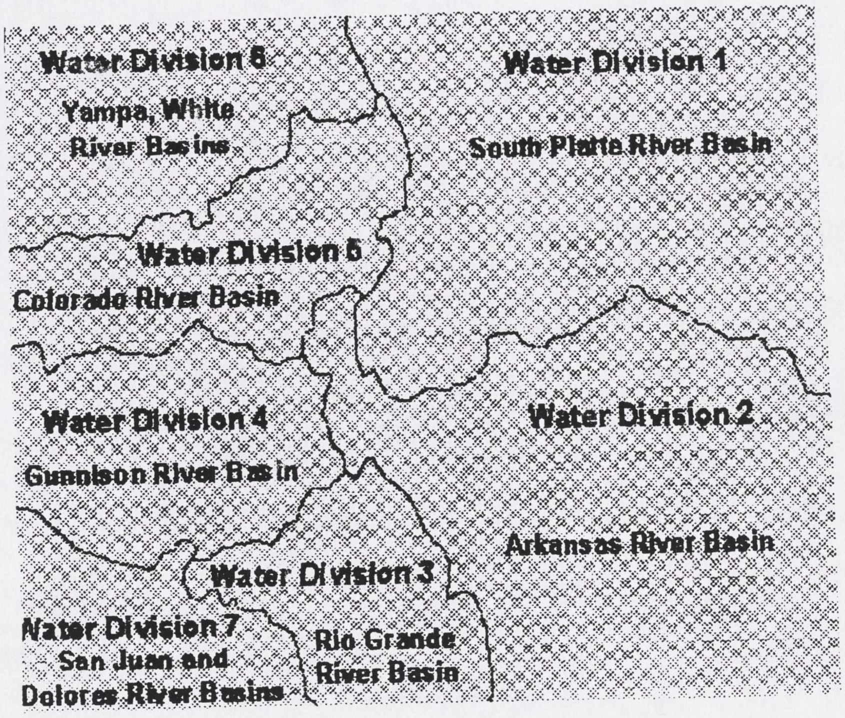
## Administrative Water Divisions

Colorado's river basins are divided into seven administrative divisions for the purposes of water management and distribution (Figure 3-1). Each division is organized around a major drainage basin or group of rivers, and therefore the divisions have ecological as well as administrative significance. The Office of the State Engineer in the Department of Natural Resources supervises staff and overall operations. Each division has its own water court and a division engineer to oversee water administration.

## Water Supply

A river's flow comes from surface runoff, subsurface water that flows laterally through the soil, and groundwater, all of which ultimately depend upon precipitation (Gordon et al. 1992; Allan 1995). In Colorado, precipitation (including rain and melted snow) varies substantially by geographic region, season, and year. Average annual precipitation ranges from less than 7 inches per year near Alamosa in the San Luis Valley to more than 60 inches in the mountains

Figure 3-1. Colorado's administrative water divisions.



east of Steamboat Springs (Doesken et al. 1991). Yearly precipitation also varies from 50 percent of the long-term average during drought years to 150-200 percent of the average during very wet years (Doesken et al. 1991).

Snowmelt draining from the mountains contributes most of the annual surface flow to Colorado rivers in spring. Streamflows typically peak during snowmelt runoff from May to July and decline to minimum levels over fall and winter. About 70% of the water available for use in Colorado comes during the spring runoff period (Colorado Water Conservation Board 1995). Fall and winter base flow is mostly due to groundwater inflow, including return flows from irrigation.

Table 3-1 summarizes the most recent statewide estimates of Colorado's annual surface water supplies and depletions by river basin (Colorado Water Conservation Board 1995). It is important to note that these data have not been updated on a statewide basis since 1970. There has been additional water development since that time, so current depletions are likely to have increased significantly from the data given in the table. For example, data for the Colorado River Basin was updated in 1985 and indicated a 37% increase in consumptive use (an additional 500,000 A-ft) since 1970 (Colorado Water Conservation Board 1995).

In 1970, Colorado's total surface water supply was about 15.6 million acre-feet per year, mostly from the Colorado River Basin. Of this total, Colorado consumed about 5.3 million acre-feet, resulting in about 10.3 million acre-feet leaving the state.

**Table 3-1. Colorado's estimated annual surface water supplies and depletions based on 1970 data, in acre-feet.**

(Source: Colorado Water Conservation Board 1995)

| **Basin** | **Native Inflow** | **Imports** | **Exports** | **Total Depletions[1]** | **Basin Outflow** |
|---|---|---|---|---|---|
| Arkansas | 875,000 | 101,000 | 7,000 | 791,000 | 178,000 |
| Colorado | 10,738,000 | 0 | 412,000 | 1,361,000 | 8,965,000 |
| Missouri | 2,394,000 | 314,000 | 0 | 1,814,000 | 894,000 |
| Rio Grande | 1,576,000 | 4,000 | 0 | 1,302,000 | 278,000 |
| **State Totals** | 15,583,000 | 419,000 | 419,000 | 5,268,000 | 10,315,000 |

[1] including consumptive uses and reservoir and conveyance losses under 1970 conditions of development

## Transmountain Water Transfers

Most surface water depletions are by users east of the Continental Divide, directly opposite the location of the majority of Colorado's water supply to the west of the Divide. As a result, Colorado's water distribution system relies on 24 major transmountain diversions that transfer Western Slope water to Eastern Slope users, including the Colorado-Big Thompson Project, completed in 1953, and the Fryingpan-Arkansas Project, completed in 1980 (Figure 3-2).

## Water Use

As in other Western states, water for irrigation (including water for crops, pasture, and recreational lands) is by far the largest use of water, amounting to over 90% of Colorado's total offstream use of water:

**Table 3-2. Offstream uses of water in Colorado in 1990, in millions of gallons per day (Mgal/D). 1 million gallons = 3.07 A-ft.**

(Source: Solley et al. 1993)

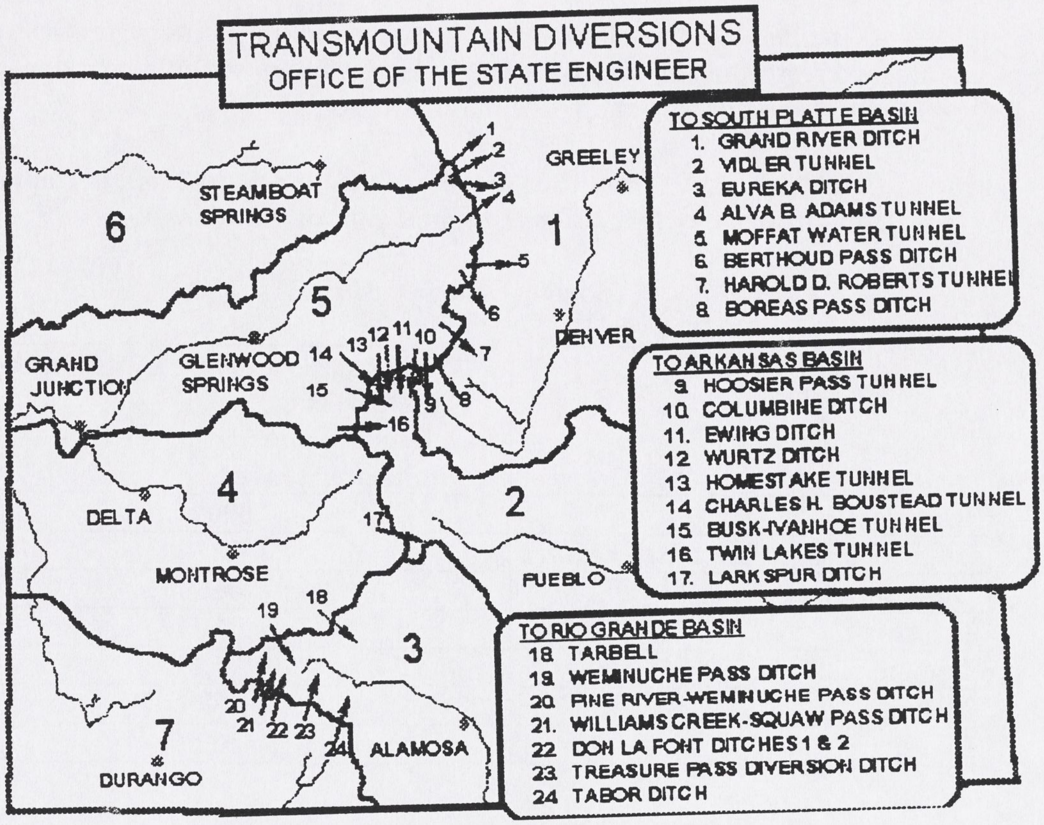
| Use Category | Withdrawals and Deliveries (surface and groundwater sources) | Consumptive Use |
|---|---:|---:|
| Irrigation | 11,600[1] | 4,960[2] |
| Thermoelectric Power Generation | 127 | 41 |
| Domestic | 460 | 139 |
| Industrial | 139 | 41 |
| Commercial | 116 | 17 |
| Mining | 84 | 18 |
| Livestock | 162 | 43 |

[1] 13 million A-ft per year
[2] 5.56 million A-ft per year

## Projected Future Water Needs

A 1996 water development study by the Colorado Farm Bureau projected Colorado's future water supply needs based on an estimated population increase from 3.75 million in 1995 to about 9 million by the year 2100 (Colorado Farm Bureau 1996). Based on the current rate of water use of 1 A-ft per family of 4 per year, the study concluded that municipal and industrial water use will more than double over the next century, reaching 2.2 million A-ft by the year 2100. On this

Figure 3-2. Major transmountain diversions of water in Colorado.



basis, the study estimated that an additional 500,000 to 1 million A-ft of water will be needed to meet projected municipal and industrial demand by the year 2100. In contrast, irrigation water use has declined by 15% over the past 15 years, and is not expected to increase over the next century.

Because only the Colorado and South Platte river basins are considered to have the potential for future additional surface water depletions, demand may exceed current surface water supply within 20 years (Colorado Water Conservation Board 1995). The Colorado Water Conservation Board (1995) estimates that the state may have only about 450,000 A-ft of Colorado River water left to develop under its Colorado River Compact apportionment. Surface water available for development could be significantly less depending on instream flow appropriations required by the recovery program for endangered fish species in the Upper Colorado River Basin.

## New Water Supply Alternatives

Traditional approaches to increasing water supplies by capturing excess streamflows and building storage facilities are falling into disfavor for both economic and environmental reasons (Bell 1997). Future construction of large storage facilities is considered unlikely. In most cases, the best reservoir locations have already been developed, and remaining sites are considered suitable only for small dams. In addition, construction costs have risen, while the potential for federal funding has greatly diminished. Moreover, increasing attention has focused on the environmental costs of dams, including reduction in fish and wildlife associated with the loss of free-flowing rivers (Collier et al. 1996). There is also increasing resistance to interbasin transfer proposals, and basin-of-origin protection is becoming a major issue.

As a result, attention is shifting to new alternatives for meeting future water demands (Bell and Torrey 1995; Bell 1997; Western Water Policy Review Advisory Committee 1997; Rozaklis 1997). Options include 1) increased water conservation, 2) water recycling and reuse, such as use of non-potable water for landscape irrigation, 3) artificial groundwater recharge through coordinated use of surface and groundwater supplies (conjunctive use), and 4) reallocation of existing supplies, including purchase or transfer of senior irrigation water rights.

However, such alternatives are limited in their ability to augment existing supplies (Bell 1997; Western Water Policy Review Advisory Committee 1997). For example, conservation only leads to an increase in supply to the extent that it reduces consumptive use. Likewise, water recycling can only help to augment supply in places where wastewater is not already being put to additional use.

Conjunctive use of groundwater is only feasible where water can be stored underground and existing groundwater use does not exceed the sustainable yield.

Moreover, new water supply alternatives are not without environmental and social costs (Bell 1997; Western Water Policy Review Advisory Committee 1997). Increased conservation and efficiency of agricultural water use can reduce irrigation return flows that have increased streamside vegetation and led to the development of new wetlands. Water transfer from an existing to a new use (water marketing) can alter flow conditions needed to sustain existing aquatic ecosystems and rural communities that have grown to depend on the water.

As a result, new water supply alternatives are not a panacea. Options must be carefully examined to determine what the environmental trade-offs are, including impacts on current hydrologic regimes, existing instream flows, and the sustainability of fishery and other aquatic resources.

# CHAPTER 4 COLORADO'S INSTREAM FLOW PROGRAM

Before looking at the impacts of water development on trout streams in Colorado, it is important to understand some aspects of the "rules of the game" that govern water development in the state. Much of the basis for widespread stream impacts can be found in the nature of water law in Colorado. Colorado's water law is complex, and this review will only touch on major features. The following discussion is limited to surface water law; ground water is managed under a separate set of state laws.

## Surface Water Law

In the eastern U.S., water law reflects the "riparian doctrine" that bases water rights on ownership of land bordering a waterway (Gillilan and Brown 1997). However, in the West, the need for water is often far from the location of water sources. As a result, water law in Colorado and other western states is based on a "first-in-time, first-in-right" or "prior appropriation" doctrine that awards a water right to the first person or organization to put the water to a "beneficial use" (Sims 1993). A water court recognizes the right by a decree that records the location of water withdrawal, the amount, and the use. A priority date is also assigned. When water is in short supply, water use is granted to those with the oldest or most senior priority dates. The Office of the State Engineer administers water rights within this priority system.

In Colorado, water rights are considered to be private property, and they can be sold or inherited (Sims 1993). However, a primary, but often overlooked, principle of water law is that a water right grants the right to **use** water, but not **ownership** of water (Gillilan and Brown 1997). By law, ownership of water rests with the public.

## The Doctrine of Prior Appropriation

The core of Colorado water law is the doctrine of prior appropriation. When Colorado was being settled, the scarcity of water made it one of the state's most valued natural resources. As demand for water began to outstrip supply on specific streams, conflicts became inevitable. Some mechanism was needed to settle these disputes. Many of Colorado's early settlers were miners who brought to water disputes the same philosophy that had been used to settle disputes over land ownership. The historic Miner's Courts developed the theory that if you were on the land first, it was your claim; those following you could not preempt your existing claim. This same theory was later applied to water and became the basis for the fundamental principle of prior appropriation: "first in time, first in right."

This approach means that the first person that claims water for *beneficial use* has a continuing right to use that water in preference to those who seek to use water at a later date. Thus, one of the key components of a water right is its *priority date* -- water rights with older priority dates are considered senior. When there is not enough water in a stream to serve all competing uses, diversion for junior water rights is curtailed in order to satisfy the senior rights.

The State Constitution incorporates this concept: "The right to *divert* the unappropriated waters of any natural stream to beneficial use shall never be denied. Priority of appropriation shall give the better right as between those using the water for the same purpose [*emphasis added*]." Note that the concept of appropriation is tied to *diversion* of the water. Until the state instream flow law was adopted in 1973, water could not be appropriated for protection of instream values of water, such as fish and wildlife habitat.

The discussion so far has dealt with *absolute* water rights, cases in which water has been taken out of the stream and put to "beneficial use." Colorado also recognizes *conditional* water rights, which can be obtained well in advance of the actual development and use of the water. A conditional water right is a means of obtaining a right that will be developed in the future while maintaining its priority until the project is completed. Upon completion of the project, the owner of the conditional right can go to court and file for an absolute right, obtaining the appropriation date for which the conditional right was awarded. In order to maintain a conditional right, the holder must show *due diligence* in pursuing completion of the project. In practice, it takes very little effort to demonstrate due diligence. For example, undertaking studies related to a project is often sufficient to meet diligence requirements.

Water rights are also tied to the concept of beneficial use. *Beneficial use* is defined in statute (CRS 37-92-103(4)) as "the use of that amount of water that is reasonable and appropriate under reasonably efficient practices to accomplish without waste the purpose for which the appropriation is lawfully made." In other words, use of water is limited (in theory at least) to that which is reasonably necessary for the specified use, and water must be used "without waste."

Another key concept of Colorado water law is *abandonment*. Water rights are a "use it or lose it" proposition. Abandonment is defined as "the termination of a water right in whole or in part as a result of the intent of the owner thereof to discontinue permanently the use of all or part of the water available thereunder." This element of the law actually provides an incentive against maximizing efficiency. If the holder of a water right uses his/her water more efficiently, and therefore needs less water, he/she risks abandonment of valuable water rights associated with the "excess" water.

## Instream Flow Legislation

In 1973, the Colorado General Assembly formally recognized instream flows for environmental protection as a beneficial use under state water law. For the first time, the state provided a mechanism for appropriating water *in a stream* and not just when it was diverted.

Senate Bill 97 established Colorado's instream flow program. Authority for appropriating and protecting instream flow rights was given to the Colorado Water Conservation Board (CWCB). A few key exceptions were made to fit the instream flow program within the existing prior appropriation system, including recognition of instream flows to protect the environment as a beneficial use of water and relaxation of the requirement that the flows be diverted to establish a water right (Sims 1993). The law specifies that, unlike diverted water rights, instream flow rights extend through a designated reach of stream rather than only a single point. In addition, instream flow rights are sometimes separated into two or more flow rates to cover requirements during different seasons.

Today, more than 1,200 instream flow rights help protect some 7,500 miles of Colorado rivers and streams (Sims 1993). However, it is important to note that although threats to fishery resources are reduced by such decrees, in most cases instream flow rights are junior rights. This means that an upstream user with a senior right can continue to divert water even if it reduces a protected instream flow downstream (Meyer 1993). Only if the instream flow right is "in priority" can it force upstream diverters to forgo their use of water.

## Status of Current Instream Flow Program

Several amendments to the original legislation have been made to clarify basic tenets of the program or to address limitations (Sims 1993).

The 1981 amendments imposed certain limitations on the CWCB to address concerns that the program would interfere with water development and consumptive uses. One provision required the CWCB to show that the natural environment will be preserved "to a reasonable degree" by the water available and without disrupting other water rights. This led the CWCB to seek separate summer and winter flow levels when appropriating an instream flow right.

In 1986, S.B. 91 was enacted to authorize donation of water rights to the instream flow program. A disadvantage of the original program was that instream flow rights were not given priority over other water rights. This means that because instream flow rights are more recent, they are usually junior to existing rights, often by as much as 70 years. As a result, senior users can continue diverting water even if it reduces flow below a specified instream flow level. To overcome this limitation, S.B. 91 authorized acquisition of senior water rights for stream reaches where instream flow rights would otherwise be too junior to provide adequate protection.

Another key amendment was S.B. 212 in 1987. It named the CWCB as the only entity entitled to hold an instream flow right. Since then, other parties have obtained approval for an alternate type of instream flow right, including the City of Fort Collins, which was awarded instream flow rights for the Poudre River Recreational Corridor (Sims 1993). Court rulings have distinguished such alternate instream flow rights from CWCB rights based on their use of diversion structures (Sims 1993).

Most recently, the CWCB added Section 7 to its rules and regulations to address concerns of water users that acquisition of conditional rights for instream flows might interfere with development of junior rights for consumptive uses (Sims 1993). The rules require the CWCB to conduct a "significant negative effect" analysis to determine if their acquisition of a water right would negatively effect any existing rights, exchanges, or potential development of conditional rights. If potential negative effects on water users outweigh potential benefits of acquiring a right for the instream flow program, the CWCB is prohibited from acquiring the right.

## Limitations of Current Program

Despite the value of the Instream Flow Program, it has several limitations:

- Instream flows as a beneficial use are limited to *minimum* flows on natural streams (or minimum levels for natural lakes) "as are required to preserve the natural environment to a reasonable degree." For coldwater streams, this has generally been interpreted to mean the minimum flows needed to maintain a coldwater fishery – usually quantified using the R2 Cross methodology. While more flows could be beneficial for fish and wildlife or for other instream values (such as recreation, aesthetics, riparian habitat), the appropriation is limited to the identified minimum flow.

- Given the long history of appropriation for out-of-stream beneficial use, instream flow rights are usually junior rights and therefore have limited value. For fully- or over-appropriated streams, instream flows cannot be protected through new appropriations under the instream flow law. Instream flows can be provided in such streams through purchase or donation of existing absolute water rights, but purchase costs can be very high.

- Instream flow rights can only be held by the Colorado Water Conservation Board; individuals or groups that wish to hold water rights for instream flows are not permitted to do so.

- The Colorado Water Conservation Board lacks adequate manpower to monitor its many rights. While volunteer monitoring projects (such as TU's "Adopt-an-Instream-Flow" partnership with the CWCB) and satellite gages help fill this gap, a large portion of instream flow rights still lack on-the-ground monitoring.

While there are numerous limitations to Colorado's Instream Flow Program, it has nonetheless provided important protections for instream flows. For example, the CWCB tracks applications in water court to ensure that other water right holders do not make changes in use that negatively affect instream flow rights.

## Emerging Instream Flow Issues

According to the original statute, flows "to protect the natural environment to a reasonable degree" are the minimum flows needed to protect existing resources, not flows to enhance resources (Shupe and MacDonnell 1993). However, in practice designated flows for fish typically fall somewhere between "bare survival" and "optimum" flows (Gillilan and Brown 1997). "Bare survival" flows are those that are thought to allow short-term survival of a small population, whereas "optimum" flows include occasional habitat-maintenance flows. Flows identified by the Colorado Division of Wildlife, one of the agencies responsible for recommending instream flows, are generally

> *greater than those required to sustain minimal populations in the short run, and so exceed bare survival requirements. But identified flows are insufficient to protect habitat in the long run and thus fall far short of optimal. The state depends upon natural hydrologic variability, particularly the existence of occasional high flows, to maintain fish habitat. In the long run, flows at the level protected by water rights, if not augmented by these occasional high flows, would allow the fishery to decline* (Gillilan and Brown 1997, p. 130).

As a result, there is increasing interest in substituting site-specific prescriptions for flows within stream reaches to protection of the entire flow regime (Richter et al. 1996; Richter et al. 1997; Roper et al. 1997; Poff et al. 1997).

# CHAPTER 5 FLOW REGIMES AND TROUT POPULATIONS

The following sections analyze land and water development impacts on the flow regimes of Colorado's major trout rivers and streams and trends in trout populations. Streams were selected for the analysis based on availability of both long-term streamflow records and trout population data. Data are organized according to Colorado's administrative water divisions for ease of comparison with other water resource studies.

Available trout population data are primarily limited to surveys by the Colorado Division of Wildlife of brown and rainbow trout populations in mainstem rivers. In addition, permanent stream gages are generally found only on larger rivers and streams. As a result, we were unable to apply our analysis to native cutthroat trout, which are limited for the most part to isolated segments of small headwater streams and have been inadequately sampled (see **Box**).

## METHODS

### I. Analysis of Flow Regimes

Trout recruitment is affected by numerous flow regime variables, and population dynamics will depend on how flow conditions in particular years interact with other factors. The particular sequence of flow conditions from year-to-year (e.g., wet versus dry years), the timing of flow extremes in a given year in relation to key life cycle events, and the influence of annual precipitation levels on water management will all interact to determine population dynamics over time.

In this report, flow regimes are analyzed using new methods for quantifying biologically significant characteristics of streamflow regimes and the degree of flow alteration due to human land and water uses (Poff and Ward 1989; Richter et al. 1996; Richter et al. 1997). The flow regime of each stream is characterized by variables derived from daily surface flow data from U.S. Geological Survey gaging stations. Flow variables define characteristics of flow regimes that are thought to be important for trout recruitment, growth, and survival and the development of trout habitat (Trout Unlimited 1997). These include the magnitude, frequency, timing, duration, and rate of change of specific flow conditions and their variability and predictability (Richter et al. 1996; Richter et al. 1997; Poff et al. 1997).

**Box: Status of native cutthroat trout in Colorado**

Few surveys provide quantitative data on the current status and distribution of Colorado's native cutthroat trout populations, and therefore information is generally limited to the professional judgement of agency biologists (Duff 1996). There are three subspecies of native cutthroat trout remaining in Colorado, the Colorado River cutthroat trout, the Rio Grande cutthroat trout, and the Greenback cutthroat trout. There have been drastic declines in native cutthroat populations, including extinction of the yellowfin cutthroat trout. However, small populations are still found in many of Colorado's major watersheds, occupying some 600 stream miles in 96 streams (Bennett et al. 1996). Most of these populations remain threatened due to habitat degradation, overharvest, and effects of non-native fish species, especially other trout (Harig and Fausch 1996; Stumpff and Cooper 1996; Young et al. 1996). Nonnative trout hybridize with native cutthroat trout and compete for space and food. Continuing habitat loss is primarily due to (1) stream dewatering, mostly as a result of diversion of water for irrigation, and (2) sedimentation resulting from road construction and streamside grazing of livestock (Stumpff and Cooper 1996; Young et al. 1996).

The Colorado River cutthroat trout is considered a likely candidate for federal listing (Bennett et al. 1996). By the 1970's the historic range, which included the Green, Yampa, Gunnison, Dolores and San Juan rivers in Colorado, had been drastically reduced (Behnke 1992). As a result of extensive stocking, nearly a third of the estimated 152 populations of Colorado River cutthroat trout still found in Colorado have sympatric populations of nonnative trout (Young et al. 1996). Only 44 of remaining populations are considered genetically pure.

The Rio Grande cutthroat trout is considered a "species of special concern" (Bennett et al. 1996). Of the 39 populations that are currently known in Colorado, most are found in the headwaters of streams that are relatively isolated (Stumpff and Cooper 1996). A recent study estimated that only 40% of the populations whose status was documented in the 1990's are stable, free of nonnative salmonids, and protected by known barriers to nonnatives (Harig and Fausch 1996).

Greenback cutthroat trout, Colorado's state fish, is federally and state listed as threatened (Bennett et al. 1996). The greenback cutthroat trout is unique to Colorado and is native to the headwaters of the Arkansas and South Platte rivers (Bennett et al. 1996). The greenback is now found in less than 5% of its former range (Behnke 1992). Of the 51 populations listed in the U.S. Fish and Wildlife Service recovery plan (including both historic and restored sites), 9 are found in waters that include nonnative trout, which pose a significant threat due to hybridization and competition.

### Indicators of Hydrologic Alteration

In the following analyses, flow regime variables are quantified using the Indicators of Hydrologic Alteration (IHA), a computer program developed by Dr. Brian Richter and others with The Nature Conservancy's Biohydrology Program (Richter et al. 1996; Richter et al. 1997). The program computes 33 flow variables from daily mean flow rates (in cubic feet per second, cfs) for each year of record.

The IHA variables are divided into five groups according to fundamental characteristics of flow regimes:

1) ***magnitude*** of flow at a given time, commonly used as a measure of habitat availability and habitat features such as wetted area
2) ***timing*** of occurrence of particular flow conditions, important in relation to the timing of life cycle events
3) ***frequency*** of certain flow conditions, such as extreme low flows, that can influence reproductive events, mortality, or habitat development
4) ***duration*** of time that specific flow conditions occur, such as periods of dewatering or inundation, that can affect success of particular life cycle stages such as egg incubation
5) ***rate of change*** in flow conditions, including rapid changes that can strand fish, interfere with spawning, or disrupt the stream bed

Table 5-1 summarizes the variables computed by the IHA program according to these five groups of flow characteristics.

Statistics computed by the IHA program include estimators of central tendency (mean or median) and dispersion (coefficient of variation or coefficient of dispersion) for the time series of values for each IHA parameter. Richter et al. (1996) note that the mean is the best measure of central tendency even when data are not normally distributed, as is usually the case with hydrologic data. For this reason, the following analyses use the mean to estimate the central tendency, or average value, of streamflow variables and the coefficient of variation (CV) to estimate variation about the mean.

### Reference Conditions

In most cases, streamflow records do not predate the onset of water development in Colorado, making it difficult to determine how current regimes differ from natural conditions. However, Poff and Ward (1989) developed a classification of several natural stream types, making it possible to compare characteristics of current flow regimes with those of a reference type reflecting

## Table 5-1. Indicators of Hydrologic Alteration and Their Characteristics

(based on Richter et al. 1996)

| IHA Statistics Group | IHA Parameters |
|---|---|
| Group 1: Mean Monthly Flows | Mean value for each month |
| Group 2: Magnitude and Duration of Extreme Flows | Annual 1-, 3-, 7-, 30-, and 90-day means of flow minima<br>Annual 1-, 3-, 7-, 30-, and 90-day means of flow maxima<br>Base flow (7-day minimum flow/mean for the year)<br>Number of zero-flow days per year (days daily mean flow is zero) |
| Group 3: Timing of Annual Extreme Water Conditions | Date of 1-day maximum flow<br>Date of 1-day minimum flow |
| Group 4: Frequency and Duration of High and Low Flow Pulses | High pulse level (mean plus one standard deviation)<br>No. of high pulses per year<br>Average duration of high pulses per year<br>Low pulse level (mean minus one standard deviation)<br>No. of low pulses per year<br>Average duration of low pulses per year |
| Group 5: Rate and Frequency of Flow Changes | Rise rate (means of all positive differences between consecutive daily means)<br>Fall rate (means of all negative differences between consecutive daily means)<br>No. of reversals (daily changes) |

natural conditions. Colorado streams are classified as "snowmelt streams" and are characterized by high predictability of seasonal flooding, although the quantity of flow is highly variable from year to year depending on annual precipitation. Streamflows typically peak with snowmelt runoff in spring and gradually decline over summer. Flows remain low throughout fall and winter. For each stream discussed below, the current hydrograph is compared to these characteristics of the natural hydrograph to estimate how the current regime may vary from natural conditions.

For rivers with relatively long-term flow records, we examined the historical range of variation in flow parameters using the "Range of Variability Approach" (RVA) of Richter et al. 1997. The RVA method uses the IHA program to compute the range of variation in each IHA parameter (based on the mean + or – 1 standard deviation) for a period of record (for a minimum of 20 years) that best represents relatively unaltered conditions. If the distribution of parameter values is highly skewed, limits may fall outside the range of variation of historical data. In these cases, 25th and 75th percentile values are used instead of standard deviations (Richter et al. 1997). The advantage of the RVA approach is that current flow conditions can be compared to the baseline range of variation calculated by the IHA program to give quantitative measures of the degree of flow regime alteration.

### Pre- and Post-Impact Flow Conditions

Flow changes resulting from particular water projects or water management practices are analyzed by comparing flow conditions before and after the date of the impact or change. Statistics are computed for the pre- and post-impact IHA parameter values for each IHA statistics group in Table 5-1. Statistics include the mean and the coefficient of variation, a measure of how much the mean value varies. The high pulse level is defined as the mean plus one standard deviation and the low pulse level is the mean minus one standard deviation, except when a specific management target is analyzed instead. In cases where a flow level falls outside the range of the pre-impact data, the 25th and 75th percentile values are used instead of standard deviations (Richter et al. 1996).

### Trend Analysis

In some streams, gradual changes that have accumulated over time due to a variety of water development impacts are more important than single impacts or management changes. In these cases, we conducted a trend analysis to assess potential cumulative impacts. This involved using the IHA program to compute a linear regression analysis of the streamflow data. Results are presented as graphs showing any increasing or decreasing trend over time.

## II. Trout Population Data

Trout population data are from field surveys of brown and rainbow trout populations by the Colorado Division of Wildlife (CDOW) at various stream sites over the past 25 years (references cited below in the analysis for each stream). Population data are presented in graphical form to show current status and any long-term trends. Flow regime characteristics for the years of population data are also discussed, along with their implications for trout recruitment. Population and flow data are presented according to water year (i.e., October 1 through September 30).

Although CDOW trout surveys provide the best population estimates available, it is important to note several limitations to the data. For example, annual surveys for some streams have only been conducted sporadically due to funding constraints and manpower shortages. In other cases, surveys have not been ongoing because they were only designed to examine effects of specific management actions. Surveys are also not available for many waters, especially smaller tributary streams. Such gaps in population data make it difficult to know how and why trout populations have changed over time in many Colorado waters.

In particular, underlying causes of trout population changes are difficult to assess with the available data. Numerous factors in addition to streamflows influence trout recruitment in the streams we discuss, including physical and chemical characteristics affected by pollution or other human impacts, fish stocking, fishing regulations, and fish diseases (e.g., whirling disease). This constrains analysis of population data for potential correlations or causality related to streamflows alone. Instead, we discuss the implications for trout of streamflow changes based on known or suspected effects on reproductive success, survival, or habitat characteristics.

Among the most important factors in addition to the flow regime that influence trout populations in the streams we discuss are stocking and whirling disease. Since 1981 wild rainbow trout fry from the Colorado River and from Colorado River hatchery brood stock have been stocked in several of the rivers discussed in this report, including the Arkansas, Blue, Dolores, Fryingpan, upper Gunnison, and Rio Grande rivers (Bennett et al. 1996). In recent years the stocking program has been affected by the spread of whirling disease (Bennett et al. 1996; Nehring and Walker 1996; Nehring and Thompson 1997). The CDOW estimates that over the past decade some 2,550 stream miles in Colorado have been exposed to the whirling disease parasite (Bennett et al. 1996). At present, 26% of these waters have tested positive, and it is estimated that the parasite's range is increasing by about 5% each year (Deloitte and Touche 1995).

Whirling disease is caused by a parasite that infects the nervous system and cartilage of young fish, producing skeletal deformities, black tails, and a whirling motion when the fish is stressed. Newly hatched rainbows infected with the parasite seldom survive, but most fish are able to withstand the disease once they reach fingerling size. Because brown trout evolved with the parasite in Europe, they are thought to be less susceptible to the disease. However, recent studies by the CDOW suggest that recruitment of both rainbow and brown trout is being affected (Nehring and Thompson 1997). Studies in the Colorado River indicate that brook trout and Colorado River cutthroat trout show even greater susceptibility (Bennett et al. 1996).

Fish health is influenced by environmental conditions, including flow-related reductions in habitat and nutritional resources, and susceptibility to disease is often greatest in degraded rivers (Trout Unlimited 1997). In Colorado, trout infection with whirling disease is most prevalent in the state's most highly modified rivers, including those examined in this report (Nehring and Walker 1996; Bennett et al. 1996). Whirling disease is dramatically reducing recruitment of rainbow trout in the Cache La Poudre, Colorado, Gunnison, Rio Grande, and South Platte rivers. Brown trout are showing declines in sections of the upper Colorado River below Granby Reservoir and the upper South Platte River below Cheesman Reservoir. In addition, the whirling disease parasite and/or associated tissue damage has been detected in wild rainbow, brook, and brown trout in the Arkansas, Blue, Big Thompson, Conejos, Dolores, Fryingpan, Roaring Fork, and Taylor rivers.

## RESULTS

### Division 1: South Platte River Basin

Division 1 includes the South Platte, Laramie and Republican rivers and tributaries to the South Platte River, including the Cache La Poudre and Big Thompson rivers and St. Vrain and Clear creeks.

Water is imported into the South Platte River Basin from the Colorado River Basin through the Roberts and Moffat tunnels, the Colorado-Big Thompson and Windy Gap projects, and the Grand River Ditch (Colorado Office of Water Conservation 1996; Denver Water Board 1997). Additionally, Aurora brings water from the Colorado and Arkansas drainages through the Otero Pump Station and into Spinney Mountain Reservoir. In total, the South Platte system includes 370 reservoirs and 6418 miles of canals. About 80% of the Division's water supply is diverted for agriculture, with most of the remaining supply for municipal and domestic uses. The South Platte Basin currently supplies an average of 265,000 A-ft of water per year to the Denver Water system, 44,000 A-ft per year to the City of Aurora (from the Homestake and other small diversions) and 37,000 A-ft per year to the City of Thornton (U.S. Forest Service 1997).

Amid great controversy, the recent proposal for a 1.1 million A-ft Two Forks Reservoir below the confluence of the South Platte and the North Fork of the South Platte River was prohibited by the Environmental Protection Agency under the Clean Water Act. However, other water development proposals are expected in the future as metropolitan water providers attempt to meet rising demand (Eisel and Aiken 1997).

To prepare for increased demand in its service area, the City of Aurora is developing the South Park Conjunctive Use Project (McHugh 1997). The project is designed to pump water from two high-country aquifers in Park and Eagle counties during dry years and then replace it with excess water during wet years. Proponents of the project argue that recharging aquifers is preferable to building new reservoirs for water storage. It is expected that the plan will take several more years to win approval from the state water court.

A recent planning study by the Denver Water Board (1997) indicates an 80,000 A-ft surplus in its water storage system each year. Despite this, the study predicted that future demand in the Denver Water service area could exceed supply as early as 2013, with an additional 100,000 A-ft needed by 2045. However, the study concluded that future demand can be met through measures such as increased water conservation, water reuse, and system refinements.

A study by the engineering firm Hydrosphere, Inc. (Rozaklis 1997) concluded that Front Range water providers can meet projected growth in demand for another 50 years or more by:

- an additional 92,000 A-ft of water conservation
- an additional 93,000 A-ft of transfers from basin agriculture
- an additional 123,000 A-ft of water reuse
- an additional 121,000 A-ft of transbasin imports
- development of an additional 44,000 A-ft of South Platte supply
- use of Denver Basin groundwater, increasing from 25,000 A-ft to 62,000 A-ft per year

Most of the 93,000 A-ft of South Platte irrigation water that is expected to be converted to municipal and industrial uses involves water rights that are already owned or controlled by municipal water providers. This represents less than a 7 percent reduction in South Platte Basin irrigation water use over the next 50 years.

The Denver Water Department and the Douglas County Water Resources Authority are currently examining a conjunctive use plan to recharge the Denver Basin Aquifer with additional Colorado River and South Platte River surface water supplies (Rozaklis 1997). Groundwater recharge would reduce the projected future depletion of 62,000 A-ft of Denver Basin groundwater. Critics of the proposal argue that additional use of both West and East Slope rivers would increase impacts on recreation and fisheries and reduce flows for endangered species in the Colorado River (*Grand Junction Daily Sentinel* 1/2/98). About half of the runoff to be used to increase groundwater supplies under the conjunctive use plan would be diverted from the Blue River via Dillon Reservoir. This amounts to some 30,000 A-ft. The project would also result in more frequent drawdowns of Dillon Reservoir. The Colorado River Water Conservation District is currently examining the question of whether recharge of Front Range groundwater is an allowed use under the Blue River Decree of 1955.

Other projects that may be pursued in the near future include: (1) expansion of Gross Reservoir (on South Boulder Creek) or construction of a new reservoir at Leyden Gulch, allowing for greater use of Moffat Tunnel diversions; (2) expansion of Elevenmile Reservoir on the South Platte mainstem; (3) expansion of Antero Reservoir on the South Fork of the South Platte; and (4) increased use of Chatfield Reservoir for water supply operations (the reservoir's primary purpose is now flood control).

## South Platte River

The South Platte River has its headwaters in the mountains along the northern half of the east slope of the Front Range, and flows northeast to join the North Platte River in southwestern Nebraska (Dennehy et al. 1993). Several major reservoirs in the upper basin are part of the water collection and delivery system of Denver Water: Antero Reservoir, Elevenmile Canyon Reservoir, Cheesman Reservoir, and Strontia Springs Reservoir (Denver Water Board 1997). Water is stored in the reservoirs to satisfy seasonal fluctuations in supply and demand and to provide storage for dry years. Most reservoir releases are conveyed to Denver's water treatment plants, but some water is for irrigation and industrial purposes, or is provided to local suppliers such as the city of Arvada (Denver Water Board 1997).

