Linking Policy Changes and Resource Management Decisions: A Game Theoretic Analysis of Coordinated Water Management in Colorado *

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Introduction

Water suppliers and providers in the Western United States face difficult management and policy choices regarding the most effective and efficient use of scarce water resources. Conflicts among various consumptive needs are growing, while available sources of water are limited. This dilemma is complicated by the fact that periods of highest consumptive needs usually come during the driest seasons. In some areas of the West, water providers have responded to these problems by coordinating the management of groundwater and surface water ("conjunctive water management"). One of the factors that affects the ability of water providers to coordinate the management of ground and surface water resources are the institutional arrangements, or rules of operation and policies, under which they must operate (Blomquist 1992; US ACIR 1991, Western States Water Council 1990).

The purpose of this paper is to evaluate the policies governing ground and surface water in two major watersheds in the state of Colorado – the South Platte River basin and the Arkansas River basin (depicted in Appendix A) – and their effects on coordinated water management. I first discuss the physical and institutional setting surrounding the management of ground and surface water supplies in the two basins. Second, I outline the evolution of coordinated water management strategies in the two basins over the past thirty years. I then analyze the decisions to engage in coordinated management in relation to their institutional setting using different game theoretic modes of interaction.

Problems of Appropriation: Groundwater and Surface Water Interaction

Colorado is a semi-arid state, receiving about 12 to 16 inches of rainfall per year on its eastern plains, which is comprised largely of the South Platte and Arkansas valleys (Radosevich et al. 1976). (See map of basins in Appendix A) Like many western states, Colorado uses about 85% of its water for agriculture (Colorado Water Resources Research Institute 1991). The South

Platte and Arkansas River valleys have a long history of farming and irrigation, accounting for a large portion of the state's irrigated acres and water consumption (Colorado Division of Water Resources 1998). The development of irrigation in these semi-arid areas was made feasible in the mid-1800s when farmers in these valleys started settlements such as the Fort Collins Agricultural Society to develop irrigation diversions from the basins' major rivers (Grantham 1991). These companies built canals from the rivers, and provided a share of the water to individual farmers for irrigation. Due to this development, most surface flows in the Arkansas and South Platte basins were over-appropriated by the late 19th century, meaning that the quantity of water to which water users claimed rights had exceeded available supplies.

Irrigators in the South Platte and Arkansas valleys started pumping groundwater to supplement surface flows by the early 1900s, but groundwater use was minor compared to surface consumption (MacDonnell 1988). However, three of the state's four major groundwater basins are located in these two river valleys, and these major groundwater basins have the potential to contain over 177 million acre-feet of water (Radosevich 1976).[1] In the 1940s, changing technology increased well capacity, allowing irrigators to make greater use of groundwater. With a severe drought in the 1950s, irrigators in the South Platte and Arkansas basins began to pump increasing supplies of groundwater and to drill hundreds of new wells. In 1929 there were around 800 wells in the state and by 1959, the number had grown to over 8,900 (Radosevich et al. 1976). The increase in pumping, however, had a detrimental effect on surface flows.

The problem was that many of the new wells were located in aquifers that are tributary to streams in the South Platte and Arkansas basins. Tributary aquifers have a water table elevation

[1] One acre-foot is equivalent to about 325,000 gallons. It is enough water to cover about one acre of land with one foot of water.

that is higher than the stream surface elevation (Glennon and Maddock 1997). Normally, groundwater in tributary aquifers flows in the direction of streams. According to Glennon and Maddock (1997) streams gain water from tributary aquifers at a rate that is proportional to the difference between the groundwater table elevation and the stream elevation. Groundwater pumping, however, can reduce the groundwater table if natural recharge is less than pumping, which then reduces the surface flow by an equivalent amount. If the groundwater table drops far enough, so that it is lower than the surface of the stream, eventually the stream will begin to lose water to the groundwater basin. Logically then, the significant rise in groundwater pumping in the mid-twentieth century in the dry plains of eastern Colorado reduced the available quantity of surface water, which was already over-appropriated (Radosevich 1976; MacDonnell 1988).

The reduction in Colorado's South Platte and Arkansas flows was not immediately apparent for a couple reasons. First, there is a lag between pumping groundwater and depleted surface flows (Glennon and Maddock 1997; MacDonnell 1988). Second, many new surface diversions had been developed in the early part of the century to bring water from western Colorado to the eastern irrigators, which provided more irrigation seepage into streams. By the mid-1960s, however, the impact of groundwater pumping on surface water flows became glaring. In fact, flows in the South Platte had decreased by nearly 300,000 acre-feet between 1947 and 1970 (Radosevich 1976).

