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The Political Ecology of Water Use and Development

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Abstract: *Political ecologists use various approaches to understand the human-environment interaction and mechanisms for environmental change. An actor-centered analysis is one approach that can provide valuable insight to first world water resource issues by providing a deeper understanding of environmental change not available through traditional policy or resource analysis. In the case study described in this paper anthropogenically modified water resource systems can be seen as resulting from the actions of all the actors who are using and appropriating water and resources in the riparian corridor. The case study uses the Boulder Creek watershed in Colorado, USA to describe how the process of Euro-American settlement and development has permanently and irreversibly altered river hydrology, ecology, and geomorphology in many western North American watersheds. The observed character of streams today represents the cumulative result of the motivation and interactions, both collectively and independently, of the various actors who have appropriated water, extracted resources, and modified the environment to meet their various needs. With over 140 years of development, the streams in the Boulder Creek watershed bear little resemblance to what once existed. The water has been fully appropriated, lakes created where there were none, native riparian vegetation replaced or dominated by introduced species, and native fish species replaced by introduced species. Additionally, the stream channels have been bridged, channelized, modified by flood control structures, inundated by reservoirs, and encroached by all forms of urbanization.*

Keywords: *Political ecology, Boulder, Colorado, water development, water appropriation, environmental change.*

Introduction

The process of Euro-American settlement and development has permanently and irreversibly altered river hydrology, ecology, and geomorphology many western North American watersheds. The character of streams today is the cumulative result of the motivation and interactions, both collectively and independently, of the various actors who have appropriated water, extracted resources, and modified the environment to meet their various needs. A deeper understanding of contemporary first world water use and development can be obtained by describing the political ecology of actors and their affects on water resources. By understanding the actors that affect water resources, anthropocentric stresses placed on water systems and the environmental manifestations of those stresses can be better understood. This paper provides a case study of water use and development in the Boulder Creek watershed (Figure 1) to look at political ecology in a first world setting.

Actors Influencing Water Resource

Management perspectives on water resource management are as variable as they are numerous, with important works centering on policy and law (Coggins and Wilkinson, 1987; Goldfarb, 1988; Getches, 1990; Western Water Policy Review Advisory Commission, 1998; Corbridge and Rice, 1999) or engineering (Dunne and Leopold, 1978; Loucks et al., 1981). However, works that bridge the political aspects of water management with the observed environmental consequences by holistically considering the actors and their impacts on hydrology and riparian corridors are conspicuously absent. Political ecology provides insight into the human motivations behind actions that take place on the ground and that alter environments and as such provides techniques to gain fresh insights on water resource management. Although there is a rich political ecology literature (Blaikie, 1985; Ferguson, 1990; Bryant and Bailey, 1997; Zimmer and Young, 1998), few studies deal explicitly with water resource management. The few studies that do address water resource management from a political ecology perspective are generally centered on the third world (Allen, 2000; Turton, 2000), although Sheridan (1995) is a notable exception.

Political ecologists use various approaches to understand the human-environment interaction and mechanisms for environmental change. The approach used here is the actor-centered analysis effectively utilized by Bryant and Bailey (1997). This approach describes the various state

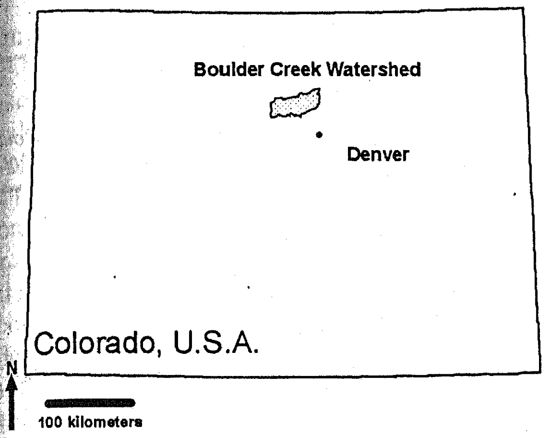

Figure 1. A map showing the location of the Boulder Creek Watershed in relation to Denver, Colorado.

and non-state actors whose actions have environmental consequences. By using an actor-centered approach in a first world setting fresh insights not available through traditional policy analysis can be achieved. Political ecologists describe environmental impacts as an outcome of unequal power relation's occurring at variable temporal and spatial scales. Furthermore, the connections and relations between actors provide insight into the types of actions taken by the actors. Thus, the underlying cause of cumulative impacts on specific environmental systems can be better understood.

While political ecology analysis provides insight to the cause of cumulative impacts, it is fundamentally different from cumulative impact analysis. Cumulative impact analysis has been defined as the impact on the environment which results from past, present, or reasonably foreseeable future actions, and includes individually minor but collectively significant actions (Preston and Bedford, 1988). Central to cumulative impact analysis is the evaluation of physical actions made to the environment at varying temporal and spatial scales through direct synergistic and incremental actions. Political ecology, however, deals with the materialistic motivations both political and economic that lead to the physical actions that are the subject of cumulative impact analysis. For this reason political ecology provides a useful tool for policy analysts interested in modifying the underlying motivations for particular actions.

In the Boulder Creek watershed, key actors involved in water resource management include the various levels of government, business interests, nongovernmental organizations, and grassroots individuals and interests. A notable departure from the third world is absence from the local scene of multilateral organizations such as the Word Bank and International Monetary Fund. Although local and regional actors are responsible for development on the ground, the forces of globalization and international trade are likely the ultimate stimulus for growth in this region. In the 1990s trade globalization coupled with access to transportation and communications infrastructure and the availability of an educated work force influenced computer software and high technology industries to locate offices and plants in the Boulder-Denver transportation corridor.