The mainstem of the South Platte River from Elevenmile Canyon Reservoir to the Strontia Springs Reservoir was recently declared eligible for Wild and Scenic River designation, along with a segment of the North Fork of the South Platte River from Insmount to its confluence with the South Platte (U.S. Forest Service 1997). Metropolitan water providers are opposed to the designation, and the Denver Water Board is currently leading an effort to develop an alternative proposal (*Draft Upper South Platte Streamflow Management Plan* 11/5/97).

## Flow Regime and Trout Populations below Cheesman Dam

The flow regime below Cheesman Dam is mostly controlled by reservoir operations. During spring runoff from May to July, natural flows are reduced as peak flows are stored in the reservoir. In summer, natural flows are increased as water is released to supply downstream users.

### 1) Overview of Findings

- loss of spring peak flows has resulted in a lack of flushing flows that are needed for channel maintenance and habitat-forming processes, including removal of accumulated sediments and building of gravel bars and pools

- reduction in flow quantity reduces the river's ability to dilute increased pollution from expanding development of the South Platte watershed

- reservoir operations result in sudden drops in daily flows in fall that may interfere with brown trout spawning and egg incubation

- increased stabilization of the flow regime reduces natural flow variation and limits habitat development

### 2) IHA Analysis of Flow Regime (USGS # 06701500)

In 1985, the Denver Water Department agreed to modify their operation of Cheesman Reservoir based on CDOW recommendations for trout (*Draft Upper South Platte Streamflow Management Plan* 11/5/97). Since 1985, flow management goals have included:

- maintenance of 50 cfs minimum flows April through July (optimum 100 cfs)
- maintenance of 35 cfs minimum flows August through March (optimum 50 cfs)
- reduction of extreme spring peak flows that can be harmful to trout during the post-emergence period
- reduction of daily streamflow fluctuations and flow reversals

IHA analysis of flow data indicates that average monthly flows have increased an average of 53% following changes to reservoir operations in 1985 (Figure 5-1; Table 5-2, Group 1). However, the monthly distribution of flows is now even less like the natural hydrograph than before management changes. In unmodified snowmelt streams, flows gradually recede over summer as spring runoff declines, and remain low over fall and winter. In contrast, below Cheesman Dam the descending limb of the natural hydrograph is now absent (Figure 5-1; Table 5-2, Group 1). In addition, fall and winter baseflows are now significantly more variable from year to year (Figure 5-2). Years of low baseflows will reduce habitat quantity.

Current recommendations for minimum flows for trout below Cheesman Dam are 50-100 cfs April through July and 35-50 cfs August through March (*Draft Upper South Platte Management Plan* 11/5/97). However, IHA results show that annual minima continue to average less than 50 cfs (Table 5-2, Group 2). Analysis of daily minima by month indicates that the 7-day minimum averages only slightly above the target optimum of 50 cfs from November through March, while the average for April remains below the target optimum of 100 cfs (Figure 5-3).

Despite management changes, there has been little change in daily streamflow fluctuations (Table 5-2, Group 4). Although in most months daily decreases in flow average less than 15% of the monthly flow, the rate for November averages as high as 25% (Figure 5-4). This higher rate of day-to-day decreases in flow during November increases the possibility of low flow periods that can interfere with brown trout spawning or egg incubation, particularly in dry years. In the upper South Platte, brown trout begin to spawn in mid-October (Nehring and Anderson 1993).

Finally, the IHA analysis indicates a continued trend towards increased stabilization of flows. Since 1985 variability of mean monthly flows (Table 5-2, Group 1) and of annual minima and maxima (Table 5-2, Group 2) has declined an average of 42% and 36%, respectively. Moreover, annual high and low flow pulses (based on the yearly average streamflow plus or minus one standard deviation) have been similar for most of the past 25 years, and high pluses rarely exceed 50 cfs (Figure 5-5). Flow stabilization can promote survival of vulnerable early life stages, but lack of flow variation also limits habitat development (Poff et al. 1997; Trout Unlimited 1997). For example, occasional high flows are needed to maintain the stream channel, "flush" accumulated fine sediments, and prevent excess algal growth. High levels of sediment deposited on the streambed can smother incubating trout eggs, and excess algal growth lowers oxygen levels in stream water (Ward and Stanford 1979; Petts 1984; Reiser et al. 1987; Sear 1995). High flows are also needed to build pools and gravel bars and to transport large woody debris into the stream channel (Stanford et al. 1996).

Figure 5-1. South Platte below Cheesman Dam before (1925-84) and after (1985-95) changes to reservoir operations to support the fishery.

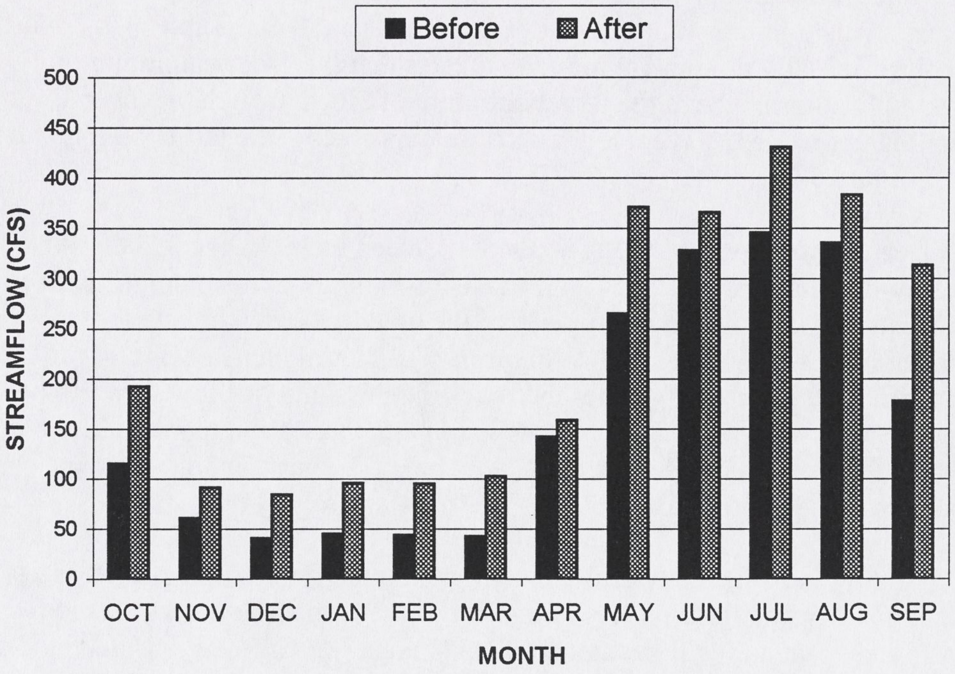


**Table 5-2. Results of IHA analysis for the South Platte River below Cheesman Dam.**

| | | Means | | | CVs | |
|---|---|---|---|---|---|---|
| IHA Statistics Group | Before | After | % Change | Before | After | % Change |
| **Group 1: Mean Monthly Magnitude (cfs)** | | | | | | |
| October | 120.0 | 158.1 | 31.7 | 0.54 | 0.49 | -9.9 |
| November | 64.3 | 67.1 | 4.3 | 0.67 | 0.50 | -25.2 |
| December | 40.4 | 75.6 | 87.2 | 0.60 | 0.39 | -35.4 |
| January | 45.0 | 95.6 | 112.6 | 0.66 | 0.29 | -56.9 |
| February | 43.7 | 94.9 | 117.3 | 0.68 | 0.31 | -54.6 |
| March | 42.6 | 102.3 | 140.2 | 0.74 | 0.47 | -36.0 |
| April | 142.6 | 158.9 | 11.4 | 1.19 | 0.48 | -59.9 |
| May | 265.2 | 371.0 | 39.9 | 1.04 | 0.66 | -37.1 |
| June | 328.1 | 365.9 | 11.5 | 0.77 | 0.95 | 24.2 |
| July | 345.3 | 430.1 | 24.6 | 0.51 | 0.86 | 69.4 |
| August | 335.3 | 382.6 | 14.1 | 0.50 | 0.36 | -28.7 |
| September | 177.6 | 313.2 | 76.4 | 0.47 | 0.31 | -34.0 |
| **Mean % Change (absolute value)** | | | **53.3** | | | **38.5** |
| **Mean Annual Flow** | 165.4 | 223.9 | | | | |
| **Group 2: Magnitude (cfs) and Duration of Annual Extremes** | | | | | | |
| 1-day minimum | 14.3 | 32.5 | 127.7 | 0.61 | 0.29 | -52.4 |
| 3-day minimum | 14.7 | 34.5 | 133.7 | 0.62 | 0.22 | -64.8 |
| 7-day minimum | 16.1 | 38.5 | 139.7 | 0.64 | 0.26 | -59.8 |
| 30-day minimum | 21.6 | 50.9 | 135.1 | 0.69 | 0.32 | -53.5 |
| 90-day minimum | 31.4 | 75.9 | 141.8 | 0.67 | 0.18 | -73.5 |
| 1-day maximum | 964.2 | 992.4 | 2.9 | 0.72 | 0.52 | -27.2 |
| 3-day maximum | 885.3 | 953.6 | 7.7 | 0.69 | 0.51 | -25.6 |
| 7-day maximum | 767.1 | 880.2 | 14.8 | 0.63 | 0.52 | -17.7 |
| 30-day maximum | 542.2 | 652.4 | 20.3 | 0.59 | 0.60 | 2.3 |
| 90-day maximum | 391.4 | 475.5 | 21.5 | 0.55 | 0.53 | -4.2 |
| Base flow (7-day min/annual mean) | 0.10 | 0.2 | 87.6 | 0.56 | 0.49 | -12.5 |
| **Mean % Change (absolute value)** | | | **75.7** | | | **35.8** |
| **Group 3: Timing of Annual Extremes** | | | | | | |
| Date of annual 1-day minimum | 7-Jan | 10-May | | | | |
| Date of annual 1-day maximum | 2-Jul | 14-Jul | | | | |
| **Group 4: Frequency and Duration of High and Low Pulses** | | | | | | |
| High Pulse Level (cfs) | 1000.0 | | | | | |
| Low Pulse Level (cfs) | 35.0 | | | | | |
| Low pulse number (per yr) | 4.1 | 1.5 | -62.5 | 0.64 | 1.13 | 78.0 |
| High pulse number (per yr) | 0.6 | 0.5 | -22.1 | 1.85 | 1.51 | -18.2 |
| Low pulse duration (days) | 19.7 | 3.8 | -80.8 | 0.69 | 1.29 | 85.6 |
| High pulse duration (days) | 1.4 | 5.1 | 266.2 | 2.05 | 2.32 | 13.0 |
| **Group 5: Rate and Frequency of Flow Changes** | | | | | | |
| Fall rate (avg cfs/day) | -32.5 | -34.5 | -1.8 | -0.41 | -0.23 | -42.9 |
| Rise rate (avg cfs/day) | 36.3 | 35.4 | -0.8 | 0.45 | 0.25 | -45.0 |
| Number of flow reversals (per yr) | 70.7 | 66.7 | -4.0 | 0.21 | 0.24 | 11.5 |

Figure 5-2. Historic (1925-49) and current (1971-95) average monthly streamflow (cfs) in fall (September, October, November) and winter (December, January, February), South Platte River below Cheesman Dam.

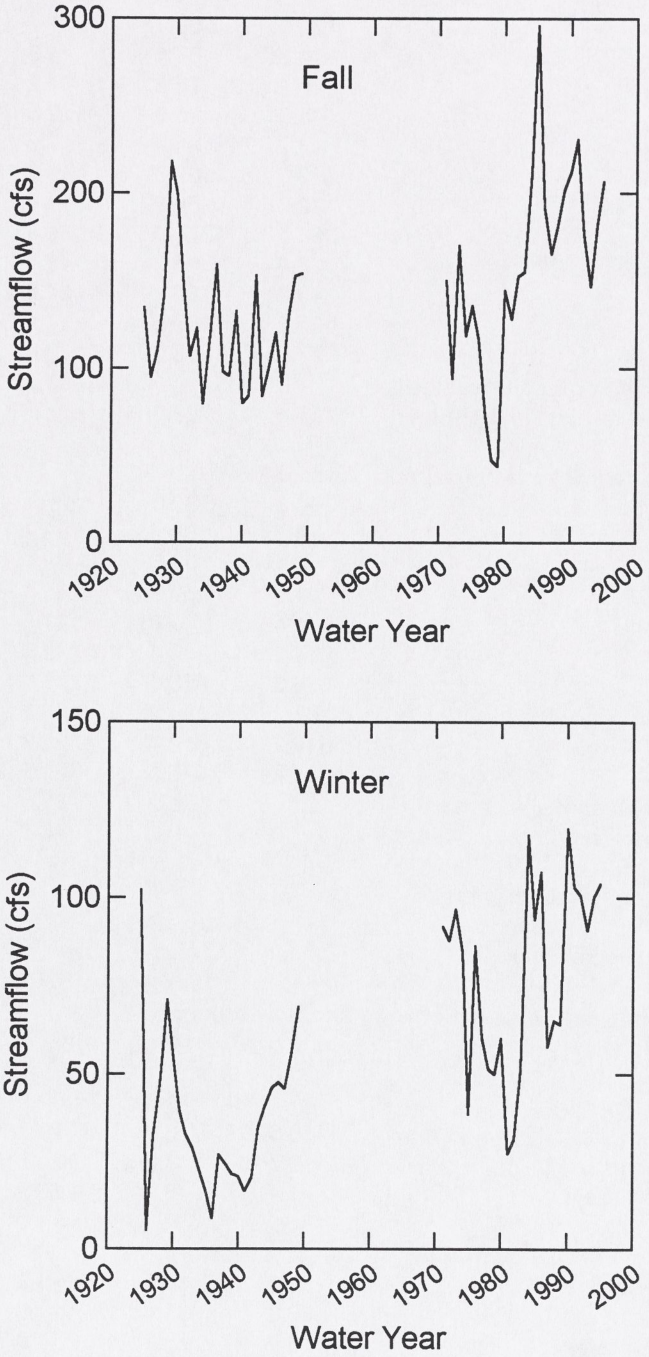


Figure 5-3. Average 7-day minimum flow (cfs) by month, South Platte River below Cheesman Dam, 1985-95. Dashed lines indicate target optimum for April through July (100 cfs) and for August through March (50 cfs).

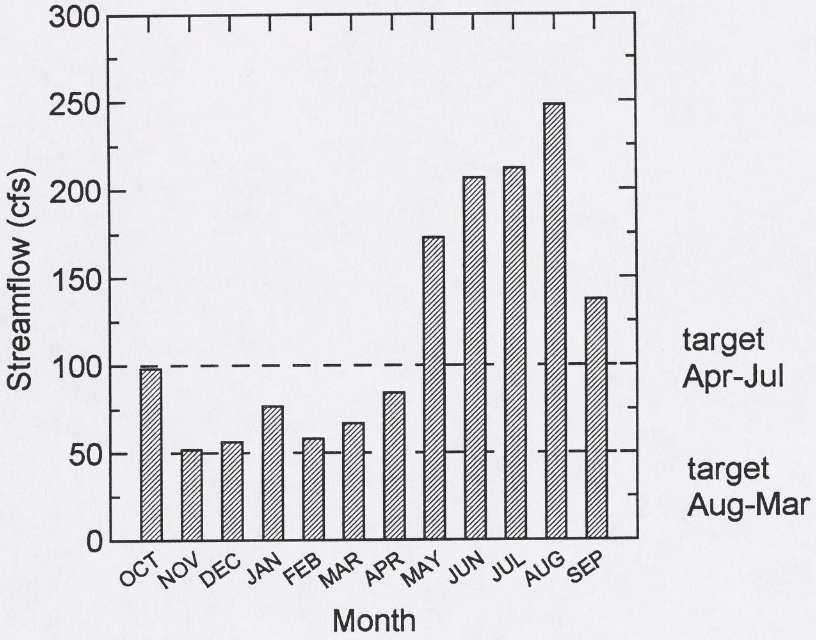


Figure 5-4. Average monthly rate of hydrographic fall as a percent of average monthly streamflow, South Platte River below Cheesman Dam, 1985-95.

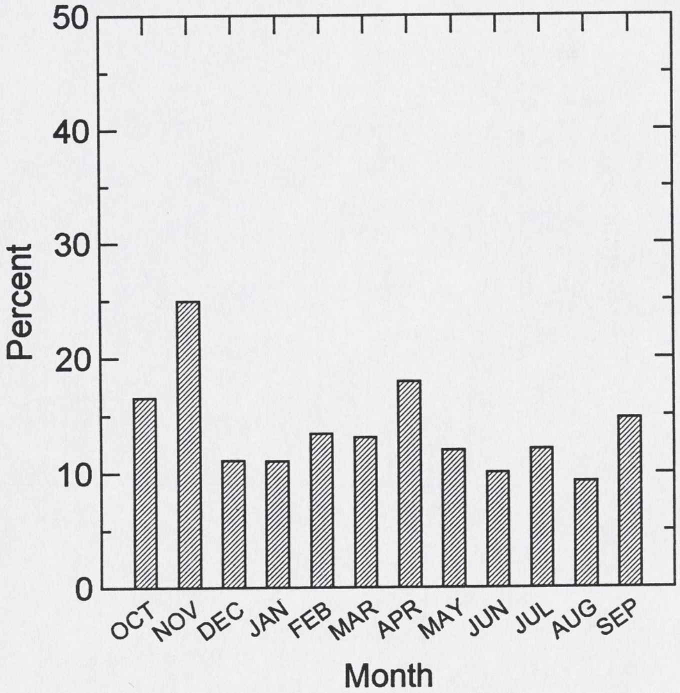
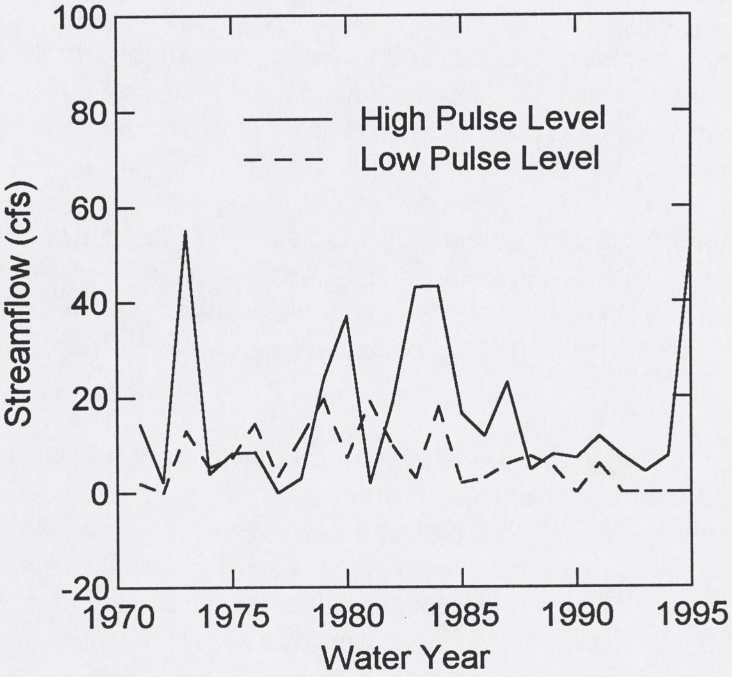


Figure 5-5. High and low flow pulses over the past 25 years, South Platte River below Cheesman Dam. Pulses are defined as +/- one standard deviation from the annual mean flow.



### 3) Trout Population Data

Since the 1978-79 water year, the CDOW has conducted trout surveys along several reaches of the South Platte River below Cheesman Reservoir (Nehring 1988; Nehring and Anderson 1993; Nehring and Thompson 1997). This section of the South Platte is one of the premier trout fisheries in Colorado, but there is evidence of recent declines in production despite management changes aimed at improving the fishery (Nehring and Thompson 1997).

Data for a representative site above Deckers indicate that brown trout density increased steadily from WY 1985-1992 (except during the 1987-88 water year) (Figure 5-6). However, density also increased and reached similar levels in the early 1980's, making it difficult to know if increases after 1985 were related to the changes in reservoir operations. Moreover, annual flows in the mid-1980's were above average, which made more water available for habitat development at the time of brown trout increases. Rainbow trout have apparently been unaffected by the changes in reservoir operations (Figure 5-6).

Recent recruitment failure among both species is thought to be related to whirling disease (Nehring and Thompson 1997). Beginning with the 1991-92 water year, recruitment of both rainbow trout and brown trout has declined sharply, with rainbow trout showing complete year class failure from WY 1991 on (Figure 5-6).

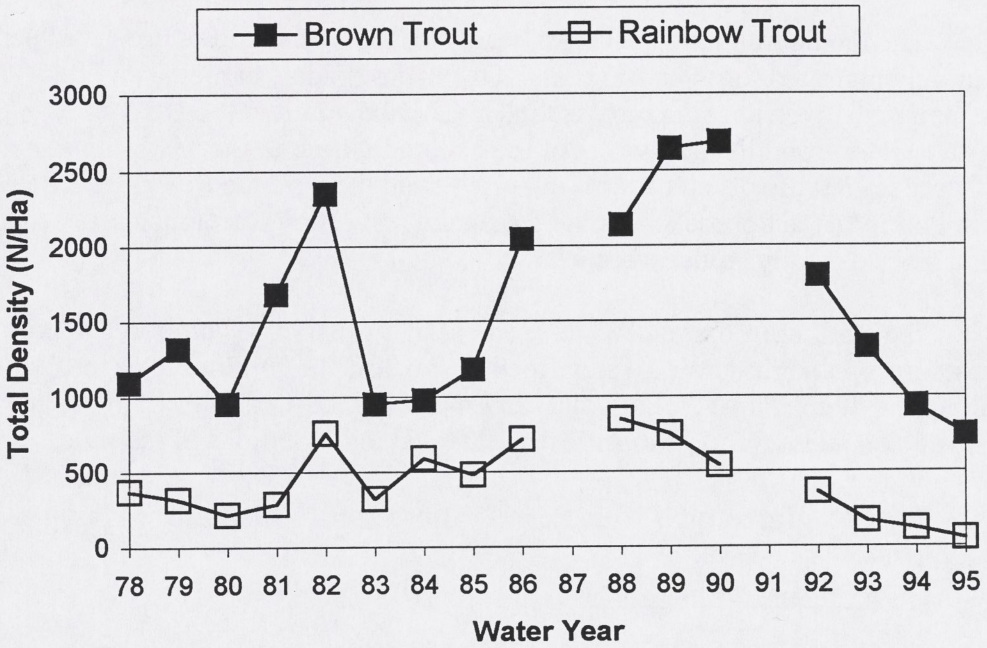
Factors related to the flow alterations outlined above may also have contributed to recent trout declines. Below Cheesman Dam, the quantity and quality of trout habitat is reduced by lack of channel maintenance flows. Recent increases in algal growth along some reaches below the dam may reflect insufficient quantity of flow to adequately dilute increased nonpoint sources of pollution and the lack of flushing flows needed to scour the stream channel. In addition, the higher average rate of hydrographic fall relative to average flow for November raises the possibility of low flow periods that may interfere with brown trout spawning and egg incubation during dry years.

## Cache La Poudre River

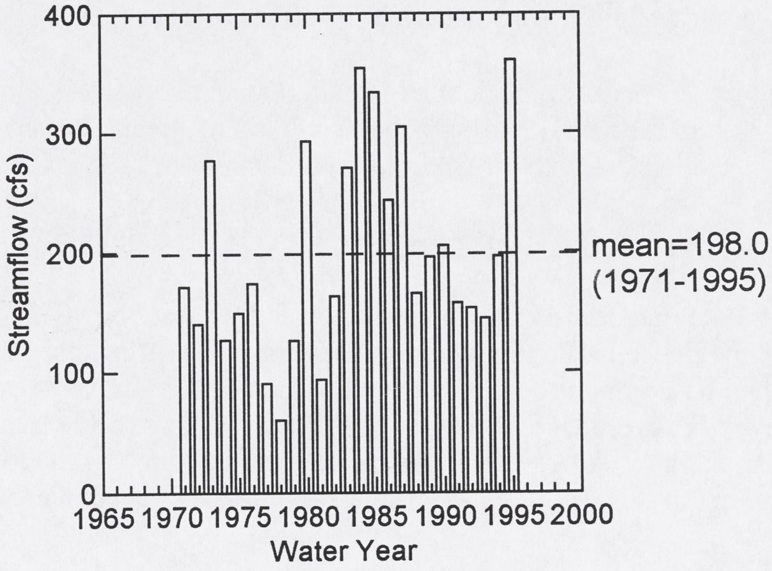
The Cache La Poudre River is a major tributary of the South Platte River. It begins in Rocky Mountain National Park and then flows north and east through Roosevelt National Forest, descending 7000 feet from its headwaters to its confluence with the South Platte River east of Greeley. The river is the major drainage for the northern part of the Front Range. The North Fork of the

Figure 5-6. Total trout density (N/ha) and annual mean streamflow (cfs), South Platte River below Cheesman Dam.

Total trout density, CDOW site above Deckers. No data for WY 1987, 1991. (Source: Nehring and Thompson 1997)



Annual mean streamflow (cfs) for the past 25 years, South Platte below Cheesman Dam.



Cache La Poudre is a major tributary, with headwaters near the Wyoming border. Both streams have high quality trout fisheries in the upper reaches. A 30-mile reach of the upper Cache La Poudre is Colorado's first and only National Wild and Scenic River. Another 45 miles are classified as "recreational." Within these areas, no new dams or diversions can be built.

Like the South Platte mainstem, waters of the Cache La Poudre have been intensively managed for over 100 years. One of Colorado's earliest transmountain diversion structures is the Grand Ditch, built in the 1890's. It transfers water from the headwaters of the Colorado River to the headwaters of the Cache La Poudre. Water is also imported from the Laramie River Basin and North Park. As the Poudre leaves the mountains, diversions for agriculture and municipal use greatly reduce streamflows.

The Northern Colorado Water Conservancy District has proposed a large mainstem dam and reservoir at Grey Rock, just below the confluence of the Cache La Poudre with the North Fork (Colorado Environmental Coalition 1996). The Wild and Scenic Legislation specifically excluded these portions of the river.

## Flow Regime and Trout Populations, mouth of Poudre Canyon

### 1) Overview of Findings

- minimum flows have declined substantially, reducing the quantity and quality of habitat available during times of little precipitation
- daily changes in streamflows have increased significantly; daily flow reversals can produce rapid cycles of wetting and drying that can harm developing trout eggs and fry and cause high mortality of bottom-dwelling insects that are food for adult trout
- flows in November and December can fall dramatically from one day to the next, increasing the likelihood of stream dewatering that will interfere with brown trout reproduction

### 2) IHA Analysis of Flow Regime (USGS # 06752000)

Like unmodified snowmelt streams in the western U.S. (Poff and Ward 1989), the Cache La Poudre has snowmelt runoff in spring and early summer, and perennial base flow throughout the rest of the year (Figure 5-7; Table 5-3). However, IHA results indicate that annual minima have decreased substantially over time as a result of water development, as illustrated by the trend for the 7-day minimum flow (Figure 5-8). Annual minima averaged over 1- to 90-day

Figure 5-7. Mean monthly streamflow (cfs), Cache La Poudre River at mouth of canyon, 1890-1995.

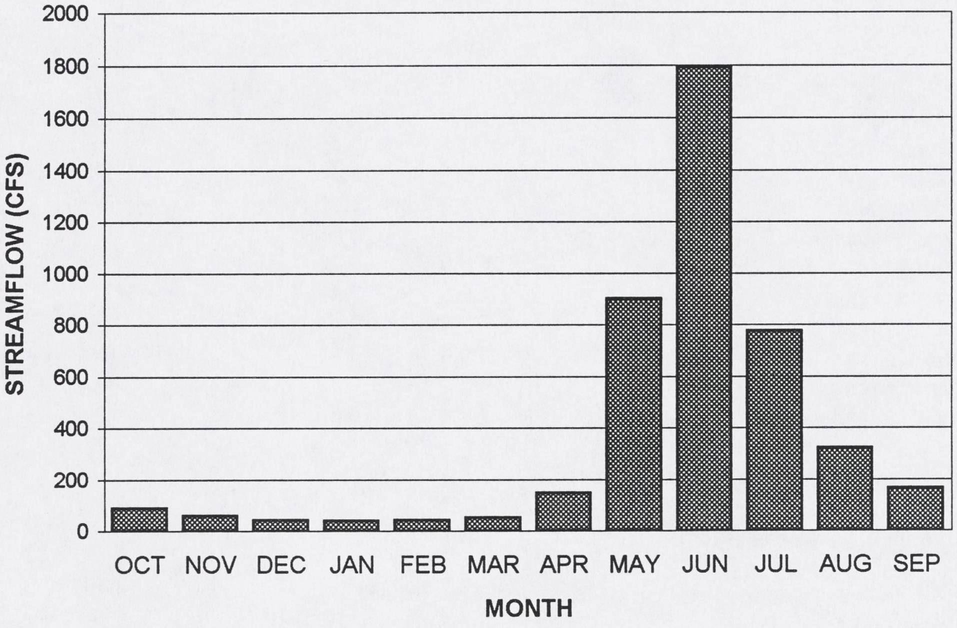
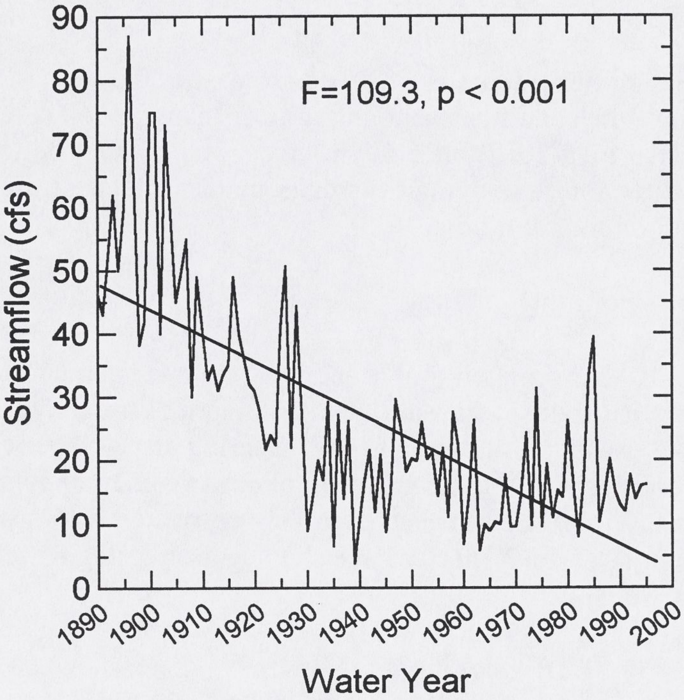


**Table 5-3. Results of IHA analysis for the Cache La Poudre River at the mouth of Poudre Canyon over the period of record (1890-1995).**

| IHA Statistics Group | Mean | CV |
|---|---|---|
| **Group 1: Mean Monthly Magnitude (cfs)** | | |
| October | 88.0 | 0.55 |
| November | 59.0 | 0.49 |
| December | 42.8 | 0.51 |
| January | 38.7 | 0.60 |
| February | 41.1 | 0.60 |
| March | 51.1 | 0.55 |
| April | 146.5 | 0.80 |
| May | 899.6 | 0.51 |
| June | 1790.6 | 0.43 |
| July | 775.6 | 0.52 |
| August | 322.2 | 0.42 |
| September | 164.4 | 0.50 |
| **Mean Annual Flow** | 368.9 | |
| **Group 2: Magnitude (cfs) and Duration of Annual Extremes** | | |
| 1-day minimum | 21.8 | 0.83 |
| 3-day minimum | 24.1 | 0.75 |
| 7-day minimum | 26.8 | 0.64 |
| 30-day minimum | 31.3 | 0.55 |
| 90-day minimum | 36.6 | 0.52 |
| 1-day maximum | 2898.9 | 0.43 |
| 3-day maximum | 2700.0 | 0.41 |
| 7-day maximum | 2472.8 | 0.41 |
| 30-day maximum | 1929.4 | 0.41 |
| 90-day maximum | 1187.2 | 0.39 |
| Base flow (7-day min/annual mean) | 0.08 | 0.58 |
| **Group 3: Timing of Annual Extremes** | | |
| Date of annual 1-day minimum | 1-Feb | |
| Date of annual 1-day maximum | 9-Jun | |
| **Group 4: Frequency and Duration of High and Low Pulses** | | |
| High Pulse Level (cfs) | 1008.0 | |
| Low Pulse Level (cfs) | 40.0 | |
| Low pulse number (per yr) | 6.1 | 0.80 |
| High pulse number (per yr) | 2.3 | 0.56 |
| Low pulse duration (days) | 17.4 | 1.46 |
| High pulse duration (days) | 24.9 | 0.75 |
| **Group 5: Rate and Frequency of Flow Changes** | | |
| Fall rate (avg cfs/day) | -50.6 | -0.41 |
| Rise rate (avg cfs/day) | 63.8 | 0.47 |
| Number of flow reversals (per yr) | 105.2 | 0.29 |

Figure 5-8. Trend in the annual 7-day minimum streamflow (cfs), Cache La Poudre River at mouth of canyon, 1890-1995.



periods have averaged less than 37 cfs over the period of record (Table 5-3, Group 2). The baseflow parameter is only 0.08, indicating that the 7-day minimum flow averages only 8% of the annual mean flow. Moreover, low flow pulses (of 40 cfs or less, based on 1 standard deviation below the mean annual flow) can last for weeks at a time, averaging 17 days each (Table 5-3, Group 4).

Low minimum flows and high rates of hydrographic fall can interact to increase the possibility of stream dewatering. IHA analysis of average monthly fall rates over the past 25 years indicates that significant flow declines are most likely in November and December, when fall rates average 29% and 66% of mean monthly flows (Figure 5-9). Low flow periods at this time may interfere with spawning and egg incubation of brown trout, which begins in mid-October in the Cache La Poudre (Nehring and Anderson 1993).

Another significant trend is a marked increase in the annual number of reversals in daily flow conditions, amounting to as many as 160 reversals per year in recent years (Figure 5-10; Table 5-3, Group 5). Rapid shifts between wet and dry conditions can harm developing trout eggs and fry and cause high mortality of insects that are food for adult trout.

### 3) Trout Population Data

The CDOW has sampled brown and rainbow trout populations in the Cache La Poudre River at several sites near the mouth of the canyon in most years since the 1979-80 water year (Nehring 1988; Nehring and Anderson 1993; Nehring and Thompson 1997). Recruitment of brown and rainbow trout at the Upper Wild Trout Water site has been positively correlated within years (Figure 5-11). Since WY 1987, both species have shown a decreasing trend in recruitment.

Analysis by CDOW biologists for WY 1979-1985 indicated a negative correlation between brown trout recruitment and mean flows during June and between rainbow trout recruitment and mean flows in June and July (Nehring and Anderson 1993). Both species showed a sharp drop in recruitment during the exceptionally high water year in 1983 (Figure 5-11).

Populations of both species are also likely to be affected by the frequent reversals in flow conditions indicated by the IHA analysis and by declines in minimum flows (Figure 5-10). In addition, reproductive success of brown trout may decline in response to reduced flows in fall and winter (Figure 5-7) and by sudden drops in November and December flows (Figure 5-9).

Degraded stream conditions may also increase susceptibility to whirling disease. Beginning in the 1987-88 water year, wild trout in the Cache La Poudre

Figure 5-9. Average monthly rate of hydrographic fall as a percent of average monthly streamflow, Cache La Poudre River at mouth of canyon, 1971-95.

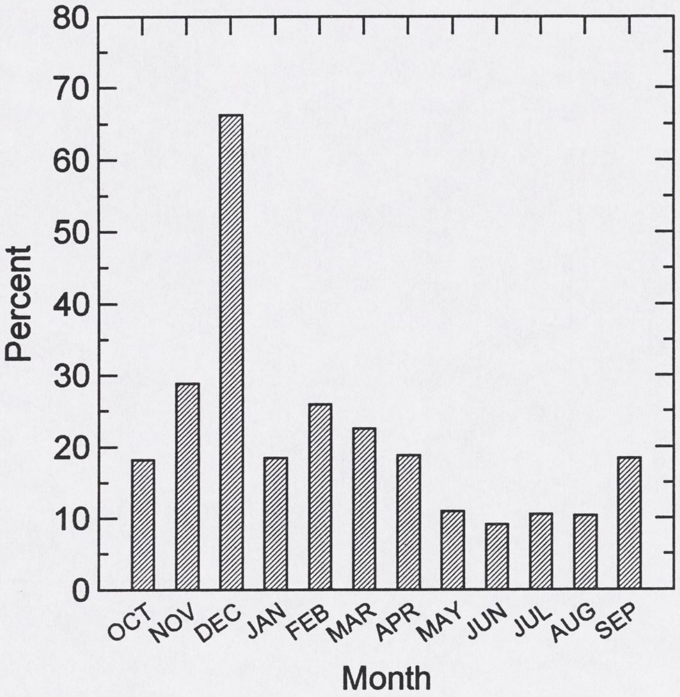


Figure 5-9. Average monthly rate of hydrographic fall as a percent of average monthly streamflow, Cache La Poudre River at mouth of canyon, 1971-95.