The effects of increased tributary groundwater pumping on surface water flows in Colorado's South Platte and Arkansas watersheds are a form of "appropriation externality." Appropriation (or demand) externalities arise when the increased consumption of a resource "reduces the average return others receive from their costly investments in appropriation"

(Ostrom, Gardner, and Walker 1994, 10).[2] In other words, groundwater pumping made it difficult for surface water users to make use of adequate water supplies for irrigation and receive the benefits they expected from investing in establishing their rights to certain quantities of water and from developing diversion systems. In recognizing these impacts, the state and water users began to look for ways to resolve this dilemma.

The Institutional Setting

Ostrom, Gardner, and Walker (1994) explain that institutions, or rules and policies will affect the choices made by users of common pool resources, such as ground and surface water supplies, in trying to resolve problems related to over-appropriation or problems of maintaining resource supplies. In Colorado, the rules governing ground and surface water are complex. They involve federal, state and local laws, which are administered through a complex set of federal and state regulatory agencies, courts, municipalities, and special districts. Here I focus on describing the evolution of Colorado's state and basin-level laws governing the use of inter-related ground and surface water supplies.

The rules that developed to govern the relationship between tributary groundwater and surface water in these two basins are tied to Colorado's surface water rights doctrine. Since the 1880s, the doctrine of prior appropriation, which has its beginning in the use of water for mining, has been used to assign property rights to Colorado's surface waters (Radosevich et al. 1976). The appropriation doctrine establishes that individuals have rights to divert or appropriate any water that they put to "beneficial" use; and individuals who put the water to use at the earliest

[2] Appropriation externalities are associated with the use of common pool resources, such as ground and surface water supplies, because common pool resources are defined by difficulty in excluding users from the resource and highly subtractable resource flows (Ostrom, Gardner and Walker 1994).

time have the highest priority to use the water.[3] Therefore, early water users have rights that are considered to be “senior” to more recent users, and, in times of shortage, senior rights must be satisfied first.

In 1876, Colorado recognized the prior appropriation doctrine formally, through the Colorado Constitution, and ensured that state citizens have rights to the beneficial use of any of the state’s unappropriated water resources (Grantham 1991). The Colorado legislature first provided for the administration of surface water rights in 1879 by establishing water commissioners to prioritize rights in small ditch districts in the South Platte and Arkansas valleys. In 1881 the legislature created the Office of the State Engineer to administer and monitor surface water usage, based on the rights that had been established by water commissioners. In 1887, Division Engineers (then Superintendents of irrigation) were formed to oversee water use in each of the state’s seven major watersheds (See Appendix D).

Prior to 1957, groundwater usage was not managed or administered by the state. While new wells required permits starting in 1957, there were still no clear rules establishing that tributary groundwater appropriators were subject to the same priority rules as surface water users (Radosevich 1976). When surface water users recognized the problems caused by increased groundwater pumping in the 1950s and early 1960s, the State Engineer’s office lacked the authority to control pumping in a way that would protect senior surface water users in accordance with the prior appropriation doctrine. Even if the State Engineer had ordered wells to shut down when surface users made a call to claim their senior water rights during a period of

[3] The prior appropriation doctrine establishes who has rights to appropriate water resources based on where and when they first put water to beneficial use. It also clearly specifies the restrictions placed on the quantity of water that can be used and specifies that transfers of rights must be consistent with the type of use, timing of use, and location of use of the original water right.

shortage, such an action would have been futile due to the lag time between pumping and reduced stream flows (MacDonnell 1988).

The legislature responded to this crisis first in 1965, by authorizing the State Engineer to administer tributary groundwater use under the prior appropriation doctrine, yet the legislation emphasized that under the Colorado Constitution, the use of state waters should benefit Colorado's citizens to the greatest extent possible.[4] Then, in 1969 the legislature passed the Water Rights and Determination Act, which encouraged the adjudication of tributary groundwater rights in order to bring well owners under the same prior appropriation system as surface water users. The act also charged the Division Engineers to devise rules that maximize the use of the state's water resources. To promote "maximum" use of the state's water resources, the legislature allowed the Division Engineers to restrict groundwater diversions only if the state demonstrated that a well caused direct material injury to senior users. The legislature also offered the Division Engineer an alternative enforcement solution, known as Augmentation Plans, that would allow well owners to continue pumping if they replaced depleted stream flows (Radosevich 1976). These major legislative changes are outlined in Table 1 below.

[4] Tributary ground water is defined by statute as any underground water that is hydrologically connected to a stream or that influences the rate and/or direction of stream flow. See Col. Rev. Stat. section 37-92-103(11).