Boulder Creek Watershed, Boulder County, Colorado, USA

In the 1990s Boulder County was one of the fastest growing counties in the United States. Because of the growth in jobs in the high technology sector coupled with a perceived high quality of life available in the area, various communities in the county experienced unprecedented growth. The United States 2000 census data shows that the Boulder County population grew 29 percent from 225,339 in 1990 to 291,288 in 2000. Many of these people live in the Boulder Creek watershed. This population growth led to large increase in water demand and changes in water use patterns. Table 1 depicts estimated water use for municipalities in the Boulder Creek watershed based on per capita water use of 0.62 meters^3 per person per day in 1990 and 0.57 meters^3 per person per day in 2000 for the City of Boulder (data adapted from Heaney et al., 1999). Decreased per capita use is likely due to higher population density and effectiveness of conservation measures.

As for the streams, the hydrology in the Boulder Creek watershed is dominated by snowmelt and by summer thunderstorms. For the streams that arise near the continental divide the snow melt is the dominant influence on stream flow. For streams that arise at elevations of about 2,285 to 2,598 meters (7,500 to 8,500 feet) or less, thunderstorms are the dominant influence on stream flow.

The Boulder Creek watershed rises to over 3,960 meters (13,000 feet) along the continental divide. Above the town of Nederland, tributaries of Boulder Creek flow through glacial valleys. Below Nederland, Boulder Creek flows through a heavily timbered canyon. The City of Boulder lies at the mouth of the canyon. East of the City of Boulder, Boulder Creek flows through the high plains and joins with St. Vrain Creek at an elevation of about 1,460 meters (4,800 feet). Boulder Creek has three major tributaries, North, Middle, and South Boulder Creeks, that contribute approximately 20, 30, and 39 percent, respectively, of the basin's average natural flow of approximately 172,690,000 meters^3 (140,000 acre-feet) of water per year. Coal Creek is an important tributary because of its length, but because its headwaters are at a maximum elevation of only about 3,350 meters (11,000 feet) snow melt contributes less water which results in this creek contributing only about one percent of the total flow in the basin.

Natural flows in Boulder Creek typically range from a peak of over 11.3 meters^3/ second (400 cubic feet per/ second) in June to a low of less than 1.4 meters^3/ second (50 cubic feet/second) in January or February. However, water storage and delivery operations now dominate Boulder Creek's hydrology.

Table 1. Population and Estimated Domestic Water Consumption in Boulder County Communities

	Total Population 1990	*Water Use of Citizens in meters³ (acre-feet) based on .62 meters³ per person per day*	*Total Population 2000*	*Water Use in meters³ (acre-feet) based on .57 meters³ per person per day*	*Increase in Domestic Water Use 1990–2000*
Superior	255	57,699 (47)	9,011	1,879,163 (1,523)	3434%
Erie	1,258	284,649 (231)	6,291	1,311,931 (1,604)	400%
Lafayette	14,548	3,291,788 (2,671)	23,197	4,837,525 (3,922)	59%
Nederland	1,099	248,672 (202)	1,394	290,706 (236)	27%
Broomfield	24,638	5,574,860 (4,524)	38,272	7,981,280 (6,470)	55%
Louisville	12,361	2,796,933 (2,270)	18,937	3,949,140 (3,202)	53%
Longmont	51,555	11,665,391 (9,467)	71,093	14,825,802 (12,019)	38%
Boulder	83,312	18,851,073 (15,298)	94,673	19,743,198 (16,006)	14%

The riparian zones associated with streams in the Boulder Creek watershed have been permanently altered by development. Since the 1840s, streams in the Front Range of Colorado, Boulder Creek included, have been systematically modified by the activities of fur trappers, placer miners, road and railroad construction, timber harvesting and railroad tie drives, grazing and recreation (Wohl, 2001). These activities, along with the water management and urban development impacts described in this paper have led to the transformation of Boulder watershed streams. For example, a riparian vegetation study performed near the City of Boulder (Gershman, 1999) found that only one of the four most common trees are native, with riparian forests being dominated by crack willow (*Salix fragilis*, introduced), plains cottonwood (*Populus deltoides monilifers*, native), green ash (*Fraxinus pensylvanica lanceolata*, introduced), and Russian olive (*Elaeagnus angustifolia*, introduced). Furthermore, of 28 species of mature trees recorded, 11 were introduced, 11 were cultivated varieties that have been naturalized or planted, and just six are native. In the same study, there were 105 exotic and 98 native herbaceous species recorded, with the vast majority of the common herbaceous species being weedy exotic plants. The majority of the introduced species are development related being either escaped ornamentals or weeds that have spread out of disturbed areas. In a study of avian diversity on streams near the City of Boulder it was determined that "open space and undeveloped reaches were found to have higher richness and biodiversity value than residentially and commercially developed reaches" (Stone, 1999).