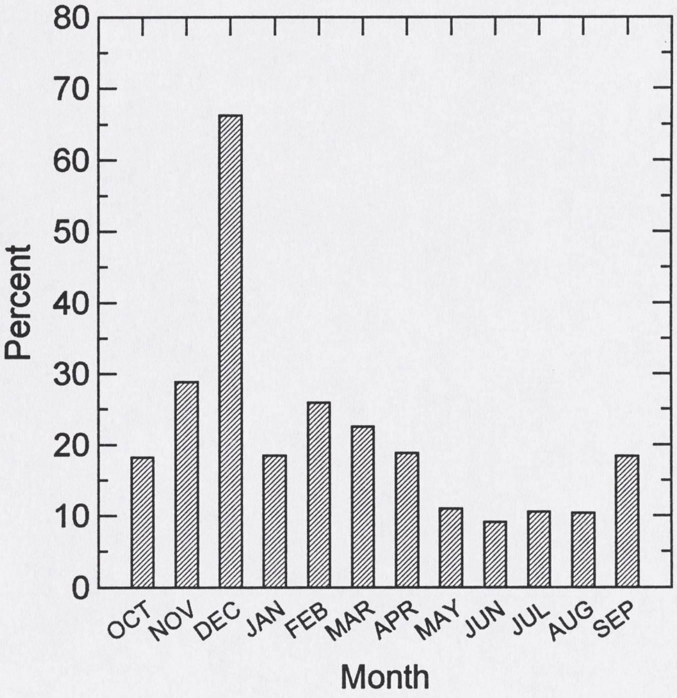
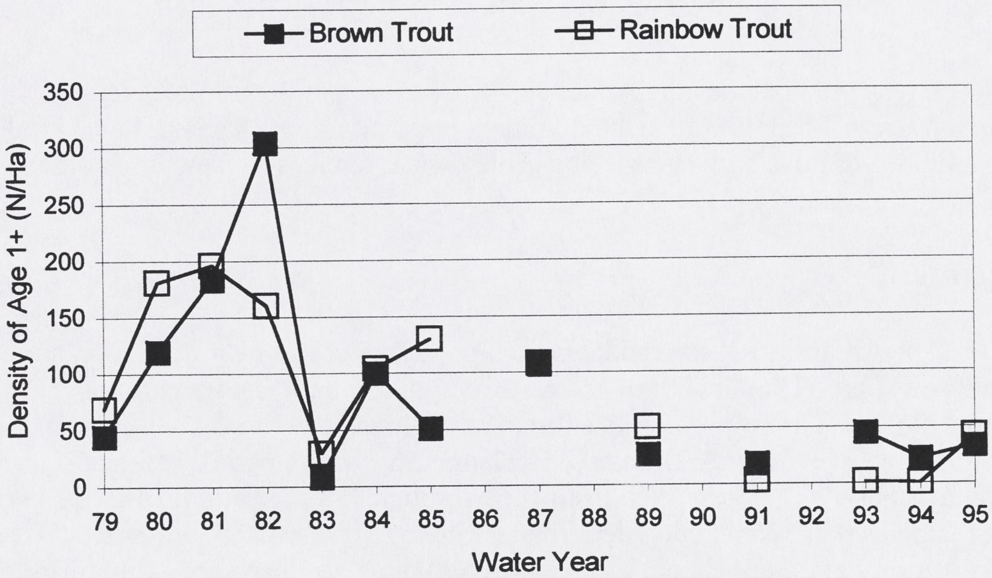
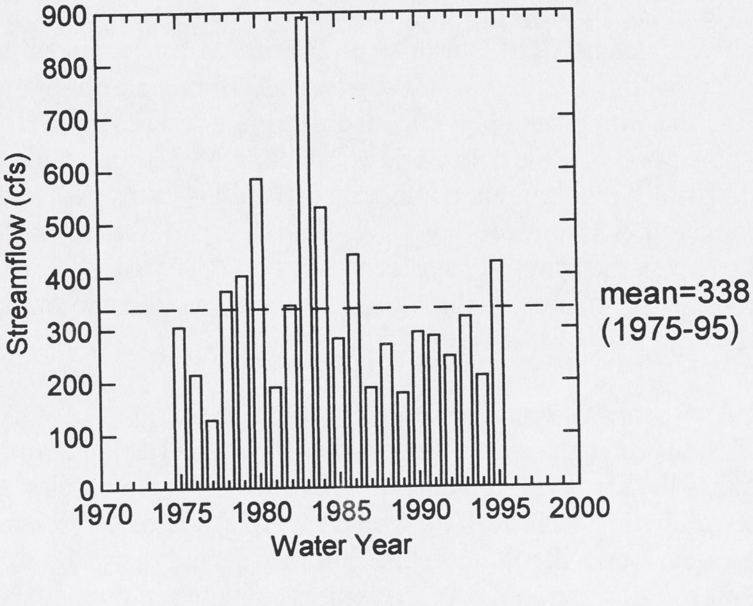


Figure 5-11. Density of age 1+ trout (N/ha) and annual mean streamflow (cfs), Cache La Poudre River at mouth of Canyon.

Trout recruitment, CDOW site at upper wild trout water.
No data for WY '86, '88, '90, '92.
(Source:Nehring and Thompson 1997)



Annual mean streamflow (cfs), Cache
La Poudre at mouth of canyon, 1975-95.



tested positive for the whirling disease parasite. CDOW biologists believe that declines in rainbow recruitment since that time, with nearly complete year-class failure since WY 1991, are due to effects of whirling disease (Nehring and Thompson 1997).

## Division 2: Arkansas River Tributary System

Division 2 includes the Arkansas, St. Charles, and Purgatoire rivers and Fountain Creek. Agriculture is the dominant water use in the basin, totaling over 1.8 million A-ft from both surface and groundwater sources (League of Women Voters of Colorado 1992).

### Arkansas River

The Arkansas River originates in the central Rockies near Leadville, and then flows some 315 miles south and east through southern Colorado to the Kansas border. The river conveys substantial amounts of water imported from the Western Slope via the U.S. Bureau of Reclamation's Fryingpan-Arkansas Project (known as Fry-Ark), constructed from 1963 through 1980. Features of the project in the upper Arkansas include three tributary storage reservoirs (Turquoise Reservoir on Lake Fork Creek, Twin Lakes on Lake Creek, and the Mount Elbert Forebay) and one mainstem reservoir, the Pueblo Reservoir, built in 1978.

Colorado Springs has proposed a new mainstem reservoir at Elephant Rock, three miles north of Buena Vista (Colorado Environmental Coalition 1996). The project would require two pump stations, 70 miles of pipeline running parallel to the Homestake pipeline, and a storage reservoir on West Monument Creek, northwest of Colorado Springs. Among objections to the project is concern that it would inundate a famous whitewater run. As an alternative, Colorado Springs is considering a low-head diversion 10 miles north of Buena Vista known as the Mount Princeton Diversion (Colorado Environmental Coalition 1996). However, this would also involve transmountain pumping of water through a new pipeline.

Another issue concerns augmentation of summer flows to enhance rafting on the Arkansas River. According to the Bureau of Reclamation, the Upper Arkansas is the top commercial rafting river in the U.S., serving approximately 267,000 rafters in 1995. Rafters would like to see releases from an upstream reservoir near Leadville increased in summer during dry years to prolong the rafting season downstream. An agreement to augment flows in 1990 and 1991 called for:

- a 250 cfs minimum flow year-round
- 700 cfs minimum flow July 1-August 15

However, in 1991, Trout Unlimited filed a restraining order to stop augmented flows, arguing that it would not meet fishery or ecosystem needs (League of Women Voters of Colorado 1992). Studies by the CDOW using the Instream Flow Incremental Methodology (IFIM, Orth and Maughan 1982, 1986), which models potential relationships between flow and fish habitat, predict that if Arkansas River flows exceed 700 cfs, only 22% of river area will be available as trout habitat (Anderson and Krieger 1994). CDOW studies also suggest that the average size of brown trout observed at the end of winter is less when Arkansas flows are high in August and September (Anderson and Krieger 1994; G. Policky, CDOW, *Draft Report on the Arkansas River 1996*). However, rather than a direct result of high late summer flows, this may be due to above-average runoff years that prolong suboptimal temperatures, thereby reducing trout growth (R. Behnke, Colorado State University, *personal communication*).

In 1992, the U.S. Forest Service, Bureau of Land Management, Bureau of Reclamation and the Colorado Division of Wildlife signed a memorandum of understanding to conduct a "Water Needs Assessment" to address the issue of augmented summer flows. The completed study is due in 1998, but preliminary results of IFIM studies suggest that trout habitat is optimized at 250-450 cfs (as measured at the Wellsville gage) (G. Policky, CDOW, *Draft Report on the Arkansas River 1996*). On this basis, CDOW biologist Greg Policky suggests that in average years flow management to protect the brown trout fishery should include:

- 250-450 cfs during spawning and early development from October 15-July 15
- base flow or 250 cfs (whichever is greater) July 16-October 14
- daily flow changes limited to 25% or less

He also suggests that in high or low runoff years, when flows may be above or below optimal levels, highest priority should be given to maintaining flows of 250-450 cfs from April 1 to May 15, the time considered most critical for survival of brown trout fry in the Arkansas.

### Flow Regime and Trout Populations at Wellsville

#### 1) Overview of Findings

- transbasin imports have increased the volume of native flow in the Arkansas River by an average of 21%

- although water imports that have increased the quantity of flow, the natural seasonal pattern of flows has been preserved

- transfers of imported water from upper basin reservoirs to Pueblo Reservoir increase fall and winter flows near Wellsville an average of 28% and increase June flows an average of 22%; flows in other months have declined or increased only slightly

- flow augmentation to date has not impacted brown trout, which show stable, self-sustaining populations in the upper Arkansas River

- additional flow augmentations that alter current conditions that appear to benefit brown trout should be carefully evaluated

### 2) IHA Analysis of Flow Regime (USGS # 007093700)

It is estimated that water imported by the Fry-Ark Project (built 1963-1980) makes up 21% of Arkansas River flow in an average year, increasing the volume of native flow by an average of 115,000 A-ft per year (Anderson and Krieger 1994). Because flow records do not begin until the early 1960's, it's not possible to assess the project's impact by comparing current to natural conditions. However, it is possible to see what changes occurred in the upper Arkansas once the mainstem reservoir was added at Pueblo.

Results of IHA analysis of the flow regime at Wellsville indicate that mean monthly flows have increased an average of 12% since construction of the downstream reservoir at Pueblo (Figure 5-12, Table 5-4, Group 1). This results from water transfers from Twin Lakes and Turquoise reservoirs to increase storage capacity in fall and to meet downstream irrigation demands in summer (Witte 1995). Beginning in October, the Bureau of Reclamation transfers from upper basin reservoirs to Pueblo Reservoir water that has been imported over the summer. Between mid-November and mid-March, water is stored in Pueblo Reservoir for release later in the year.

Seasonal effects consistent with the pattern of upper basin reservoir releases are apparent in flow records for the Wellsville gage. Since construction of Pueblo Reservoir, mean monthly flows from November through March have increased an average of 28% and June flows have increased by 22%, whereas flows in other months have declined or increased only slightly (Figure 5-12; Table 5-4, Group 1).

The IHA analysis also indicates how often mean daily flows in different seasons fall below or exceed IFIM-based upper and lower limits for optimal

Figure 5-12. Mean monthly streamflow (cfs), Arkansas River at Wellsville, before (1961-1976) and after (1977-1995) completion of Pueblo Reservoir.

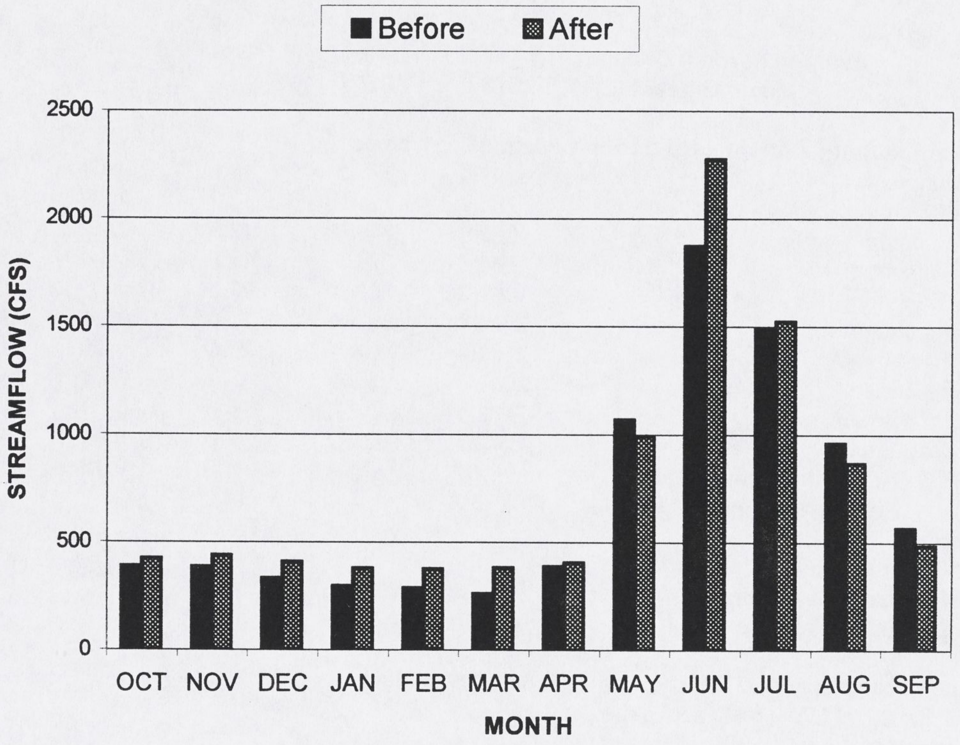


**Table 5-4. Results of IHA analysis for the Arkansas River near Wellsville before (1961-76) and after (1977-95) construction of Pueblo Reservoir.**

| | **Means** | | | **CVs** | | |
|---|---|---|---|---|---|---|
| **IHA Statistics Group** | **Before** | **After** | **% Change** | **Before** | **After** | **% Change** |
| **Group 1: Mean Monthly Magnitude (cfs)** | | | | | | |
| October | 388.3 | 422.7 | 8.9 | 0.36 | 0.32 | -8.7 |
| November | 385.1 | 439.0 | 14.0 | 0.25 | 0.21 | -15.5 |
| December | 332.1 | 408.4 | 23.0 | 0.17 | 0.22 | 30.8 |
| January | 297.7 | 378.5 | 27.1 | 0.21 | 0.28 | 35.4 |
| February | 288.6 | 376.7 | 30.6 | 0.20 | 0.37 | 81.0 |
| March | 262.9 | 382.5 | 45.5 | 0.14 | 0.34 | 149.8 |
| April | 387.1 | 405.4 | 4.7 | 0.48 | 0.33 | -31.3 |
| May | 1069.2 | 991.4 | -7.3 | 0.31 | 0.50 | 60.0 |
| June | 1873.2 | 2277.0 | 21.6 | 0.27 | 0.40 | 48.3 |
| July | 1491.4 | 1524.7 | 2.2 | 0.43 | 0.56 | 31.3 |
| August | 960.1 | 868.0 | -9.6 | 0.27 | 0.49 | 83.3 |
| September | 565.6 | 484.4 | -14.4 | 0.36 | 0.35 | -0.4 |
| **Average Percent Change** | | | **17.4** | | | **48.0** |
| **Mean Annual Flow** | 673.9 | 747.7 | | | | |
| **Group 2: Magnitude (cfs) and Duration of Annual Extremes** | | | | | | |
| 1-day minimum | 198.4 | 225.3 | 13.6 | 0.17 | 0.25 | 42.1 |
| 3-day minimum | 206.7 | 234.0 | 13.2 | 0.18 | 0.24 | 33.5 |
| 7-day minimum | 219.1 | 246.8 | 12.6 | 0.15 | 0.23 | 53.1 |
| 30-day minimum | 245.6 | 276.5 | 12.6 | 0.11 | 0.20 | 90.5 |
| 90-day minimum | 267.3 | 327.0 | 22.3 | 0.11 | 0.23 | 100.0 |
| 1-day maximum | 2904.4 | 3566.3 | 22.8 | 0.24 | 0.42 | 73.4 |
| 3-day maximum | 2807.1 | 3397.4 | 21.0 | 0.24 | 0.42 | 74.2 |
| 7-day maximum | 2647.7 | 3131.4 | 18.3 | 0.26 | 0.41 | 57.5 |
| 30-day maximum | 2132.1 | 2464.2 | 15.6 | 0.29 | 0.43 | 49.1 |
| 90-day maximum | 1572.7 | 1687.6 | 7.3 | 0.26 | 0.41 | 56.2 |
| Base flow (7-day min/annual mean) | 0.32 | 0.35 | 8.0 | 0.13 | 0.25 | 93.6 |
| **Average Percent Change** | | | **13.9** | | | **60.3** |
| **Group 3: Timing of Annual Extremes** | | | | | | |
| Date of annual 1-day minimum | 8-Mar | 15-Apr | | | | |
| Date of annual 1-day maximum | 10-Jun | 12-Jun | | | | |
| **Group 4: Frequency and Duration of High and Low Pulses** | | | | | | |
| High Pulse Level (cfs) (1 SD above mean) | 1336.0 | | | | | |
| Low Pulse Level (cfs) (1 SD below mean) | 51.0 | | | | | |
| Low pulse number (per yr) | 0.0 | 0.0 | | 0.00 | 0.00 | |
| High pulse number (per yr) | 4.1 | 2.3 | -44.3 | 0.38 | 0.60 | 60.9 |
| Low pulse duration (days) | 0.0 | 0.0 | | 0.00 | 0.00 | |
| High pulse duration (days) | 13.6 | 28.7 | 110.5 | 0.66 | 1.00 | 50.8 |
| **Group 5: Rate and Frequency of Flow Changes** | | | | | | |
| Fall rate (avg cfs/day) | -50.6 | -48.4 | -4.3 | -0.26 | -0.33 | 27.1 |
| Rise rate (avg cfs/day) | 61.9 | 59.0 | -4.7 | 0.25 | 0.36 | 43.7 |
| Number of flow reversals (per yr) | 122.8 | 127.1 | 3.5 | 0.16 | 0.08 | -49.0 |

brown trout habitat in the Arkansas of about 700 and 250 cfs (as measured at the Wellsville gage) (Anderson and Krieger 1994; G. Policky, CDOW, *Draft Report on the Arkansas River 1996*). Results indicate changes that may benefit the brown trout fishery (Table 5-5). For example, there have been decreases in the average number and duration of flows below 250 cfs from October through April. At the same time, there have been no major increases in the number or duration of high flow pulses of 700 cfs or more.

### 3) Trout Population Data

Beginning in WY 1980-81, the CDOW has conducted annual surveys on the Arkansas River near Wellsville (Figure 5-13; Nehring and Anderson 1993; G. Policky, CDOW, *Draft Report on the Arkansas River 1996)*. Analysis for the period 1979-1985 indicated that brown trout recruitment is negatively correlated with June flows (Nehring and Anderson 1993). Other studies suggest that brown trout growth may be reduced in years of high runoff due to prolonged suboptimal temperatures (Anderson and Krieger 1994; G. Policky, CDOW, *Draft Report on the Arkansas River 1996*; R. Behnke, Colorado State University, *personal communication*). Nonetheless, despite such potential effects of high water years, a relatively stable brown trout population has developed in the upper Arkansas.

In contrast to the success of brown trout, rainbow trout remain less than 10% of the Arkansas River fish community despite annual stocking (Figure 5-13; G. Policky, CDOW, *Draft Report on the Arkansas River 1996*). Rainbow trout have shown some increases in recent years, but total density since 1980 has averaged less than 17 per acre at the Wellsville site compared to 209 per acre for brown trout (G. Policky, CDOW, *Draft Report on the Arkansas River 1996*).

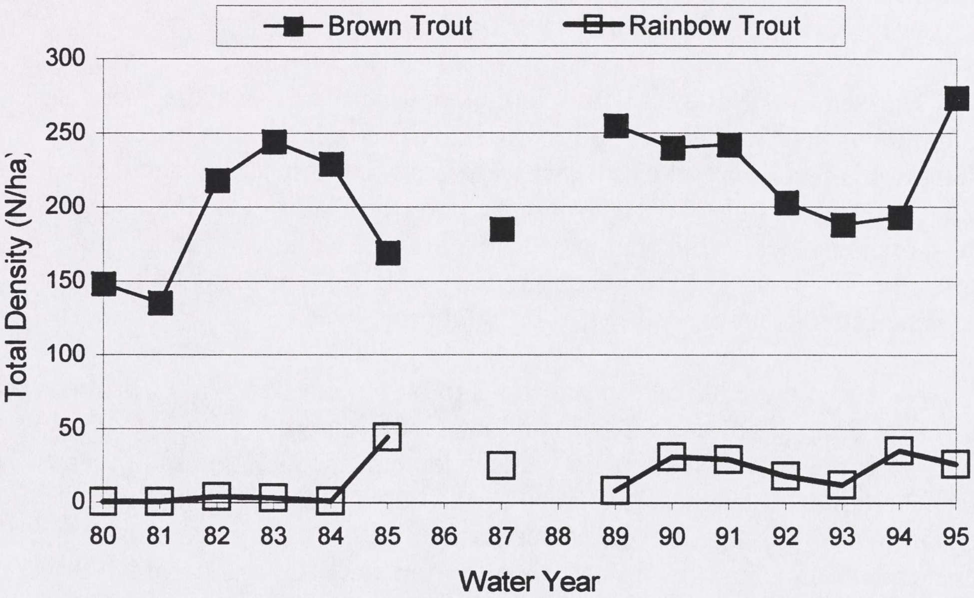
The reasons for the lack of success of rainbow trout are unclear. However, there are few fish of either species over 14 inches or 4 years of age (G. Policky, CDOW, *Draft Report on the Arkansas River 1996*). Studies by the CDOW in the late 1980's suggested that cadmium pollution from mining may contribute to the lack of older trout because of increased cadmium accumulation in liver and kidney tissue with increasing age (Colorado Division of Wildlife 1986). In 1992 the Leadville Mine Drainage Tunnel and Treatment Plant began operation to mitigate heavy metal impacts in the Arkansas. Since then, levels of cadmium, copper, lead, manganese, and zinc have declined (Clark and Lewis 1996). Improvement was greatest near Leadville, gradually declined downstream, and was not detectable below Wellsville.

**Table 5-5. Comparison of average frequency and duration of low (<250 cfs) and high (>700 cfs) flow pulses for different seasons, Arkansas River at Wellsville before (1961-76) and after (1977-95) construction of Pueblo Reservoir.**

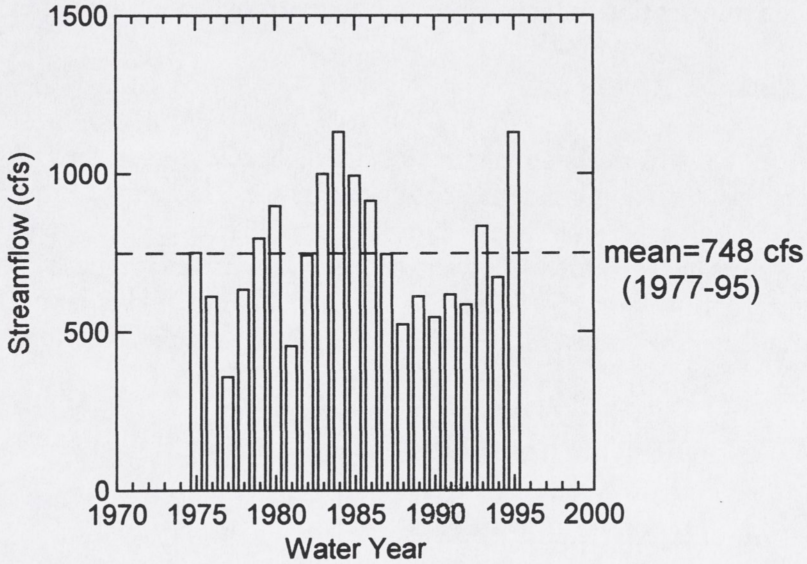
| October through April | Before | After |
|---|---|---|
| | | |
| Low pulse count | 6.0 | 2.7 |
| Low pulse duration (days) | 10.0 | 4.5 |
| High pulse count | 1.1 | 1.2 |
| High pulse duration (days) | 2.3 | 1.5 |
| | | |
| **May through July** | **Before** | **After** |
| | | |
| Low pulse count | 0.1 | 0.3 |
| Low pulse duration (days) | 0.6 | 1.3 |
| High pulse count | 2.1 | 2.2 |
| High pulse duration (days) | 37.6 | 39.4 |
| | | |
| **August and September** | **Before** | **After** |
| | | |
| Low pulse count | 0.1 | 0.2 |
| Low pulse duration (days) | 0.1 | 0.1 |
| High pulse count | 1.9 | 1.8 |
| High pulse duration (days) | 4.7 | 2.2 |

Figure 5-13. Total trout density (N/ha) and annual mean streamflow (cfs), Arkansas River at Wellsville.

Total trout density, Arkansas River at Wellsville.
No data for WY 1986 and 1988.
(Source: G. Policky, CDOW, unpublished data)



Annual mean streamflow (cfs), Arkansas River at Wellsville, 1975-95.



# Division 3: Rio Grande River Basin

Division 3 encompasses the Rio Grande River Basin in south-central Colorado and includes the Alamosa, Rio Grande, and Conejos rivers and Saguache, Trinchera, and Culebra creeks. The Rio Grande flows 180 miles in Colorado across the middle of the San Luis Valley from west to east and then south from Alamosa. The Conejos River flows along the southern edge of the valley until meeting the Rio Grande near La Sauses.

The San Luis Valley is a high mountain desert with an average annual precipitation of just 7 inches. The Rio Grande Reservoir and the Bureau of Reclamation's San Luis Valley Project were designed to help manage water shortages. The San Luis Valley Project includes the Platoro Dam and Reservoir on the Conejos River, completed in May 1952, and the Closed Basin Drain, completed in the early 1990's, which salvages water in the basin and transports it to the Rio Grand River for use elsewhere (Simonds 1996).

Recently, there have been proposals to pump San Luis Valley groundwater to the Front Range (Colorado Environmental Coalition1996). Stockman's Water Company proposes to drill about 50 wells in the confined aquifer and pump some 100,000 acre feet of groundwater over Poncha Pass to the Arkansas River for diversion by Front Range users (*Denver Post*, 11/17/97). However, residents of the San Luis Valley fear the project would dry up wetlands and harm wildlife, with significant negative impacts on the local economy. The Colorado Water Conservation Board proposes to fund a Rio Grande Decision Support System to provide information on current surface and groundwater resources.

## Rio Grande River

About 15 miles downstream from its headwaters in the San Juan Mountains, the Rio Grande is impounded by the Rio Grande Reservoir, built in 1912. The river's trout fishery extends through a 75-mile stretch from the headwaters to Del Norte. Flows near Del Norte are increased by about 25% by tributary inflow from the South Fork of the Rio Grande, but below Del Norte much of the Rio Grande's flow is diverted for irrigation (Nehring and Anderson 1993).

### Flow Regime and Trout Populations near Del Norte

#### 1) Overview of Findings

- monthly flow magnitudes have declined an average of 26%, which can reduce the quantity of trout habitat

- annual high flow extremes have also declined; lack of flushing flows reduces both the quality and quantity of trout habitat

- winter flows have declined in magnitude and are now significantly more variable from year to year; as a result, flow and habitat conditions during the time of brown trout egg incubation may not be dependable or sufficient from year to year

### 2) IHA Analysis of Flow Regime (USGS # 08220000)

The flow regime of the Rio Grande near Del Norte was analyzed by comparing flow conditions over the past 30 years (1960-95) with flows for an early period of record (1910-30) chosen to represent relatively unaltered conditions before major increases in land development and water use. Results indicate that although the seasonal pattern of flows has not changed, there has been an average decrease of 26% in monthly flow magnitudes (Figure 5-14; Table 5-6, Group 1) and a decline of 22% in the magnitude of annual minima and maxima (Table 5-6, Group 2; Figure 5-15). Trout habitat can be reduced by such declines in the quantity of streamflow.

Other results show reduced magnitude and increased variation in winter flows (Table 5-6, Group 1; Figure 5-16). As a result, flow and habitat conditions during the time of brown trout egg incubation may not be dependable or sufficient from year-to-year.

### 3) Trout Population Data

The CDOW has sampled trout populations at several sites on the Rio Grande since the early 1980's (Nehring and Anderson 1993; Nehring and Thompson 1997). Fingerling CRR rainbow trout have been stocked at the State Bridges site since 1985, but rainbow trout have failed to establish a self-sustaining population (Figure 5-17). Flows in this reach of the river are colder due to the influence of coldwater inflow from the South Fork of the Rio Grande, and this may contribute to the lack of success of rainbow trout (Nehring and Anderson 1993). However, rainbow trout declines are also apparent at a site near Creede that is unaffected by tributary inflows of cold water (Figure 5-18).

Brown trout have developed self-sustaining populations at sites both above and below the coldwater inflow from the South Fork (Figures 5-18 and 5-19). However, since WY 1991 there has been a significantly decreasing trend in brown trout numbers at the Collier State Wildlife Area (Figure 5-19).

**Figure 5-14. Mean monthly streamflow (cfs), Rio Grande River near Del Norte, before (1910-30) and after (1960-95) major land and water development.**

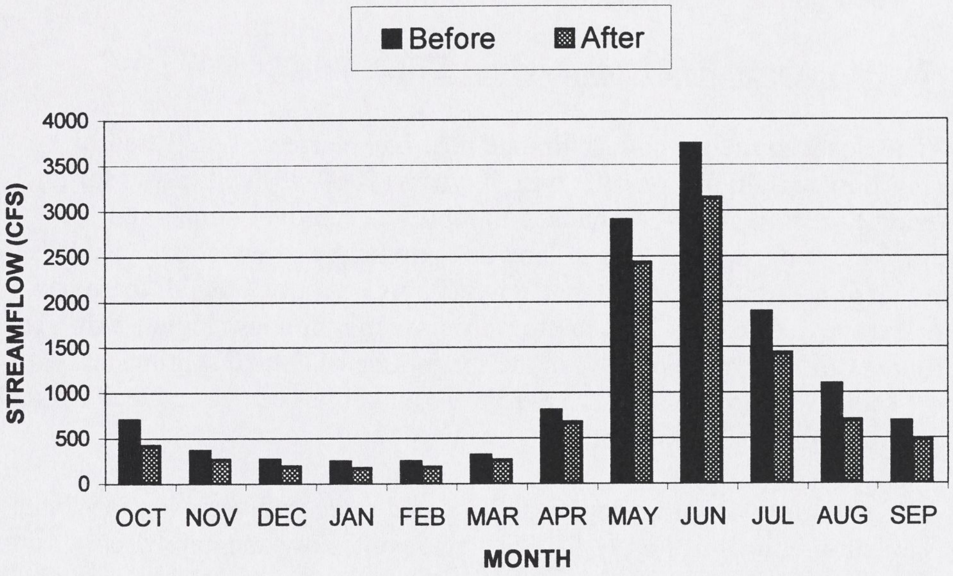
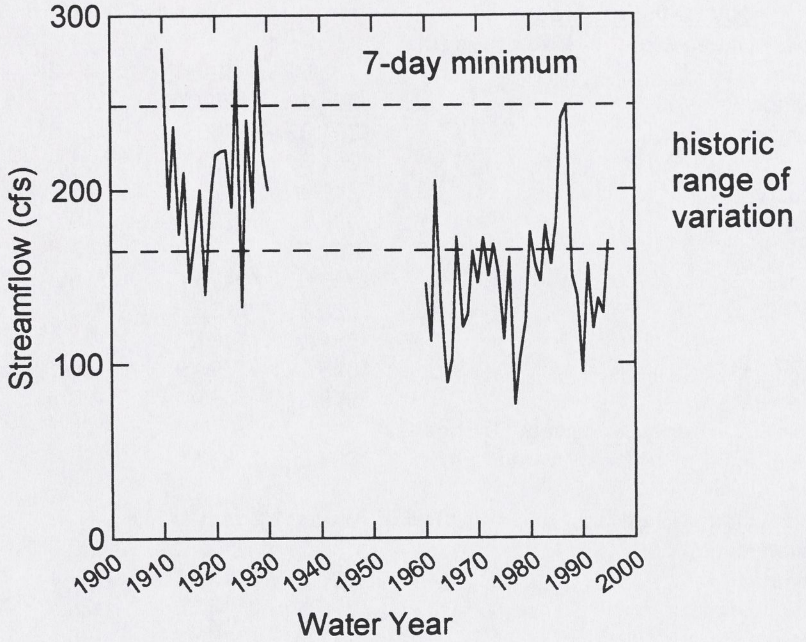


**Table 5-6. Results of IHA analysis for the Rio Grande River near Del Norte comparing flow conditions before (1910-30) and after (1960-95) major land and water development.**

| | | Means | | | CVs | |
|---|---|---|---|---|---|---|
| IHA Statistics Group | Before | After | % Change | Before | After | % Change |
| **Group 1: Mean Monthly Magnitude (cfs)** | | | | | | |
| October | 703.5 | 420.6 | -40.2 | 0.74 | 0.43 | -41.5 |
| November | 364.3 | 263.7 | -27.6 | 0.38 | 0.43 | 15.6 |
| December | 261.8 | 189.1 | -27.8 | 0.30 | 0.28 | -8.9 |
| January | 244.3 | 168.7 | -31.0 | 0.20 | 0.26 | 30.7 |
| February | 241.0 | 179.9 | -25.4 | 0.15 | 0.23 | 58.5 |
| March | 316.2 | 256.0 | -19.0 | 0.33 | 0.29 | -12.0 |
| April | 807.7 | 672.2 | -16.8 | 0.29 | 0.42 | 44.7 |
| May | 2896.0 | 2426.4 | -16.2 | 0.27 | 0.32 | 20.9 |
| June | 3729.5 | 3139.5 | -15.8 | 0.34 | 0.44 | 29.4 |
| July | 1884.0 | 1431.3 | -24.0 | 0.32 | 0.60 | 91.1 |
| August | 1095.1 | 694.9 | -36.5 | 0.29 | 0.50 | 73.2 |
| September | 678.3 | 486.3 | -28.3 | 0.57 | 0.52 | -8.7 |
| **Average Percent Change** | | | **25.7** | | | **36.3** |
| **Mean Annual Flow** | 1094.0 | 862.8 | | | | |
| **Group 2: Magnitude (cfs) and Duration of Annual Extremes** | | | | | | |
| 1-day minimum | 188.2 | 132.0 | -29.9 | 0.24 | 0.27 | 12.7 |
| 3-day minimum | 199.3 | 139.3 | -30.1 | 0.21 | 0.27 | 27.7 |
| 7-day minimum | 206.6 | 147.8 | -28.5 | 0.20 | 0.25 | 25.4 |
| 30-day minimum | 217.9 | 162.3 | -25.5 | 0.18 | 0.26 | 45.3 |
| 90-day minimum | 233.9 | 175.5 | -25.0 | 0.15 | 0.24 | 57.8 |
| 1-day maximum | 6360.5 | 4777.2 | -24.9 | 0.45 | 0.34 | -23.8 |
| 3-day maximum | 6013.3 | 4585.8 | -23.7 | 0.39 | 0.33 | -13.9 |
| 7-day maximum | 5424.8 | 4341.3 | -20.0 | 0.33 | 0.33 | 0.6 |
| 30-day maximum | 4238.4 | 3597.1 | -15.1 | 0.31 | 0.34 | 11.5 |
| 90-day maximum | 2892.3 | 2399.6 | -17.0 | 0.24 | 0.38 | 56.4 |
| Base flow (7-day min/annual mean) | 0.19 | 0.2 | -4.2 | 0.24 | 0.28 | 19.4 |
| **Average Percent Change** | | | **22.2** | | | **26.8** |
| **Group 3: Timing of Annual Extremes** | | | | | | |
| Date of annual 1-day minimum | 23-Dec | 30-Dec | | | | |
| Date of annual 1-day maximum | 9-Jun | 4-Jun | | | | |
| **Group 4: Frequency and Duration of High and Low Pulses** | | | | | | |
| High Pulse Level (cfs) | 2442.7 | | | | | |
| Low Pulse Level (cfs) | 272.0 | | | | | |
| Low pulse number (per yr) | 4.0 | 5.1 | 27.0 | 0.73 | 0.46 | -37.3 |
| High pulse number (per yr) | 4.0 | 1.9 | -52.6 | 0.40 | 0.49 | 21.7 |
| Low pulse duration (days) | 31.9 | 36.4 | 13.9 | 0.96 | 0.77 | -19.2 |
| High pulse duration (days) | 14.4 | 22.5 | 56.7 | 0.60 | 0.75 | 24.4 |
| **Group 5: Rate and Frequency of Flow Changes** | | | | | | |
| Fall rate (avg cfs/day) | -130.1 | -70.7 | -45.6 | -0.27 | -0.33 | 21.3 |
| Rise rate (avg cfs/day) | 170.6 | 85.1 | -50.1 | 0.32 | 0.32 | 0.7 |
| Number of flow reversals (per yr) | 76.5 | 117.0 | 53.0 | 0.19 | 0.10 | -49.8 |

Figure 15. Average 7-day minimum and maximum streamflow (cfs), Rio Grande near Del Norte, before (1910-30) and after (1960-95) major land and water development.



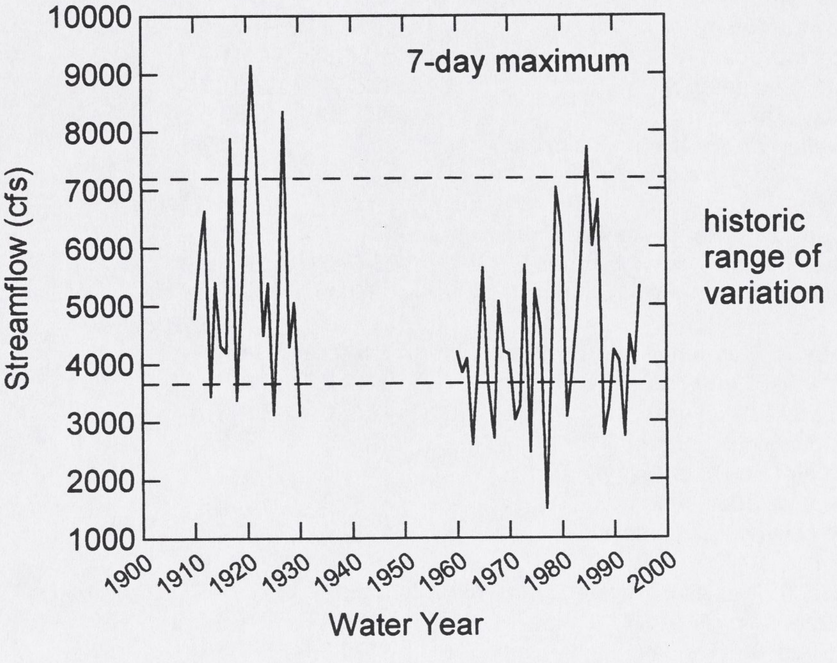


Figure 5-16. Average February streamflow (cfs), Rio Grande near Del Norte, before (1910-30) and after (1960-95) major land and water development.