Table 1:
Major Legislative Changes Affecting Ground and Surface Water Management in Colorado

Year	Law	Effect on Collective Choice Decisions
1879	Legislature creates part of current administrative system	· Divides state into ten water districts (9 in South Platte valley and 1 in Arkansas valley). · Provides water commissioner to apportion water rights according to the prior appropriation doctrine.
1881	Office of the State Engineer created	· Provides administrative authority for monitoring water diversions
1887	Division Engineers created	· Authorizes basin-level administration of water usage in 7 major watersheds
1957	Groundwater Law of 1957 (Colo. Rev Stat. §148-18-2)	· Required that state engineer be responsible for issuing permits for new wells
1965	Legislative Bill (1965 Colo. Sess. Laws ch. 318 §1)	· Authorizes state engineer to administer tributary groundwater under the prior appropriation doctrine for surface water.
1969	Water Rights Determination and Administration Act (Colo. Rev. Stat. §§37-92-101 to 602)	· Authorizes division engineers to devise rules that maximize the use of the state's water resources; · Encourages adjudication of groundwater rights into the prior appropriation doctrine; · Authorizes restrictions on junior diversions (including tributary pumping) only if causing "material injury" to senior users. · Created water courts around watershed boundaries

The authority given to division-level offices of the State Engineer by the 1969 act led the South Platte Division Engineer to devise new groundwater management rules in the early 1970s (MacDonnell 1988). The rules required all tributary groundwater rights in the division to be decreed through adjudication as part of the same prior appropriation system governing groundwater. To promote adjudication, the rules permitted early applicants to obtain priority dates based on when the well was first used, rather than on the date of the application.[5] This process provided information to the State Engineer on well locations, volume of water pumped, and years in use, which could be used to assess the extent of well use in the basin and the impacts on surface flows. The second major rule change in the South Platte division was the authorization of augmentation plans, allowing junior groundwater users to pump out of priority

[5] Well owners could adjudicate wells prior to 1972 and get a priority date based on the time they first pumped, instead of on the time of application, which is traditionally used as the priority date for surface water. This was an important incentive to encourage groundwater users to adjudicate their wells quickly (Schlager 1999).

as long as they replaced the water lost to senior surface users at the time and place of injury. In essence, these augmentation plans provided a way to skirt the prior appropriation doctrine because well owners under decreed plans could continue to pump water out of priority if they had an augmentation plan.

Unlike the South Platte, the Division Engineer in the Arkansas basin struggled to develop a system that would facilitate the integration of groundwater pumpers and surface water users under the prior appropriation doctrine (Schlager 1999). The Division Engineer's office adopted rules in 1973 that limited groundwater pumping to three days per week. The Division Engineer proposed to develop rules similar to the South Platte Division, which would have phased out wells that were not part of augmentation plans. However, well owners balked, and filed a lawsuit against the state. Well owners won when the state Supreme Court found insufficient evidence that the plans would satisfy senior water users. The Division Engineer was forced to create new tributary groundwater rules in the early 1990s following a lawsuit by the state of Kansas against Colorado for failing to provide sufficient flows in the Arkansas River. The new rules, finalized in 1996, created Replacement Plans, which require pumpers to fully replace the flow reductions caused by pumping. However, the Replacement Plans are not adjudicated like the South Platte Division's Augmentation Plans.

Operational Strategies and Water Management Outcomes

This section describes the various water management decisions that evolved alongside the changing institutional environment in the South Platte and Arkansas basins. It focuses on how water users have coordinated the management of ground and surface waters in Colorado's South Platte and Arkansas basins. It also compares the success of the use of coordinated ground and surface water management across the two basins.

The South Platte Basin Management

In the South Platte basin, well owners began to manage pumping in coordination with surface flows in the early 1970s, through "Plans of Augmentation," which are decreed through water courts, and through temporary augmentation plans, known as "Substitute Supply Plans". The Division Engineer approves the temporary plans on a yearly basis. The temporary plans started in 1972, before the basin-level rules were finalized in 1974, when a group of well owners formed the Groundwater Appropriators of the South Platte (GASP). GASP worked with the Division Engineer to come up with a plan for annual approval that lists all members, wells, estimates of pumping and amount of water they would provide for injury (MacDonnell 1988). Members of GASP pay annual fees depending on the quantity of water each member expects to pump each year. GASP uses membership fees to purchase surplus replacement water or to pump additional water from different wells and then replaces pumping depletions at the appropriate time and location. Even though many other groundwater users have gone through the court procedure to decree permanent Augmentation Plans, GASP has been able to continue to receive approval from the Division Engineer for its temporary plan on a yearly basis.

Many other individual well owners and organizations since approval of the GASP plan have made use of the yearly Substitute Supply Plans as a means to coordinate groundwater and surface water needs. In 1998, more than fifty substitute supply plans were approved for use in the South Platte Division (Colorado Division of Water Resources 1998). These temporary plans, however, have been criticized because they appear to be less stringent than decreed Augmentation Plans. They may not fully account for groundwater users' impacts on stream flows and they do not guarantee that pumpers will be able to obtain replacement supplies on a long-term basis (MacDonnell 1988; Schlager 1999).