Modifications are not limited to the riparian vegetation. Fish habitat alteration in Colorado has occurred from mining and industrial activities in the stream bed, industrial and municipal discharges, urbanization, nonpoint agricultural discharge, channelization, and dewatering (Woodling, 1985), activities that have all occurred in the Boulder Creek watershed. The fishery in the Boulder creek watershed has also been altered by deliberate species introductions and by an accidental introduction of fish disease. By summarizing fish survey data in the watershed (Bestegen and Kondratieff, 1996; Nestle, et al., 1997; VanBuren, 1999) it can be seen that today 38 percent of the fish, 26 species, currently present in the watershed have been introduced (Table 2). Two additional native fish species are known to be exterpiated from the South Platte basin and 11 more were found in the South Platte River and its tributaries (Nestler et al., 1997) but not in the Boulder Creek watershed. Since Boulder Creek is a tributary of the South Platte,

Table 2. Fish Species in Lakes and Tributaries Found in Recent Inventories that Include Boulder, South Boulder, and Coal Creeks

Abundance	*Species*	*Scientific Name*
Abundant	Flathead Minnow	*Pimephales promelas*
	Longnose Dace	*Rhinichtys cataractae*
	White Sucker	*Catostomus commersoni*
	Creek Chub	*Semotilus atromaculatus*
	Sand Shiner	*Notropis stramineus*
Common	Longnose Sucker	*Catostomus catostomus*
	Stoneroller	*Campostoma anomalum*
	Green Sunfish	*Lepomis cyanellus*
	Johnny Darter	*Etheostoma nigrum*
	Iowa Darter	*Etheostoma exile*
	Plains Topminnow	*Fundulus sciadicus*
Uncommon	Common Shiner	*Luxilus cornutus*
	Greenback cutthroat trout	*Oncorhynchus clarki stomias*
	Brassy Minnow	*Hybognathus hankinsoni*
	Brown Trout	*Salmo trutta*
	Largemouth Bass	*Micropterus salmoides*
Introduced	Rainbow Trout	*Oncorhynchusmykiss*
	Black Crappie	*Pomoxis nigromaculatus*
	Bluegill	*Lepomis macrochirus*
	Yellow perch	*Perca flavescens*
	White crappie	*Pomoxis annularis*
	Pumpkinseed	*Lepomis gibbosus*
	Mosquito fish	*Gambusia affinis*
	Golden shiner	Notemigonus crysoleucas
	Tiger Muskie	Esox luciusx Esox masquinongy
	Common Carp	*Cyprinus carpio*

Source: Nestler et al., 1997; Bestegen and Kondratieff, 1996; VanBuren, 1999.

as many as 13 additional fish species may have once been present, but since comprehensive surveys were never undertaken before the advent of development the actual number will never be known.

A further aquatic impact is the introduction of fish disease. The Colorado Division of Wildlife is believed to be responsible for accidentally importing whirling disease (*Myxobolus cerebralis*) into the basin by stocking diseased fish. Whirling disease affects salmonids, especially rainbow and cutthroat trout, and is caused by a microscopic parasite (Schisler, 2000). Furthermore, the highly invasive aquatic weed, Eurasian watermilfoil (*Myriophyllum spicatum L.*) was discovered in Boulder Creek in 2001 and poses an as yet unquantified threat to endemic aquatic vegetation.

Water Rights and the Appropriation of Water in the Boulder Creek Watershed.

Modifications to native flows have occurred since 1859 by the diversion and storage of water for agricultural, municipal, and industrial water uses. Colorado's use of the prior appropriation doctrine for the creation and administration of water rights dominates every aspect of water use and development.

By the late 1860s all available water from direct flow sources were essentially appropriated. Figure 2 shows cumulative appropriations on South Boulder Creek as an example. This figure does not distinguish particular dates during the year for individual appropriations. Although numerous appropriations were made since the 1860s, these later appropriations are in priority only during periods of high stream flow and are therefore of low reliability for many uses. Many direct flow appropriations from the mid-1870s onward are also related to the construction of dams in which these water rights are stored for later use.

The unreliability of the junior direct flow water rights are demonstrated by the decreasing number of days that water was run in ditches during wet, dry, and average flow years. Figure 3 shows the relationship between the average number of days water was run in ditches over a 50-year period versus the water right appropriation date for those ditches. Generally the number of days a ditch is run is related to the needs of water users on the ditches and the "call" on the river, or the priority date that can be satisfied by available flows. When a senior call is made all junior appropriators affected by that call have their headgates closed by the water commissioner, the state official that administers water right priorities. The number of days a ditch is run may also be affected to operational issues on the ditch.

In response to decreasing reliability of direct flow rights, water users began to construct dams and reservoirs to collect water that was not being used during the winter, the spring snow melt runoff, and other times of high flows. Appropriation of storage rights in the Boulder Creek watershed began in the 1870s and is illustrated by Figure 4, which shows the cumulative storage rights versus appropriated date for South Boulder Creek.

Once direct flow and storage rights were appropriated, development requiring water could only take place by importing water into the basin, developing low yield aquifers, or transferring water from one use to another. The process of importing water began with the creation of the Northern Colorado Water Conservancy District and the construction of the U.S. Bureau of Reclamation Colorado-Big Thompson (CBT) Project in 1936. Coincidentally, while the CBT project began importing water into

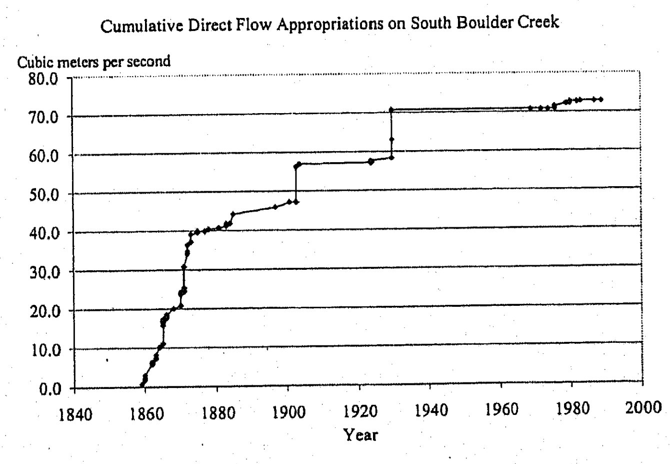

Figure 2. During the 1860s, direct flows were rapidly developed under the prior appropriation doctrine. On South Border Creek, the rate of appropriations declined when the reliability of water from direct flow sources diminished. Nevertheless, direct flow appropriations continued and are mostly associated with filling reservoirs. This figure does not distinguish dates during the year when particular appropriations were made.

