W A T E R R E S O U R C E S
IMPACT

RIPARIAN ECOSYSTEM CONSEQUENCES OF WATER REDISTRIBUTION ALONG THE COLORADO FRONT RANGE

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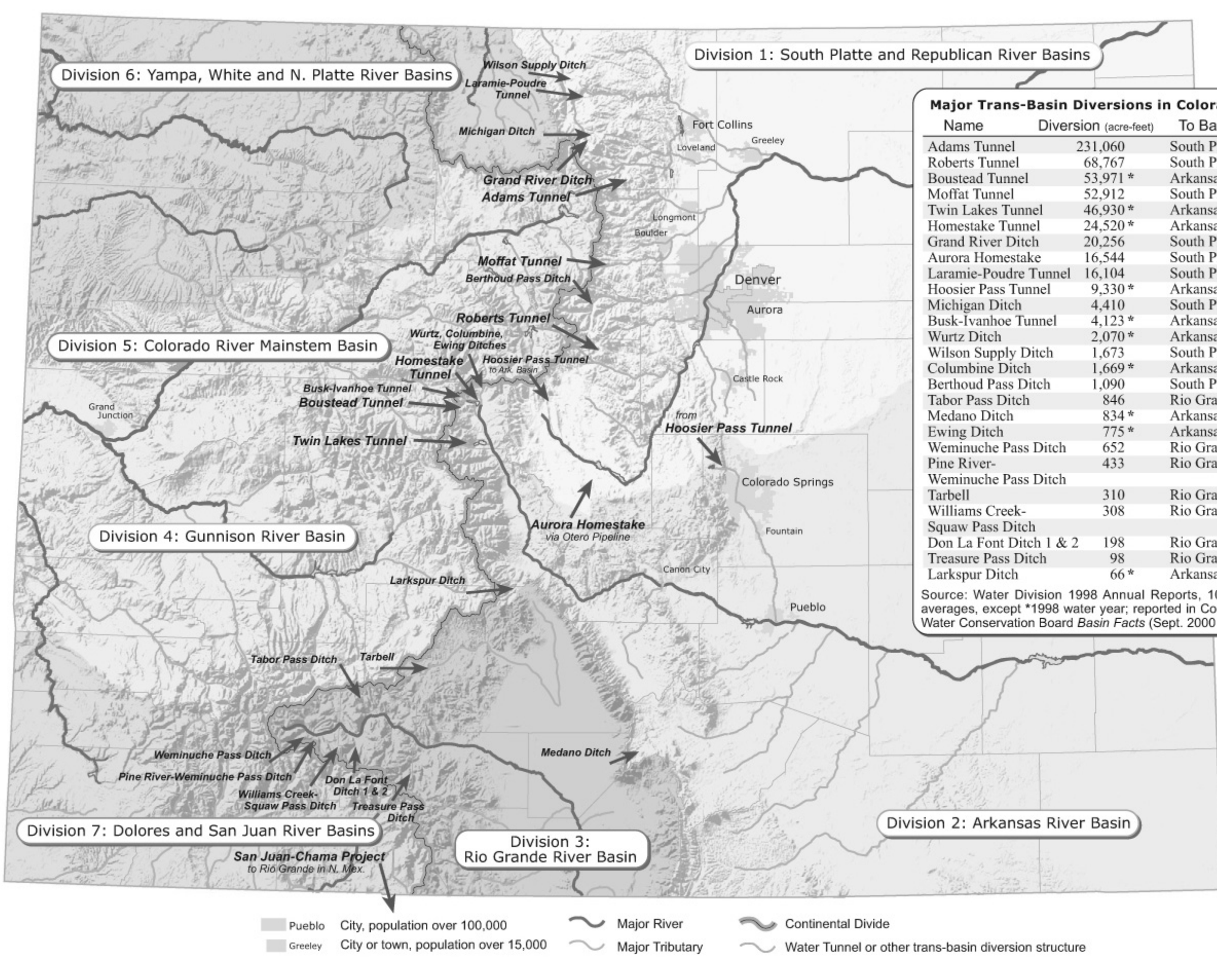
INTRODUCTION