The method of management, known as Augmentation Plans, authorized under the original 1974 South Platte Rules and Regulations also has been used extensively throughout the basin. A sub-district of the Central Colorado Water Conservancy District started one of the earliest Augmentation Plans in 1973. The sub-district was created specifically to help coordinate the management of groundwater pumpers and surface water users in the district (MacDonnell 1988). Through its court approved augmentation plan, the district demonstrated its ability to replenish fully all impacts on surface flows caused by pumping. Since 1979, the district has used supplemental surface supplies to recharge tributary aquifers artificially along reaches of the South Platte River as a one of its primary replacement methods. Recharge occurs by placing water in constructed ponds or shallow basins along the river and the seepage returns water to the aquifer. This allows water to flow back to the stream system at a particular point where senior surface users need the water.

Water rights records from the State Engineer's Office indicate that a few large well-owner associations' Augmentation Plans cover thousands of wells in South Platte basin today and hundreds of individual plans are in place. Many of those plans, especially in the Fort Morgan district of the basin, store water at permitted recharge sites, as has been done by the Central Colorado Water Conservancy sub-district. The well owners operating recharge projects purchase or lease surface water supplies to replace their stream flow depletions through recharge. Some of the water users in the South Platte have organized these recharge projects under the umbrella of well owner associations or irrigation districts. For example, in the South Platte's Fort Morgan district (one of sixteen districts in the division), six large irrigation districts or companies were responsible for nearly 40 recharge sites in 1990. (See Appendix A.) In some cases, irrigation companies operate the site in conjunction with other well owners, water companies, or individual farms. A handful of these recharge sites, such as the Fort Morgan Canal, have been recharging the tributary aquifer since the late 1970s. In the Fort Morgan district of the South Platte division, the cumulative total recharge into the aquifer has been over 900,000 acre-feet of water as of 1998. (See Appendix A.) Compared to the other six major watershed divisions, the South Platte has been the most active in recharge and augmentation. Appendix B shows that the South Platte basin accounted for nearly 84 percent of the state's augmentation and recharge diversions between 1994 and 1998.

The Arkansas Basin

In the Arkansas basin from the 1960s through the 1980s, rather than engaging in coordinated management, groundwater users and the State Engineer went through a series of conflicts. In 1966, the State Engineer ordered 39 out of an estimated 1600 to 1900 tributary wells to be shut down in the Arkansas basin, leading to conflicts between groundwater pumpers and the state engineer (Radosevich 1976). Groundwater pumpers in the basin formed large associations and sued the State Engineer after ordering the shut down. The State Supreme Court's review of the case upheld the State Engineer's authority to regulate pumping, but concluded that the state did not demonstrate proof of protection for senior surface users and did not act under its actions (MacDonnell 1988).[6] The conflicts between groundwater groups and the Division Engineer led the state to devise the 1973 new rules and regulations governing well owners. However, in 1978 following another lawsuit against the state, the Supreme Court ordered that these rules were also insufficient to satisfy senior rights. Thus, most pumpers did not comply with the 1973 rules, nor were they enforced (Schlager 1999).

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[6] See *Fellhauer v. People*. 167 Colo. 320, 447 P.2d 986 (1969).

In the past decade, management of ground and surface waters in the Arkansas Basin has changed. A handful of decreed Augmentation Plans were approved each year in the Arkansas Basin water courts beginning in the 1980s. As of 1998, about 230 court decreed plans were estimated to operate in the basin (Personal Communication with Dale Straw, 1998). However, court records suggest that most of the decrees are for small wells and subdivisions. In fact, the volume of water delivered for augmentation and recharge in the Arkansas Basin has been very small, averaging about 7,800 acre-feet per year between 1994 and 1998 (Colorado Division of Water Resource 1998b). During that period, recharge and augmentation water uses were only about .002 percent of the total water deliveries in the basin, which averaged about 3.3 million acre-feet per year. Conversely, in the South Platte basin, augmentation and recharge accounted for about 40 percent of the basin's total water deliveries each year, which averaged about 4.14 million-acre feet between 1994 and 1998.

The largest water usage within the Arkansas basin, like the rest of the state, has come from irrigation, yet unlike some of the domestic wells, which pursued augmentation decrees, irrigators began coordinating surface and groundwater uses only recently. Following the approval of the Amended Rules and Regulations for the basin in 1996, irrigators began to operate under Replacement Plans, which are similar to the South Platte basin's Substitute Supply Plans in that they are approved on a yearly basis. In 1997, thirteen Replacement Plans received yearly approval for replacing depleted stream flows. In 1998 the Division Engineer approved fourteen Replacement Plans in accordance with the 1996 Amended Rules and Regulations (Bagenstos 1998). Appendix C shows that the wells authorized under the 1998 Arkansas Basin Replacement Plans were expected to pump over 180,000 acre-feet of water, and the estimated stream depletion from that pumping (equal to the required replacement quantities), totaled over 47,000 acre-feet for that year. The largest plans are undertaken by irrigation associations such as the Lower Arkansas Water Management Association (LAWMA), the Arkansas Groundwater Users Association (AGUA), and the Colorado Water Protection and Development Association (CWPDA), which combined cover about 2450 wells.