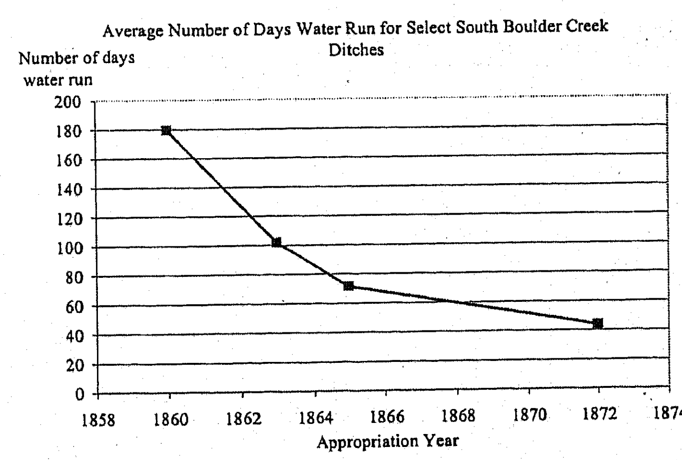

Figure 3. The figure demonstrates the fundamental nature of the prior appropriation doctrine in that water rights of senior water right holders are more reliable than that of junior water right holders. This relationship is shown for ditches with no storage on Boulder and South Boulder Creeks, and is based on 50 years of data.

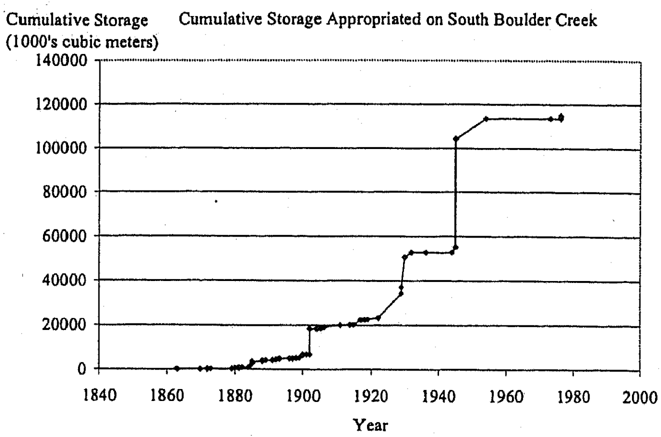

Figure 4. As junior direct flow rights became more unreliable, water users began to construct dams and reservoirs to store water during seasons of higher availability for later use. The appropriation of storage rights in the Boulder Creek watershed begain in the 1870s and is illustrated by the cumulative storage rights versus appropriation date for South Boulder Creek.

the north side of the basin, the City of Denver constructed a diversion to export water from South Boulder Creek and Colorado River sources. Once surface water rights were completely appropriated the transfer of water rights from agriculture to municipal and industrial uses became the most important source of water to satisfy new development. The few low yield aquifers that exist have never been an important water source.

The number of water right changes that have been made to individually named water rights illustrates transfer of water rights from one use to another. In the Boulder Creek Basin as a whole, there were 2,111 individually named water rights existing by the end of 1991. Of that number there are an additional 3,471 changes to those named water rights (Table 3). These change cases include abandonments, changes in point or time of use, and augmentation. What is notable is that many of the changes involve only parts of individual water rights, such as when a municipality transfers the water associated with shares it owns in a ditch company to its municipal intake without changing the shares of other shareholders in the ditch.

Lakes and Ponds in the Boulder Creek Watershed

In addition to alterations in stream hydrology, the creation of lakes where there had been essentially none adds a new feature to the landscape. It is commonly noted that there are few natural lakes in the high plains of Colorado, with the vast majority of water bodies having been constructed. To my knowledge up until now no quantification of the relative types, numbers and sizes of lakes and ponds have ever been undertaken. Yet collecting data of this type provides a richer insight into the actors affecting water resources and the relative importance of their actions.

Table 3. Numbers of Named Water Rights and Changes to those Water Rghts in the Boulder Creek Watershed*

Stream	*Number of Individually Named Water Rights*	*Number of Water Rights Changed to Named Water Rights*
Boulder Creek	206	533
South Boulder Creek	179	919
Middle Boulder Creek	25	48
North Boulder Creek	30	57
Coal Creek	85	149
Springs	183	202
Groundwater	944	1,016
Other Tributaries	459	547
Total Boulder Creek Basin	2,111	3,471

*Information for several small tributary streams is not included. Data is current through 1991.

Overall there are 1,262 lakes and reservoirs that have been identified in the watershed, of which 850 lie east of the mountain front. East of the mountains within the Boulder Creek watershed farmers, ranchers, gravel mining interests, and coal mining interests were responsible for the construction of most water bodies. Only later on did municipalities play a greater role and this was largely through the purchase and transfer of rights in reservoirs from farms and ranches.

In 1999 and 2000, 176 lakes, ponds, and reservoirs were visited as part of a comprehensive water resources inventory for the City of Boulder Open Space and Mountain Parks Department. This number of lakes represents all open water bodies that could be identified using high-resolution orthophotography that was flown in 1993 on the approximately 14,975 hectares (37,000 acres) of land owned and managed by the department. This survey represents 14 percent of all lakes in the watershed, or 21 percent of the lakes east of the mountain front. Since some of the lakes in the mountains are of glacial origin this survey is not representative of the situation in the western part of the watershed. I believe that this survey does provide a representative sample of lakes on the high plains east of the mountains, because the water bodies in the surveyed area were already present when the Boulder Open Space and Mountain Parks Department began purchasing the land from private parties in 1967.