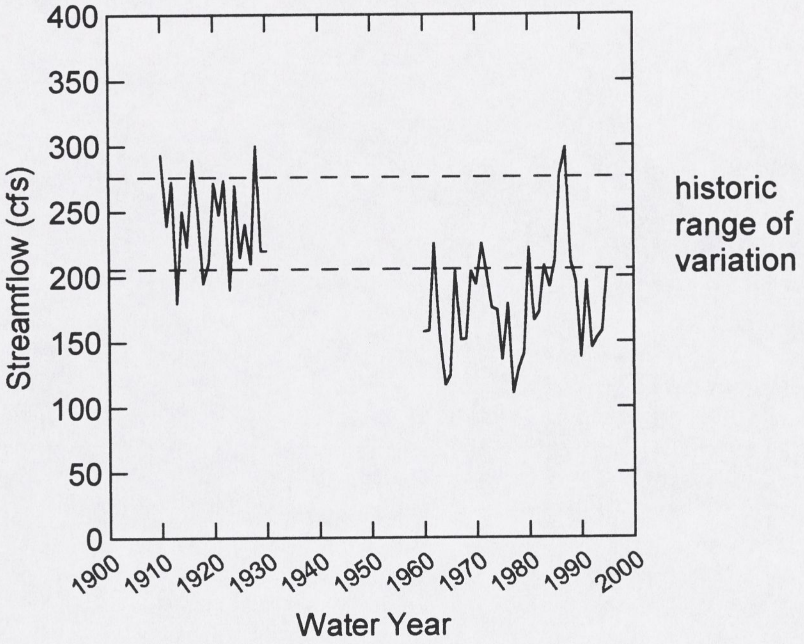
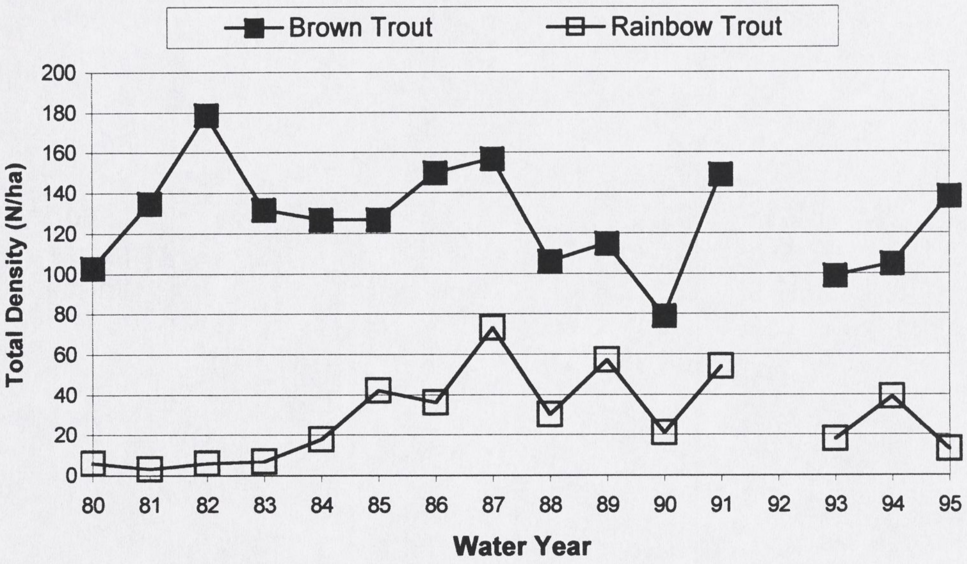


Figure 5-17. Total trout density (N/ha) and annual mean streamflow (cfs), Rio Grande near Del Norte.

Total trout density, Rio Grande near Del Norte. No data for WY 1992. Published rainbow trout numbers were converted to density based on the estimated area for brown trout density. (Source: Nehring and Thompson 1997)



Annual mean streamflow (cfs), Rio Grande River near Del Norte, 1975-95.

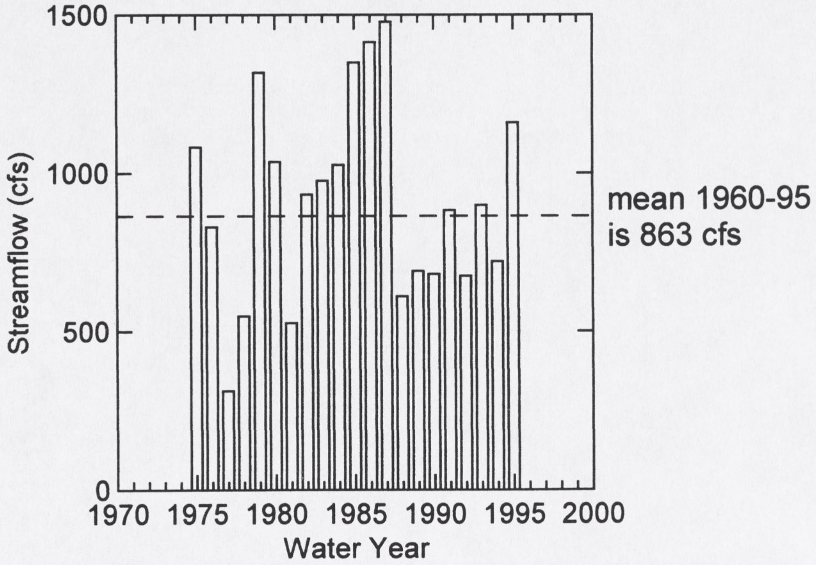


Figure 5-18. Total trout density (N/ha), Rio Grande near Creede.

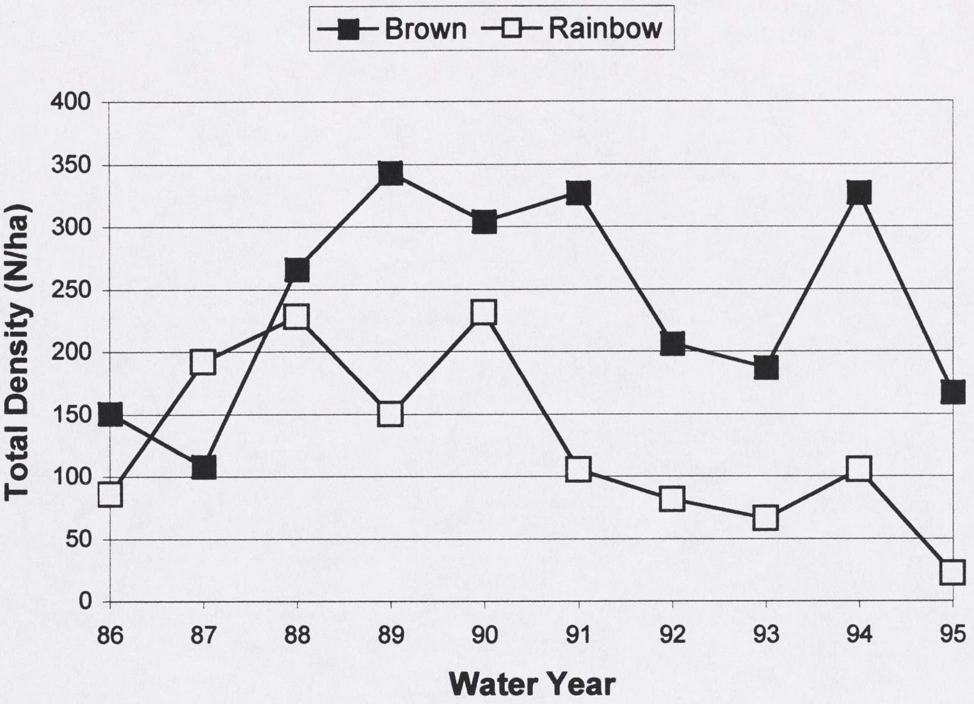
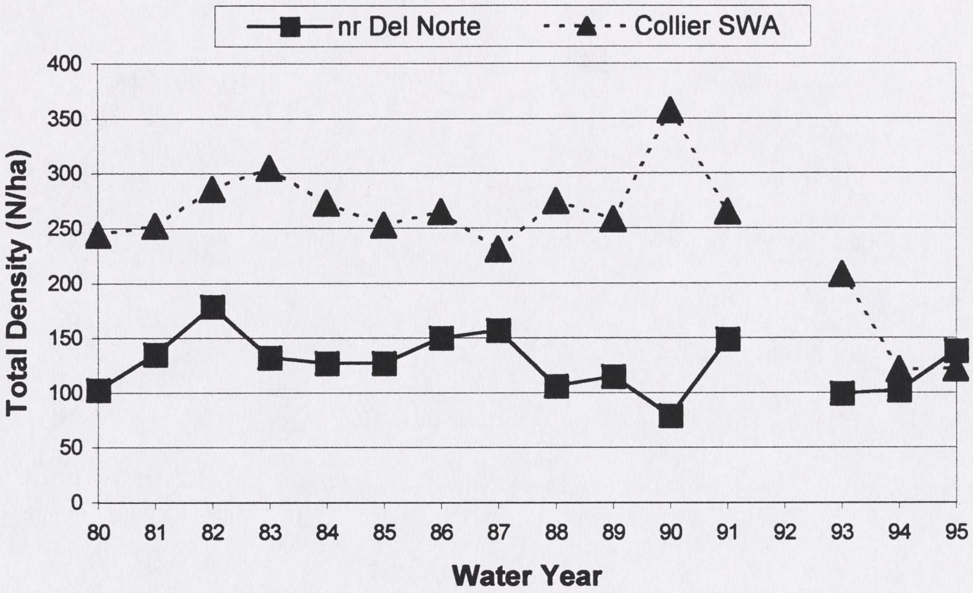
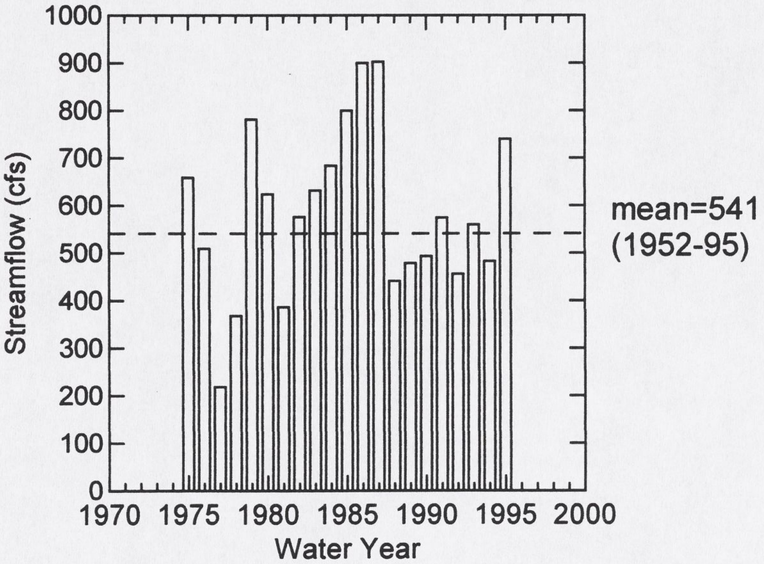


Figure 5-19. Total brown trout density (N/ha) at CDOW sites near Del Norte and the Collier State Wildlife Area and annual mean streamflow (cfs), Rio Grande at Wagon Wheel Gap.

Total trout density, Rio Grande near Del Norte and the Collier State Wildlife Area. No data for WY 1992.
(Source: Nehring and Thompson 1997)



Annual mean streamflow (cfs), Rio Grande River at Wagon Wheel Gap, 1975-95.



The period of decline of brown trout at the Collier State Wildlife Area (Figure 5-19) coincided with that of rainbow trout near Creede (Figure 5-18). This is also when stocking of rainbow trout with the whirling disease parasite first occurred in the Rio Grande drainage (Nehring and Thompson 1997). However, rainbow trout have not been stocked at the site near Creede since 1988, and declines of both species were apparent at both sites prior to the first detection of the parasite in wild trout in April 1994 (Nehring and Thompson 1997). This suggests that factors other than or in addition to whirling disease are responsible for trout declines in the Rio Grande (Nehring and Thompson 1997).

Brown trout declines are not apparent at the site near Del Norte, where flows are elevated due to tributary inflow. This raises the question of whether some reduction in flow quantity is a factor in trout declines above the South Fork tributary. Streamflow data for a site at Wagon Wheel Gap, between Creede and the Collier Wildlife Area, indicate that annual flows were at or below the mean for several years between WY 1988 and WY 1994 (Figure 5-19). Successive years of below-average flows may have reduced trout habitat. Moreover, the mean annual flow at Wagon Wheel Gap is 541 cfs compared to 863 cfs at Del Norte, and years of low flow may therefore have a comparatively greater impact on trout populations at this site.

## Conejos River from Platoro Reservoir to Mogote

The Conejos River flow regime varies seasonally according to spring snowmelt runoff and releases from Platoro Reservoir to supply downstream irrigators. Platoro Dam was built in 1952 for flood control and to provide supplemental irrigation water for about 74,000 acres. However, under the terms of the 1938 Rio Grande Compact, which requires annual delivery of water to New Mexico, Colorado had a water debt that was not retired until the mid-1980s. As a result, Platoro Reservoir has only recently stored water for irrigation use.

### Flow Regime below Platoro Reservoir (USGS # 08245000)

#### 1) Overview of Findings

- the current flow regime often fails to meet minimum flow targets established by the Conejos Water Conservancy District and there are few trout found below Platoro Dam

- reservoir inflows are often less than releases required to meet downstream calls, and as a result winter flows are below levels needed to sustain trout populations

- significant day to day changes in flows during November may interfere with brown trout spawning and egg incubation

### 2) IHA Analysis of Flow Regime

The Conejos Water Conservancy District is required to maintain:

- Platoro Reservoir releases of 7 cfs October through April
- bypass flow of 40 cfs or natural inflow (whichever is less) May through September
- even flows during brown trout spawning October to December

However, reservoir inflows are often less than releases required to meet downstream calls, and winter flows can fall below the target minimum of 7 cfs. Results of IFIM (Instream Flow Incremental Methodology) modeling by the CDOW suggest that the optimal flow in winter to sustain wild trout populations would be at least 40-50 cfs (John Alves, CDOW, *unpublished*).

Figure 5-20 presents the annual hydrograph for the flow regime below Platoro Reservoir and Table 5-7 presents IHA results averaged over the period of record (1953-95). Results indicate that the current flow regime does not meet management targets in several respects. Mean flows from December through March barely exceed the 7 cfs minimum, and monthly means for most months vary significantly from year to year (Table 5-7, Group 1). In addition, average 1-day minimum flows barely exceed the target minimum of 7 cfs from October through April and are below 40 cfs in August and September (Figure 5-21). Moreover, daily flows rise and fall substantially above and below the monthly average during November, the time of brown trout spawning and egg incubation (Figure 5-22). Such high rates of daily changes in flows can produce rapid cycles of wetting and drying that can interfere with trout reproductive activities.

## Flow Regime below Mogote (USGS # 08246500)

### 1) Overview of Findings

- the magnitude of fall flows has increased, while flows from April through June have declined an average of 20%; such conditions may favor the fall-spawning brown trout compared to rainbow trout

- annual maxima have declined significantly; lack of flushing flows limits the quality and quantity of trout habitat

Figure 5-20. Mean monthly streamflow (cfs), Conejos River below Platoro Reservoir, 1953-1995.

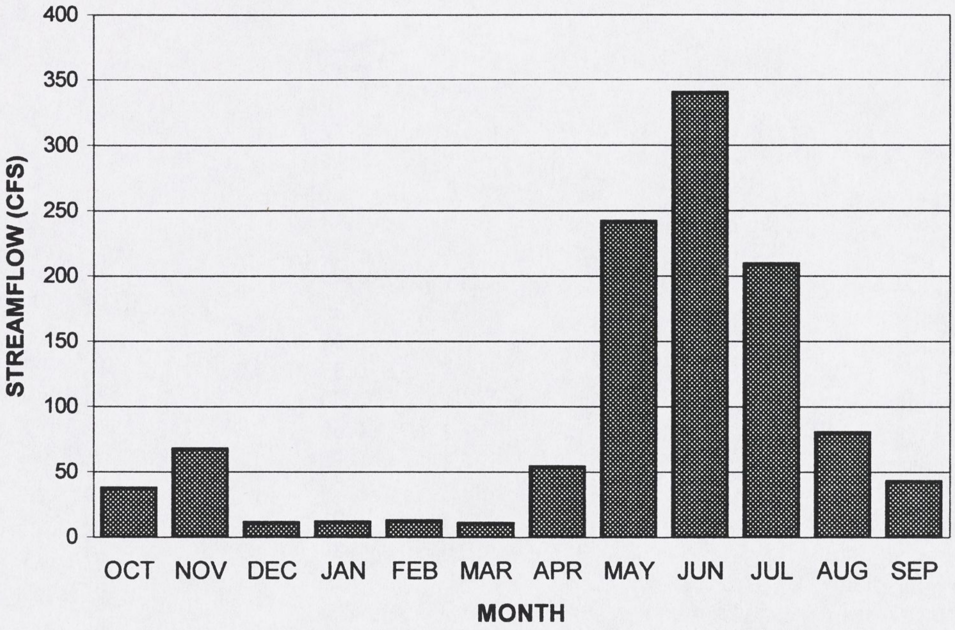


**Table 5-7. Results of IHA analysis for the Conejos River below Platoro Reservor (1953-1995).**

| IHA Statistics Group | Mean | CV |
|---|---|---|
| **Group 1: Mean Monthly Magnitude (cfs)** | | |
| October | 37.5 | 0.92 |
| November | 67.5 | 1.52 |
| December | 11.1 | 0.72 |
| January | 11.5 | 0.81 |
| February | 12.4 | 1.23 |
| March | 10.8 | 0.43 |
| April | 54.0 | 1.12 |
| May | 241.7 | 0.39 |
| June | 340.4 | 0.36 |
| July | 209.4 | 0.72 |
| August | 80.1 | 0.71 |
| September | 42.6 | 0.87 |
| **Mean Annual Flow** | 93.5 | 1.68 |
| **Group 2: Magnitude (cfs) and Duration of Annual Extremes** | | |
| 1-day minimum | 4.5 | 0.55 |
| 3-day minimum | 4.8 | 0.51 |
| 7-day minimum | 5.4 | 0.55 |
| 30-day minimum | 7.4 | 0.53 |
| 90-day minimum | 9.2 | 0.56 |
| 1-day maximum | 691.2 | 0.23 |
| 3-day maximum | 669.2 | 0.24 |
| 7-day maximum | 622.8 | 0.25 |
| 30-day maximum | 446.5 | 0.23 |
| 90-day maximum | 277.6 | 0.24 |
| Base flow (7-day min/annual mean) | 0.06 | 0.60 |
| **Group 3: Timing of Annual Extremes** | | |
| Date of annual 1-day minimum | 29-Sep | |
| Date of annual 1-day maximum | 3-Jul | |
| **Group 4: Frequency and Duration of High and Low Pulses** | | |
| High Pulse Level (cfs) | 251.0 | |
| Low Pulse Level (cfs) | 9.0 | |
| Low pulse number (per yr) | 2.8 | 0.76 |
| High pulse number (per yr) | 4.7 | 0.42 |
| Low pulse duration (days) | 45.5 | 1.31 |
| High pulse duration (days) | 11.2 | 0.49 |
| **Group 5: Rate and Frequency of Flow Changes** | | |
| Fall rate (avg cfs/day) | -34.6 | -0.36 |
| Rise rate (avg cfs/day) | 38.6 | 0.37 |
| Number of flow reversals (per yr) | 50.7 | 0.28 |

Figure 5-21. Average 1-day minimum flow (cfs) by month in relation to management targets, Conejos River below Platoro Reservoir, 1953-95.

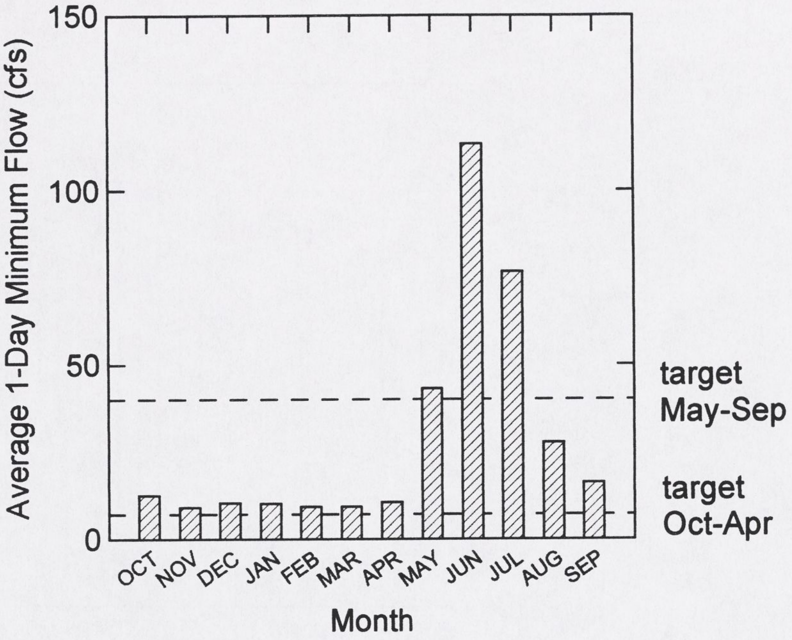
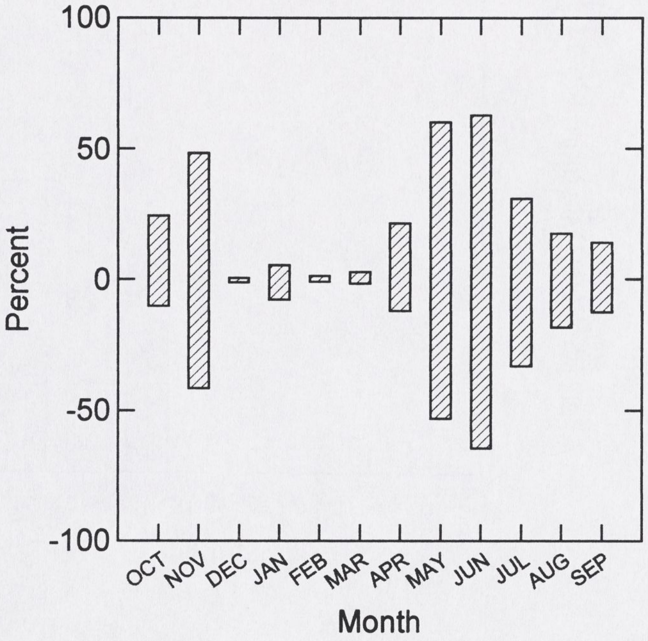


Figure 5-22. Average monthly rates of daily rises and falls in flows as a percent of average monthly streamflow, Conejos River below Platoro Reservoir, 1953-95.



### 2) IHA Analysis of Flow Regime

IHA analysis for the Conejos River near Mogote compared flow conditions for a period before (1915-45) and after (1960-95) the upstream dam at Platoro was in operation. Following dam construction, the magnitude of fall flows increased, while flows from April through June declined an average of 20% (Figure 5-23; Table 5-8, Group 1).

In addition, year to year variation in fall and winter flows increased significantly, especially in November and February (Table 5-8, Group 1). Figure 5-24 compares the variability of November and May flows to the historic range of flow variation. IHA results indicate that the variability of November flows increased dramatically during the first decades of dam operation. In contrast, during many years spring flows have remained within the historic range. Since 1980 November flows have also returned to historic levels (Figure 5-24).

Magnitudes of annual minima have generally increased, while annual maxima have declined by an average of more than 20% (Table 5-8, Group 2). The average 1-day minimum often falls within the historic range of variation, but can also show substantial increases in high runoff years (Figure 5-25). In contrast, the average 1-day maximum has declined, and in many years falls significantly below the historic range (Figure 5-25).

### 3) Trout Population Data

For the past 10 years, there has been extensive management of Conejos River trout populations by the CDOW from Platoro Reservoir downstream to Mogote (John Alves, CDOW, *personal communication*). This involves stocking of fingerling Colorado River rainbow trout in sections from the confluence with the South Fork Conejos River downstream to Bear Creek. Fishing regulations include a bag limit of 2 fish, 16 inches or more, and fly fishing or artificial flies and lures. Intensive use management is applied to the river immediately below Platoro Reservoir, including standard angling methods and bag and possession limits.

The CDOW has sampled Conejos River trout populations since 1989 (John Alves, CDOW, *unpublished data*). Data for a section from Menkhaven Ranch (about 5 miles below Manga Creek) to Bear Creek show that the brown trout population dominates the fishery (Figure 5-26). Since 1987, fingerling rainbow trout have been stocked on an annual basis but a stable, self-reproducing rainbow trout population has failed to develop. Habitat limitations and whirling disease are considered to be the main factors limiting the rainbow population (John Alves, *personal communication*). In addition, regulations allow the harvest

Figure 5-23. Mean monthly streamflow (cfs), Conejos River near Mogote, before (1915-45) and after (1960-95) Platoro Reservoir.

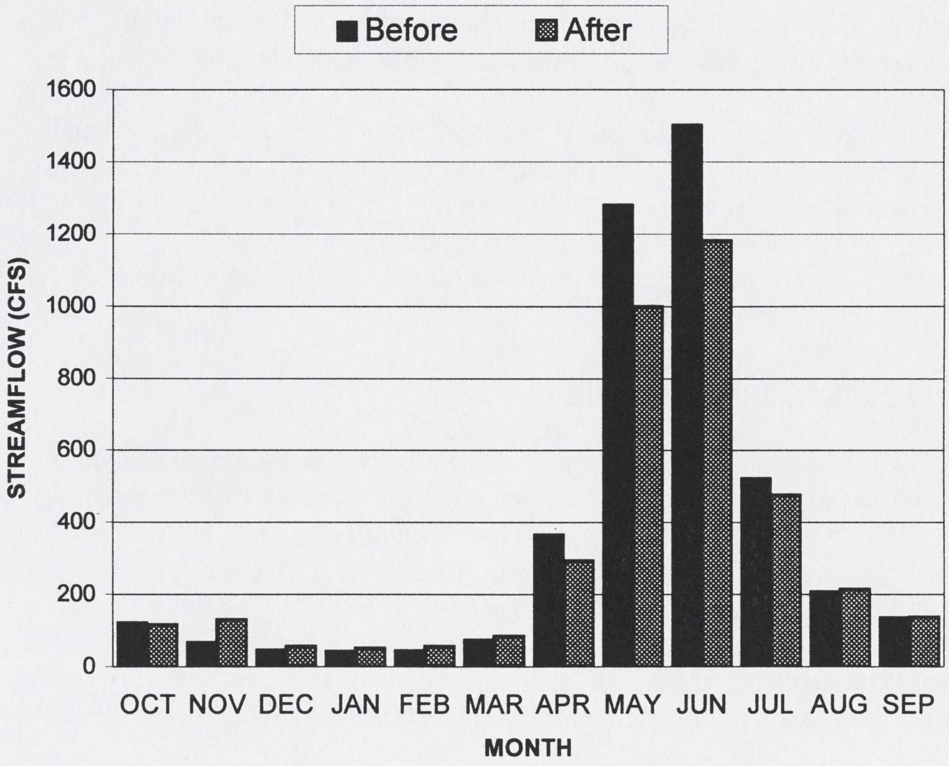
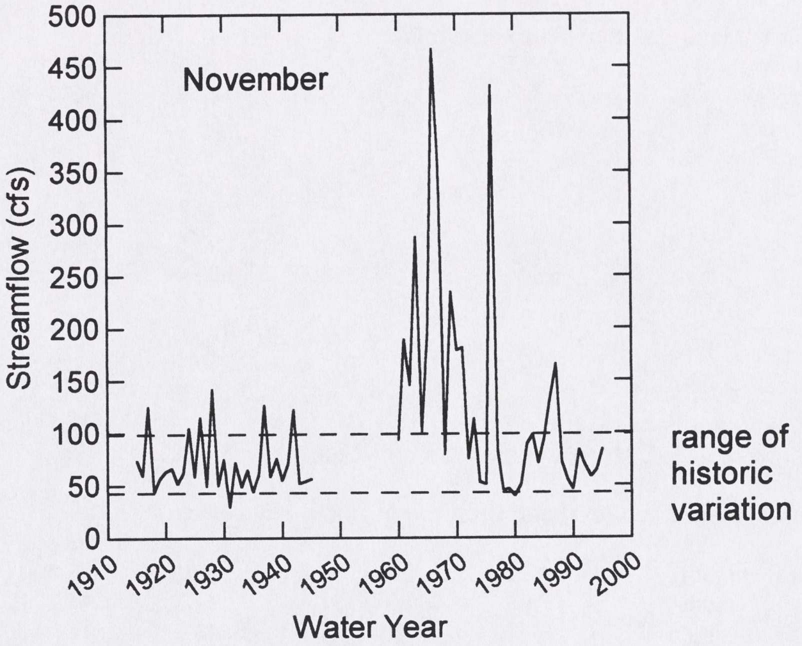


**Table 5-8. Results of IHA analysis for the Conejos River near Mogote before (1915-1945) and after (1960-95) construction of Platoro Reservoir.**

| | Means | | | CVs | | |
|---|---|---|---|---|---|---|
| IHA Statistics Group | Before | After | % Change | Before | After | % Change |
| **Group 1: Mean Monthly Magnitude (cfs)** | | | | | | |
| October | 124.5 | 116.1 | -6.8 | 0.70 | 0.54 | -23.6 |
| November | 70.7 | 129.8 | 83.6 | 0.40 | 0.82 | 105.7 |
| December | 49.3 | 56.0 | 13.8 | 0.29 | 0.34 | 20.2 |
| January | 45.2 | 50.6 | 12.1 | 0.24 | 0.33 | 36.4 |
| February | 47.7 | 56.9 | 19.3 | 0.17 | 0.40 | 128.1 |
| March | 77.9 | 84.5 | 8.5 | 0.24 | 0.34 | 43.9 |
| April | 369.1 | 293.6 | -20.5 | 0.48 | 0.49 | 3.0 |
| May | 1283.4 | 999.6 | -22.1 | 0.33 | 0.28 | -15.5 |
| June | 1504.4 | 1181.6 | -21.5 | 0.43 | 0.43 | -1.7 |
| July | 524.5 | 476.8 | -9.1 | 0.59 | 0.67 | 12.1 |
| August | 211.0 | 215.1 | 2.0 | 0.51 | 0.50 | -0.9 |
| September | 139.2 | 136.7 | -1.8 | 0.77 | 0.67 | -13.2 |
| **Mean % Change (absolute value)** | | | **19.5** | | | **34.6** |
| **Mean Annual Flow** | 368.7 | 317.1 | | | | |
| **Group 2: Magnitude (cfs) and Duration of Annual Extremes** | | | | | | |
| 1-day minimum | 34.4 | 37.7 | 9.8 | 0.30 | 0.31 | 3.4 |
| 3-day minimum | 36.0 | 39.1 | 8.6 | 0.26 | 0.29 | 12.8 |
| 7-day minimum | 37.1 | 41.2 | 11.2 | 0.25 | 0.28 | 12.6 |
| 30-day minimum | 40.0 | 46.2 | 15.5 | 0.20 | 0.30 | 45.9 |
| 90-day minimum | 44.8 | 51.7 | 15.5 | 0.16 | 0.28 | 72.9 |
| 1-day maximum | 2446.1 | 1913.6 | -21.8 | 0.28 | 0.25 | -9.4 |
| 3-day maximum | 2337.4 | 1806.9 | -22.7 | 0.28 | 0.24 | -13.5 |
| 7-day maximum | 2182.4 | 1693.2 | -22.4 | 0.29 | 0.25 | -14.7 |
| 30-day maximum | 1779.1 | 1395.8 | -21.5 | 0.31 | 0.29 | -5.1 |
| 90-day maximum | 1165.9 | 925.1 | -20.7 | 0.32 | 0.34 | 8.0 |
| Base flow (7-day min/annual mean) | 0.11 | 0.14 | 28.7 | 0.36 | 0.29 | -20.4 |
| **Mean % Change (absolute value)** | | | **18.0** | | | **19.9** |
| **Group 3: Timing of Annual Extremes** | | | | | | |
| Date of annual 1-day minimum | 1-Dec | 14-Jan | | | | |
| Date of annual 1-day maximum | 30-May | 2-Jun | | | | |
| **Group 4: Frequency and Duration of High and Low Pulses** | | | | | | |
| High Pulse Level (cfs) | 956.4 | | | | | |
| Low Pulse Level (cfs) | 53.0 | | | | | |
| Low pulse number (per yr) | 5.0 | 6.4 | 28.3 | 0.74 | 0.60 | -19.1 |
| High pulse number (per yr) | 2.7 | 2.6 | -3.6 | 0.53 | 0.49 | -8.5 |
| Low pulse duration (days) | 29.5 | 16.1 | -45.4 | 1.05 | 1.49 | 42.0 |
| High pulse duration (days) | 23.5 | 15.5 | -33.9 | 0.78 | 0.66 | -14.6 |
| **Group 5: Rate and Frequency of Flow Changes** | | | | | | |
| Fall rate (avg cfs/day) | -50.3 | -34.9 | -30.5 | -0.43 | -0.29 | -31.2 |
| Rise rate (avg cfs/day) | 67.2 | 40.6 | -39.6 | 0.40 | 0.29 | -27.6 |
| Number of flow reversals (per yr) | 86.8 | 120.2 | 38.5 | 0.26 | 0.09 | -64.2 |

Figure 5-24. Average streamflow (cfs) for November and May, Conejos River near Mogote, before (1915-45) and after (1960-95) Platoro Reservoir. Dotted lines indicate range of variation before the reservoir (based on mean + or - 1 SD).



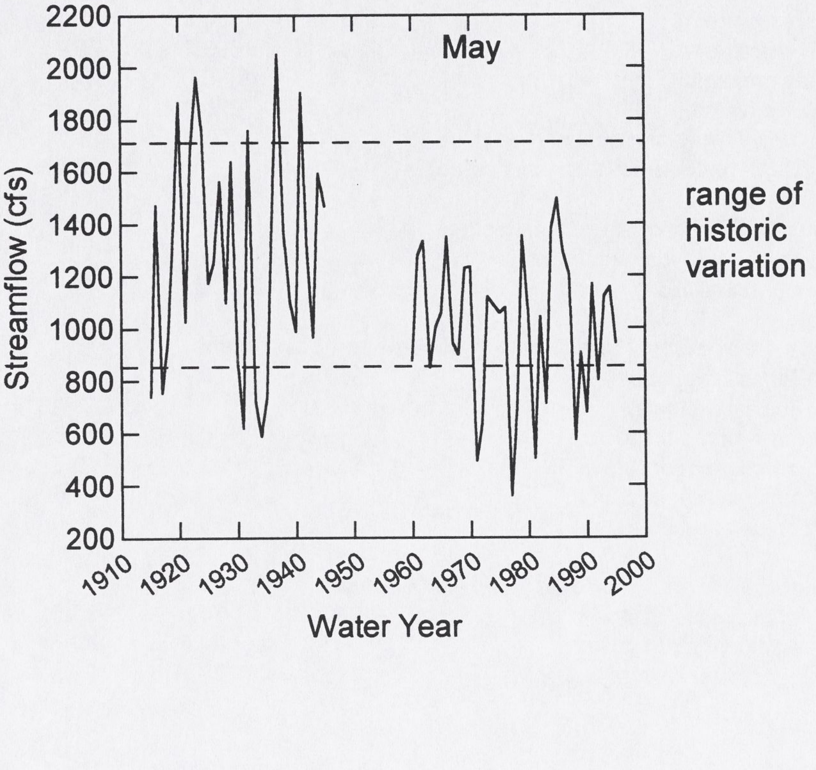


Figure 5-25. Average 1-day minimum and maximum streamflow (cfs), Conejos River near Mogote, before (1915-45) and after (1960-95) Platoro Reservoir. Dotted lines indicate range of variation before the reservoir (based on mean + or - 1 SD).

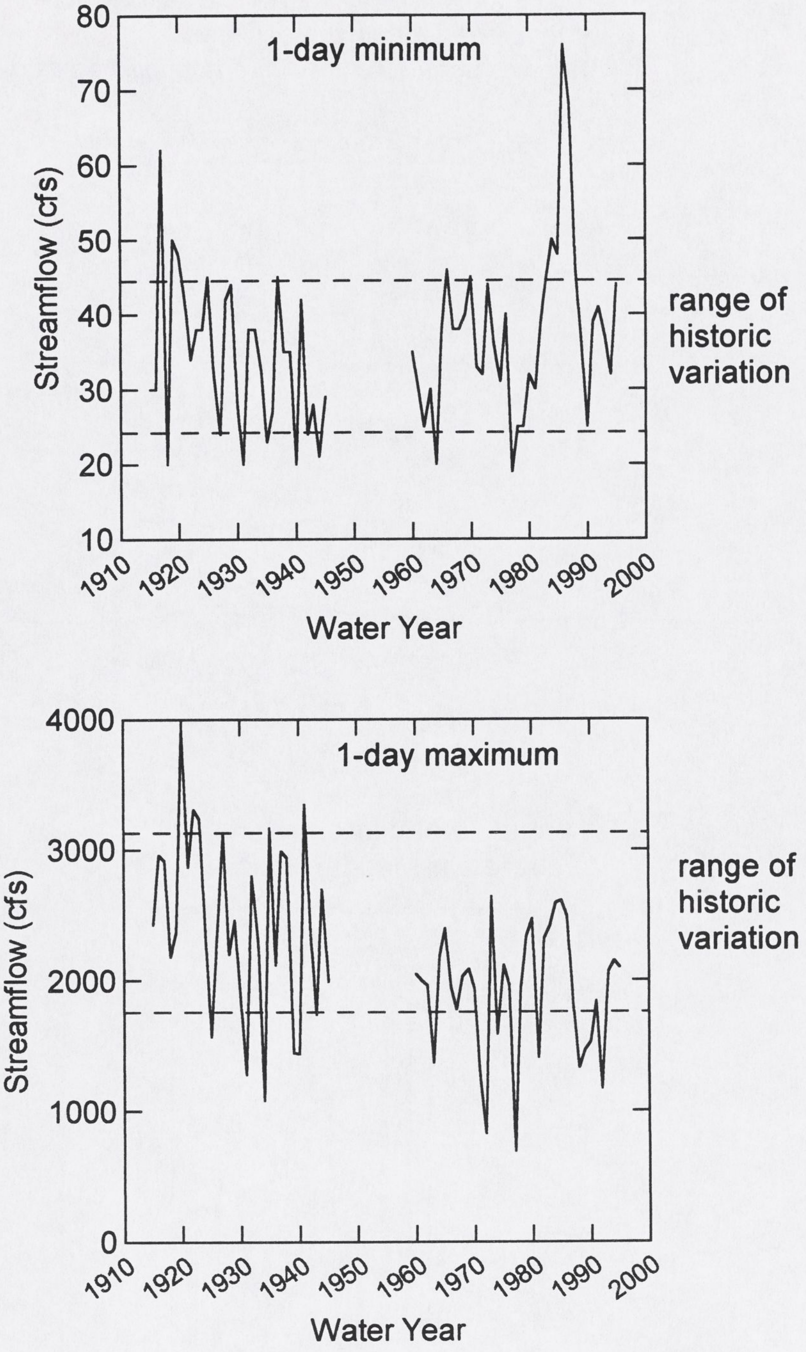
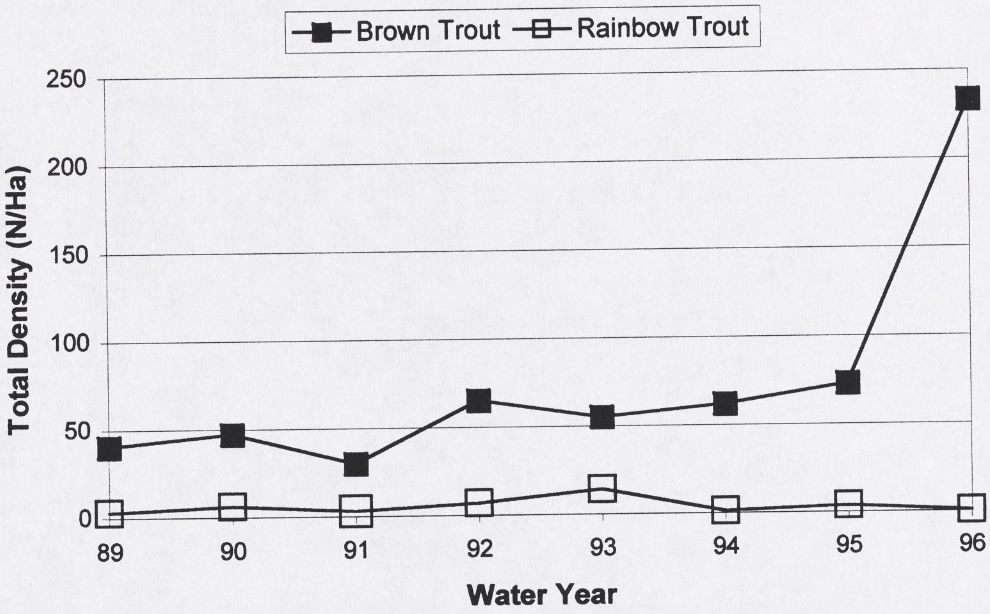
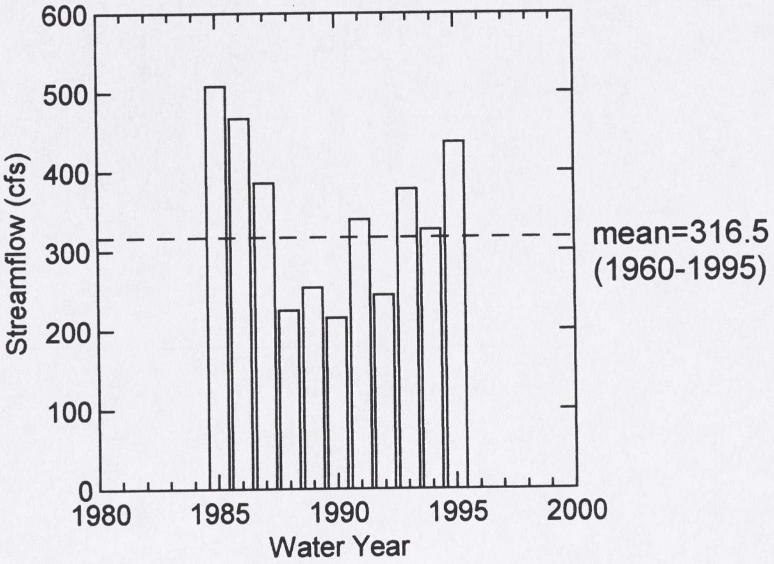


Figure 5-26. Total trout density (N/ha) and annual mean streamflow (cfs), Conejos River near Mogote.