The actors involved in replacement plans in the Arkansas basin provide surface water in-lieu of their expected depletions, rather than engaging in direct groundwater recharge as is done extensively in the South Platte. The surface water supplies are acquired through leases or purchases from cities, the federal government or districts operating storage and distribution facilities (Schlager 1999). Unlike the South Platte users, Arkansas well owners have less physical capacity to directly recharge the groundwater basin. The aquifer has little room for direct storage and unlike the South Platte, the Arkansas rarely has sufficient flows to provide excess surface water, even in non-irrigation seasons, for direct recharge projects. Therefore, surface supplies that irrigators lease or purchase from water projects and reservoirs are delivered directly to the stream at the appropriate time and location. The Division Engineer monitors the pumping, stream flows, and replacement quantities and uses that information to ensure that the compact with Kansas is satisfied.

To summarize the differences in management decisions, the South Platte water users improved water management outcomes across the basin earlier and more successfully than in the Arkansas basin. Indeed, water users in both basins have used temporary plans that are approved on a yearly basis, which are subject to weaknesses because they are not incorporated into the state's prior appropriation system. This means that they cannot assure the availability of replacement supplies if severe shortages arise (Schlager 1999). Although, in the South Platte basin, unlike the Arkansas basin, water users have been able to implement many decreed augmentation plans, guaranteeing more long-term resilience of coordinated management efforts. Compared to the Arkansas basin, the South Platte success is evidenced by the long-term use of augmentation and recharge in the division, as well as by the high percentage of waters used for augmentation relative to total water use in the basin. Table 2 summarizes these management outcomes are in relation to the division level rule changes.

Table 2: **Division Engineer Rule Changes Affecting Ground and Surface Water Management in Colorado**		
South Platte Basin Division		
Year	**Rule / Action**	**Effect on Operational Decisions**
1972-1974	Rules and Regulations Governing the South Platte and Tributaries	· Phase out groundwater pumping, except a) those covered by decreed augmentation plan or b) those demonstrating no impairment on senior surface users. · Begins authorized use of Plans for Augmentation allowing well owners to offset depleted surface flows through recharge or supplemental surface deliveries.
1972 – present	State Engineer begins yearly approval of replenishment program proposed by Groundwater Appropriators of the South Platte (GASP)	· Authorizes the use of substitute supply plans, in lieu of decreed augmentation plans. · Allows groundwater users to continue pumping, provided they receive yearly authorization for replenishing depleted surface flows.
Arkansas Basin Division		
Year	**Rule/ Action**	**Effect on Operational Decisions**
1965	State Engineer responds to 1965 law and regulates pumping that affects surface flows	· 39 wells ordered to shut down. (Order reversed by State Court following law suit by well owners)
1973	Rules adopted to restrict well pumping	· Limited use to 3 days/week in Arkansas Valley.
1974	Proposed Rules and Regulations Governing Tributary Groundwater	· 3 year phased-in curtailment proposed for groundwater pumping, unless proof of no injury to senior surface users.
1996	Amended Rules and Regulations Governing Tributary Groundwater	· Determines pumping allowances for wells with rights adjudicated before and after an Interstate Compact with Kansas. · Sets standards for adequacy of replacement plans for those wells and information requirements for measuring diversions.