Using the inventory data, all open water bodies were characterized as to whether the water body is a permanent year round feature or if it is ephemeral in nature. All open water bodies were also characterized by its origin, such as a natural feature, gravel pit pond, stock pond, reservoir, and so forth. By characterizing the origin of the water bodies, an insight into the types of actors and their relative importance for creating open water bodies can be inferred. The data indicates that by area natural lakes consist of less than 1 percent of the total surface area (Table 4). This number is consistent with early survey maps of

Table 4. Few Natural Lakes Exist East of the Mountains in the Boulder Creek Watershed - Surveying the Types of Lakes Present Provide an Insight into the Relative Importance of Various Actors in Creating Lakes in this Semiarid Region

Lake Type	*Total Area (hectares)*	*Percent of Total by Lake Area*	*Total by Lake Type*	*Percent of Total by Lake Type*
Stock Pond	12.3	2.7	64	38.1
Storm water retention pond	0.6	0.1	1	0.6
Tailings Pond	0.5	0.1	7	4.2
Gravel pit pond	111.4	24.4	60	35.7
Natural	3.5	0.8	13	7.7
Other	1.9	0.4	14	8.3
Reservoir	325.9	71.5	9	5.4
Total Area	456.1	0.0	168	100.0

Boulder Valley, which are conspicuous for their lack of natural lakes. This number also indicates the vast increase in the amount of surface water present as a result of human actions. In contrast, reservoirs constitute 72 percent of the area, gravel pit ponds 24 percent of the area, and stock ponds 3 percent of the area.

By using an average gross evaporation value for the Boulder Creek watershed (Farnsworth et al., 1982) and a long term average precipitation of 36 cm, evaporation from lakes on the high plains portion of the Boulder Creek watershed is estimated at about 4,751,000 meters^3 per year. Evaporation from lakes in the high plains portion of the watershed is equivalent to about 2.8 percent of the surface water flow in the basin.

When quantified by the number of water bodies that are present, natural water bodies (oxbow lakes and wind blow-outs) represent just 8 percent of the total, whereas stock ponds are most abundant at 36 percent, gravel pit ponds at 36 percent, and reservoirs at 4 percent of the total (Table 4). Of the lakes and ponds present, 84 percent were determined to be permanent water bodies and the remaining 16 percent are ephemeral.

Actors Influencing and Developing Water in the Boulder Creek Watershed

Now that major changes to the riparian ecology and hydrology of the Boulder Creek watershed have been identified, the focus will shift to the various actors and their political networks that have had roles in the observed changes. Using an actor-centered analysis to understand development is not new. Navarez (1996) effectively used an actor-centered analysis by identifying the motivations and techniques of manipulation that lead to the County of Santa Barbara, California into hooking up to the State Water Project. This paper's approach is to relate how the various actors have effected the environment, and not just evaluate the politics of water development. What follows is a summary of the roles and impacts of various government, business, nongovernment organizations, and grass roots actors that are at work in the Boulder Creek watershed.

Government Actors

Government actors influencing water management in the Boulder Creek watershed include federal, state, and local divisions of government along with quasi-governmental organizations that possess certain limited state powers. Each government actor generally has well-defined roles and authority to perform specific water related management actions. Their management actions result in clearly identifiable hydrologic and riparian impacts.

Contrary to the situation in other parts of the west (Worster, 1985; Reisner, 1986), the federal role in water development is limited and largely indirect and has had little day-to-day impact on water management decisions. It is beyond the scope of this paper to provide an exhaustive description of the various federal actors and their local consequences so the description will be limited to a brief description of the single most influential federal actor.

The U.S. Department of Interior Bureau of Reclamation through its Colorado Big Thompson Project (CBT) diverts Colorado River water into the east slope of Colorado including the Boulder Creek basin for municipal and agricultural uses. Because of the CBT project, the Bureau of Reclamation has supported sprawl in the basin in communities like Superior, Erie, and Broomfield that rely on CBT water for their growth. All other federal actors have an indirect role in water management that is generally limited to permitting or oversight of water quality and quantity matters, or water management decisions effecting national forests and endangered species.

At the state level, since its inception Colorado has fostered the appropriation and administration of water resources for use by agricultural, municipal, and industrial interests. Actions by the State Legislature, Courts, and Executive Branch have had a profound but indirect affect on streams and riparian areas in Boulder County. Conversely, the state has also played role in protecting riparian corridors by appropriating minimum instream flows and acquiring some riparian habitat. Colorado is unique among western states in that the courts and not the executive branch approve all new water right applications. Externalities other than impacts to other water right holders are not considered in the water court process. Therefore, environmental impacts of water appropriation and use are externalized from the granting or changing of water rights and are effectively a state subsidy for water development.

One State entity, the Colorado Water Conservation Board (CWCB) is responsible for administering Colorado's instream flow program. Since instream flow rights were first created in 1974, they are almost entirely junior to other water rights unless senior water rights are donated to the program. Instream flow rights nevertheless prevent the deterioration of water quantities below a certain threshold suitable for aquatic habitat from junior diversions, but do nothing to prevent depletion's from senior appropriators. The CWCB places great emphasis on local support for instream flow appropriations which has led to appropriating instream flow rights on Boulder, South Boulder, North Boulder, and several other high elevation streams in the basin. However the CWCB is also risk adverse and tends to back away from making any instream appropriations that may interfere the future diversion plans of water developers.