Water has shaped the American West. Nowhere is this more evident than along the Front Range of Colorado. At the west end of the famous Great Plains rainfall gradient, the Front Range extends most of the length of Colorado and is one of the fastest growing metropolitan regions in the nation (Figure 1). Annual precipitation along the Front Range averages about 16 inches, and regional development has been possible only through the manipulation of Rocky Mountain rivers. Since the late 1830s, human changes to water flows have gone from the destruction of the beaver – the earliest water impounders and sediment trappers – to managing and moving just about every drop of available water. The distinctive river flow regime, with seasonal peak discharge driven by spring snowmelt, has been harnessed to accommodate agricultural, industrial, and municipal use, especially to the city of Denver and its ever-expanding metropolitan area. The Front Range of Colorado has no unappropriated water left, which means that any new use of water, including instream flow protection for aquatic and riparian habitat, will require either a reallocation from an existing use or importation of water from another basin.

HISTORY OF LAND AND WATER DEVELOPMENT

Human needs for water and flood protection have changed the flows of streams and rivers throughout Colorado, and have altered riparian habitats and functions. Even in high elevation alpine areas, diversions to support irrigation and mining affected first-order and second-order streams starting with the 1859 Gold Rush. Although irrigation began with Native Americans in south-



Major Trans-Basin Diversions in Colorado

Name	Diversion (acre-feet)	To Basin
Adams Tunnel	231,060	South Platte
Roberts Tunnel	68,767	South Platte
Boustead Tunnel	53,971 *	Arkansas
Moffat Tunnel	52,912	South Platte
Twin Lakes Tunnel	46,930 *	Arkansas
Homestake Tunnel	24,520 *	Arkansas
Grand River Ditch	20,256	South Platte
Aurora Homestake	16,544	South Platte
Laramie-Poudre Tunnel	16,104	South Platte
Hoosier Pass Tunnel	9,330 *	Arkansas
Michigan Ditch	4,410	South Platte
Busk-Ivanhoe Tunnel	4,123 *	Arkansas
Wurtz Ditch	2,070 *	Arkansas
Wilson Supply Ditch	1,673	South Platte
Columbine Ditch	1,669 *	Arkansas
Berthoud Pass Ditch	1,090	South Platte
Tabor Pass Ditch	846	Rio Grande
Medano Ditch	834 *	Arkansas
Ewing Ditch	775 *	Arkansas
Weminuche Pass Ditch	652	Rio Grande
Pine River-Weminuche Pass Ditch	433	Rio Grande
Tarbell	310	Rio Grande
Williams Creek-Squaw Pass Ditch	308	Rio Grande
Don La Font Ditch 1 & 2	198	Rio Grande
Treasure Pass Ditch	98	Rio Grande
Larkspur Ditch	66 *	Arkansas

Source: Water Division 1998 Annual Reports, 10-year averages, except *1998 water year; reported in Colorado Water Conservation Board *Basin Facts* (Sept. 2000 draft).

Figure 1. State of Colorado Showing the Seven Major Watershed Basins and Largest Trans-Basin Water Diversions. The Colorado Front Range extends from the Wyoming-Colorado state line south to the Arkansas River. (Sources: Colorado Division of Water Resources, Office of the State Engineer, Colorado Water Conservation Board; U.S. Bureau of Reclamation, U.S. Geological Survey. Map by Thomas Dickinson.)

ern Colorado more than a thousand years ago, European immigrants began withdrawing irrigation water from the Arkansas River about 1850 to supply the Santa Fe Trail travelers following the fur trade routes. Throughout the 1860s pioneers diverted water from mountain and prairie streams and rivers, and built numerous ditches along the Front Range. Nearly 68,000 surface water diversions – many related to early homesteading and mining activities – are located either within or bordering Colorado's national forests and grasslands. In the 1870s, large-scale development along the South Platte River began, and by 1883, the area along the foothill portions of its tributaries was described as "one vast network of irrigating canals" (Wohl, 2001). In 1904, farmers seeking more water built the Grand River Ditch (also called the Grand Ditch) at 10,300 feet in what is now Rocky Mountain National Park. The Grand River Ditch was the first trans-basin, trans-mountain diversion that moved water from west of the Continental Divide into the South Platte River, east of the Divide (Figure 1). There are still more than 4,200 miles of canals and ditches in the South Platte basin.