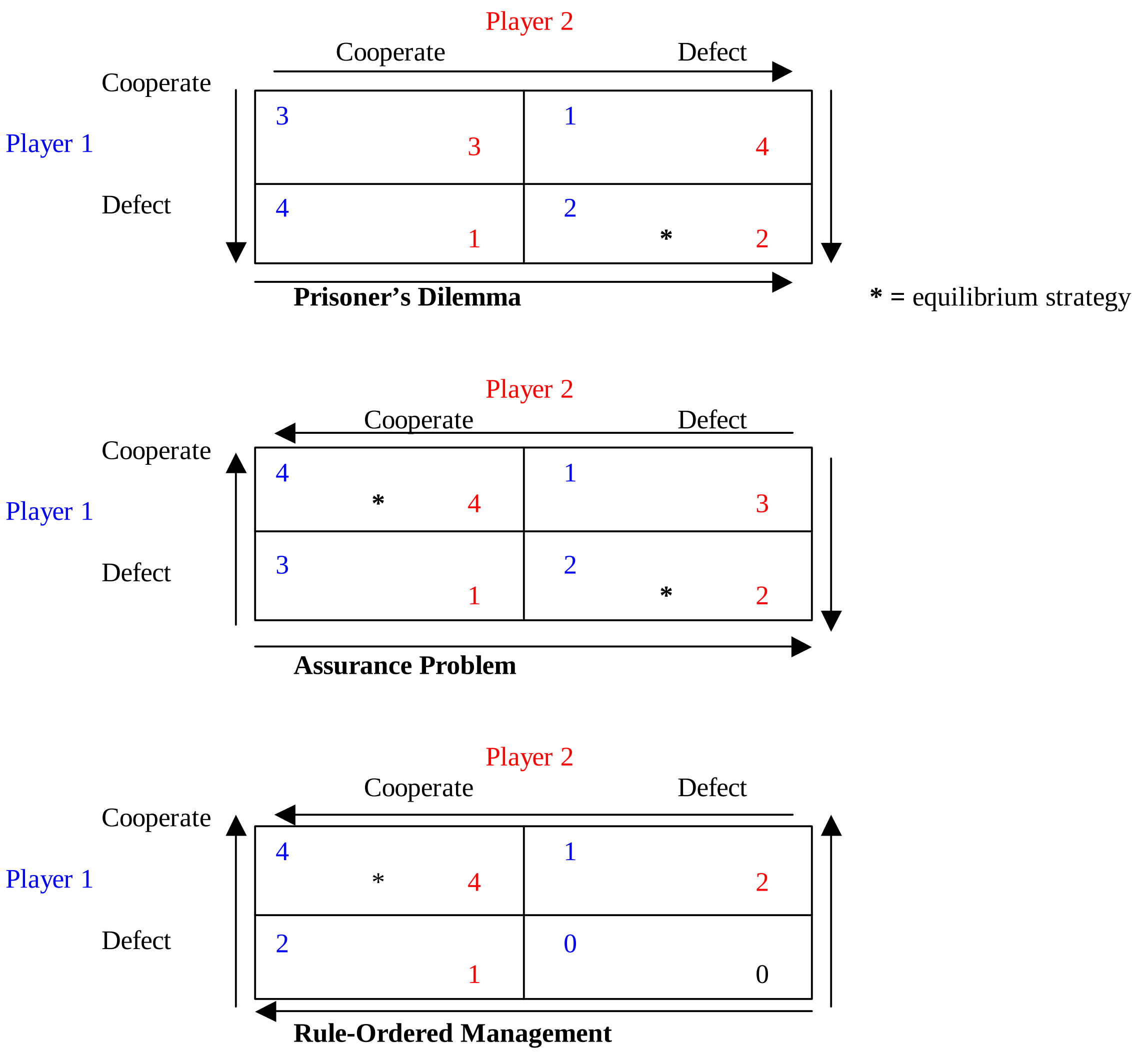
Game Structures and Modes of Interaction

Given the changing institutional setting in the two basins and the management strategies actors pursued, how can game models clarify the relationship between these institutions and outcomes? First, it is useful to consider some models that have proven to be useful in explaining natural resource management situations. I then examine how these models help explain the games that occurred in the two basins. According to Scharpf (1997), a game exists if the actions of individuals or groups of individuals are interdependent, so that the choices of all actors affect the outcome. Therefore, in analyzing the two basins, I consider actors to include both groundwater pumpers and surface water users, as they both affect the outcomes in the inter-connected water systems. The Colorado State Engineer and its division offices, which administer, monitor, and enforce the rules in the basins, affect the preferences and payoffs to these actors.[7] It is important to note that as appropriators of the same system, surface and ground water users act in a multi-person game. While the games are drawn as two-person games for clarity purposes, this does not necessarily mean that groundwater pumpers as a group act against surface water users. As individual appropriators, they all act collectively with each other. In these games, I will assume that, in general, the preferences of individual groundwater and surface water users would be to maximize their use of water resources.[8]

The prisoner's dilemma game (shown as a simple 2-person game in Figure 1a below) is a model for collective decision-making situations where the dominant strategy always is not to cooperate, regardless of the other player's strategy (Scharpf 1997). This leads to an equilibrium outcome that is sub-optimal for all actors (2,2), even though actors could achieve a better outcome through cooperation. If everyone undertakes the costs of cooperation in this game, then all players could obtain a higher payoff (3,3). Since defection always has a unilaterally higher outcome (a payoff of 4), then players will not cooperate. Moreover, if individuals try to coordinate their actions through cooperation, they risk the lowest payoff (1) if others defect.

[7] Ostrom, Gardner and Walker (1994) have pointed out that modern game theory often assumes that enforcers are external to games, yet in evaluating CPR settings it is important to bring enforcers inside the game in order to understand the effects of monitoring on strategies.
[8] In applying these models to real-world settings, rather than experimental settings, I assume that individuals act under conditions of "bounded" rationality. Boundedly rational actors may have incomplete information and uncertain preferences, yet they will still act purposefully to satisfy their own interests (Ostrom, Gardner, and Walker 1994; Scharpf 1997).