Another state agency, the Colorado Department of Transportation, is responsible for extensive riparian impacts. On South Boulder Creek alone, the department manages at least three state and one federal highway bridges. An additional 14 Boulder County and four City of Boulder bridges along with numerous roads within the riparian zone have had long term impacts to geomorphology and riparian vegetation.

The state has also had wildlife impacts with its Division of Wildlife being responsible for introducing numerous non-native fishes into the Boulder Creek watershed to satisfy recreational fishing interests. These introductions have led to competition with and decline of native fish species. The spread of whirling disease has also contributed to the decline of the federally threatened native greenback cutthroat trout (*Oncorhynchus clarki stomias*).

Also significant within the basin are strong state connections between the aggregate and mining industries with the Mined Land Reclamation Board (MLRB) that approves mining permit applications and mined land reclamation plans. The MLRB has issued permits authorizing mining along Coal, South Boulder, and Boulder creeks, which has permanently altered the character of the riparian environment.

In Colorado, county governments are also responsible for numerous riparian impacts. However, county governments are generally not in the water supply business, and Boulder County is no exception. Thus the county role in modification of area streams is limited to land use planning and approval of water construction projects in areas under its jurisdiction. Additionally, with the strong support of the environmental community, the county has included wildlife habitat preservation into comprehensive plans and has developed an open space program that is funded by the acquisition of farms and water rights along Boulder Creek.

More than any other level of government, municipalities have overwhelmingly supported development, diversion and use of water, and construction in and use of riparian corridors. Environmental preservation is generally of secondary importance when transportation, utilities, and recreational development are proposed in riparian corridors.

Municipal public works and utility departments have aggressively worked to meet growing demand for water through conversions of water rights and importation of water into the basin. With the notable exception of an instream flow program developed by the City of Boulder Utility Department, no other municipality in the County provide water or manage its water resources for any instream purposes. The City of Boulder's instream flow program has sustained flows through the city, but the program nevertheless allows instream flow water rights to be diverted to municipal uses in times of drought.

Undeveloped and agricultural land has also been acquired by municipalities for open space purposes since the City of Boulder first dedicated a sales tax for open space purposes in 1967. Consequently the City of Boulder Open Space and Mountain Parks department now owns significant amounts of riparian land (Crifasi, 1999) and is also the single largest owner of agricultural water rights in the basin.

Another municipal actor is the City of Denver, which constructed the South Boulder Diversion Canal and other facilities in 1936 to transport Colorado River and South Boulder Creek water to Denver. Denver also completed Gross Reservoir in 1951 on South Boulder Creek. To improve water delivery efficiency, Denver channelized approximately 23 kilometers of South Boulder Creek. All of Denver's projects are operated as one unit of its water system. Overall, Denver's projects have modified the geomorphology, depleted water below its facilities, increased flows above its facilities, inundated portions of the stream, and modified water temperatures on South Boulder Creek.

Several quasi-governmental agencies that are chartered under Colorado State Law operate in the Boulder Creek watershed. These quasi-governmental agencies hold certain powers of condemnation, and may have limited taxing authority. Boards of these agencies are not elected but appointed and thereby have little accountability to voters. Districts are often controlled or organized by development interests and implement projects to meet specific development agendas. After all, who would organize a district if they did not want it to take actions benefiting the actors that organized the district in the first place?

One such quasi-governmental agency is the Northern Colorado Water Conservancy District that was created in 1936 to import Colorado River water from the Bureau of Reclamation's Colorado Big-Thompson project to the east slope of Colorado. The district serves seven Colorado counties, including Boulder. A judicially-appointed board of directors oversees operations of the district. Judicial appointments have been criticized by environmental NGO's who maintain that water development decisions need greater transparency and public scrutiny, whereas water users and development interests maintain that decisions should be in the hands of professional water managers who are not influenced by short term political considerations. In the Boulder Creek basin, the district manages Boulder Reservoir, the Boulder Feeder Canal, Boulder

Creek Supply Canal, and the South Platte Supply Canal. With numerous water supply facilities and limited public oversight, the Northern Colorado Water Conservancy District is a major supporter of development that has had substantial impacts on riparian systems in the basin.

Another quasi-governmental district is the Left Hand Water District, which is the principle provider of treated water in unincorporated areas of Boulder County. The Left Hand Water district is essentially the only option for developers and owners of land who wish to be hooked up to a water utility but are not eligible for service from municipal utilities. By acquiring and developing water supplies to meet and expand its service the Left Hand Water District supports growth within its district boundaries. Although the Left Hand Water District does not divert water from Boulder Creek, water taps it has sold has contributed to development within the riparian zone of Boulder Creek.

Business Interests

Business interests with the greatest direct effects on water and the riparian zone include ditch companies, subdivision and business developers, electricity producers, and the rock products industry. Many of these companies however are catering to local demands generated by a robust economy that is powered by the global forces that brought high technology and computer services businesses to the Boulder Valley.

Ditch companies have traditionally been part of the agricultural sector, but as urbanization has progressed in the basin, the ownership in many of these companies has shifted away from agriculture and toward municipal use. There are approximately 49 incorporated and unincorporated ditch companies active in Boulder County. The incorporated ditch companies are generally not for profit corporations chartered under the laws of the State of Colorado, while the unincorporated ditches are owned by deed by individuals and municipalities. The mission of ditch companies is to deliver water to shareholders. Shareholders in ditch companies own a pro-rata interest in the companies water rights and facilities. Instream flows and riparian ecosystem considerations are rarely considered in the operation of these companies. Indeed, the pressure to incorporate environmentally-sensitive management practices is often seen as a threat to the operation of these companies and is vigorously resisted.