The need to regulate flow accompanied the development of irrigation. To match supply to demand, and Coloradans began storing water on a large scale in the South Platte basin in the 1880s. By 1910, reservoirs to accommodate storage for over 600,000 acre-feet of water had been built. Now, Colorado has over 1,300 dams large enough to be listed in the Army Corps of Engineers national inventory.

As the dominant Front Range city, Denver began filing for municipal water rights in the Colorado River Basin (west of the Continental Divide) in the 1920s, and completed the Moffat Tunnel in 1936 to transfer more than 81,500 acre-feet of water per year through the Front Range mountains. Denver's Dillon Reservoir was completed in 1963 and stores 254,000 acre-feet of water at 9,017 feet; the associated Roberts Tunnel can transfer over 133,000 acre-feet, again from west to east of the Continental Divide, into the South Platte River Basin. Other Front Range cities have also developed substantial trans-basin diversions.

To supply a combination of agricultural and municipal needs, several new federal projects became important in the 1950s. The combination of dams, diversions, interbasin transfers, ditches, and canals has turned Colorado's rivers into an elaborate plumbing network. In 1954, the very large Colorado–Big Thompson Bureau of Reclamation Project was completed. Through a system of tunnels and canals, almost 270,000 acre-feet are transferred from the Colorado River Basin through the Front Range mountains into the South Platte Basin. The last completed large project was the Frying Pan–Arkansas Bureau of Reclamation project, bringing up to 69,000 acre-feet per year into the Arkansas River Basin.

Colorado water laws were devised to encourage water development and distribution, first for the benefit of mining and agriculture, and then to enable the "great and growing cities" to reserve huge quantities of water in anticipation of future needs. The Colorado Constitution (1876) promotes maximum use of water and guarantees the right to appropriate water. The prior appropriation system means that the oldest water right will be fulfilled first, and then the next, and so forth, so that the oldest water rights are the most reliable and therefore the most valuable.

The water distribution for agriculture and urban uses has brought trees, different wildlife, and new habitats that are treasured by urban people, as can be seen from real estate values and the enormous use of water-feature recreational areas, often created along canals and reservoirs

Recent trends in water redistribution continue to be directed towards serving the fast-growing human population. As the cost of 'new' supply and distant-source trans-basin water rises, there is increasing pressure to transfer water from agricultural to municipal uses. Because the legal, engineering, and logistical costs of moving water are high, the transfers tend to be large. In the predominantly agricultural areas of eastern Colorado, social and economic impacts of water transfers to Front Range cities can be huge (Colorado Water Conservation Board, 2004). Cumulative social and environmental impacts of such transfers have not been addressed.

The prior appropriation system also means that water rights for instream purposes, such as channel maintenance and provision of aquatic and riparian habitat, must be legally acquired like any other water right. Prior to 1970, it was not possible to obtain an instream flow water right in Colorado; today, only the Colorado Water Conservation Board is allowed to apply for or hold an instream water right (Gillilan and Brown, 1997). In most cases, rights to maintain instream flows are "junior" delivered only after all "senior" (earliest) water rights have been fulfilled.

ECOLOGICAL CONSEQUENCES

The ecological consequences of water redistribution across Colorado are wide-ranging (Strange *et al.*, 1999). Radical changes in flow regimes have dramatically altered riparian environments, particularly in low gradient, prairie portions of the major rivers. The iconic cottonwood trees and willow understory, which depended on specific flow conditions to regenerate, are severely impacted by the capture and storage of peak flows. In many areas, remnant cottonwood populations, established just before the flow regime was flattened, are senescing and not regenerating. Invasive Tamarisk and Russian Olive now flourish in the new riparian conditions. In the mountains, impacts of flow alteration on riparian vegetation remain largely unknown. Native aquatic biodiversity, including algal, insect, and fish taxa, has declined and invasive nonnative species are now dominant in most developed river systems (Baron, 2002; Strange *et al.*, 1999).