Total trout density at CDOW site near Mogote (Menkhaven Ranch to Bear Creek).
(Source: John Alves, CDOW, unpublished data)



Annual mean streamflow (cfs), Conejos River near Mogote, 1985-95.



of fish 16 inches or longer, and this is apparently contributing to an absence of larger trout of both species (John Alves, CDOW, *unpublished data*).

In contrast to the Menkhaven Ranch section, very few trout are found in the Conejos River immediately below Platoro Reservoir (John Alves, CDOW, *personal communication*). The CDOW stocks catchable-size rainbow trout in summer to provide a put and take fishery. In addition, the CDOW and the San Luis Valley chapter of Trout Unlimited are planning a habitat improvement project. However, IHA results indicate that fishery enhancement will also require changes to reservoir operations. IFIM studies by the CDOW suggest that winter flows should be at least 40-50 cfs, significantly above current levels immediately below the reservoir (Figure 5-20). In addition, annual minima only just meet current minimum flow targets in fall and winter (Figure 5-21). Finally, there is a need to stabilize the erratic fluctuations in daily flows below the reservoir in November (Figure 5-22).

## Division 4: Gunnison and San Miguel River Basins

Division 4 includes the Gunnison, San Miguel, North Fork of the Gunnison, Taylor, and Uncompahgre rivers and parts of the Dolores River in Mesa and Montrose counties.

### Gunnison River

The Gunnison River begins at the confluence of the Taylor and East Rivers above the city of Gunnison, Colorado. There are 1,500 active diversion structures in the Gunnison River basin, providing water to 300,000 acres of irrigated land (Colorado Division of Water Resources 1996).

Water development in the Gunnison River basin can be divided into three distinct periods (Colorado Division of Water Resources 1996). From the early 1900's until 1937, the Gunnison Tunnel was the major water project supplying water for the Uncompahgre Valley Water Users Association (UVWUA). The Gunnison Tunnel and Diversion Dam were completed in 1913 as part of the Uncompahgre Project. The AB Lateral diverts Gunnison River water to the Uncompahgre River and several large canals for irrigation in the Uncompahgre Valley. In 1937, Taylor Park Reservoir was built upstream to help reduce late-season shortages. Water releases from the reservoir were channeled through upper basin headgates to the Gunnison Tunnel. In 1966, construction of the Aspinall Unit began. The project allowed the UVWUA to draw its Taylor Park storage water from Blue Mesa Reservoir, eliminating the need to transfer releases past several intervening headgates.

Once completed, the Aspinall Unit included three reservoirs on the mainstem of the Gunnison River, beginning 30 miles below the town of Gunnison (Colorado Division of Water Resources 1996; Smith et al. 1996). Blue Mesa Reservoir was completed in 1966, followed by Morrow Point Reservoir in 1968, and Crystal Reservoir in 1976. Crystal Reservoir is at the site of the Gunnison Diversion Tunnel. Blue Mesa is the only one of the three reservoirs that is drawn down in fall and winter and filled in summer.

The Bureau of Reclamation operates the Aspinall Unit for hydropower production (U.S. Bureau of Reclamation 1997a). Blue Mesa and Morrow Point are peaking power plants, operating on hourly or daily cycles, but Crystal Reservoir is mostly used for flow regulation (Colorado Division of Water Resources 1996). A study is underway as a part of Endangered Species Act, Section 7 consultation with the U.S. Fish and Wildlife Service to determine the effect of various release patterns from the Aspinall Unit on habitat, reproductive success, and the reintroduction of endangered native fish, including the Colorado squawfish (U.S. Bureau of Reclamation 1997a). The Colorado River Storage Project Act authorizes up to 148,000 A-ft of water in the Aspinall Unit to mitigate depletions in the Dolores and Dallas Creek Projects (Colorado Division of Water Resources 1995). Release of Aspinall waters for endangered fish occurs July through October to alleviate low flow conditions.

The Gunnison River is currently targeted for a number of new water projects (Colorado Environmental Coalition 1996). Although a District 4 Water Court limited the water available for future diversion to 20,000 acre feet (League of Women Voters 1992), three projects remain under consideration. The AB Lateral Extension would increase the amount of water diverted by the existing AB Lateral (Colorado Environmental Coalition 1996). In addition, the extension would continue the lateral to a power plant on the Uncompahgre River to generate hydropower revenue for the UVWUA and a group of out-of-state investors, even though there is currently an oversupply of power in the region (Colorado Environmental Coalition 1996). It is thought that the project would significantly reduce the Gunnison's flow through the Black Canyon National Monument (a segment that has been declared suitable for Wild and Scenic designation) and could increase bank stability problems on the Uncompahgre River (Colorado Environmental Coalition 1996).

Other proposed projects include Austin Dam, to be built near the confluences of the Smith Fork and North Fork with the Gunnison, and the Dominguez project, a proposal by a regional developers' group, the Dominguez Reservoir Corporation, to dam the Gunnison below Delta (Colorado

Environmental Coalition 1996). The proposed Dominguez Reservoir would inundate 27 miles of the Gunnison River, including the lower end of the Dominguez Canyon Bureau of Land Management Wilderness Study Area.

## Flow Regime and Trout Populations below Gunnison Tunnel

### 1) Overview of Findings

- upstream reservoirs have eliminated May and June peak flows and increased winter baseflows

- annual maxima and the duration of high flow pulses have declined, suggesting that flushing flows now rarely occur; flushing flows are needed to maintain the stream channel and for habitat development

- average 1- and 3-day minimum flows fall below the management target of a minimum of 300 cfs through the Black Canyon of the Gunnison National Monument

- the number of day-to-day reversals in flow conditions increased by 63% after construction of the Aspinall Unit; however, efforts to minimize such flow reversals are evident in data for the past decade

### 2) IHA Analysis of Flow Regime (USGS # 09128000)

Water development impacts on the Gunnison River are clearly evident by comparing flows below the Gunnison Tunnel before and after major water development projects. Before the first reservoir of the Aspinall Unit (Blue Mesa) was completed during the 1966-67 water year, the hydrograph was characterized by low flows in fall and winter, increasing flows due to snowmelt runoff beginning in April and peaking in May and June, and gradually receding flows over summer (Figure 5-27). Although the river below Gunnison Tunnel now has a USBR-generated baseflow that is well-above the historic gaged flow (Colorado Division of Water Resources 1996), the average annual flow has actually declined (Table 5-9, Group 1). Upstream reservoirs have eliminated May and June peak flows and increased winter baseflows (Figure 5-27; Table 5-9, Group 1). Winter flows are also significantly more variable from year-to-year, as indicated by increases in coefficients of variation for mean winter flows (Table 5-9, Group 1) and the dramatic change in yearly variation in January flows (Figure 5-28).

Operation of the Aspinall Unit is designed to meet delivery requirements of the Uncompahgre Valley Project while also maintaining a minimum of 300 cfs flowing through the Black Canyon of the Gunnison National Monument (U.S.

Figure 5-27. Mean monthly streamflow (cfs), Gunnison River Below Gunnison Tunnel, before (1911-65) and after (1966-95) Aspinall Unit.

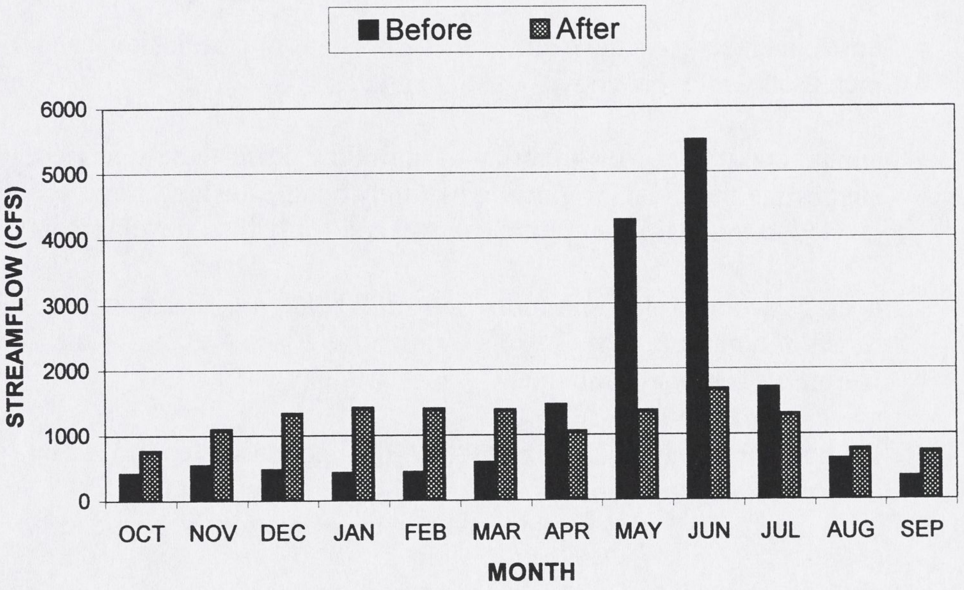
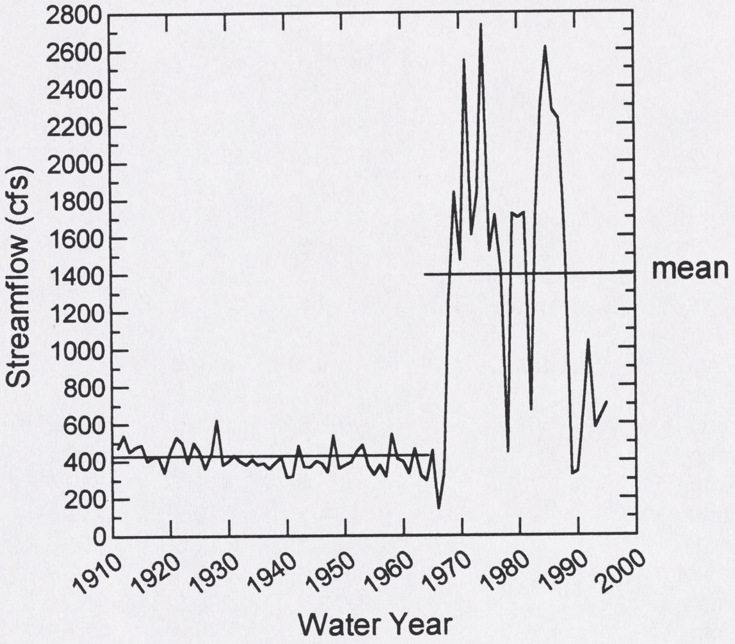


**Table 5-9. Results of IHA analysis for the Gunnison River below Gunnison Tunnel before (1911-65) and after (1966-95) Aspinall Unit.**

| | **Means** | | | **CVs** | | |
|---|---|---|---|---|---|---|
| **IHA Statistics Group** | **Before** | **After** | **% Change** | **Before** | **After** | **% Change** |
| **Group 1: Mean Monthly Magnitude (cfs)** | | | | | | |
| October | 402.6 | 757.6 | 88.2 | 1.00 | 0.58 | -42.0 |
| November | 531.7 | 1084.1 | 103.9 | 0.36 | 0.53 | 47.3 |
| December | 463.1 | 1329.1 | 187.0 | 0.21 | 0.50 | 142.7 |
| January | 413.9 | 1414.0 | 241.6 | 0.17 | 0.54 | 224.6 |
| February | 425.2 | 1394.3 | 227.9 | 0.16 | 0.61 | 275.3 |
| March | 575.9 | 1376.7 | 139.1 | 0.30 | 0.66 | 118.0 |
| April | 1455.7 | 1048.9 | -27.9 | 0.60 | 0.83 | 37.6 |
| May | 4267.0 | 1356.9 | -68.2 | 0.49 | 0.91 | 86.0 |
| June | 5487.5 | 1688.3 | -69.2 | 0.51 | 1.09 | 112.3 |
| July | 1703.6 | 1295.6 | -23.9 | 0.93 | 1.24 | 33.8 |
| August | 613.9 | 766.1 | 24.8 | 0.89 | 0.70 | -21.2 |
| September | 338.3 | 729.3 | 115.6 | 1.28 | 0.55 | -57.0 |
| **Average Percent Change** | | | **102.4** | | | **96.3** |
| **Mean Annual Flow** | 1372.8 | 1185.8 | | | | |
| **Group 2: Magnitude (cfs) and Duration of Annual Extremes** | | | | | | |
| 1-day minimum | 48.6 | 219.6 | 352.1 | 1.71 | 0.88 | -48.9 |
| 3-day minimum | 53.8 | 274.5 | 409.9 | 1.61 | 0.82 | -49.1 |
| 7-day minimum | 66.4 | 323.0 | 386.1 | 1.47 | 0.78 | -46.8 |
| 30-day minimum | 125.8 | 439.1 | 249.1 | 1.08 | 0.68 | -37.2 |
| 90-day minimum | 244.1 | 570.2 | 133.6 | 0.57 | 0.69 | 21.7 |
| 1-day maximum | 9134.3 | 3811.6 | -58.3 | 0.42 | 0.70 | 65.5 |
| 3-day maximum | 8801.3 | 3555.8 | -59.6 | 0.43 | 0.73 | 66.9 |
| 7-day maximum | 8233.4 | 3299.0 | -59.9 | 0.44 | 0.72 | 62.5 |
| 30-day maximum | 6385.9 | 2695.4 | -57.8 | 0.45 | 0.70 | 53.5 |
| 90-day maximum | 4091.3 | 2143.8 | -47.6 | 0.46 | 0.58 | 26.7 |
| Base flow (7-day min/annual mean) | 0.04 | 0.29 | 569.5 | 1.14 | 0.64 | -44.3 |
| **Average Percent Change** | | | **216.7** | | | **47.6** |
| **Group 3: Timing of Annual Extremes** | | | | | | |
| Date of annual 1-day minimum | 14-Sep | 18-Sep | | | | |
| Date of annual 1-day maximum | 3-Jun | 13-May | | | | |
| **Group 4: Frequency and Duration of High and Low Pulses** | | | | | | |
| High Pulse Level (cfs) | 3577.2 | | | | | |
| Low Pulse Level (cfs) | 350.0 | | | | | |
| Low pulse number (per yr) | 7.2 | 6.7 | -7.8 | 0.65 | 0.88 | 36.0 |
| High pulse number (per yr) | 2.7 | 1.0 | -1.7 | 0.55 | 2.00 | 261.4 |
| Low pulse duration (days) | 11.0 | 9.9 | -1.0 | 1.02 | 1.03 | 0.8 |
| High pulse duration (days) | 18.0 | 5.0 | -13.3 | 0.86 | 2.74 | 218.4 |
| **Group 5: Rate and Frequency of Flow Changes** | | | | | | |
| Fall rate (avg cfs/day) | -194.3 | -104.9 | -46.0 | -0.42 | -0.64 | 54.0 |
| Rise rate (avg cfs/day) | 247.2 | 103.1 | -58.3 | 0.47 | 0.64 | 36.3 |
| Number of flow reversals (per yr) | 84.6 | 137.9 | 63.1 | 0.31 | 0.18 | -40.7 |

Figure 5-28. Mean January streamflow (cfs) before (1911-65) and after (1966-95) Aspinall Unit, Gunnison River below Gunnison Tunnel.



Bureau of Reclamation 1997a). However, declines in streamflow have resulted in average 1- and 3-day minima below Gunnison Tunnel that are under 300 cfs, averaging 220 cfs and 275 cfs, respectively (Table 5-9, Group 2).

Annual maxima have also declined and are now significantly more variable from year to year (Figure 5-29; Table 5-9, Groups 1 and 2). In addition, the average duration of high flow pulses (defined as 1 standard deviation above the annual mean) fell from 18 to 5 days (Table 5-9, Group 4). These data suggest that flushing flows now rarely occur. Such flows are needed to scour the streambed, build gravel bars, and carry pool-forming woody debris into the stream.

Although the magnitude of day-to-day changes in flow conditions has declined, the number of day-to-day reversals in flow conditions increased by 63%, from 85 to 138 reversals per year, after construction of the Aspinall Unit (Figure 5-30; Table 5-9, Group 5). However, efforts to minimize large daily fluctuations to protect the fishery and to increase recreation potential in the Black Canyon are evident in data for the past decade (Figure 5-30).

### 3) <u>Trout Population Data</u>

Trout populations in the Gunnison River at a CDOW site in the Black Canyon showed sharp increases in the mid-1980s, followed by declines that, in the case of rainbow trout, have continued (Figure 5-31). Rainbow trout declines are thought to result from whirling disease (Nehring and Thompson 1997).

Other population changes may be related to flow conditions. For example, flow and population records suggest that trout recruitment may be higher in above-average water years as long as peak flows do not occur during critical early life stages (Figure 5-31). A peak in recruitment in 1986 was associated with consecutive years of high annual flows that probably increased habitat for both species. However, poor recruitment was observed during WY 1983 and 1984, when annual maxima occurred in June. In below-average water years, including 1981, 1982, 1989, and 1990, annual minima occurred in fall or early spring, and recruitment of both species declined (Figure 5-31). Low flows in fall can interfere with brown trout spawning, while low flow periods in spring can interfere with incubating brown trout eggs and with rainbow trout spawning and egg incubation.

## Taylor River

The Taylor Park Reservoir was built on the Taylor River in 1937 as a part of the Uncompahgre Project (Colorado Division of Water Resources 1996). Water stored in Taylor Park Reservoir was originally planned to supplement project canals

Figure 5-29. Average June flow (cfs) and 7-day maximum flow before and after major water development, Gunnison River below Gunnison Tunnel. Dotted lines indicate pre-impact range of variation (based on mean + or - 1 SD).

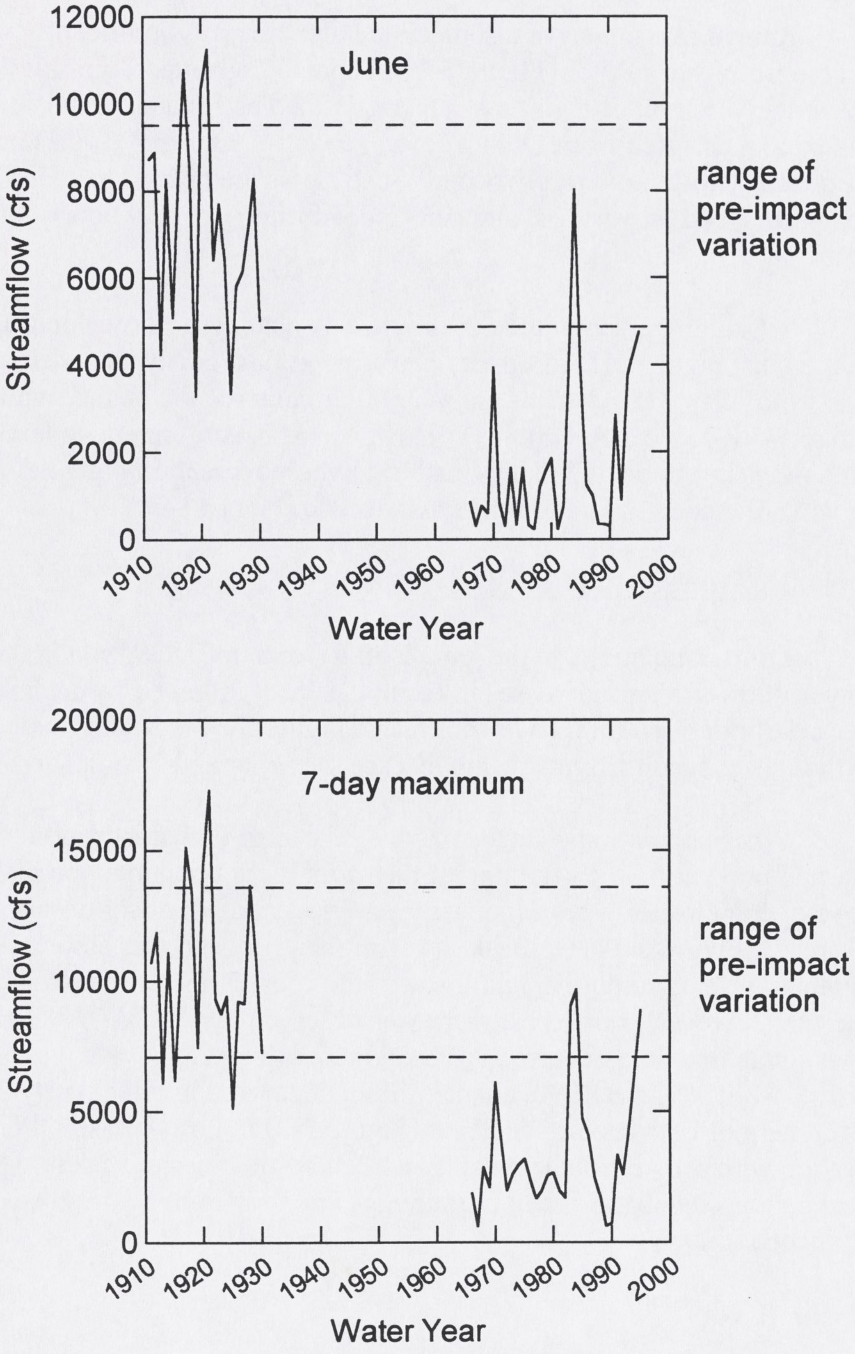


Figure 5-30. Trend in annual number of daily reversals in flows over the period of record, Gunnison River below Gunnison Tunnel.

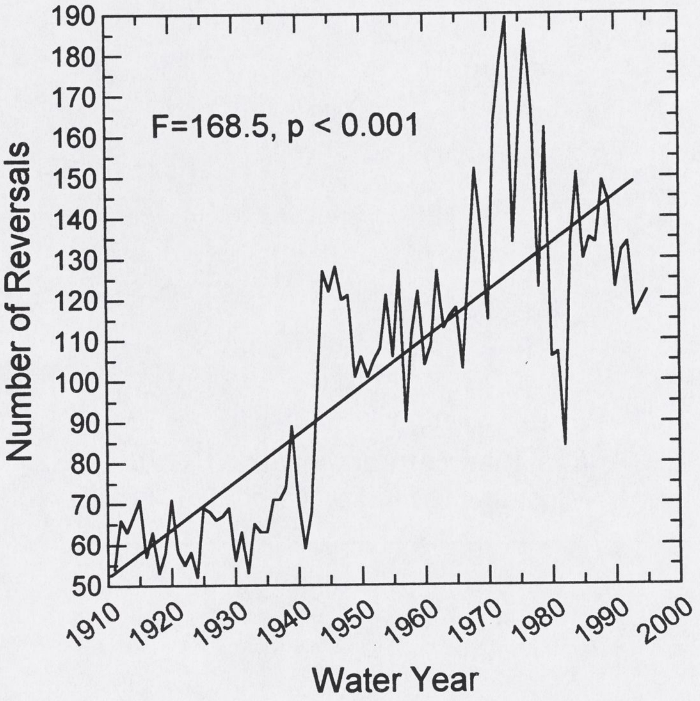
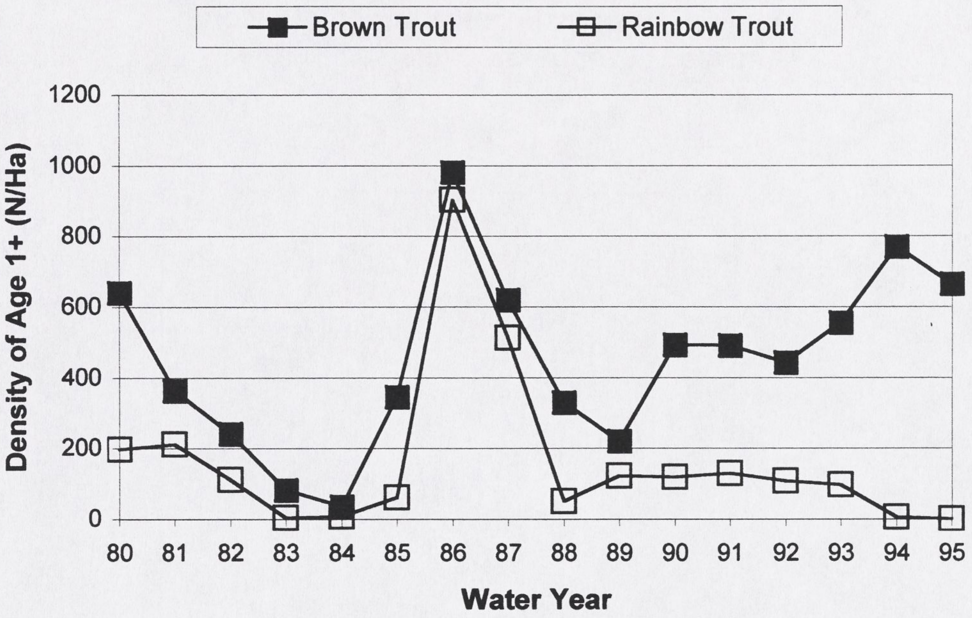
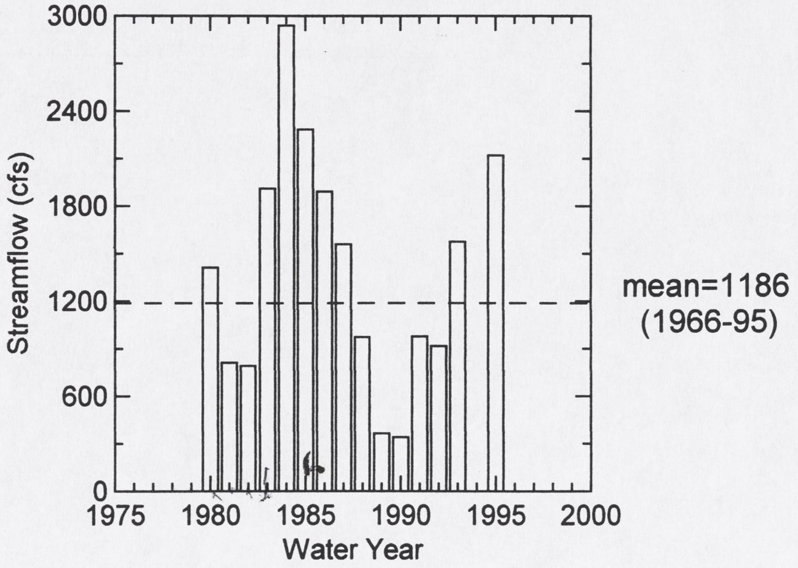


Figure 5-31. Recruitment of brown trout and rainbow trout (N/ha) and annual mean streamflow (cfs), Black Canyon of the Gunnison River.

Trout recruitment, Gunnison River, Black Canyon.
(Source: Nehring and Thompson 1997)



Annual mean streamflow (cfs), Gunnison River below Gunnison Tunnel, 1980-95.



and diversions from the Uncompahgre and Gunnison Rivers for late-season irrigation in the Uncompahgre Valley. However, since 1966 these deliveries have been made from Blue Mesa Reservoir.

A district water court judge recently ruled against Arapahoe County's claim to water rights at the headwaters of the Gunnison River for its proposed Union Park Project (*Denver Post* 4/8/98). The project was to be built two miles south of Taylor Park Dam on Lottis Creek and was designed to store water diverted during wet years from the headwaters of the Taylor and East rivers that flow into the Gunnison (*Denver Post* 12/8/97). A series of pipes and tunnels was designed to transport the water to the South Platte River to provide water for Arapahoe County users. The project was expected to yield about 70,000-100,000 acre feet of water annually, supplying 100,000 Arapahoe County families (*Denver Post* 12/8/97). Arapahoe County still may appeal the water court's decision.

## Flow Regime and Trout Populations below Taylor Reservoir

### 1) Overview of Findings

- operation of Taylor Park Reservoir can result in excessively high flows from October through mid-December due to releases to prepare for storage of spring runoff, followed by lower flows over winter as releases stop; the CDOW believes that such a discharge pattern is harmful to the fall-spawning brown trout

- improvements in reservoir operations have decreased flow variability in fall and winter substantially, but fall flows continue to be elevated

### 2) IHA Analysis of Flow Regime (USGS #09109000)

Taylor Park Reservoir is operated to provide water storage and delivery for water users in downstream valleys. When the reservoir was built in 1937 the descending limb of the natural hydrograph over summer was eliminated, and flows increased from April through August and peaked in September. After the Taylor Park Exchange agreement in 1966, flows from October through mid-December became excessively high due to releases to prepare for storage of spring runoff. Once adequate storage capacity was achieved releases stopped, producing a sudden drop in winter flows.

Beginning in WY 1976-77, fall releases were reduced, winter flows were increased, and fall and winter flows were made less variable because of concerns that the artificial discharge pattern was harming the brown trout fishery (Burkhard 1977; Nehring and Anderson 1993). Despite the changes, fall flows continue to be elevated compared to natural conditions, and the natural recession in flows over summer is still absent (Figure 5-32; Table 5-10, Group 1). However, flow variability in fall and winter has decreased substantially (Figure 5-33).

### 3) **Trout Population Data**

Opposum shrimp (*Mysis relicta*) were stocked in Taylor Park Reservoir in the 1970's and provided an excellent and abundant food supply to trout below the dam. There is an excellent tailwater fishery below the reservoir to the town of Almont.

During the 1970's and 1980's, the CDOW regularly sampled Taylor River trout populations at a site just below the reservoir to examine the influence of reservoir operations on trout recruitment (Nehring and Anderson 1993; Nehring and Thompson 1997). Brown trout spawn in the Taylor River from mid- to late October and emerge from mid-May into June (Nehring and Anderson 1993). CDOW biologists evaluated the effect of changes to reservoir operations beginning in WY 1976-77 by comparing brown trout recruitment before and after the changes (Nehring and Anderson 1993). Although improvement was seen over the period 1978-1981, brown trout recruitment below the reservoir declined again in 1986 (Figure 5-34).

The CDOW has not surveyed the adult brown trout population on a regular basis since the mid-1980's (Nehring and Thompson 1997). However, collections of YOY trout fry have continued, and wild rainbow fry have been observed since the early 1990s (Nehring 1988; Nehring and Shuler 1992; Nehring 1993). It is thought that these fry result from wild rainbow on the Gunnison River that move up the Taylor River and its tributaries to spawn (Nehring and Thompson 1997). Because there haven't been any electrofishing surveys since the mid-1980s, it is not known if these young rainbow are recruiting to the Taylor River trout population.

The decline in brown trout recruitment in 1986 may have resulted in part from the way Taylor Park Reservoir operations are adjusted according to yearly precipitation levels. Over the period 1984 through 1986, annual mean flows were significantly above average (Figure 5-34). In wet years, flow releases in fall are higher, and higher flows at this time may interfere with brown trout spawning (Nehring and Anderson 1993). Moreover, higher flows in June during high runoff years can increase mortality of emerging fry (Nehring and Anderson 1993). The additional effect of reduced spawning success as a result of high flow releases in fall may result in especially poor recruitment in wet years. This suggests that reservoir operations may need to be adjusted further during years of high runoff.

Figure 5-32. Mean monthly streamflow (cfs) before (1966-75) and after (1976-95) changes to reservoir operations to enhance the trout fishery, Taylor River below Taylor Park Reservoir.

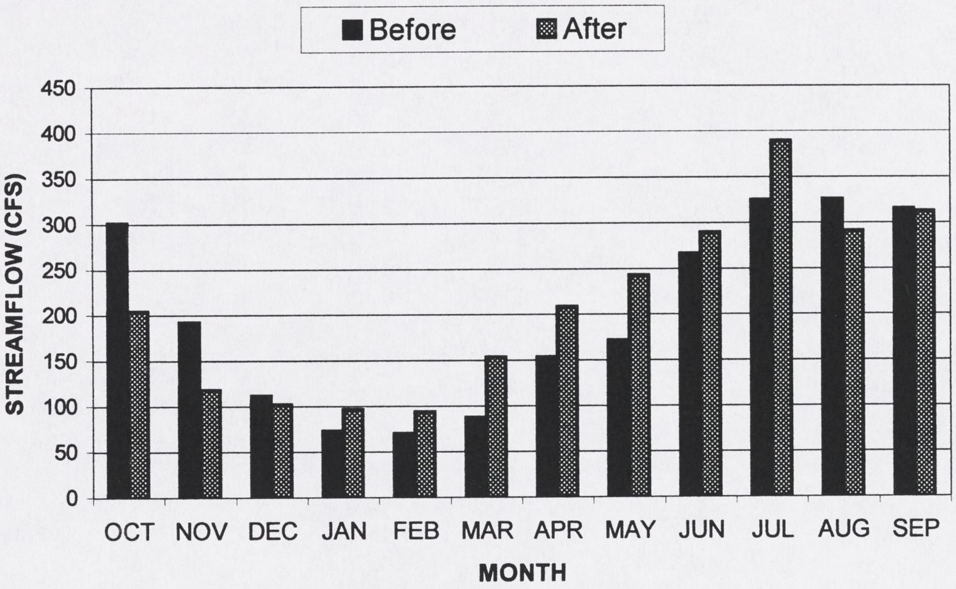


**Table 5-10. Results of IHA analysis for the Taylor River below Taylor Reservoir before (1966-75) and after (1976-95) changes in release patterns for fishery enhancement.**

| | | Means | | | CVs | |
|---|---|---|---|---|---|---|
| IHA Statistics Group | Before | After | % Change | Before | After | % Change |
| **Group 1: Mean Monthly Magnitude (cfs)** | | | | | | |
| October | 301.4 | 204.6 | -32.1 | 0.48 | 0.49 | 1.5 |
| November | 192.9 | 118.3 | -38.6 | 0.67 | 0.40 | -40.5 |
| December | 112.1 | 101.9 | -9.1 | 0.89 | 0.21 | -76.8 |
| January | 73.3 | 97.0 | 32.4 | 0.65 | 0.18 | -72.5 |
| February | 70.5 | 93.7 | 32.9 | 0.67 | 0.21 | -68.4 |
| March | 87.7 | 153.5 | 75.0 | 0.69 | 0.55 | -20.5 |
| April | 153.7 | 208.6 | 35.7 | 1.33 | 0.52 | -61.0 |
| May | 172.1 | 242.5 | 40.9 | 0.74 | 0.46 | -37.2 |
| June | 266.1 | 289.4 | 8.8 | 0.59 | 0.48 | -19.2 |
| July | 324.7 | 389.4 | 19.9 | 0.29 | 0.64 | 116.4 |
| August | 325.3 | 291.0 | -10.6 | 0.35 | 0.30 | -14.6 |
| September | 314.8 | 312.2 | -0.8 | 0.45 | 0.34 | -24.1 |
| **Average Percent Change** | | | **25.4** | | | **45.9** |
| **Mean Annual Flow** | 200.7 | 209.1 | | | | |
| **Group 2: Magnitude (cfs) and Duration of Annual Extremes** | | | | | | |
| 1-day minimum | 39.1 | 64.0 | 63.6 | 0.57 | 0.36 | -35.9 |
| 3-day minimum | 40.1 | 67.6 | 68.8 | 0.55 | 0.33 | -40.2 |
| 7-day minimum | 47.6 | 71.2 | 49.5 | 0.38 | 0.28 | -26.3 |
| 30-day minimum | 51.7 | 78.4 | 51.7 | 0.32 | 0.23 | -26.8 |
| 90-day minimum | 60.1 | 89.4 | 48.6 | 0.43 | 0.19 | -56.3 |
| 1-day maximum | 610.7 | 615.0 | 0.7 | 0.29 | 0.70 | 141.1 |
| 3-day maximum | 603.7 | 602.7 | -0.2 | 0.29 | 0.68 | 136.1 |
| 7-day maximum | 586.5 | 576.5 | -1.7 | 0.27 | 0.65 | 137.9 |
| 30-day maximum | 507.7 | 467.7 | -7.9 | 0.21 | 0.56 | 165.9 |
| 90-day maximum | 384.5 | 358.6 | -6.7 | 0.23 | 0.41 | 81.6 |
| Base flow (7-day min/annual mean) | 0.25 | 0.37 | 49.5 | 0.40 | 0.40 | 0.2 |
| **Average Percent Change** | | | **31.7** | | | **77.1** |
| **Group 3: Timing of Annual Extremes** | | | | | | |
| Date of annual 1-day minimum | widely distributed throughout year | | | | | |
| Date of annual 1-day maximum | widely distributed throughout year | | | | | |
| **Group 4: Frequency and Duration of High and Low Pulses** | | | | | | |
| High Pulse Level (cfs) | 371.4 | | | | | |
| Low Pulse Level (cfs) | 29.0 | | | | | |
| Low pulse number (per yr) | 0.4 | 0.1 | -75.0 | 1.75 | 4.47 | 155.8 |
| High pulse number (per yr) | 2.9 | 2.1 | -27.6 | 0.68 | 1.10 | 62.3 |
| Low pulse duration (days) | 12.1 | 0.1 | -99.6 | 3.12 | 4.47 | 43.4 |
| High pulse duration (days) | 21.7 | 15.3 | -29.3 | 0.74 | 1.19 | 61.7 |
| **Group 5: Rate and Frequency of Flow Changes** | | | | | | |
| Fall rate (avg cfs/day) | -21.9 | -12.1 | -44.8 | -0.41 | -0.59 | 42.2 |
| Rise rate (avg cfs/day) | 21.1 | 12.3 | -41.7 | 0.48 | 0.63 | 31.0 |
| Number of flow reversals (per yr) | 40.5 | 60.0 | 48.1 | 0.16 | 0.24 | 48.2 |

Figure 5-33. Mean monthly streamflow (dots) and variation about the mean (+ or - 1 SD), Taylor Park River below Taylor Park Reservoir, before (1966-75) and after (1976-95) changes in reservoir operations for fishery enhancement.