Many ditch companies were originally created to serve water to arid lands not suitable for agriculture. By delivering water to arid lands, land speculators and developers were able to market land to farmers and ranchers and make a profit from the added value the water brought to the land. Entrepreneurial agricultural developers, farmers, and ranchers built most ditches in the Boulder concurrently with the expulsion of native Americans from the area. Today, established agriculture is in decline and is becoming less viable as rising land and water prices make new entrants into the agricultural sector uncommon. By the year 2000, majority ownership in many ditch companies has shifted toward municipalities and industries and away from agriculture as irrigated lands were urbanized (Table 5). For example, Farmers Ditch Company incorporated in 1863 delivered water wholly to local farmers and ranchers. The City of Boulder today owns approximately 72 percent of the company with the remaining shares owned by ranchers, farmers, and homeowners who irrigate turf.

Yet ditch companies were and remain agents of change. By diverting water, constructing headgates and diversion dams and by maintaining the ditch and appurtenant facilities, ditch companies have permanently altered riparian hydrology and ecology. Ironically, the ditches themselves are important for maintaining riparian vegetation and now contain approximately 18 to 20 percent of the riparian tree and shrub vegetation found on City of Boulder open space lands.

Much of the pressure to convert agricultural ditch shares to municipal use originate with subdivision developers who work with municipal governments to built tract homes in their jurisdictions. Subdivision developers typically purchase a farm or ranch and any associated water rights to develop the property. Numerous sprawl-related water and riparian impacts occur as result of this development. This includes the transfer of water rights from agricultural uses to municipal use, changes in the consumption pattern of the transferred water, location of return flows and water quality of water passed through water treatment plants. Increased impervious surfaces also affect the timing and magnitude of storm runoff. A substantial amount of the water imported into the basin has occurred to meet the demands of subdivision developers. Other impacts are non-point water pollution and floodplain encroachment. Further impacts from subdivisions to the riparian zone are from the escape of ornamental plants, roving cats

Table 5. Originally Each of the Ditches Listed Below Were Only Delivering Water for Agricultural Purposes*

Ditch Company	*Percent Private*	*Percent Municipal*	*Percent Industrial*	*Percent Institutional*
Andrews Farwell	81.0	8.0	0.0	11.0
Jones Donnelly	23.5	21.2	54.5	0.8
Leyner Cottonwood	59.9	39.2	0.1	0.8
Dry Creek #2	23.5	73.5	2.2	0.8
Dry Creek Davidson	57.1	42.9	0.0	0.0
East Boulder Ditch	7.0	4.1	88.9	0.0
Farmers Ditch	27.5	72.5	0.0	0.0
Green	45.3	54.7	0.0	0.0
Howard	7.5	88.1	1.8	2.5
Average	36.9	44.9	16.4	1.8
Standard Deviation	25.4	29.9	32.5	3.6

*Ownership information is current through 2000. The percentage of private ownership includes ranches and farms.

and dogs, and recreational developments such as trails.

Two general mechanisms are used to transfer water from agriculture to municipal uses. In the first mechanism, developers initially acquire land and associated water rights for projects. As part of the development approval or annexation process, the developer then transfers title to the water rights to the city. The city in turn brings the water rights through the water court process to transfer the water to municipal uses. Additional development fees are then levied to build the distribution system that the developer needs. Finally, the transferred water is incorporated in the municipal system and served to the development.

In the second mechanism, the developer pays tap fees to the municipality to obtain a water supply for the development. The municipality uses the tap fees to acquire water and build infrastructure that the developer then uses to supply the development. In some instances the tap fees are used to buy the very water rights that came off the developed land.

Numerous developers are operating in the region and are cooperating with cities to pursue development that will expand the tax base. For example, the City of Broomfield is reported (Obmascik, 2001) to have paid a tax subsidy to the Flatiron Crossing mall developer in excess of US$279 million dollars. The subsidy is intended to offset the cost of water, sewer, roads, and other infrastructure that smaller developments are normally required to pay. Additionally the Flatiron Crossing mall developer received a cap on water and sewer fees worth in excess of $50,000 per year. In short, cities cooperate with developers and compete against other area cities by providing essentially free water and sewer service at the ultimate expense of the riparian environment.

Yet another development related business actor with significant impacts to the riparian zone is the aggregate mining industry. As mentioned earlier, 36 percent of the water bodies present east of the mountains are former gravel mine sites. Industry groups such as the Colorado Rock Products Association advocate aggregate mining for their clients, effectively lobbying the Colorado Legislature and the MLRB for laws and regulations favorable to the industry.

The electric power generation industry has also impacted water resources in the basin. Barker Dam, a hydroelectric power plant built in 1906, has resulted in the inundated and dewatered parts of Middle Boulder Creek and modified downstream diurnal flow patterns. A thermal electric power plant in the basin also consumes water for cooling. Water supplies needed for power generation came from new appropriations, transfers from agriculture, and importation from the Northern Colorado Water Conservancy district.

Development in the watershed have been indirectly supported by various, "wise use" and industry advocacy groups such as the Colorado Farm Bureau, Colorado Cattlemen's Association, Colorado Rock Products Association, Colorado Water Congress, and the Colorado Home Builders Association. These organizations have also been very effective in blocking growth management legislation that would benefit instream uses of water and the preservation of riparian corridors.

Non-Governmental Organizations (NGO's)

Environmental NGO's have, at the federal level, provided a force to protect wetlands and water quality, and may serve to protect riparian corridors by suing to list riparian species under the federal Endangered Species Act.