With these changes, it is helpful to visualize the ecological state of Colorado's reservoirs and rivers, such as the South Platte River and associated water bodies, as hybrid freshwater ecosystems. The South Platte River as one sees it today is the product of human and nonhuman activity – decades of human alteration have dramatically modified the hydrology, ecology, and geomorphology of the river (Crifasi, 2005). Nevertheless, a wide variety of biophysical processes continue within the constraints that human development has placed on the ecology. Riparian forests, wetlands, and South Platte's fishery are present but severely modified from earlier states. In addition, numerous novel lacustrine ecosystems are present in the thousands of reservoirs and gravel pits that were built in areas that were once dry land. These ecosystems are neither wholly natural nor wholly artificial. The contemporary South Platte River and its tributaries still contain many important natural attributes despite having been modified by several centuries of increasingly intensive human influences.

In the transition zone, where the foothills meet the prairie, we have created a new ecology from what was a steppe into what is now a pond-spotted, greened-up, highly-enriched new urban-suburban-peri-urban landscape. In one of the few studies of these changes, an astounding 99% of all standing surface water was human-made, while the human-created riparian/creekside/ditchside environments may now be more extensive than the natural riparian areas ever were. The water distribution for agriculture and urban uses has brought trees, different wildlife, and new habitats that are treasured by urban people, as can be seen from real estate values and the enormous use of water-feature recreational areas, often created along canals and reservoirs.

Across the prairies of eastern Colorado, the irrigation systems have created new habitats developed from canal seepage and return flows. Applying irrigation water via the old-fashioned canal systems creates return flows (to the river) that often amount to half of what was applied. Commonly 15-20% of the water diverted into those grand old canals of the 1880s-1890s is lost to evaporation and seepage. This explains how the amount of water diverted can be so much greater than the natural flow – the water can be and is rediverted and used many times. Water use for agriculture has also greatly modified the seasonal playas and perennial wetlands of central and eastern Colorado.

The great snow-melt floods are gone, local humidity has increased from irrigation evaporation (Baron, 2002), and the green spread over the land is far more extensive than it was prior to European settlement. Water redistribution has affected every form of biota, from plants and insects to fish, birds, and bats. Dampening of high flows, decreased rates of peak flow recession, and increased summer base flows have changed channel forms and directly impacted aquatic biota and riparian vegetation, resulting in secondary impacts to avifauna and other vertebrates. With irrigation came a rise in water tables and the development of riparian vegetation along ditches and canals. Remarkably, the changing Platte River has functioned as a dispersal corridor for eastern bird species, such as the Blue Jay, to immigrate into Colorado. In other regions, and sometimes simultaneously, the simplification of multi-storied riverine forests spells habitat loss for riparian-dependent songbirds, yet water storage reservoirs provide new refueling habitats for migrating waterfowl and shorebirds. Big brown bats have moved their maternity roosts from the Rocky Mountain foothills to the cities. The remarkable resilience of the plains wildlife, highly adapted to environmental variability, has served some species well under conditions of novel stability, except where those conditions favor newcomers and invasives.

FUTURE DIRECTIONS IN WATER REDISTRIBUTION

The growth of cities and industry in the corridor from Fort Collins south to Pueblo has accelerated the demand for municipal water. Because the most senior (earliest) water rights are largely on the Plains of eastern Colorado, flows have been maintained to deliver water downstream to them. Yet today, cities will pay a premium for all or part of these reliable "senior" rights. The definition of this "part" is complex. Legally, the return flow is part of the river; it is claimed by other water rights and therefore rights to it cannot be transferred. The only part of the river water that can be sold and moved away is what was historically consumed by crops or evaporated, often determined by engineers and lawyers in court. For the new riparian and wetland habitats created by return flows and existing habitat maintained by in-channel flows moving downstream to agricultural users, a new concern is emerging as water is redistributed once again, this time from agriculture to cities. Water rights are defended in water court in Colorado, but riparian and wetland habitats have no legal standing for protection.