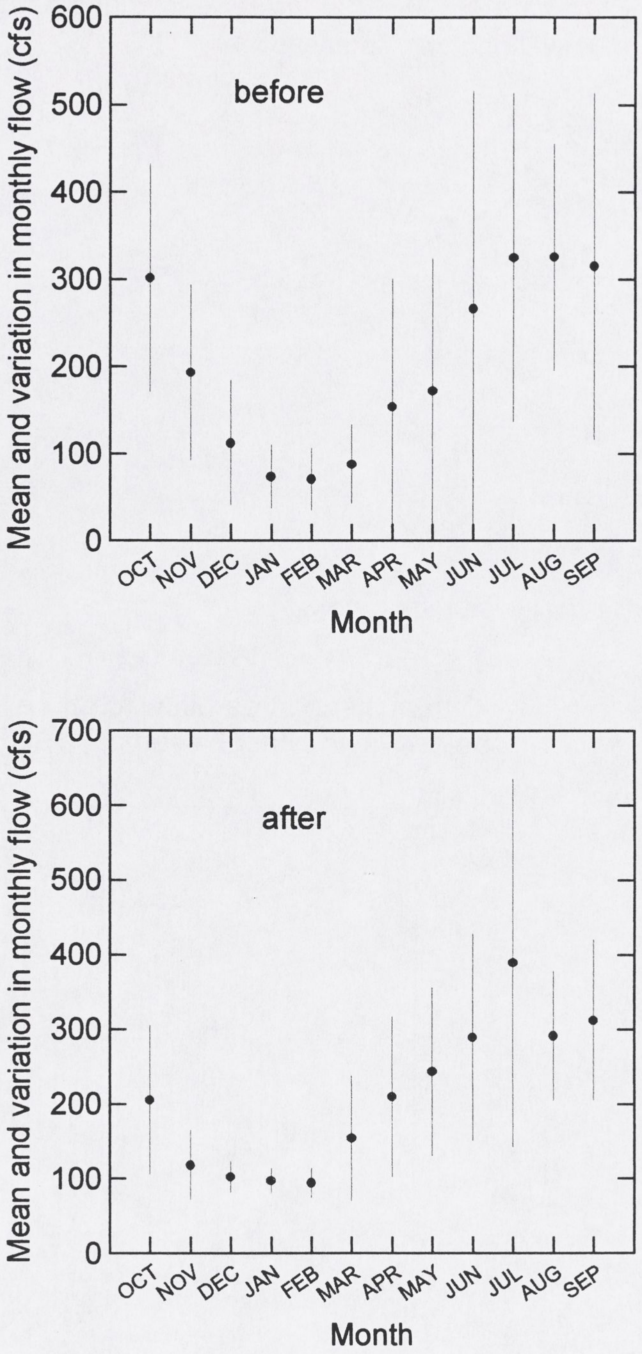
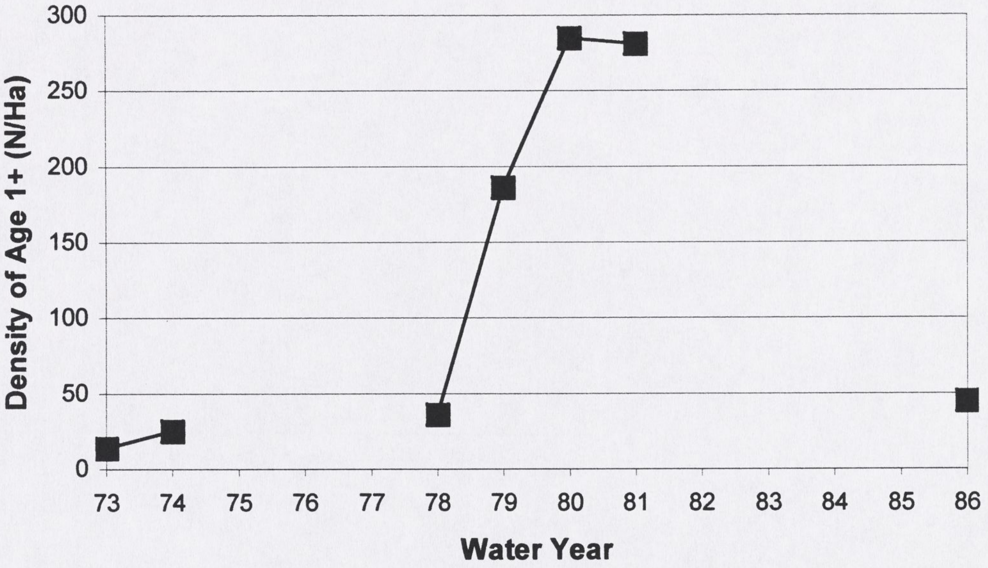
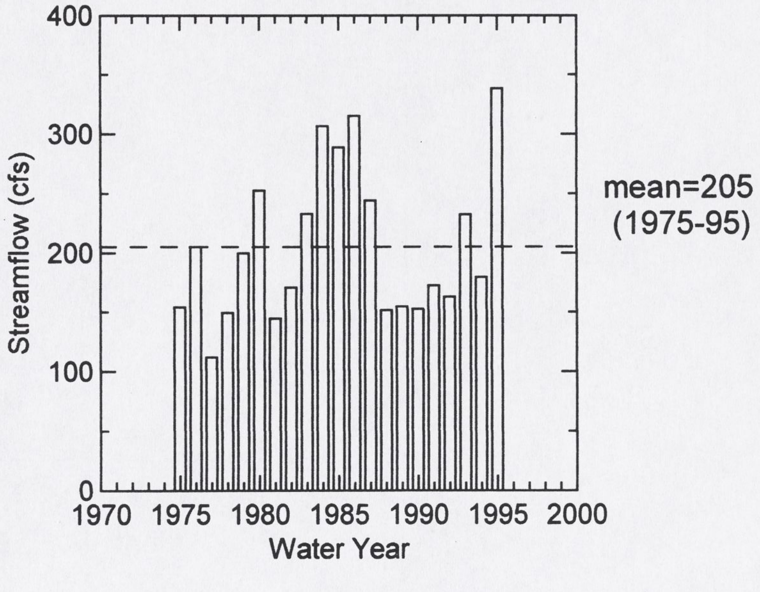


Figure 5-34. Brown trout recruitment (N/ha) and annual mean streamflow (cfs), Taylor River below Taylor Park Reservoir.

Density of age 1+ brown trout (N/ha), Taylor River below Taylor Park Reservoir. No data for WY 1975-77 and WY 1982-85. (Sources: Nehring and Anderson 1993; Nehring and Thompson 1996)



Annual mean streamflow (cfs), Taylor River below Taylor Park Reservoir, 1975-95.



## Division 5: Colorado River (excluding the Gunnison River Basin)

Division 5 includes the Colorado River in northwestern Colorado and its major tributaries, the Blue, Eagle, Fraser, and Roaring Fork rivers. Water in the Colorado River Basin is divided between upper basin states (Colorado, Wyoming, Utah, and New Mexico) and lower basin states (California, Arizona, and Nevada) according to the 1922 Colorado River Compact (Colorado Division of Water Resources 1996). The Upper Colorado River Basin Compact (1948) specifies how the upper basin states divide up their water allotment from the 1922 compact, with Colorado getting 51.75 percent.

### Upper Colorado River

The main stem of the Colorado River originates in the north-central mountains of Colorado and flows southwesterly, joining the Gunnison River at Grand Junction and continuing west into Utah. About 225 miles of the Colorado River are within Colorado.

An average of 230,000 A-ft of water are collected annually from the upper Colorado River Basin and transported to the East Slope via a 13-mile tunnel through the mountains as part of the Colorado-Big Thompson (C-BT) Project, built from 1938-1957 (*Northern Colorado Water Conservancy District*). The West Slope Collection System includes 5 reservoirs and two pump plants. Snowmelt runoff is stored in Lake Granby, or is collected and pumped from Willow Creek Reservoir into Lake Granby. From there the water is pumped into Shadow Mountain Reservoir, flows into Grand Lake, and then is transported to the East Slope through the Alva B. Adams Tunnel. The water is used to generate electricity as it passes through four power plants on its way to East Slope storage reservoirs including Horsetooth Reservoir, Carter Lake, and Boulder Reservoir. The water is then delivered to some 120 ditches and 60 reservoirs for agricultural, municipal, and industrial uses. The Windy Gap Project, below Granby, was added to the system in 1986.

#### Flow Regime and Trout Populations at Hot Sulphur Springs

#### 1) Overview of Findings

- upstream reservoirs have dramatically reduced the quantity of streamflow; annual mean flow has declined from an average of 709 cfs to 244 cfs

- storage of spring runoff has led a reduction in the magnitude of peak flows in May and June by an average of 70%

- flushing flows needed for habitat formation and to maintain the stream channel have declined substantially in magnitude, frequency, and duration; loss of flushing flows greatly reduces the quality and quantity of trout habitat

- annual 1-, 3-, and 7-day minimum flows have declined by an average of almost 75% and now occur in August instead of January

- fall flows have also declined significantly, reducing habitat availability for the fall-spawning brown trout

### 2) **IHA Analysis of Flow Regime** (USGS # 09034500)

Since completion of the C-BT Project in 1957, mean annual flow has declined dramatically at Hot Sulphur Springs, from 709 cfs to 244 cfs (Figure 5-35, Table 5-11, Group 1). Flow reductions are due to upstream storage operations at Granby Reservoir and Windy Gap. Storage of spring runoff has led to a loss of peak flows, with the magnitude of flows in May and June reduced by an average of 70% (Figure 5-35, Table 5-11, Group 1).

Studies by CDOW biologists indicate that flow depletions have reduced spawning habitat of both brown and rainbow trout (Nehring and Anderson 1993). However, spawning habitat of rainbow trout appears to be relatively less affected. IHA results indicate that although flows during rainbow trout spawning in April generally fall below the pre-development mean, higher flows do sometimes occur (Figure 36, bottom). In contrast, flows during the time of brown trout spawning in fall have declined substantially and no longer reach historic levels (Figure 5-36, top). Flow-dependent habitat in June is important for both species (Nehring and Anderson 1993), and IHA results show that June flows have declined in both magnitude and range of variation (Figure 5-37).

The annual 1-, 3-, and 7-day maximum flows have declined by an average of 74% (Table 5-11, Group 2). The number and duration of high flow pulses has also declined (Table 5-11, Group 4). The annual 7-day maximum now averages less than 1200 cfs compared to 4625 cfs before the C-BT Project (Figure 5-38). High flows are needed to scour and reconfigure the streambed and to connect instream and floodplain habitats (Stanford et al. 1996). In the absence of flushing flows, fine sediments accumulate and the stream channel narrows (Graf et al. 1997). If sand completely fills the spaces between gravel, trout fry cannot emerge from the streambed and they die.

**Figure 5-35. Mean monthly streamflow (cfs) before (1905-37) and after (1958-95) construction of the C-BT Project, Colorado River at Hot Sulphur Springs.**

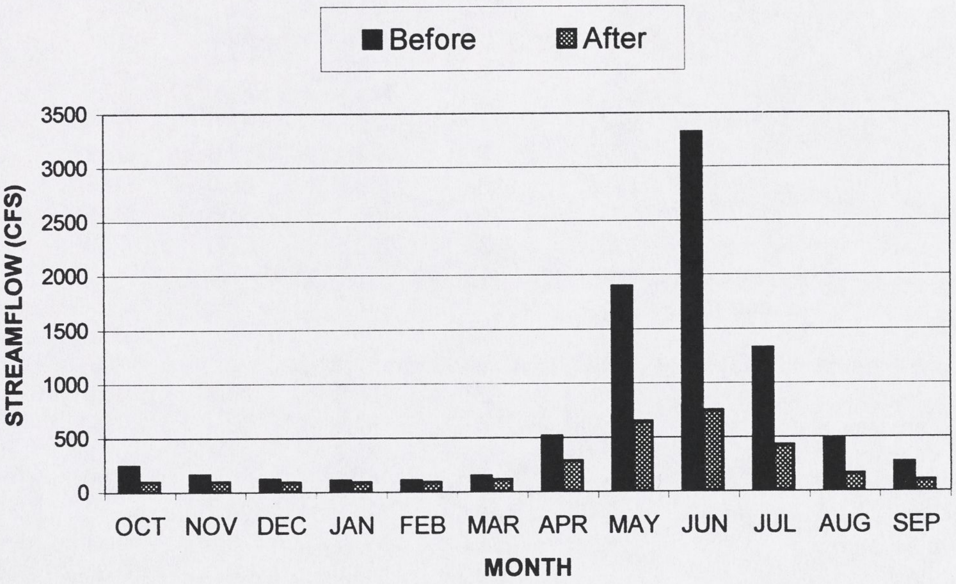


**Table 5-11. Results of IHA analysis for the Colorado River at Hot Sulphur Springs before (1905-1937) and after (1958-95) construction of the CB-T Project.**

| | Means | | | CVs | | |
|---|---|---|---|---|---|---|
| IHA Statistics Group | Before | After | % Change | Before | After | % Change |
| **Group 1: Mean Monthly Magnitude (cfs)** | | | | | | |
| October | 239.9 | 96.3 | -59.8 | 0.30 | 0.41 | 38.8 |
| November | 157.0 | 94.7 | -39.7 | 0.21 | 0.32 | 55.0 |
| December | 117.5 | 87.1 | -25.9 | 0.29 | 0.65 | 124.3 |
| January | 105.6 | 85.8 | -18.7 | 0.20 | 0.91 | 361.1 |
| February | 103.8 | 87.4 | -15.8 | 0.17 | 0.89 | 435.7 |
| March | 146.0 | 114.1 | -21.8 | 0.40 | 0.74 | 83.4 |
| April | 513.1 | 281.6 | -45.1 | 0.41 | 0.78 | 87.4 |
| May | 1894.3 | 643.5 | -66.0 | 0.35 | 0.75 | 114.3 |
| June | 3319.2 | 744.2 | -77.6 | 0.37 | 0.78 | 113.6 |
| July | 1322.6 | 423.4 | -68.0 | 0.49 | 0.89 | 82.5 |
| August | 475.9 | 160.3 | -66.3 | 0.36 | 0.55 | 53.5 |
| September | 263.8 | 100.5 | -61.9 | 0.30 | 0.79 | 164.7 |
| **Average Percent Change** | | | **42.2** | | | **139.6** |
| **Mean Annual Flow** | 708.5 | 243.7 | | | | |
| **Group 2: Magnitude (cfs) and Duration of Annual Extremes** | | | | | | |
| 1-day minimum | 92.6 | 55.9 | -39.7 | 0.26 | 0.18 | -31.6 |
| 3-day minimum | 94.6 | 57.6 | -39.1 | 0.23 | 0.17 | -26.7 |
| 7-day minimum | 95.8 | 59.7 | -37.7 | 0.22 | 0.17 | -21.5 |
| 30-day minimum | 98.0 | 65.9 | -32.7 | 0.20 | 0.17 | -13.1 |
| 90-day minimum | 105.5 | 74.8 | -29.1 | 0.18 | 0.35 | 88.7 |
| 1-day maximum | 5222.6 | 1367.7 | -73.8 | 0.37 | 0.81 | 118.1 |
| 3-day maximum | 4969.1 | 1293.0 | -74.0 | 0.36 | 0.80 | 119.0 |
| 7-day maximum | 4624.7 | 1181.0 | -74.5 | 0.35 | 0.78 | 124.4 |
| 30-day maximum | 3619.7 | 896.8 | -75.2 | 0.33 | 0.79 | 135.5 |
| 90-day maximum | 2230.6 | 629.1 | -71.8 | 0.30 | 0.72 | 140.7 |
| Base flow (7-day min/annual mean) | 0.14 | 0.29 | 111.9 | 0.27 | 0.37 | 34.9 |
| **Average Percent Change** | | | **60.0** | | | **77.7** |
| **Group 3: Timing of Annual Extremes** | | | | | | |
| Date of annual 1-day minimum | 14-Jan | 22-Aug | | | | |
| Date of annual 1-day maximum | 6-Jun | 7-Jun | | | | |
| **Group 4: Frequency and Duration of High and Low Pulses** | | | | | | |
| High Pulse Level (cfs) | 1859.9 | | | | | |
| Low Pulse Level (cfs) | 125.0 | | | | | |
| Low pulse number (per yr) | 2.4 | 5.8 | 145.5 | 0.75 | 0.43 | -42.1 |
| High pulse number (per yr) | 2.9 | 0.6 | -80.9 | 0.46 | 2.17 | 377.5 |
| Low pulse duration (days) | 52.7 | 20.3 | -61.6 | 0.78 | 0.70 | -11.2 |
| High pulse duration (days) | 21.0 | 1.7 | -91.9 | 0.82 | 2.35 | 187.7 |
| **Group 5: Rate and Frequency of Flow Changes** | | | | | | |
| Fall rate (avg cfs/day) | -98.4 | -25.6 | -74.0 | -0.39 | -0.73 | 88.6 |
| Rise rate (avg cfs/day) | 138.6 | 29.0 | -79.1 | 0.46 | 0.67 | 46.0 |
| Number of flow reversals (per yr) | 76.5 | 107.6 | 40.6 | 0.35 | 0.23 | -35.7 |

Figure 5-36. Annual October and April streamflow (cfs) before and after major water development, Colorado River at Hot Sulphur Springs. Dotted lines indicate historic range of variation (based on mean + or - 1 SD).

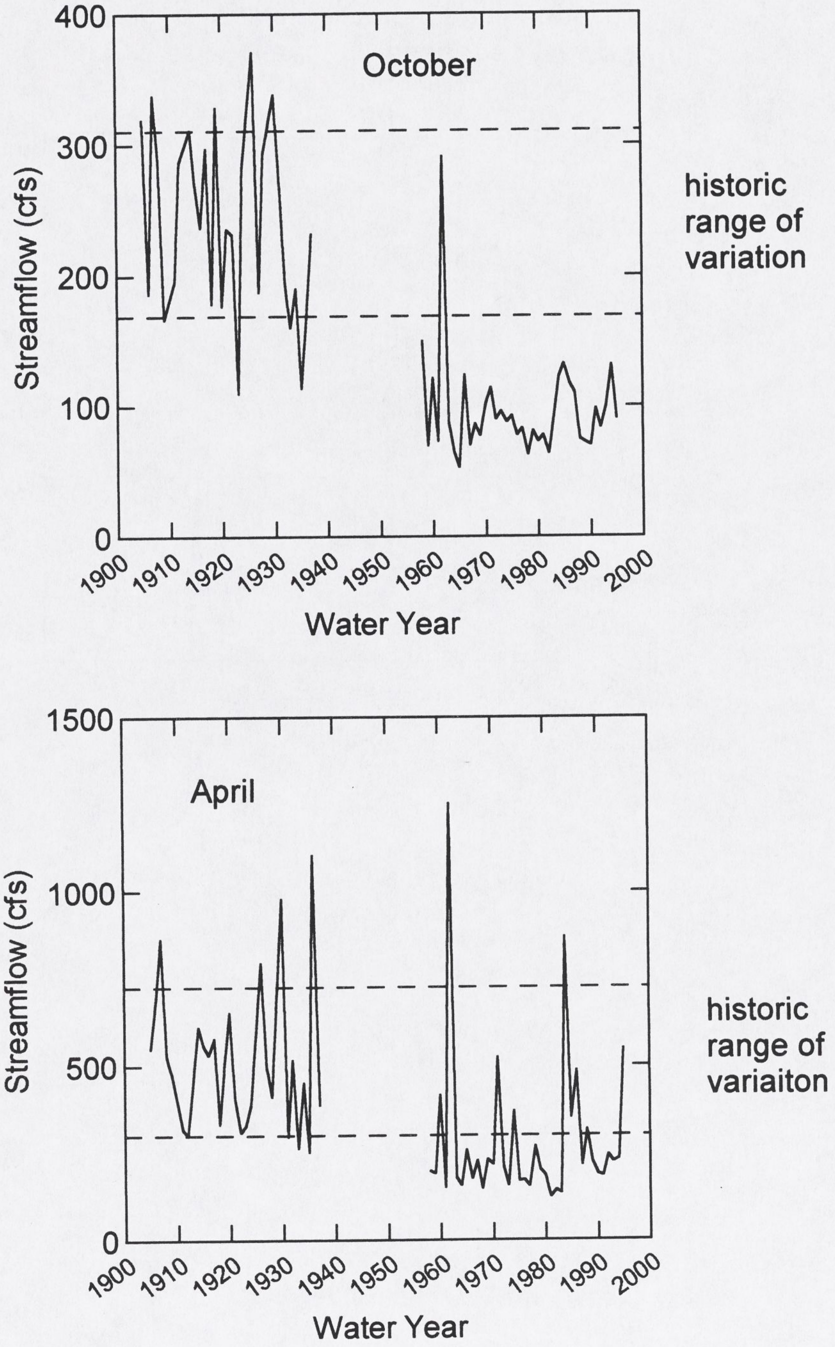


Figure 5-37. Annual June streamflow (cfs) before and after major water development, Colorado River at Hot Sulphur Springs. Dotted lines indicate historic range of variation (based on mean + or - 1 SD).

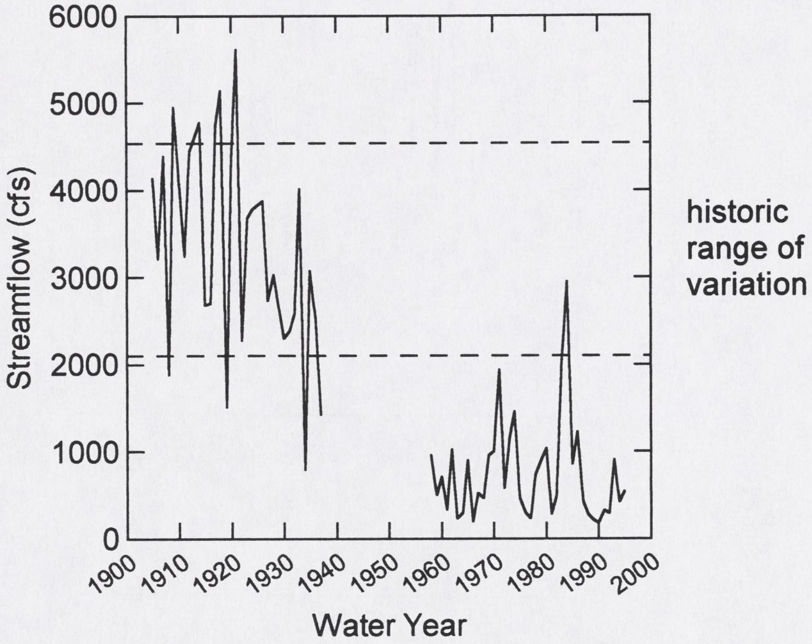
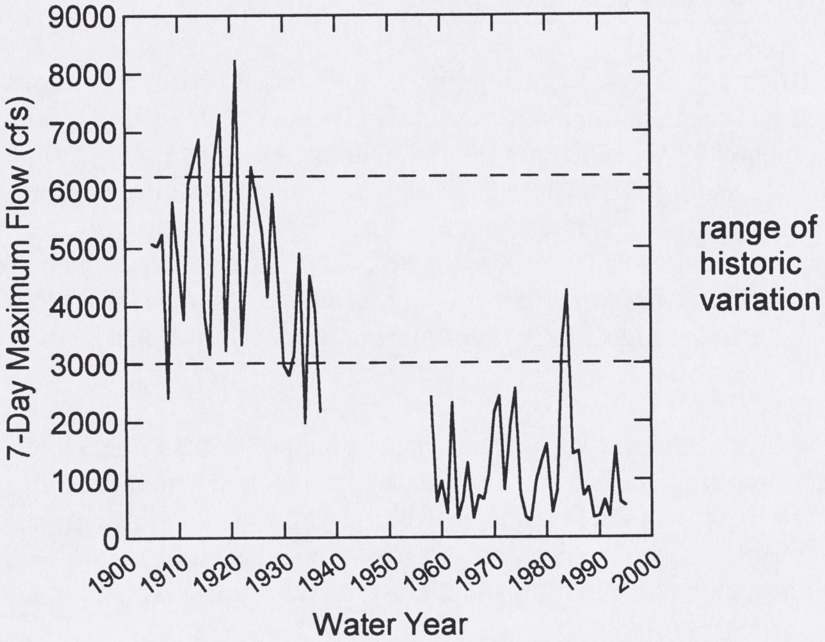


Figure 5-38. Annual 7-day maximum flow (cfs) before and after major water development, Colorado River at Hot Sulphur Springs. Dotted lines indicate historic range of variation (based on mean + or - 1 SD).



Annual minima are also lower since completion of the C-BT Project. Average 1-, 3-, and 7-day minimum flows are nearly half of what they were before the project, and now average less than 60 cfs (Table 5-11, Group 2). As with peak flows, the annual 7-day minimum flow no longer shows the range of variation from year-to-year that characterized the flow regime before the C-BT Project (Figure 5-39). While stable flow conditions can promote survival of early life stages of trout, lack of variation in flow conditions simplifies and reduces habitat.

### 3) Trout Population Data

Effects of flow regime alterations on Colorado River trout populations are indicated by results of annual trout surveys by the CDOW (Figure 40; Nehring and Thompson 1997). Changes in annual densities of trout populations at the Paul Gilbert Wildlife Area near Hot Sulphur Springs have been associated with availability of flow-dependent habitat at times of critical life cycle events (Nehring and Anderson 1993). In general, flow reductions in fall and winter due to upstream reservoir storage are thought to reduce spawning and incubation habitat for brown trout, limiting brown trout production (Nehring and Anderson 1993).

Whirling disease has now reached epidemic levels in the Colorado River, and recent recruitment failures of rainbow trout are attributed to whirling disease (Figure 40; Nehring and Thompson 1997). Symptoms of whirling disease among fry, fingerling, and juvenile brown trout have also been observed in upper reaches of the Colorado between Granby and Hot Sulphur Springs (Nehring and Thompson 1997).

## Blue River

Dillon Reservoir was constructed on the Blue River in the early 1960's as a part of Denver Water's Roberts Tunnel Collection System (Denver Water Board 1997). The system is the last of Denver Water's West Slope supplies to be used. It is generally only used when there is inadequate supply available from storage reservoirs in the South Platte Basin. As a result, relatively little water is diverted through the Roberts Tunnel in wet years, while significant quantities are diverted in dry years (Colorado Department of Water Resources 1997).

Dillon Reservoir typically fills by the end of June, and once the reservoir is filled, Denver Water begins to deliver storage water through Roberts Tunnel. Terms of a Federal right-of-way provide for a minimum release to the Blue River of 50 cfs or the natural inflow to Dillon Reservoir, whichever is less (U.S. Forest Service 1997). To date, the minimum release has averaged 180 cfs (*Denver Post*

Figure 5-39. Annual 7-day minimum flow (cfs) before and after major water development, Colorado River at Hot Sulphur Springs. Dotted lines indicate historic range of variation (based on mean + or - 1 SD).

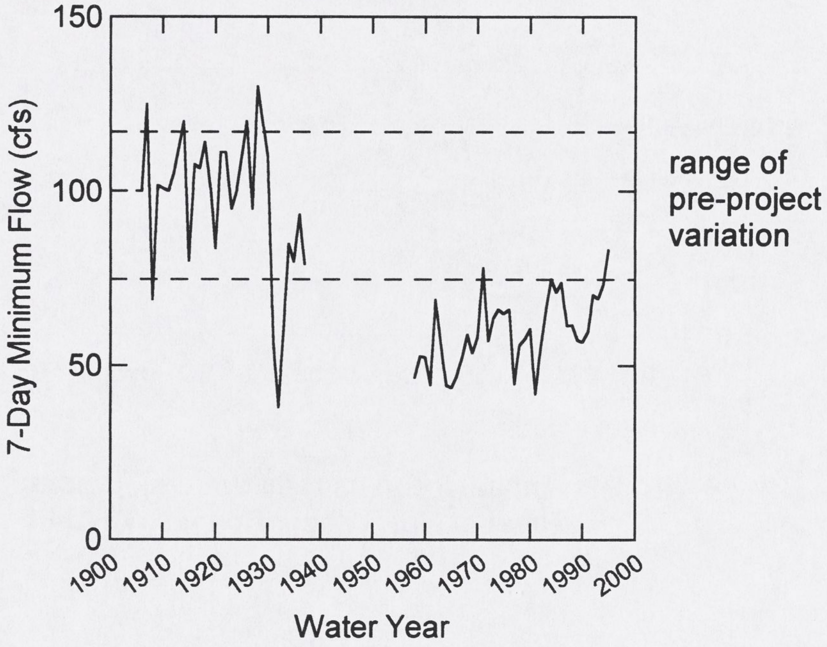
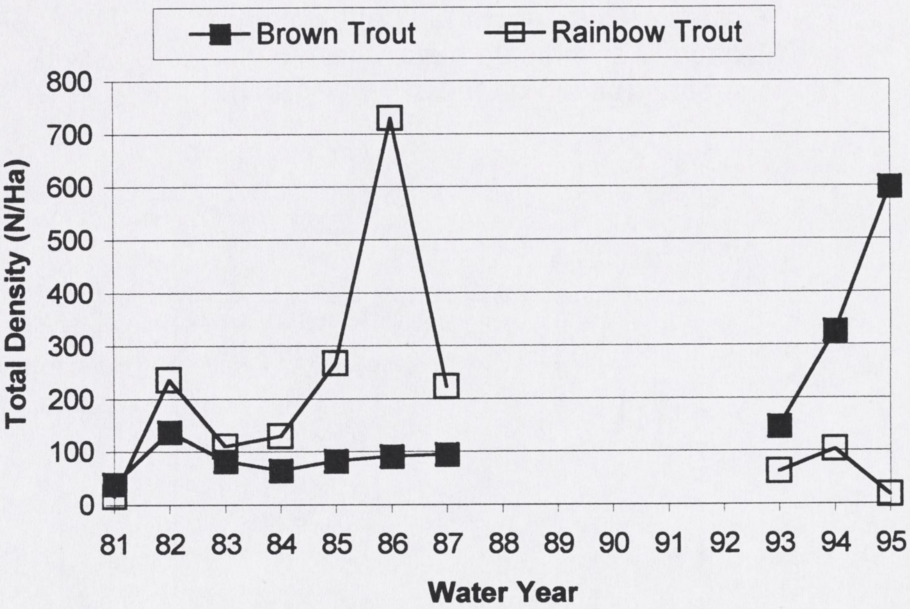
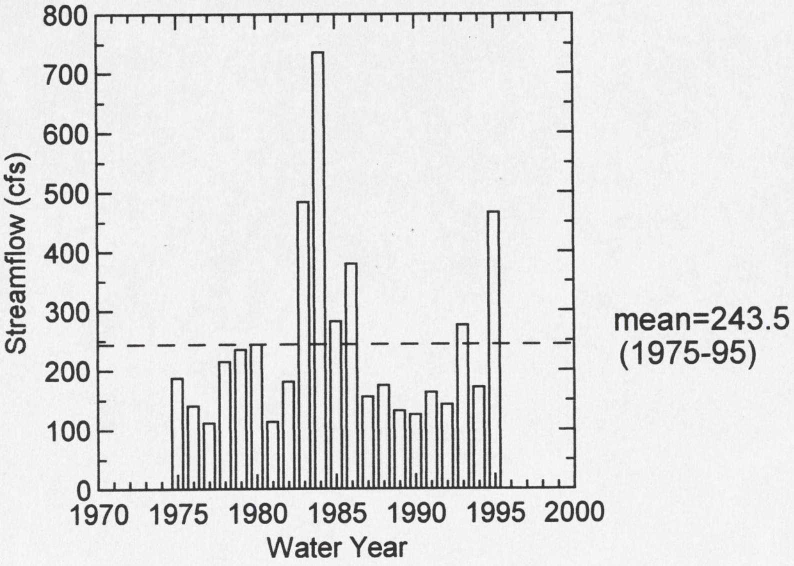


Figure 5-40. Trout density (N/ha) and annual mean streamflow (cfs), Colorado River near Hot Sulphur Springs.


Total trout density (N/ha), CDOW site at Paul Gilbert Wildlife Area, Colorado River near Hot Sulphur Springs. No data for WY 1988-92. (Source: Nehring and Thompson 1997)


Annual mean streamflow (cfs), Colorado River at Hot Sulphur Springs, 1975-95.

1/4/98). This combined with downstream tributary inflows has been sufficient to satisfy senior water rights of downstream irrigators (U.S. Forest Service 1997).

The Denver Water Department is currently working on a plan to develop 30,000 acre-feet of junior water rights on the Blue River (*Denver Post* 12/14/97). The water would be available only in "normal" or "wet" years. Under the plan, 30,000 acre-feet would be diverted to Dillon Reservoir and then through the Roberts Tunnel to Denver's Strontia Springs Reservoir. From there, it would be sent to a reservoir south of Highlands Ranch to supply water to about 30,000 families in Douglas and Arapahoe counties to reduce pumping from aquifers such as the Dawson Aquifer that are now being depleted (*Denver Post* 12/7/97). The Summit County Board of Commissioners is opposed to the proposal (*Denver Post* 1/4/98). Commissioners argue that the project would result in the Denver Water Board reducing releases below Dillon Dam from the current 180 cfs to only 50 cfs year round. The Board believes that this would significantly impact recreational activities, including trout fishing, which the Commissioners argue is optimal between 200 and 700 cfs.

## Flow Regime and Trout Populations below Dillon Dam

### 1) Overview of Findings

- the quantity of streamflow is regulated within a relatively narrow range as a result of reservoir operations; lack of natural flow variation reduces habitat complexity

- in some years, base flow is reduced to less than 10% of the annual mean flow

- at other times, large daily fluctuations can lead to cycles of inundation and dewatering that are harmful for young trout and benthic insects that provide food for adult trout

- the timing of annual minimum and maximum flows is highly irregular and base flow conditions vary widely; this can interfere with the natural timing of environmental cues important for the timing of critical life cycle events

### 2) IHA Analysis of Flow Regime (USGS # 09050700)

Flow records for the Blue River below Dillon Dam do not predate the construction of the reservoir and dam in the early 1960's, making it difficult to evaluate the project's impacts on the natural flow regime. Results of IHA analysis indicate that the annual hydrograph is like that of natural snowmelt streams, with peak flows in May and June, declining flows over summer, and low flows in winter (Figure 5-41). However, results also indicate that the quantity of flow is highly regulated within a relatively narrow range. Mean annual flow averages 211 cfs, and mean monthly flows range from a low of 72 cfs in January to a high of only 718 cfs in June (Table 5-12, Group 1). The 1-, 3-, and 7-day annual minima average 37 cfs, while the 1-, 3-, and 7-day annual maxima average about 1100 cfs (Table 5-12, Group 2).

Despite such regulation, the timing of extreme flow conditions can be highly variable. Dates of the annual 1-day minimum and maximum flows are widely distributed throughout the year (Table 5-12, Group 3). As a result, habitat conditions within the year can be very unpredictable, which can interfere with the timing of life cycle events of trout.

The baseflow index for the period of record indicates that the 7-day minimum has ranged from under 10% of the annual mean flow to over 50% (Figure 5-42). Years of low baseflow are likely to provide poor conditions over the winter months for brown trout egg incubation.

Finally, IHA results indicate that rates of daily flow fluctuations can be high during above-average water years, such as occurred in the early 1980's (Figure 5-43). Large fluctuations in daily flow conditions can produce cycles of dewatering and inundation of shallow, near-shore habitat needed by young trout and benthic insects that provide food for adult trout (Stanford et al. 1996).

### 3) Trout Population Data

Beginning in WY 1983-84, the CDOW has sampled brown trout populations at several sites on the Blue River below Dillon Dam (Nehring 1992; Nehring and Anderson 1993; Nehring and Thompson 1994). In 1983 special fishing regulations went into effect, which was followed by steady increases in brown trout numbers (Figure 5-44). Improvement in the brown trout population has also been associated with significant increases in baseflows and lower day-to-day changes in flow conditions from the mid-1980s on (Figures 5-41 and 5-42).