Figure 1:
Water Management Games: Prisoner's Dilemma, the assurance problem, and Rule-Ordered Management**



**Adopted from Blomquist (1994) and Ostrom, Gardner and Walker (1994)

The prisoner's dilemma game often is used to model open-access resource settings, without rules or external enforcement authorities, which is referred to as the "the tragedy of the commons" situation (Runge 1992). In the two-person game in Figure 1a, the second worst payoff for each actor (2,2) results when all actors in open access settings have a dominant incentive not to cooperate to maintain the resource or to limit their use of an open access resource. If a resource user limited his or her use of a resource to achieve sustainable yields and no one else cooperated, then the individual would be stuck with both the costs of their efforts and the detrimental effects caused by others on the productive capacity of the resource. Since the payoff to all individuals for not cooperating is always higher than cooperating (in a two-person or multi-person game), the dominant strategy is to use as much of the resource as possible and wind up diminishing the resource flows (Runge 1992). In certain settings with few boundary and authority rules governing the resource, there is empirical support for the use of this model in explaining unsuccessful management outcomes (Ostrom, Gardner and Walker 1994).

There is evidence that in both the South Platte and the Arkansas basins in 1960s water users were structured within a prisoner's dilemma game. Prior to 1969, groundwater users had very few restrictions on pumping, even when the state passed the 1965 act. Surface water users, under the prior appropriation doctrine had strict limitations on who could use water, where, and when. Yet, groundwater users, who took water from the same resource system as surface water users, were not subject to those rules. While groundwater and surface water users could have coordinated their efforts to reduce the impacts on stream flows, either by limiting pumping or finding excess supplies to supplement depletions, there were no assurances that all users of the system would actually support that coordination. Furthermore, these management strategies required investing in additional flows or limiting pumping at certain times. Surface water users had no incentive to engage in replacing stream flows or coordinated management because there was no assurance that groundwater users would stop pumping or that other surface water users would participate. Similarly, water users had no incentive to coordinate water management efforts because there was no guarantee that other water users would do the same. The outcome was that surface water users wound up with reduced flows and groundwater pumpers risked being shut down, even though the coordinated management outcome would have left everyone better off.

Other games also have proven to explain fairly accurately the management of common pool resources. Ostrom, Gardner, and Walker (1994) suggest that where problems of resource provision exist, such as how to maintain sufficient resource supply, the games appropriators play sometimes resemble the "assurance problem". There are no dominant strategies under an assurance problem game (see Figure 1b); rather the strategies depend on the expectations of others. If one actor cooperates, there is an incentive for the other to cooperate (as shown in outcome 4,4). If one player defects, then the incentive for the other also is to defect (as shown in outcome 2,2). Runge (1992) explains why this is useful for many common property settings. He says that in small-scale "village economy" settings, individuals maintain norms and mutual expectations about each other's behavior. Such norms or expectations makes cooperating less costly and facilitates the establishment of rules that encourage cooperation. In a multi-person assurance problem, Runge (1992) shows that the highest benefits can be achieved when everyone cooperates, but beneficial outcomes for the group can also be achieved when a critical mass cooperates. In these settings by "providing the assurance that others will not misuse common resource, common property institutions can make it rational for the individual to respect them" (Runge 1992, 29).

Given that the assurance problem game structure can lead to more optimal management outcomes, Blomquist (1994) notes that we should not be interested in whether the assurance problem or the prisoner's dilemma correctly characterizes a resource setting, "but in how a change *from* a PD structure *to* an AP structure could be brought about" (295). Blomquist (1994) further has shown that the assurance problem can be transformed into a "rule-ordered pumping" game among groundwater appropriators (Figure 1c). This game theoretically arises when actors within the assurance problem devise rules in an effort to discourage defection completely, which is still an equilibrium outcome of the assurance problem game. They do this because the assurance game makes them aware that repeated cooperation is ultimately much better than the risks of winding up with the lower payoff from the mutual defection outcome. Blomquist (1994) shows that the change to a rule-ordered game can happen when monitoring rules provide extensive information on players' actions and when sanctions for non-cooperation are high, so that cooperation payoffs will be larger than defection, even if others defect. In the case of Colorado water users participating in coordinated water management, I will label this game as a "rule-ordered" management game. Given that these two games lead to more stable outcomes, what evidence is there that actors in the basin engaged in an assurance problem game and, ultimately, a rule-ordered game when the rules of the game changed?

While the 1965 legislation attempted to change the rules of the game and bring groundwater users, under the same system as surface water users, it was insufficient to create the assurances that water users needed to coordinate their management efforts. The 1969 act provided the State Engineer with the power to devise authority rules to limit new wells and give priority to early well decrees, which encouraged tributary groundwater pumpers to adjudicate their wells. To enforce the priority rules, the 1969 act formally gave the Division Engineers the authority to restrict junior well pumping if pumpers' actions reduced stream flows, which did increase the costs of not cooperating and created some assurances that cooperating could lead to higher payoffs. However, enforcement of these rules became unlikely when groundwater pumpers challenged them in court. To avoid being challenged in court by groundwater users the

Division Engineers learned they had to establish specific rules for these restrictions to be enforceable and thus reduce non-cooperative payoffs effectively.