Of the irrigated lands now in use, 12 to 23% or more could be affected by future water right transfers; to be economically feasible, these transfers are likely to be very large. Since most water rights are being transferred from agricultural to municipal uses, many social and environmental impacts will be geographically concentrated on the Great Plains of central and eastern Colorado. There are no environmental assessments and few predictions of the ecological consequences of these changes. Riparian and wetland habitat created by irrigation and return flows are at risk; however, restoration of native shortgrass prairie and of watersheds with historic playas and wetlands are also potential outcomes. In urbanizing areas, increased awareness and concern about environmental quality, as well as recreational opportunities and other amenities provided by instream flows, may lead to transfer of water rights that will allow more water to actually remain in natural stream and river channels. The need for information about the impacts of water development and management on riparian and wetland resources has never been greater.

REFERENCES

Baron, J.S. (Editor), 2002. Rocky Mountain Futures: An Ecological Perspective. Island Press, Washington, D.C.

Colorado Water Conservation Board, 2004. Statewide Water Supply Initiative, Phase 1 and Phase 2. http://cwcb.state.co.us/IWMD/. *Accessed* March 14, 2008.

Crifasi, R.R., 2005. Reflections in a Stock Pond: Are Anthropogenically Derived Freshwater Ecosystems Natural, Artificial, or Something Else? Environmental Management 36(5):625-639.

Gillilan, D.M. and T.C. Brown, 1997. Instream Flow Protection. Island Press, Washington, D.C.

Strange, E.M., K.D. Fausch, and A.P. Covich, 1999. Sustaining Ecosystem Services in Human-Dominated Watersheds: Biohydrology and Ecosystem Processes in the South Platte River Basin. Environmental Management 24(1):39-54.

Wohl, E., 2001. Virtual Rivers. Yale University Press, New Haven, Connecticut.

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FEATURED COLLECTION ... *Water Use From Arctic Lakes: Identification, Impacts, and Decision Support*

We are pleased to present this Featured Collection, with Paul K. Sibley and Daniel M. White as Guest Associate Editors. The collection explores how water used to support ice-road construction and related industrial activity is predominantly drawn from lakes, placing increased pressure on these water reserves and their associated biota. Subjects covered by this collection include:

- Identifying candidate lakes with synthetic aperture radar (SAR);
- Comparing SAR approaches to more traditional bathymetric soundings;
- Predicting under-ice oxygen concentrations in lakes;
- Using SAR to estimate fluxes of methane from arctic lakes;
- Changes in water chemistry characteristics in lakes subject to water withdrawal for ice-road construction; and
- A comprehensive review of the potential chemical and biological effects of water-level fluctuations in arctic lakes as a result of water-withdrawal activities.

Also,

Genevieve Briand *et al.*, look at flow augmentation plans proposed for the Snake River and evaluate their effects on farm profitability. Results from a basin-wide model of agricultural production present evidence that older water rights are used towards production of less valuable crops, and flow augmentation scenarios have unequal effects on profitability across agricultural regions.

Brett B. Roper *et al.*, report on the role of observer variation in determining Rosgen stream types. In only four streams (33%) tested did measurements from all crews in all monitoring groups yield the same stream type. They report most differences could be attributed to differences in estimates of the entrenchment ratio.

Sharon E. Clarke *et al.*, capitalizing on strengths in both field and regional digital data, modeled a synthetic stream network and a variety of hydrogeomorphic attributes for the Oregon Coastal Province. Outputs of their modeling approach have been widely used to characterize the potential of streams to provide high-quality habitat for salmonids.

Candice Piercy and Theresa Wynn compared streambank root distributions for herbaceous and woody vegetation and tried to develop empirical models to predict root density. They concluded that soil erodibility and root density should be measured in the field for design and modeling purposes, rather than estimated based on empirical relationships.

A full Table of Contents may be viewed at http://www.blackwell-synergy.com/toc/jawr/44/2

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