NGO's have been of minor importance locally in affecting hydrology but have been slightly more effective in modifying the pattern of development near select riparian areas. Environmental NGO's have advocated but have had little effect in the implementation of growth control measures that would reduce growth impacts to water and riparian corridors. For example, the Colorado Environmental Coalition in 2000 was able to organize a citizen's initiative to place a growth control measure on the state ballot. That ballot measure would have prevented cities from serving water outside of their urban service area to new developments without public review. The measure was subsequently defeated at the polls in the aftermath vigorous opposition by certain legislators and overwhelming spending in opposition by development interests.

Besides addressing sprawl, a lawsuit brought by another NGO, the Biodiversity Legal Foundation, led to the federal listing of the Preble's meadow jumping mouse (*Zapus hudsonius preblei*) as a federally threatened species. This mouse is almost exclusively found in riparian areas. Since a large population of the mouse is found on South Boulder Creek, the federal protections afforded to the mouse will likely affect future development patterns on this stream.

Grassroots Actors

Grassroots actors such as ranchers and farmers were some of the original agents of change in the Boulder Creek watershed. Today their ongoing impact is diminishing as land is sold for development or to open space programs. However, most of the remaining undeveloped land or land that is not owned by an open space program east of the mountains is in agricultural use. Although ranchers and farmers provide the benefit of open spaces to nearby urban residents, their management often includes intensive grazing and farming within the riparian corridor and use of water delivered through ditches.

Various locally based environmental groups, local landowners, and recreational users also affect the riparian zone. One local group, Plan Boulder, is an advocate for quality of life issues in Boulder Valley and has been active in the creation of both the City of Boulder and Boulder County open space programs. These open space programs in turn have been effective in limiting sprawl in the vicinity of the City of Boulder. This has led developers to shop for more willing municipal partners in the eastern part of Boulder County. The net effect is that open space and riparian values are protected in some areas and damaged in others as the pattern of sprawl shifts eastward in the watershed.

Discussion

Various political and economic development forces have profoundly and permanently altered river systems in the western United States. From the earliest days of Euro-American settlement riparian resources have been appropriated for private benefit either directly or indirectly through government support of private development. Political ecology provides techniques whereby the on the ground impacts can be understood as an interaction of a rich variety of actors.

Development in general has been described as "for the most part – a top-down, ethnocentric, and technocratic approach, which treated people and cultures as abstract concepts, statistical figures to be moved up and down in the charts of 'progress'" (Escobar, 1995). Water development has also been described as a top-down effort, that if not initiated by some elite, the water developers themselves quickly become the elite and go on to wield despotic power (Wittfogel, 1957). Similarly, in the Western United States, water development has been described as a top down, state dominated process (Worster, 1985; Reisner, 1986).

However on a closer examination others (Murray, 1996; 1999; Bebbington, 2000; Blakie, 2000) see development as a rich and somewhat chaotic process with complex interactions, hybridization's, and power relations between the various actors at all levels. Sheridan (1995) seems to mirror this perspective in his study of water development in Arizona. The Boulder Creek case study supports the view that water development and its environmental effects are the result of complex interaction between various actors with differential power relations. By focusing on the actors and their impacts a better understanding of why and for whom water development occurs can be ascertained.

Rapidly growing cities in the watershed will continue to develop water supplies by transferring water from agricultural sources and by importing water into the basin. The smallest cities have had the greatest percentage growth in population and water use over the past decade. Much of this growth can be attributed to global forces that have brought high technology jobs to the Boulder-Denver corridor. Numerous externalities from this development have resulted, from the replacement of native species by exotic introductions to the modification of stream flow, the creation of lakes and the permanent alteration of the riparian corridor.

The state, business interests, NGO's, and grassroots actors have together profoundly altered the riparian and hydrologic environment by the various activities they pursue. This occurs simultaneously independently, in concert and at odds with one another. State and business actors and select grassroots actors have vigorously pursued development and appropriation of water resources. In terms of over all impact, it appears that business, local government, and quasi-governmental interests have had the most profound impact on hydrology and riparian resources. Federal and state government interests have set the policy framework for development in the Boulder Creek basin, and non-governmental and grassroots interests have done little more than affect the pattern of development by influencing local government actions. Collaboration between local governments and business actors has resulted in a shift in water from agricultural to municipal use and has led to the construction of roads, subdivisions, utilities, and business activities within riparian corridors. Mining interests continue to extract aggregate along riparian corridors to support this growth but these impacts will diminish as these resources are depleted in the watershed. Interestingly water is being exported from the basin by some interests and imported into it by others. Overall, development has resulted in further depletion of water from streams, has altered the pattern, location and timing of runoff, and has impacted water quality. Yet developers will continue to benefit from the appropriation and removal of water from the stream and the transfer of it from agricultural use, but have no responsibility for addressing the environmental externalities of their actions.

With over 140 years of development the streams present in the Boulder Creek watershed bear little resemblance to what once existed. The water has been appropriated, lakes created, riparian vegetation is dominated by introduced species, and about 38 perdent of the fish species present were introduced as well. And the stream channels have been bridged, channelized, modified by flood control structures, inundated by reservoirs, and encroached by urbanization. There is no indication that this process of development and environmental change will slow. Development has shifted the riparian ecosystem toward a new transient state, and perhaps the only way to predict what the system will look like over the next 140 years is to try to anticipate who the actors will be and how their actions will be manifested on the ground. The land-use and water-use history has resulted in a degraded and unsustainable aquatic and riparian ecosystem in today's Boulder Creek Basin, a situation that is mimicked in many parts of the American West.

In conclusion, the actor-centered evaluation of water use in a river basin helps present a more complete overview than is possible by only looking at water resources from a policy, engineering, or legal perspective or by an analysis of single projects, government agencies, or biological resources.

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