Rainbow trout have failed to establish in the Blue River below Dillon Reservoir, despite many efforts by the CDOW. Fingerling rainbow trout were stocked in the Blue River from 1987 through 1990 but failed to show evidence of

**Figure 5-41. Mean monthly streamflow (cfs), averaged over the period of record (1960-1995), Blue River below Dillon Dam.**

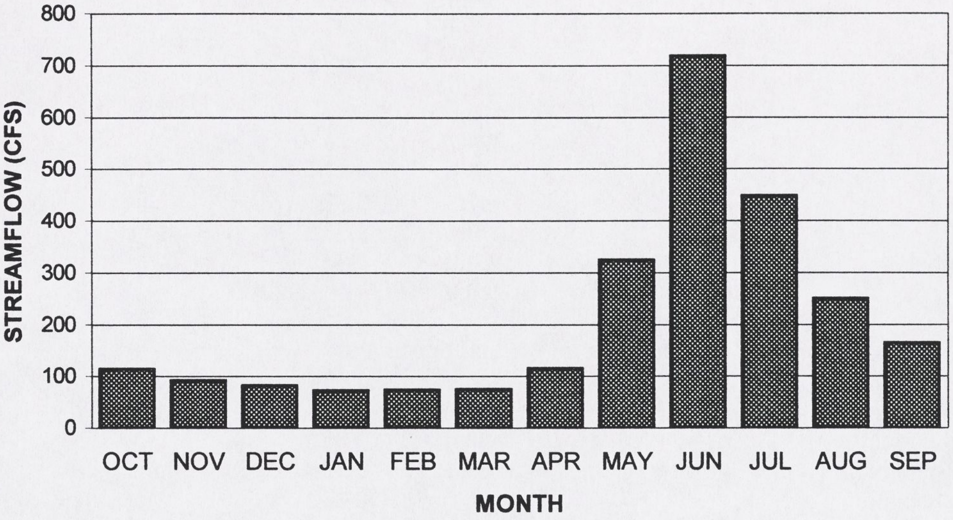


**Table 5-12. Results of IHA analysis for the Blue River below Dillon Dam.**

| IHA Statistics Group | Mean | CV |
|---|---|---|
| **Group 1: Mean Monthly Magnitude (cfs)** | | |
| October | 113.8 | 0.46 |
| November | 91.3 | 0.46 |
| December | 82.3 | 0.35 |
| January | 72.1 | 0.31 |
| February | 73.1 | 0.27 |
| March | 74.6 | 0.27 |
| April | 115.5 | 0.49 |
| May | 324.7 | 0.79 |
| June | 717.9 | 0.67 |
| July | 447.5 | 0.82 |
| August | 250.1 | 0.73 |
| September | 164.0 | 0.53 |
| **Mean Annual Flow** | 210.9 | |
| **Group 2: Magnitude (cfs) and Duration of Annual Extremes** | | |
| 1-day minimum | 35.8 | 0.58 |
| 3-day minimum | 36.7 | 0.58 |
| 7-day minimum | 38.6 | 0.55 |
| 30-day minimum | 51.1 | 0.37 |
| 90-day minimum | 62.7 | 0.30 |
| 1-day maximum | 1126.8 | 0.46 |
| 3-day maximum | 1108.1 | 0.47 |
| 7-day maximum | 1058.2 | 0.48 |
| 30-day maximum | 841.9 | 0.53 |
| 90-day maximum | 538.8 | 0.63 |
| Base flow (7-day min/annual mean) | 0.21 | 0.62 |
| **Group 3: Timing of Annual Extremes** | | |
| Date of annual 1-day minimum | dates are widely distributed throughout the year | |
| Date of annual 1-day maximum | dates are widely distributed throughout the year | |
| **Group 4: Frequency and Duration of High and Low Pulses** | | |
| High Pulse Level (cfs) | 509.3 | |
| Low Pulse Level (cfs) | 65.0 | |
| Low pulse number (per yr) | 5.2 | 0.74 |
| High pulse number (per yr) | 1.3 | 0.75 |
| Low pulse duration (days) | 16.8 | 0.72 |
| High pulse duration (days) | 26.4 | 0.91 |
| **Group 5: Rate and Frequency of Flow Changes** | | |
| Fall rate (avg cfs/day) | -22.3 | -0.51 |
| Rise rate (avg cfs/day) | 27.5 | 0.46 |
| Number of flow reversals (per yr) | 63.4 | 0.26 |

Figure 5-42. Annual base flow index (7-day minimum flow/annual mean) over the period of record, Blue River below Dillon Dam.

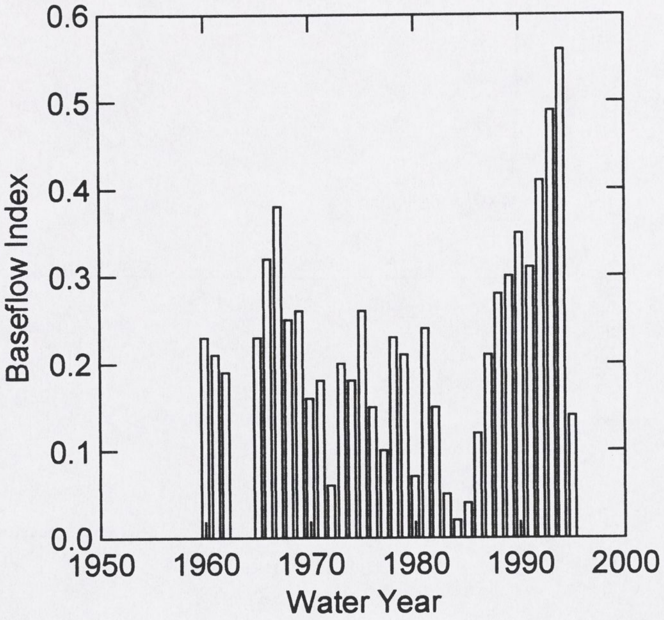


Figure 5-43. Annual rates of day-to-day increases and decreases in streamflow, Blue River below Dillon Dam.

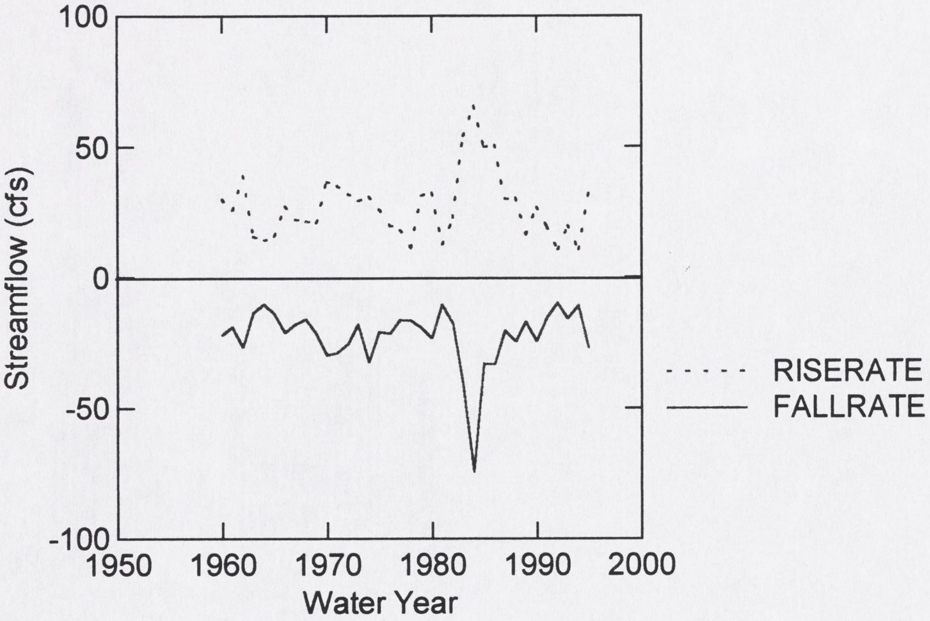
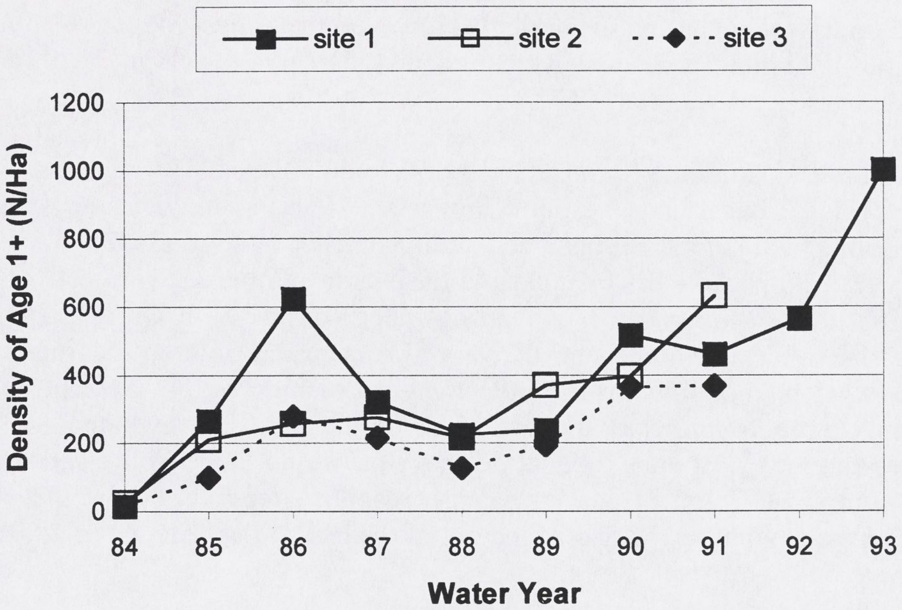
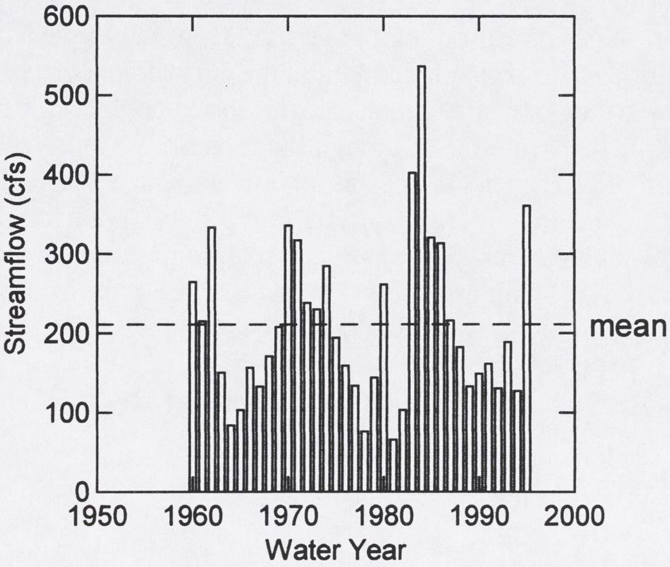


Figure 5-44. Density of age 1+ brown trout (N/ha) and annual mean streamflow (cfs), Blue River below Dillon Dam.

Brown trout recruitment, Blue River below Dillon Dam.
(Sources: Nehring and Anderson 1993, Nehring and Thompson 1994)



Annual mean streamflow (cfs), Blue River below Dillon Dam.



natural reproduction. CDOW biologists suspect that the low water temperatures due to water releases from the dam prevent development of a self-sustaining rainbow trout population (Nehring 1992).

## Eagle River

The 70-mile long Eagle River is one of the only headwater tributaries of the Colorado River that has no major dam. However, many East Slope communities hold rights to Eagle River water, and increased development of the Eagle Valley threatens water quality.

Aurora and Colorado Springs have rights to 60,000 A-ft of water in the Eagle River Basin, but their $90 million Homestake II project to divert the water over the Continental Divide has been held up in court for many years (*Denver Post* 10/5/97). Homestake II would expand the existing Homestake project (which supplies about 25,000 A-ft), diverting water from the Holy Cross Wilderness Area through tunnels for delivery to Aurora and Colorado Springs. Eagle County denied permits for the project under Colorado's 1041 law, but Aurora and Colorado Springs challenged its action in court. However, the Colorado Supreme Court upheld Eagle County's decision. Eagle County and the cities of Aurora and Colorado Springs recently reached a tentative accord that would limit the amount of water diverted out of the basin to an average of 20,000 A-ft per year.

Water quality has been a major concern since 1984, when an eight-mile stretch of the Eagle River between Belden and Minturn was designated a Super Fund clean-up site as a result of contamination from the Eagle Mine. Since 1990, the effectiveness of water quality and habitat improvements have been evaluated by annual monitoring of fish and macroinvertebrate populations by the CDOW (Woodling and Dorsch 1997). Although the river shows signs of recovery from mine contamination, the CDOW has found evidence of other pollution sources that are raising concerns. Increased nutrient inputs are contributing to excess algal growth, which can result in oxygen depletion in the river. In addition, increasing quantities of silt are being washed into the river from ground exposed by new land development in the Eagle Valley.

### Flow Regime and Trout Populations at Redcliff

#### 1) <u>Overview of Findings</u>

- peak and base flows have declined significantly from historic levels; reductions in streamflow limit the river's capacity to dilute nonpoint pollution and sedimentation

### 2) <u>IHA Analysis of Flow Regime</u> (USGS # 09063000)

Results of IHA analysis of the Eagle River flow regime at Redcliff indicate that there have been substantial declines in flows since the time of early flow records (Figure 5-45; Table 5-13, Group 1). Spring peak flows are markedly reduced, and although in some years annual maxima still fall within the historic range of variation, averages have declined to nearly half of historic levels (Figure 5-46; Table 5-13, Group 2). Winter base flows have also declined, as illustrated by the reduction in March flows (Figure 5-47). Depleted flows and reduced frequency of flushing flows may interact with nonpoint pollution and sedimentation to reduce water quality in the Eagle River, even in sections that are not subject to mine contamination. Sediment accumulation can smother incubating trout eggs. In addition, excess algal growth due to nutrient enrichment can reduce levels of dissolved oxygen in river water.

### 3) <u>Trout Population Data</u>

CDOW monitoring of Eagle River macroinvertebrate and trout populations indicates improvement between Belden and Minturn associated with the Eagle Mine remediation efforts (Woodling and Dorsch 1997). However, a decrease in brown trout density over the past three years at a reference site downstream of Avon is thought to be related to nonpoint pollution (Figure 5-48). The CDOW has observed increased "sewage fungus" (*Sphaerotilus natans*), sedimentation, and algal growth in sections of the Eagle River between Minturn and Avon (Woodling and Dorsch 1997).

Metal toxicity is not a factor at a reference site at Redcliff, upstream of the Eagle Mine site (Woodling and Dorsch 1997). Instead, it is thought that fluctuations in trout density at this site are related to the magnitude of spring snowmelt during the first year of life. Studies in other Colorado rivers indicate that there is higher mortality of trout fry in years of high runoff (Nehring and Anderson 1993). A peak in brown trout numbers at Redcliff (based on April sampling) in WY 1993-94 followed a year of low runoff (Figure 48). Density declined again the next year, following the high runoff of WY 1993-94. However, data for other years do not show correlations with the magnitude of peak flows in the year preceding the CDOW's April sampling, suggesting that additional factors may be important. For example, water quality may be declining at Redcliff due to reduced flows and increased nonpoint pollution, as observed in other sections of the river. Continued monitoring of trout populations at this site will help improve understanding of potential relationships between flow regime changes and nonpoint pollution due to increased development in the Eagle Valley.

**Figure 5-45. Mean monthly streamflow (cfs) before (1911-25) and after (1945-95) major land and water development, Eagle River at Redcliff.**

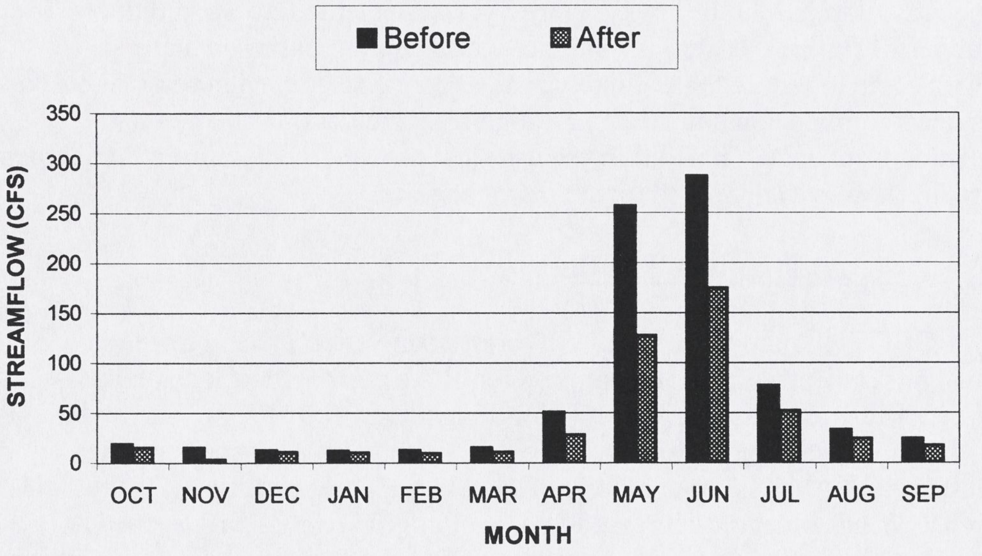


**Table 5-13. Results of IHA analysis for the Eagle River at Redcliff before (1911-25) and after (1945-95) major land and water development.**

| | | Means | | | CVs | |
|---|---|---|---|---|---|---|
| IHA Statistics Group | Before | After | % Change | Before | After | % Change |
| **Group 1: Mean Monthly Magnitude (cfs)** | | | | | | |
| October | 19.1 | 15.3 | -19.8 | 0.22 | 0.32 | 46.4 |
| November | 15.3 | 3.0 | -14.9 | 0.20 | 0.26 | 34.0 |
| December | 12.7 | 10.8 | -14.6 | 0.22 | 0.21 | -0.6 |
| January | 12.3 | 9.9 | -19.8 | 0.22 | 0.19 | -16.0 |
| February | 12.4 | 9.7 | -22.0 | 0.24 | 0.22 | -7.6 |
| March | 14.9 | 10.9 | -27.0 | 0.24 | 0.26 | 5.7 |
| April | 50.5 | 27.8 | -45.0 | 0.35 | 0.50 | 42.1 |
| May | 256.9 | 127.0 | -50.6 | 0.33 | 0.45 | 38.9 |
| June | 286.8 | 174.4 | -39.2 | 0.35 | 0.52 | 49.9 |
| July | 77.0 | 52.0 | -32.5 | 0.28 | 0.59 | 111.0 |
| August | 33.1 | 24.0 | -27.3 | 0.19 | 0.44 | 127.5 |
| September | 24.2 | 16.8 | -30.5 | 0.24 | 0.35 | 43.3 |
| **Mean % Change (absolute value)** | | | **28.6** | | | **43.6** |
| **Mean Annual Flow** | 66.3 | 41.0 | | | | |
| **Group 2: Magnitude (cfs) and Duration of Annual Extremes** | | | | | | |
| 1-day minimum | 5.6 | 7.3 | 29.9 | 0.46 | 0.24 | -48.2 |
| 3-day minimum | 6.4 | 7.7 | 21.3 | 0.37 | 0.22 | -41.0 |
| 7-day minimum | 8.0 | 8.1 | 1.9 | 0.24 | 0.22 | -7.1 |
| 30-day minimum | 10.2 | 8.9 | -13.1 | 0.19 | 0.20 | 3.4 |
| 90-day minimum | 11.4 | 9.5 | -16.6 | 0.15 | 0.19 | 27.1 |
| 1-day maximum | 565.3 | 300.7 | -46.8 | 0.33 | 0.49 | 47.9 |
| 3-day maximum | 529.2 | 288.8 | -45.4 | 0.33 | 0.48 | 43.6 |
| 7-day maximum | 481.4 | 271.6 | -43.6 | 0.34 | 0.47 | 38.2 |
| 30-day maximum | 377.9 | 208.4 | -44.8 | 0.36 | 0.45 | 24.3 |
| 90-day maximum | 213.9 | 121.7 | -43.1 | 0.26 | 0.41 | 54.8 |
| Base flow (7-day min/annual mean) | 0.12 | 0.22 | 77.0 | 0.22 | 0.32 | 2.4 |
| **Mean % Change (absolute value)** | | | **34.9** | | | **30.7** |
| **Group 3: Timing of Annual Extremes** | | | | | | |
| Date of annual 1-day minimum | 19-Nov | 27-Jan | | | | |
| Date of annual 1-day maximum | 30-May | 1-Jun | | | | |
| **Group 4: Frequency and Duration of High and Low Pulses** | | | | | | |
| High Pulse Level (cfs) | 184.2 | | | | | |
| Low Pulse Level (cfs) | 14.0 | | | | | |
| Low pulse number (per yr) | 8.8 | 6.5 | -26.4 | 0.41 | 0.55 | 34.1 |
| High pulse number (per yr) | 3.0 | 1.2 | -60.7 | 0.70 | 0.72 | 2.7 |
| Low pulse duration (days) | 14.0 | 30.5 | 118.6 | 0.98 | 0.69 | -29.4 |
| High pulse duration (days) | 18.7 | 14.1 | -24.3 | 0.70 | 1.00 | 42.5 |
| **Group 5: Rate and Frequency of Flow Changes** | | | | | | |
| Fall rate (avg cfs/day) | -12.8 | -4.2 | -66.9 | -0.64 | -0.37 | -41.8 |
| Rise rate (avg cfs/day) | 14.5 | 5.7 | -60.9 | 0.50 | 0.38 | -23.5 |
| Number of flow reversals (per yr) | 99.8 | 90.7 | -9.1 | 0.23 | 0.17 | -27.1 |

Figure 5-46. Average 1-day maximum flow (cfs) before and after major land and water development, Eagle River at Redcliff. Dotted lines indicate historic range of variation (based on mean + or - 1 SD).

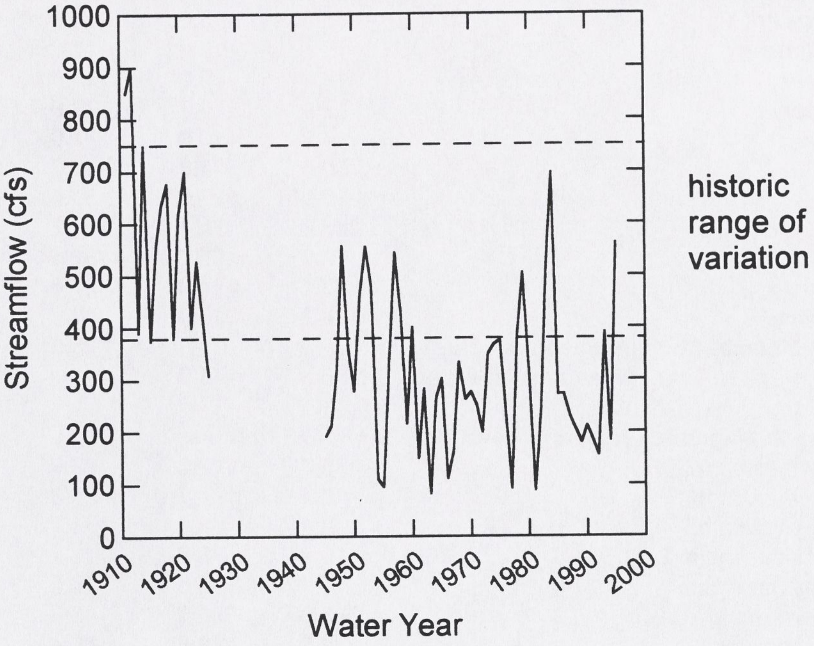


Figure 5-47. Annual March flow (cfs) before and after major land and water development, Eagle River at Redcliff. Dotted lines indicate historic range of variation (based on mean + or - 1 SD).

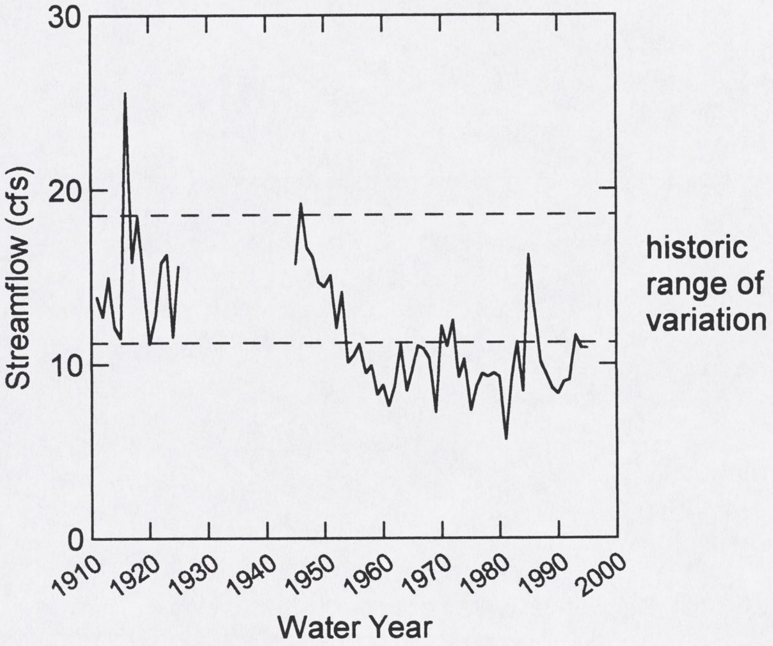
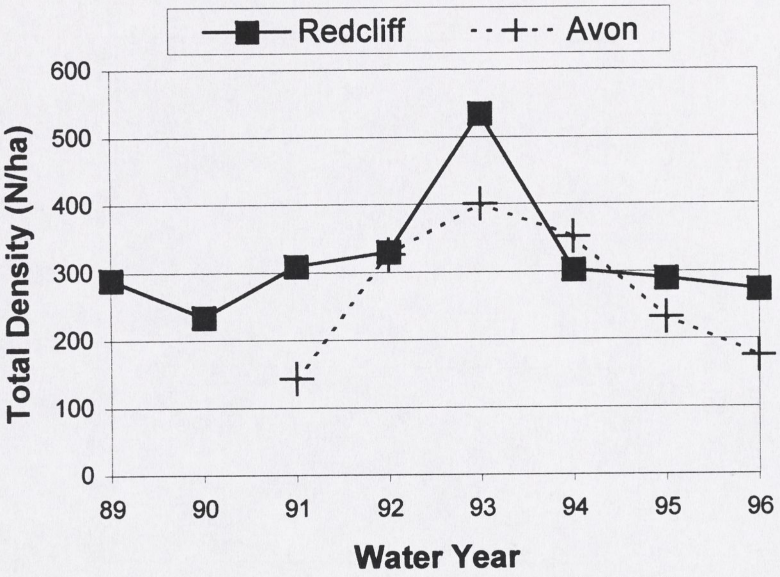
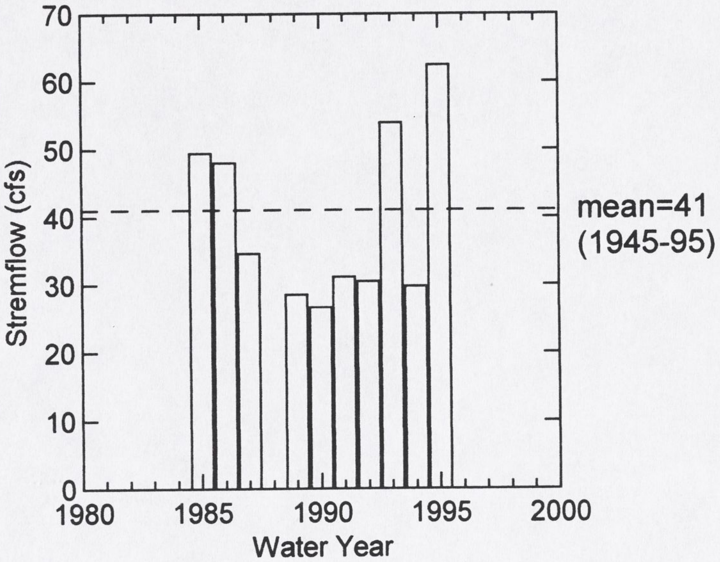


Figure 5-48. Total brown trout density (N/ha) and annual mean streamflow (cfs), Eagle River at Redcliff.


Total brown trout density (N/ha),
CDOW sites at Redcliff and downstream of Avon.
(Source: Woodling and Dorsch 1997))


Annual mean streamflow (cfs), Eagle River at Redcliff.

## Fryingpan River below Ruedi Dam

Ruedi Reservoir is one of the Western Slope facilities of the Fryingpan-Arkansas Project, built by the Bureau of Reclamation between 1963 and 1980 (Colorado Department of Natural Resources 1997). Water from the Fryingpan River is conveyed to collection facilities in the Arkansas River drainage via the Boustead Tunnel. The project supplements water supplies for municipal use and irrigation of about 280,000 acres in the Arkansas River Basin.

Since 1989 agencies involved in the Upper Colorado River Recovery Program have arranged for late-summer releases of 10,000 A-ft of water from Ruedi Reservoir to benefit critical habitat downstream in the Colorado River for endangered native fishes, including the Colorado squawfish (League of Women Voters of Colorado 1992; Young 1997). Communities in the Roaring Fork Valley were originally opposed to the releases because of fears that a declining reservoir level would reduce recreation. As a result, reservoir releases are now timed so that all recreational facilities will remain available throughout the summer.

### Flow Regime and Trout Populations near Ruedi

#### 1) <u>Overview of Findings</u>

- fall and winter flows have increased as a result of reservoir releases to increase storage capacity prior to spring runoff; this has probably improved habitat conditions for the fall-spawning brown trout

- in contrast, flows during spring runoff have declined; continued declines in peak flows will reduce trout habitat over time as channel conditions deteriorate due to lack of flushing flows

#### 2) <u>IHA Analysis of Flow Regime</u> (USGS # 09080400)

Ruedi Reservoir is typically drawn down in fall and winter (Colorado Department of Water Resources 1997). Based on projected inflow to the reservoir, fall and winter releases are managed to ensure a fill during spring or early summer. The reservoir typically fills by late June or early July. Minimum fishery bypass requirements downstream of the reservoir include:

- 39 cfs November 1 through April 30
- 110 cfs May 1 through October 31

IHA results show elevated flows in fall and winter due to reservoir releases to increase storage capacity and year-to-year variation in flows based on releases in relation to expected runoff conditions (Figure 5-49; Table 5-14). In addition, results indicate that fall and winter flows have shown an increasing trend over the years of reservoir operation, while flows during spring runoff have declined (Figure 5-50). There is also evidence of an increase in annual minima but a decline in annual maxima (Figure 5-51). It is likely that the increases in annual minima and base flows have improved habitat conditions for brown trout in fall and winter. However, continued declines in peak flows will result in reduced trout habitat over time as channel conditions deteriorate due to lack of flushing flows.

### 3) Trout Population Data

There is an excellent trout fishery through a 15-mile stretch from Ruedi downstream to the confluence of the Fryingpan with the Roaring Fork in Basalt. In most years since WY 1971-72, the CDOW has sampled trout populations below Ruedi (Figure 5-52; Nehring and Thompson 1997). A number of factors in addition to reservoir releases appear to influence ttrout abundance in the Fryingpan River (Nehring and Anderson 1993). Rainbow trout fingerlings have been stocked regularly since Fall 1981. In addition, several fishing regulations have been in effect over the years, most designed to decrease numbers of larger brown trout to benefit other trout species. In 1985 a hydropower plant began operating on Ruedi Reservoir. In that same year, *Mysis*, a rich invertebrate food source, began coming through the reservoir outlet tubes, and trout populations increased dramatically as a result (Figure 5-52).

In addition, increases in fall and winter flows may improve habitat conditions for brown trout, which have showed steady increases in CDOW surveys over the past 25 years (Figure 5-52). In contrast, populations of rainbow and brook trout declined following population peaks in the mid-1980s. This may be a result of competition from the higher numbers of brown trout (Fausch 1988). Although the whirling disease parasite was detected in wild trout in the Fryingpan River beginning in WY 1994-95, at this time there is no evidence of an effect on trout population dynamics (Nehring and Thompson 1997).

## Division 6: Yampa, White, and North Platte River Basins

Division 6 includes the Yampa, White, Green, Little Snake, and North Platte rivers in northwest Colorado. Division waters are subject to the 1922 Colorado River Compact and the Upper Colorado River Compact of 1948.

### Yampa River

The Yampa River Basin is the main basin in the Division, extending about 7,660 square miles from headwater areas near the town of Yampa west to

Figure 5-49. Mean monthly streamflow (cfs) over the period of record (1965-1995), Fryingpan River below Ruedi.

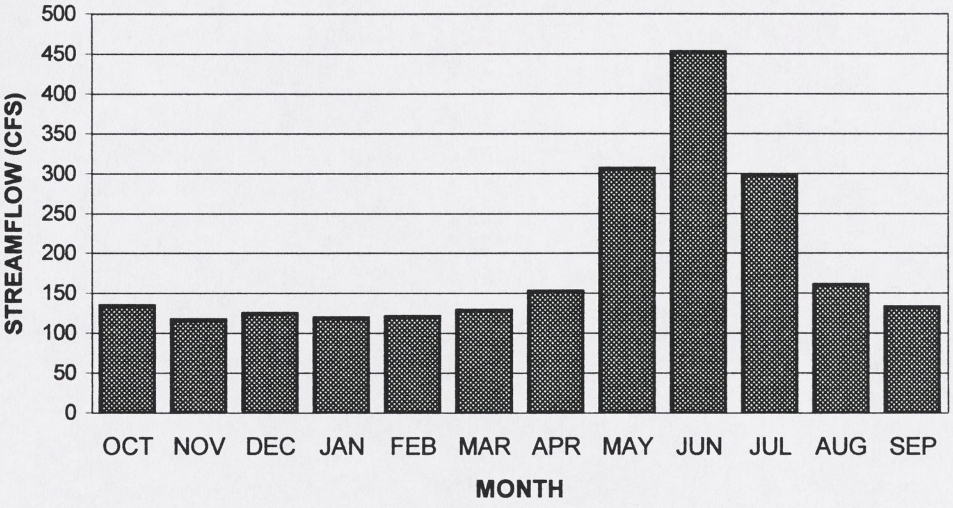


**Table 5-14 . Results of IHA analysis for the Frying Pan River below Ruedi Dam.**

| IHA Statistics Group | Mean | CV |
|---|---|---|
| **Group 1: Mean Monthly Magnitude (cfs)** | | |
| October | 134.1 | 0.45 |
| November | 116.7 | 0.35 |
| December | 124.6 | 0.42 |
| January | 119.5 | 0.45 |
| February | 120.7 | 0.49 |
| March | 128.9 | 0.48 |
| April | 153.0 | 0.52 |
| May | 305.9 | 0.58 |
| June | 452.4 | 0.73 |
| July | 297.3 | 0.70 |
| August | 160.3 | 0.30 |
| September | 132.5 | 0.31 |
| **Mean Annual Flow** | 187.4 | |
| **Group 2: Magnitude (cfs) and Duration of Annual Extremes** | | |
| 1-day minimum | 59.7 | 0.45 |
| 3-day minimum | 64.3 | 0.42 |
| 7-day minimum | 72.0 | 0.41 |
| 30-day minimum | 82.0 | 0.39 |
| 90-day minimum | 94.5 | 0.39 |
| 1-day maximum | 777.5 | 0.64 |
| 3-day maximum | 753.7 | 0.64 |
| 7-day maximum | 706.4 | 0.65 |
| 30-day maximum | 538.0 | 0.65 |
| 90-day maximum | 368.8 | 0.56 |
| Base flow (7-day min/annual mean) | 0.41 | 0.48 |
| **Group 3: Timing of Annual Extremes** | | |
| Date of annual 1-day minimum | dates are widely distributed throughout the year | |
| Date of annual 1-day maximum | dates are widely distributed throughout the year | |
| **Group 4: Frequency and Duration of High and Low Pulses** | | |
| High Pulse Level (cfs) | 372.6 | |
| Low Pulse Level (cfs) | 2.2 | |
| Low pulse number (per yr) | 0.0 | 0.00 |
| High pulse number (per yr) | 1.5 | 0.94 |
| Low pulse duration (days) | 0.0 | 0.00 |
| High pulse duration (days) | 16.0 | 1.05 |
| **Group 5: Rate and Frequency of Flow Changes** | | |
| Fall rate (avg cfs/day) | -18.8 | -0.58 |
| Rise rate (avg cfs/day) | 19.0 | 0.61 |
| Number of flow reversals (per yr) | 48.3 | 0.59 |

Figure 5-50. Trends in the annual September and June mean flows (cfs) over the period of record, Frying Pan River below Ruedi Dam.

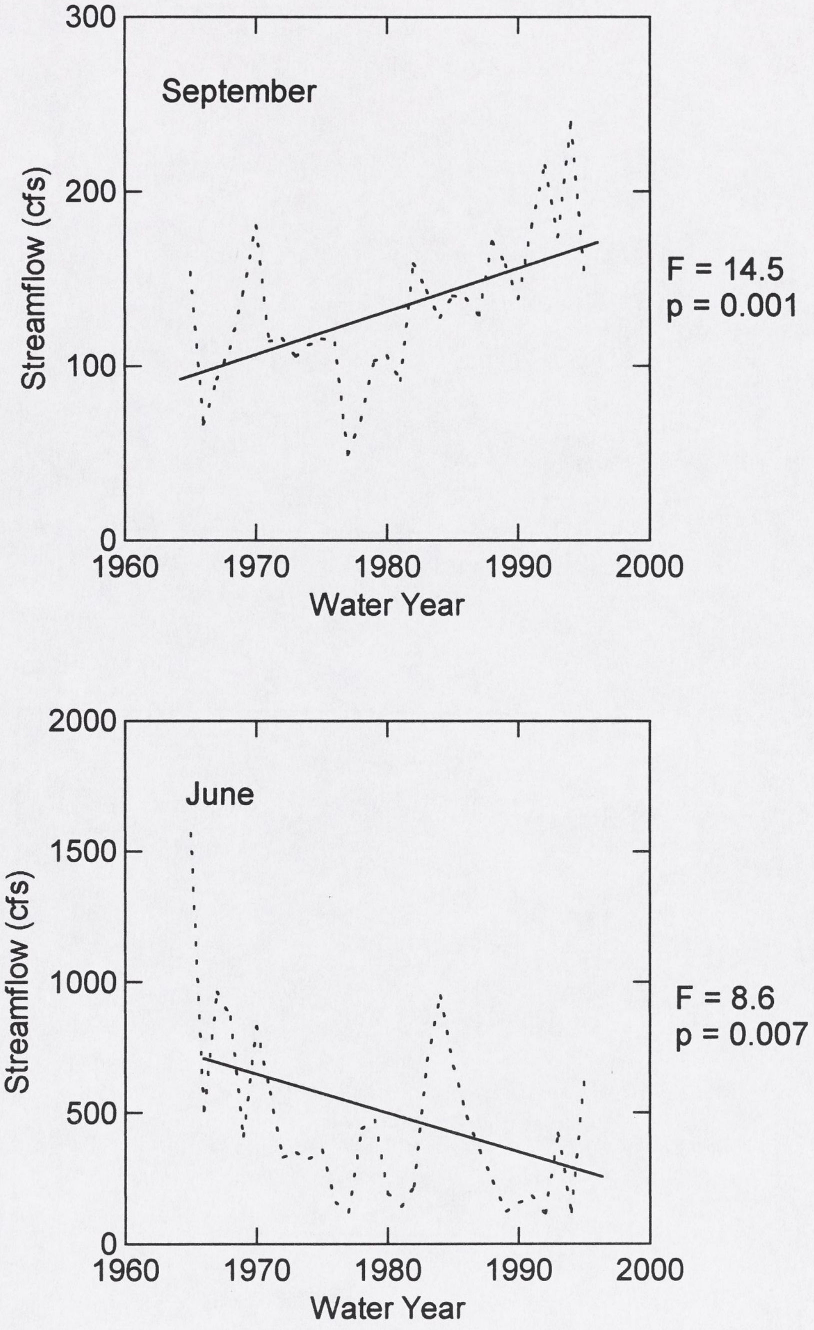


Figure 5-51. Trends in the 7-day minimum and maximum flow (cfs) over the period of record, Frying Pan River below Ruedi Dam.

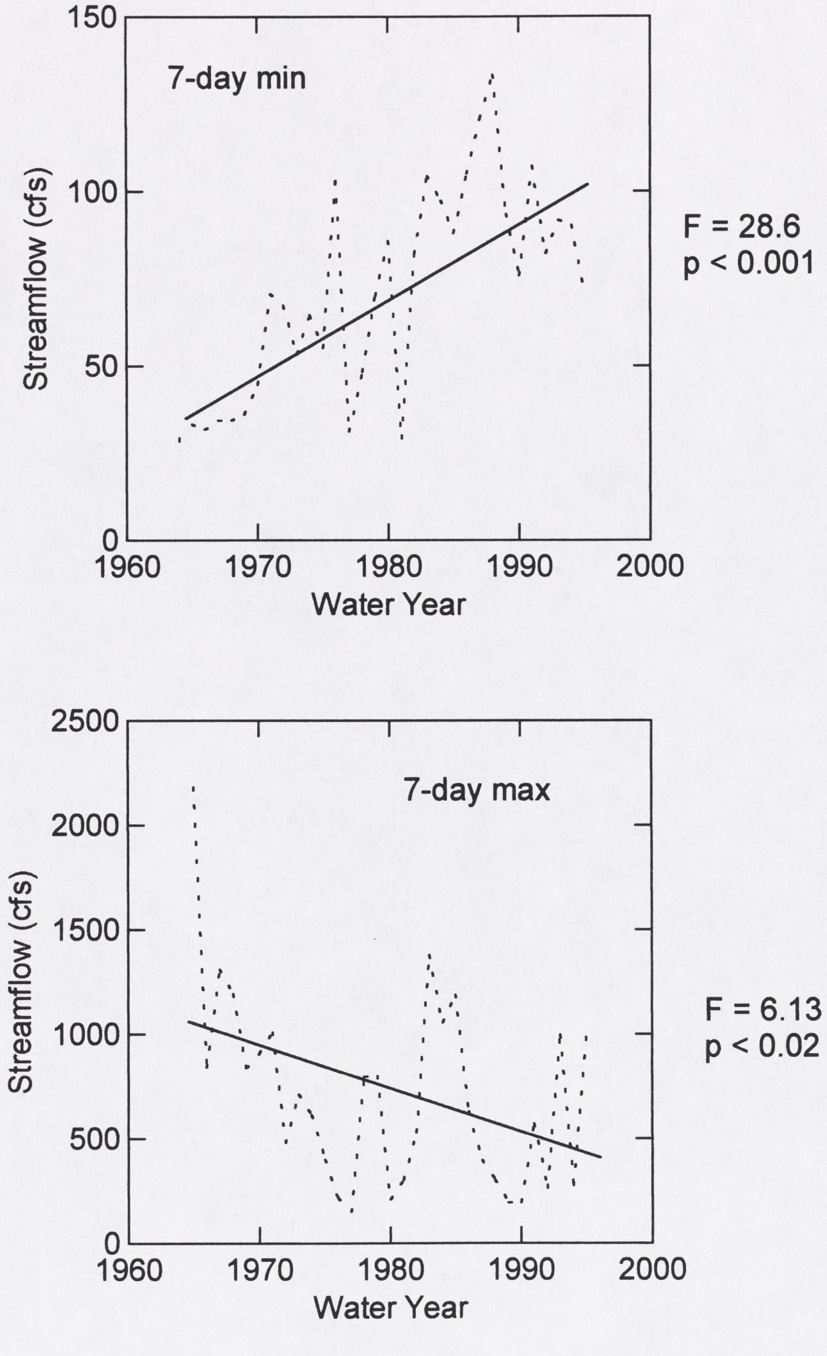
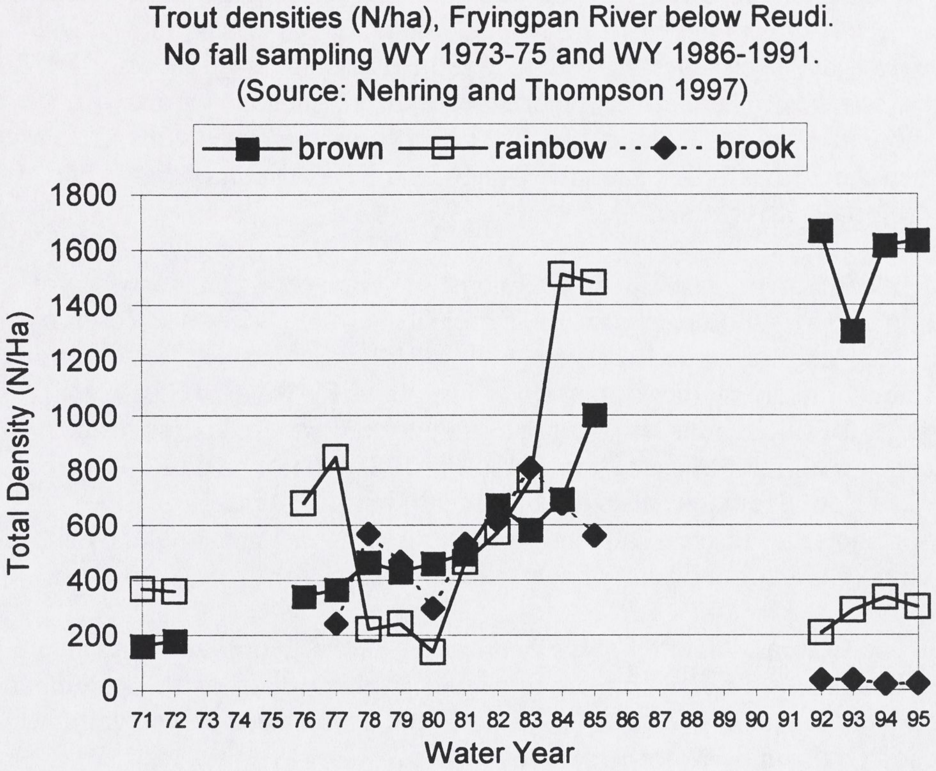
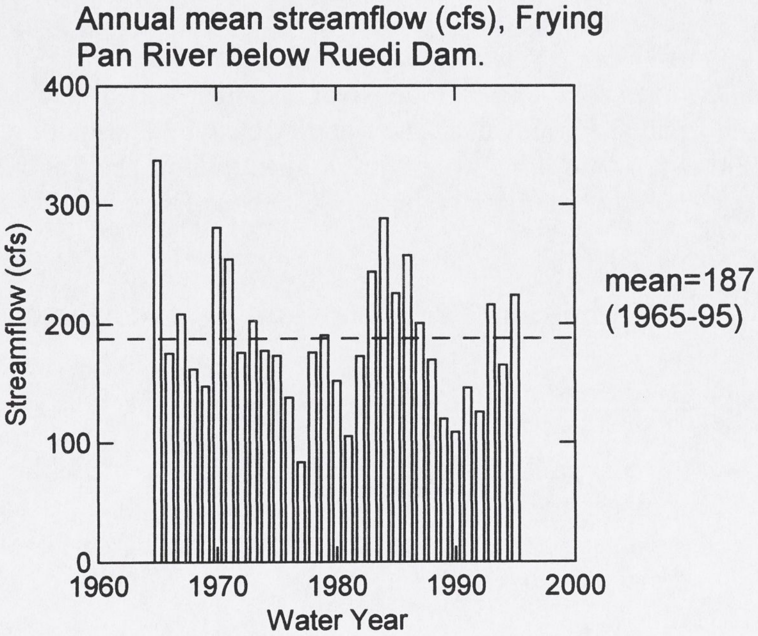


Figure 5-52. Total trout densities (N/ha) and annual mean streamflow (cfs), Fryingpan River below Ruedi Dam.





Dinosaur National Monument (Colorado Division of Water Resources 1996). The basin has undergone significant water development over the past century in the form of private irrigation systems and municipal and industrial diversions. About 71,200 acres in the basin are irrigated by hundreds of small irrigation ditches that have been diverting water from the mainstem since the late 1800s, with few changes. There are also more recent diversions for hydropower generation at Hayden and Craig, and two major transbasin diversions, the Sarvis Ditch and the Stillwater Ditch on the Upper Bear River tributary that export water to the Colorado River basin.

In addition to these direct diversions, there are several major reservoirs, including two irrigation reservoirs on Upper Bear Creak, Stillwater Reservoir, built in 1935 and Yamcolo Reservoir, built in 1981. Stagecoach Reservoir and Lake Catamount are on the Yampa River just above the town of Steamboat Springs. Lake Catamount was built primarily for recreational purposes in 1977. Stagecoach is a multiple-use reservoir built in 1988. The Yampa River below Steamboat Springs seldom receives a river call, but the Upper Bear River has irrigation shortages that are satisfied by releases from the Yamcolo and Stillwater Reservoirs (Colorado Division of Water Resources 1996).

The Colorado River Water Conservation District continues to evaluate Yampa Basin sites for development of water rights associated with the Juniper Project, including enlargement of Elkhead Creek or Stagecoach reservoirs (Colorado Division of Water Resources 1993).

In 1995 the Colorado Water Conservation Board (CWCB) filed applications for water rights to protect Yampa River streamflows between the Williams Fork and Little Snake rivers near Craig, including peak flows during spring runoff (Colorado Division of Water Resources 1995). This is part of the ongoing effort to recover Colorado River endangered fish species such as the Colorado squawfish. However, the water rights would also allow for a minimum of 52,000 A-ft of additional water development within the Yampa Basin, an increase of 50% over current water use (Colorado Division of Water Resources 1995).

## Flow Regime and Trout Populations at Steamboat Springs

### 1) Overview of Findings

- the Yampa River near Steamboat Springs provides an example of a comparatively unmodified flow regime; as with natural snowmelt streams, flows peak with runoff in spring, decline over summer, and remain low over fall and winter

### 2) **IHA Analysis of Flow Regime** (USGS # 09239500)

IHA analysis of flow records beginning in 1905 indicates no significant changes in flow parameters. Mean monthly flows (Figure 5-53) and annual mean flows (Figure 5-54) over the period of record indicate natural seasonal and annual variability in the flow regime. This makes it possible to present current flow regime characteristics as a reference point for future assessment. The IHA software provides an estimate of management targets based on the historic range of variation (RVA targets). RVA targets are based on means of IHA parameters plus or minus one standard deviation (Table 5-15). These targets provide a benchmark against which potential impacts of proposed land or water development projects can be evaluated in the future.

### 3) **Trout Population Data**

CDOW biologist Jake Bennett regularly surveys Yampa River trout populations in the town of Steamboat. Several sampling problems decrease the accuracy of the data, including high flows at the time of sampling in August and September and inexperienced electroshockers (Jake Bennett, CDOW, *personal communication*). However, surveys suggest that trout numbers have been relatively consistent from year-to-year, with no obvious trends. Rainbow, brown and Snake River cutthroat trout are stocked in the Yampa River, and there is generally good trout fishing from Steamboat Springs to Hayden (Jake Bennett, CDOW, *personal communication*).

## **Division 7: San Juan and Dolores River Basins**

Division 7 includes the San Juan, Navajo, Animas, Dolores, Los Pinos, Piedra, La Plata, Florida, and Mancos rivers and Disappointment Creek (Colorado Water Conservation Board 1996). The San Juan and its tributaries collect water in the southern regions west of the Continental Divide and carry it into New Mexico. The Dolores River drains areas north of the San Juan Basin and flows north and west to the mainstem of the Colorado River in Utah.

The Bureau of Reclamation's Dolores Project, completed in 1987, develops Dolores River water for a variety of uses, including irrigation and hydropower (Bureau of Reclamation, Western Colorado Area Office). Primary storage is provided by the McPhee Reservoir, formed by McPhee Dam and Great Cut Dike. Powerplants are located on McPhee Dam and the Towaoc Canal. The Dawson Draw Reservoir, to the west of McPhee Reservoir, stores irrigation return flows that are used for fish and wildlife enhancement. However, there is ongoing

**Figure 5-53. Mean monthly streamflow (cfs) over the period of record (1905-95), Yampa River at Steamboat Springs.**

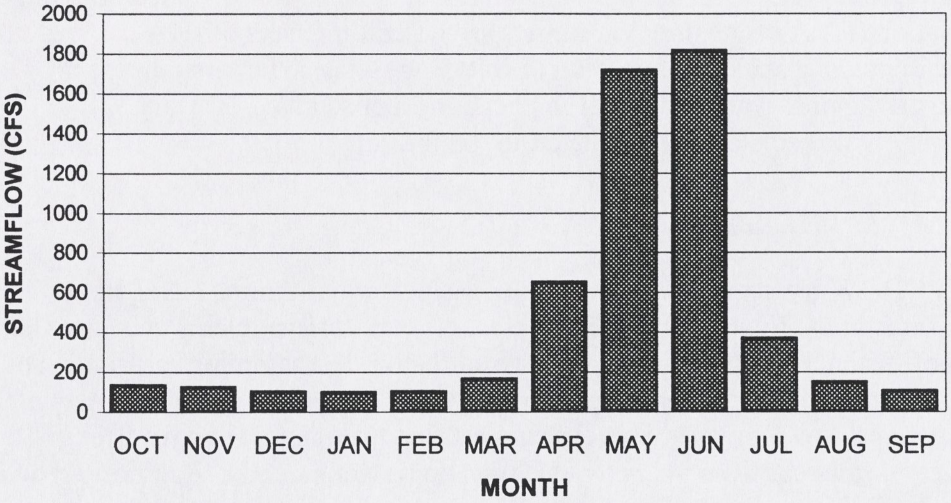


Figure 5-54. Annual mean streamflow (cfs), Yampa River at Steamboat Springs, 1905-95.

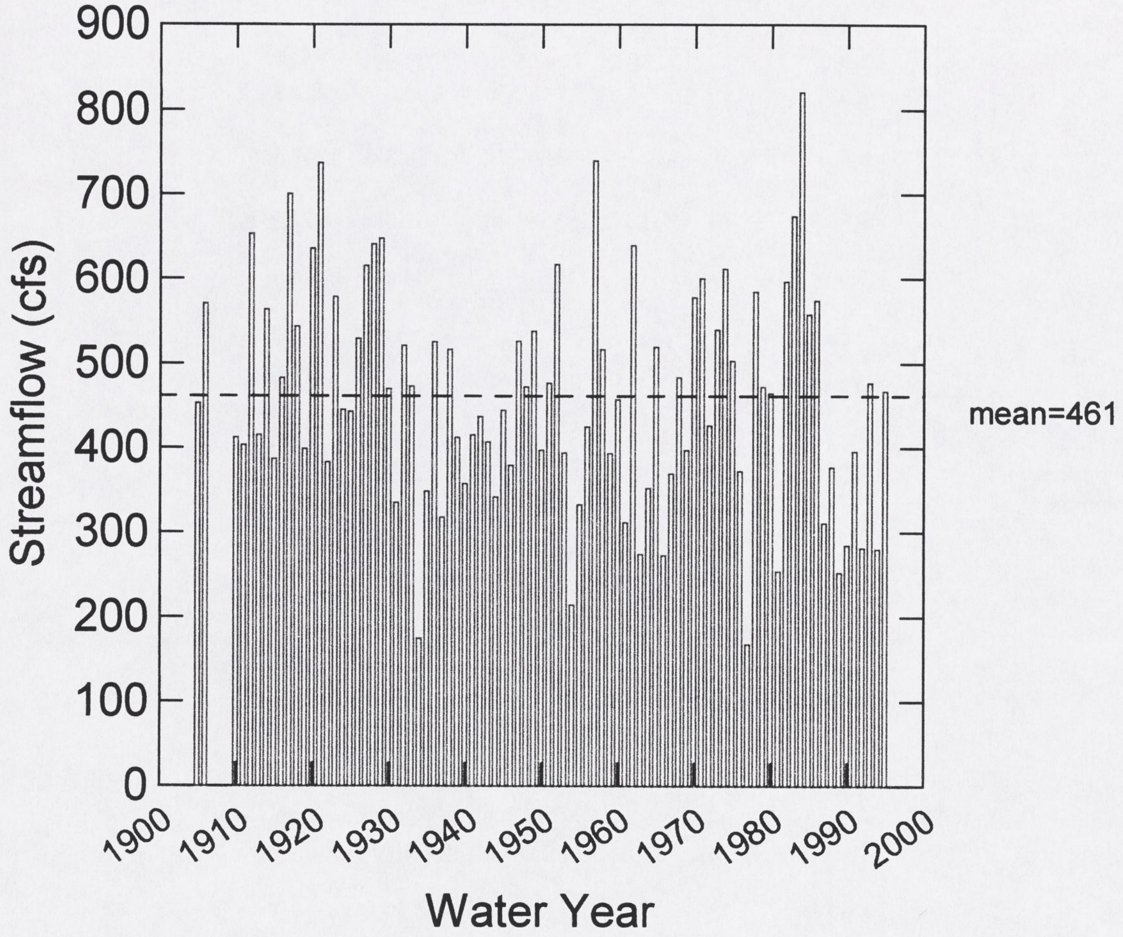


**Table 5-15. Results of IHA analysis of the Yampa River flow regime at Steamboat Springs. RVA targets indicate the range of variation in flow parameters over the period of record (1905-95) based on means + or - 1 SD.**

| | | Std. | Range Limits | | **RVA TARGETS** | |
|---|---|---|---|---|---|---|
| | Means | Dev. | Low | High | Low | High |
| Parameter | Group #1 | | | | | |
| October | 132.90 | 54.70 | 49.60 | 357.30 | 78.26 | 187.58 |
| November | 124.30 | 32.00 | 69.30 | 195.50 | 92.24 | 156.30 |
| December | 103.00 | 24.60 | 56.60 | 161.20 | 78.37 | 127.55 |
| January | 98.60 | 22.90 | 45.00 | 160.40 | 75.64 | 121.49 |
| February | 101.00 | 23.40 | 50.00 | 165.00 | 77.62 | 124.34 |
| March | 165.00 | 64.90 | 73.50 | 432.50 | 100.07 | 229.85 |
| April | 650.90 | 255.70 | 235.90 | 1674.60 | 395.20 | 906.56 |
| May | 1718.10 | 529.50 | 702.40 | 3349.70 | 1188.58 | 2247.66 |
| June | 1817.00 | 835.20 | 141.30 | 3770.70 | 981.75 | 2652.20 |
| July | 367.70 | 299.80 | 16.20 | 1684.30 | 67.88 | 667.53 |
| August | 150.40 | 70.90 | 40.50 | 386.80 | 79.51 | 221.25 |
| September | 106.20 | 46.10 | 19.50 | 238.20 | 60.14 | 152.28 |
| | | | | | | |
| Parameter | Group #2 | | | | | |
| 1-day minimum | 59.20 | 23.90 | 4.00 | 122.00 | 35.30 | 83.08 |
| 3-day minimum | 61.70 | 24.30 | 4.00 | 122.00 | 37.46 | 86.00 |
| 7-day minimum | 65.40 | 24.20 | 4.90 | 122.00 | 41.16 | 89.60 |
| 30-day minimum | 75.50 | 23.30 | 13.10 | 122.50 | 52.22 | 98.77 |
| 90-day minimum | 89.30 | 20.80 | 30.20 | 135.60 | 68.43 | 110.11 |
| 1-day maximum | 3289.80 | 1020.00 | 974.00 | 5870.00 | 2269.85 | 4309.79 |
| 3-day maximum | 3151.00 | 971.80 | 925.30 | 5530.00 | 2179.26 | 4122.78 |
| 7-day maximum | 2962.10 | 917.70 | 868.00 | 5248.60 | 2044.47 | 3879.81 |
| 30-day maximum | 2371.50 | 715.20 | 742.10 | 4240.30 | 1656.31 | 3086.68 |
| 90-day maximum | 1455.40 | 452.60 | 481.60 | 2680.50 | 1002.79 | 1907.96 |
| Number of zero days | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| Base flow | 0.14 | 0.05 | 0.00 | 0.30 | 0.10 | 0.19 |
| | | | | | | |
| Parameter | Group #3 | | | | | |
| Date of minimum | 4-Sep | 77.00 | 1-Jan | 26-Dec | 14-Jul | 26-Oct |
| Date of maximum | 31-May | 11.00 | 27-Apr | 25-Jun | 26-May | 4-Jun |
| | | | | | | |
| Parameter | Group #4 | | | | | |
| Low pulse count | 7.70 | 5.60 | 0.00 | 24.00 | 2.12 | 13.29 |
| Low pulse duration | 13.60 | 15.20 | 0.00 | 90.00 | 4.00 | 28.82 |
| High pulse count | 2.40 | 1.30 | 0.00 | 6.00 | 1.07 | 3.79 |
| High pulse duration | 24.90 | 17.30 | 0.00 | 80.00 | 7.56 | 42.18 |
| | | | | | | |
| The low pulse threshold | 96.00 | | | | | |
| The high pulse threshold | 208.40 | | | | | |
| | | | | | | |
| Parameter | Group #5 | | | | | |
| Rise rate | 65.10 | 30.30 | 21.30 | 190.20 | 34.81 | 95.49 |
| Fall rate | -53.90 | 24.80 | -149.30 | -18.00 | -78.63 | -29.12 |
| Number of reversals | 100.60 | 29.50 | 34.00 | 157.00 | 71.09 | 130.19 |

controversy over whether the Dolores Project has provided adequate fishery releases in recent years.

Within the San Juan drainage, the Bureau of Reclamation has a major proposal for development of the Animas-La Plata project. As originally conceived, the project would have featured Ridges Basin Dam and Reservoir, supplied with water pumped from the Animas River, and the Southern Ute Dam and Reservoir on the La Plata River. The project has been advanced under the auspices of meeting tribal water rights, but would also provide water to non-Indians in Colorado and New Mexico for irrigation and municipal and industrial use. In light of major environmental and budgetary obstacles, a scaled-back version of the project ("ALP Lite") has now been proposed. This smaller project would still involve construction of a dam at Ridges Basin nearly as large as that proposed under the original Animas-La Plata project.

## Dolores River

### Flow Regime and Trout Populations below McPhee Dam

#### 1) Overview of Findings

- high flow releases and rapid flow reversals during spring and early summer due to reservoir operations significantly reduce trout numbers below McPhee Dam
- flows during spill periods from April to June can reach 5000 cfs and then drop rapidly to as low as 20 cfs, resulting in stream dewatering and loss of incubating eggs and pre-emergent larvae
- high mortality of incubating eggs also occurs if water temperatures decline below 42 degrees F during spill periods
- low minimum flows and elevated water temperatures in summer during dry years cause thermal stress to trout
- lack of adequate flushing flows leads to silt accumulation and reduced production of aquatic invertebrates

#### 2) Flow Regime below McPhee Dam

The Colorado Office of the State Engineer maintains current flow records for a gaging station below McPhee Dam. However, only daily flow records for WY 1990-95 are available (Dave Dzurovchin, Office of the State Engineer, *personal communication*), so there are currently insufficient data for IHA analysis. Instead, we summarize information in CDOW reports on the history of flow management to benefit the trout fishery and trends in trout populations (Nehring 1993; Nehring and Thompson 1997).

McPhee Reservoir began storing Dolores River water in the spring of 1984 (Nehring 1993). Water releases from the reservoir are planned to create a stream fishery and to benefit whitewater boaters (Bureau of Reclamation, Western Colorado Area Office). Before the reservoir was built, there was no fishery in this reach of the Dolores River because of substantial diversions for irrigation that frequently left the stream dewatered.

An annual release of 25,400 acre-feet was originally allocated for "fishery and aesthetic purposes" downstream of McPhee Dam. Operational criteria also called for a year-round minimum flow during non-spill periods of 20 cfs during "dry" years, 50 cfs during "average" years, and 78 cfs during "wet" years. However, evidence that low minimum flows during dry years were contributing to thermal stress of trout in summer led the CDOW to suggest some changes in operations (Nehring 1993). In 1990 an "Interim Operating Agreement" designated 30,100 acre-feet of water for release during non-spill periods. It was agreed that the water should be used to insure fall to winter releases of at least 30 cfs and spring to summer releases of at least 65 cfs to keep average water temperatures below 66 degrees F during warmer weather.

In addition, the CDOW recommended a yearly downstream release of 20-30 percent of the average annual discharge into the reservoir (70,000-105,000 A-ft) because of silt accumulation and reduced production of aquatic invertebrates in the absence of adequate flushing flows (Nehring 1993). CDOW biologists noted that most of the total release for the entire year was being discharged within a relatively short spill period, leaving little of the yearly allocation to meet flow needs throughout the rest of the year (Nehring 1993). CDOW biologists continue to work with the Bureau of Reclamation to decide how best to manage reservoir operations to benefit the trout fishery (M. Japhet, CDOW, *personal communication*).

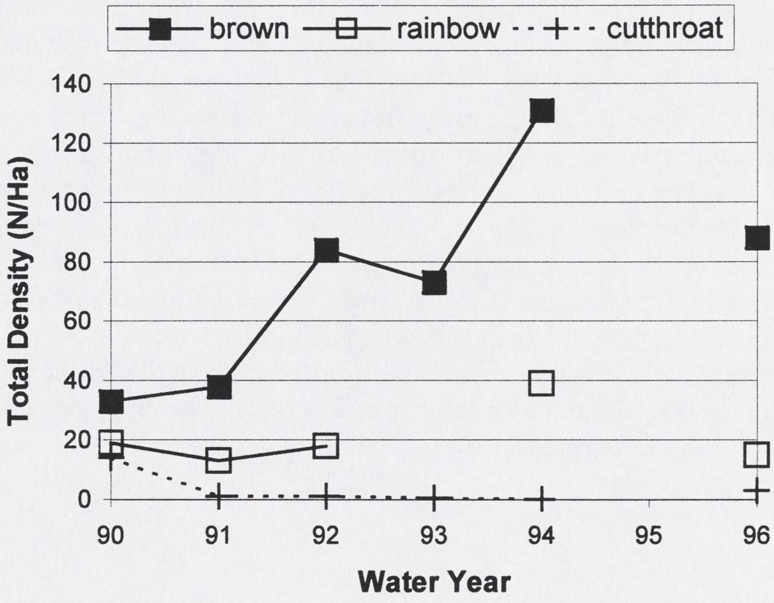
### 3) Trout Population Data

Since Fall of 1986, the CDOW has conducted annual electrofishing surveys of trout populations at 11 stations along a 12-mile reach of the Dolores River from McPhee Dam to the Bradfield Bridge (Nehring 1993; Nehring and Thompson 1997). Members of the local chapter of Trout Unlimited have assisted with many of the surveys.

Immediately prior to construction of McPhee Reservoir, there were no trout along this reach of the Dolores River (Nehring 1993). The section was typically dewatered during the irrigation season due to upstream diversions. After the reservoir was built, the CDOW began annual stocking of fingerling brown, rainbow, and Snake River cutthroat trout. By 1986 trout populations were becoming established, and in 1988 stocking of brown trout was discontinued.

Although there is now a brown trout population below McPhee Reservoir, rainbow and cutthroat trout populations have failed to develop despite annual stocking (Figure 5-55; Nehring 1993; Nehring and Thompson 1997). This is thought to be due to high releases and rapid flow reversals during spring and early summer, the time of spawning, egg incubation, and hatching of both species (Nehring 1993). Flows during spill periods from April to June reportedly can reach 5000 cfs, and then drop rapidly to as low as 20 cfs, resulting in stream dewatering and loss of incubating eggs and pre-emergent larvae. In addition, high mortality of incubating eggs occurs if water temperatures decline below 42 degrees F during spill periods (Nehring 1993). Such factors are thought to contribute to the relatively low density and biomass of trout in the Dolores River, which are substantially lower than for tailwater fisheries of the Gunnison, Blue, Frying Pan, and South Platte rivers (Nehring 1993).

Figure 5-55. Density of trout >/= 15 cm (age 1 and older), Dolores River below McPhee Dam, Metaska Campground to Bradfield Bridge. (Source: Nehring and Thompson 1997)



# CHAPTER 6 FINDINGS AND RECOMMENDATIONS

## Overview of General Findings

Results of our analysis show that human activities have profoundly modified the natural flow regimes of Colorado's major trout rivers and streams. Flow diversions, reservoir storage, and flow regulation have altered the magnitude, frequency, timing, duration and rate of change of flow conditions needed for the development of trout habitat and the completion of critical life cycle events. In most watersheds multiple projects have had interacting and cumulative effects. Moreover, flow-related reductions in habitat and nutritional resources can contribute to declines in fish health, increasing susceptibility to disease and accelerating population losses. This may be the case in Colorado, where trout infection with whirling disease is greatest in the state's most heavily modified rivers.

Throughout Colorado, streamflow conditions necessary for the long-term health of river ecosystems and the fisheries they support are highly degraded or absent. As a result, trout production is limited in many Colorado river basins, and the future sustainability of trout resources is no longer assured.

- ***Stream impoundment and reservoir operations*** result in a leveling of the natural hydrograph, eliminating natural variability in flow conditions needed for habitat development, and resulting in a reduction and simplification of habitat conditions.

- ***Interbasin water transfers*** deplete flow volumes in exporting rivers, increasing the risk of low flow periods that reduce habitat and increase mortality of early life stages of trout. In receiving rivers, especially those with small channels, flow augmentation can inundate habitat and decrease channel stability. When imports cease over winter, flow reduction is more pronounced due to the expanded channel.

- ***Flow depletions*** due to water exports and diversions reduce the capacity of rivers to dilute pollutants, impairing water quality.

- ***Summer irrigation diversions*** produce spatially and temporally discontinuous flow within stream channels and large fluctuations in day-to-day flow conditions that can harm incubating eggs and displace young trout into unsuitable habitat.

- ***Reservoir deliveries in summer for downstream users*** prolong high flow conditions during times when trout otherwise depend on naturally receding flows over summer to provide stable conditions for development of early life stages.

- ***Capture and storage of spring peak flows*** eliminate flushing flows needed for channel maintenance and habitat-forming processes, including streambed scour, transport of large woody debris into stream channels, and building of gravel bars and pools.

- ***Changes in the seasonal timing of high flows*** due to reservoir releases to increase storage of spring runoff result in excessive flows in fall that can interfere with brown trout spawning and egg incubation.

- ***High variability in the magnitude and timing of base flows*** produces rapid cycles of wetting and drying that can reduce survival in shallow, near-shore habitats of young trout and benthic insects that provide food for adult trout.

## Flow Regime Alterations of Colorado's Major Trout Rivers

Although excellent tailwater fisheries have developed below many of Colorado's major dams, impairment of flow-dependent ecological processes necessary for the long-term health of river ecosystems threatens the future sustainability of existing fisheries. In other cases, flow regime modifications fail to support self-sustaining trout populations. For example, despite regular stocking of rainbow trout in rivers and streams throughout Colorado, in many rivers healthy populations have failed to establish. In these cases, the failure of rainbow trout to thrive may signal overall ecosystem deterioration as well as a lack of specific flow conditions needed for reproduction, growth and survival. The interaction of flow regime degradation with recent widespread infection with whirling disease may result in complete elimination of rainbow trout in many Colorado rivers and streams.

This report documents specific flow regime alterations in several mainstem rivers that should be closely monitored:

- ***The South Platte River*** is impounded by numerous reservoirs that store the river's natural flows. Storage of spring peaks results in a lack of flushing flows needed for channel maintenance and habitat-forming processes, including removal of accumulated sediments and building of gravel bars and pools. Sudden drops in daily flows due to reservoir operations can lead to stream dewatering. Overall reduction in flow quantity reduces the river's ability to dilute increased pollution from expanding land development. To meet projected growth in demand over the next 50 years, Front Range water providers are considering future development of another 121,000 A-ft of transbasin imports, an additional 44,000 A-ft of South Platte supply, and increased use of Denver Basin groundwater, greatly increasing potential fisheries impacts.

- ***The Cache La Poudre River*** is subject to numerous diversions for agriculture and municipal use that significantly reduce streamflows. During dry years, use of river water to supply downstream users leaves little water flowing in the channel. As water is diverted, flows can fall dramatically from one day to the next, increasing the likelihood of stream dewatering. A proposal for a large mainstem dam and reservoir at Grey Rock, just below the confluence of the Cache La Poudre with the North Fork, would further degrade the river's flow regime and its ability to sustain trout fisheries.

- ***The Arkansas River*** receives large quantities of West Slope water via the Frying Pan-Arkansas Project, increasing the volume of native flow by over 20%. Transfers of imported water from upper basin reservoirs to Pueblo Reservoir increase flows in the upper Arkansas in fall and winter and during the month of June. At present, these conditions appear to benefit the fall-spawning brown trout. Proposals for additional augmentations that may alter current conditions therefore need to be carefully evaluated.

- ***The Rio Grande River*** is impounded by the Rio Grande Reservoir 15 miles downstream from its headwaters. Below Del Norte much of the river's flow is diverted for irrigation. Monthly flow magnitudes near Del Norte have declined an average of 26%. Lack of flushing flows reduces both the quality and quantity of trout habitat. Flow and habitat conditions during the time of brown trout egg incubation may not be dependable or sufficient from year to year due to decreased magnitude and increased variability of winter flows.

- ***The Conejos River*** flow regime varies according to releases from Platoro Reservoir to supply downstream irrigators. Immediately below Platoro Dam, the flow regime often fails to meet minimum flow targets. Reservoir inflows are often less than releases required to meet downstream calls, and winter flows are below levels needed to sustain trout populations. There are also significant daily fluctuations in flow during November that can interfere with brown trout spawning and egg incubation. Near Mogote, the magnitude of fall flows has increased, while flows from April through June have declined an average of 20%, reducing the quantity of habitat available for rainbow trout.

- ***The Gunnison River*** is subject to 1,500 active water diversion structures, including projects that transfer Gunnison River water to other basins. Upstream reservoirs store May and June peak flows and increase winter baseflows. Natural variations in seasonal flows have been largely eliminated, while daily fluctuations have increased by over 60%. There are currently three new major water projects under consideration in the Gunnison drainage.

- ***The Taylor River*** is impounded by the Taylor Park Reservoir, resulting in flows below the reservoir from October through mid-December that can become excessively high due to releases to prepare for storage of spring runoff, followed by lower flows over winter as releases stop. Improvements to reservoir operations have decreased unnatural flow variability in fall and winter, but fall flows continue to be unnaturally high.

- ***The upper Colorado River*** is subject to substantial depletions of native flows as a result of water exports to other basins. An average of 230,000 A-ft of water is transported annually to the East Slope as part of the Colorado-Big Thompson (C-BT) Project. Annual mean flow near Hot Sulphur Springs has declined from an average of 709 cfs to 244 cfs as a result of upstream reservoir storage of Colorado River water for export to other basins. Peak flows in May and June have declined by an average of 70%, while minimum flows have declined by almost 75%. Such flow declines greatly reduce both the quality and quantity of trout habitat.

- ***The Blue River*** is impounded by Dillon Reservoir, and reservoir operations regulate the quantity of streamflow below the reservoir within a narrow range, reducing natural flow variation and habitat complexity. Currently, relatively little water is diverted in wet years, while significant quantities are diverted in dry years. The timing of annual minimum and maximum flows is highly irregular, disrupting the natural timing of environmental cues that are important for the timing of life cycle events of trout. Large daily fluctuations can lead to cycles of inundation and dewatering that are harmful for young trout and benthic insects that provide food for adult trout. Denver Water is currently working on a plan to develop another 30,000 acre-feet of junior water rights on the Blue River. The project is expected to reduce releases below Dillon Dam from the current 180 cfs to only 50 cfs year round, significantly impacting the trout fishery.

- ***The Eagle River*** is one of the only headwater tributaries of the Colorado River that still has no major dam, but many East Slope communities hold rights to further develop Eagle River water. In addition, ongoing development in the Eagle Valley threatens water quality. Peak and base flows have declined significantly from historic levels, limiting the river's capacity to dilute nonpoint pollution and sedimentation.

- ***The Fryingpan River*** supplies water to the Arkansas River drainage as a part of the Fryingpan-Arkansas Project. Fall and winter flows below Ruedi Reservoir have increased as a result of releases to increase storage capacity prior to spring runoff, improving habitat conditions for the fall-spawning brown trout. However, continued declines in spring peak flows will reduce trout habitat over time as channel conditions deteriorate due to lack of flushing flows.

- ***The Yampa River*** near Steamboat Springs continues to have a comparatively unmodified flow regime, and the Colorado Water Conservation Board has filed applications for water rights to protect Yampa River streamflows between the Williams Fork and Little Snake rivers. However, the water rights would also allow for a minimum of 52,000 A-ft of additional water development within the Yampa Basin, an increase of 50% over current water use. In addition, the Colorado River Water Conservation District continues to evaluate Yampa Basin sites for development of water rights associated with the Juniper Project.

- ***The Dolores River*** below McPhee Reservoir has failed to develop self-sustaining trout populations, and there are ongoing efforts to improve reservoir operations to benefit the fishery. Reservoir spill periods from April to June can result in flows reaching as high as 5000 cfs and then dropping rapidly to as low as 20 cfs, leading to stream dewatering and loss of incubating trout eggs and pre-emergent larvae. During dry years, thermal stress can result from low minimum flows and elevated water temperatures in summer. Lack of adequate flushing flows leads to silt accumulation and reduced production of insects that provide food for adult trout.

## Watershed Management to Improve Trout Fisheries

New management approaches are needed to address ongoing alterations to Colorado's streamflow regimes. Recommendations include:

- ***manage resources at the watershed-scale*** to sustain the health of the larger ecosystems upon which trout depend

- ***expand management efforts beyond a sole focus on minimum instream flows*** to include the many other biologically significant components of flow regimes

- ***protect against further water development*** in basins that already experience chronic dewatering and other disruptions to flow regime characteristics needed to support trout fisheries and watershed health

- ***review water management activities on an ongoing basis*** in specific watersheds to determine if changes are needed to maintain or restore biologically significant flow regime characteristics

- ***monitor flow regimes and fishery resources regularly*** to establish benchmarks for evaluating any trends as well as potential impacts of proposed land or water development

- ***manipulate regulated flow regimes to the extent possible*** to restore biologically significant flow regime characteristics needed to support fishery resources and watershed processes:

    1) provide occasional flushing flows needed for channel maintenance and habitat-forming processes

    2) restore variability in flow conditions to promote habitat development

    3) restore the natural timing of different flow conditions needed for specific life cycle events

    4) insure that daily, seasonal, and yearly variation in flow conditions do not exceed biologically important natural variability

    5) stabilize artificial flow variations during low flow periods that produce rapidly reversing cycles of wetting and drying

- ***adjust management programs on an ongoing basis*** in response to improved science-based understanding of flow-dependent watershed dynamics and trout responses to flow regime alterations

These recommendations are starting points that can and should be adjusted as more information becomes available. It is now recognized that watershed restoration "is a rigorous, long-term, comprehensive, and adaptive process," requiring a more scientific approach and new management strategies that can readily adapt to the latest information (Williams et al. 1997). Our hope is that this report will contribute to this process in Colorado.

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