The evidence that appropriators moved into an assurance game in the South Platte Division appeared when more specific authority rules and information rules were devised in 1972. For example, following this rule-change, well owners established GASP in 1972 and began replacing flows on a yearly basis and in 1973, the sub-district and Fort Morgan also began operating more permanent Augmentation Plans for hundreds of users. Since well owners were required to provide full information on their pumping practices and had adjudicated their wells under the prior appropriation doctrine, all water users had more of an incentive to coordinate management strategies. Water users were fully aware of who was pumping, who was actively replacing their pumping, and who had the highest priority uses. Second, these information rules provided more assurance that pumping rules would be enforced because the Division Engineer could monitor water uses more accurately and thus ensure more effective enforcement and monitoring.

The new rules also ensured more flexibility in the authority rules governing ground and surface water users. The Division Engineer permitted out of priority pumping as long as depletions that affected surface water users later in the year were accounted for at the appropriate time. In turn, this reduced the costs involved in coordinating management strategies, relative to the costs of not cooperating. The extensive use of augmentation plans and substitute supply plans in the basins over the past 25 years offers evidence of the new equilibrium outcome of coordinated management in the South Platte basin and a move into the assurance game. Arguably, the implementation of a number of augmentation plans created a critical mass of coordination that Runge (1992) says leads to improved outcomes under the multi-person assurance problem.

The Arkansas basin case suggests that the actors in the basin did not move into an assurance problem game following the 1973 basin rules. While the rules changed officially governing the use of tributary groundwater, the de facto rules remained the same – unlimited pumping and no coordinated management. Like, the South Platte basin, water users had the option to engage in coordinated water management or not to engage. However, the incentive for defection still existed because the Division Engineer was not monitoring pumping sufficiently nor imposing sanctions when users violated the three-day pumping and augmentation rules. Furthermore, groundwater pumpers made it clear that their strategy would be to pursue lawsuits against the Division Engineer's office if the Division Engineer chose to enforce the pumping or augmentation rules. The result of non-cooperation in the 1960s through the 1980s was the loss of water to Kansas and other surface users, which created an outcome where the state undertook the costs of a long legal battle and all water users faced severe limitations on water consumption in order to satisfy Kansas' needs.

The Arkansas Division finally moved into an assurance problem when the Kansas case forced the division to devise new rules in the 1990s. The inability to change to a game that encouraged a significant level of coordinated water management is tied to the fact that until the mid-1990s the Arkansas Division Engineer was unable to create sufficient monitoring and transparency in their system of rules. In 1996, under the new rules that the Division Engineer devised, the structure of the game became more like the assurance game found in the South Platte basin in the early 1970s, allowing groundwater pumpers to resolve the problem of providing adequate flows for senior users through temporary replacement plans. These rules set strict standards on the amount of water that tributary groundwater users must put back into the stream, based on how much they pump and where they pump. Yet, the rules provide less certainty in meeting the needs of all water users than the augmentation plans used in the South Platte, because they do not force pumpers to decree their plans, which would provide more transparency and long-term assurances of compliance with the prior appropriation doctrine.

Even though water users have been able to move out of the prisoner's dilemma games in both basins, there are still some conditions that make it unlikely that either basin has moved into a rule-ordered game, thus eliminating the likelihood of a mutual defection outcome. In the South Platte, at least, the rule changes in these basins have provided sufficient information to water users and the Division Engineer, which can create a setting of "transparency" that Blomquist (1994) argues can lead to "rule-ordered" games. The problem is that many of the coordinated management efforts in the South Platte basin and most of those in the Arkansas are temporary plans, operating on a short-term yearly basis. They do not provide the assurances that they will be able to coordinate their management efforts long term because their plans do not guarantee that sufficient water supplies will be available in drought times. Second, most of the coordinated water management in both basins rests on the shoulders of groundwater pumpers. Surface water users can participate by providing supplies, but the doctrine of prior appropriation does not encourage surface water users to engage in coordinated management more actively, through projects that conserve water for drought times by storing it underground. These factors limit the likelihood that water users will maintain successful coordinated management during periods of water shortage or increase demand, suggesting a sub-optimal equilibrium still exists.

Conclusion

These games have shown that the strategies chosen by water users in the Arkansas and South Platte River basins to coordinate the use of ground and surface waters, and the performance of those strategies, are related to the different rules governing water resources. When the rules governing tributary groundwater changed in 1965 to bring pumpers under the prior appropriation doctrine, this was insufficient to move water users out of the prisoner's dilemma game that resulted in appropriation dilemmas in each basin. Once the State Engineer had the authority to devise rules at basin level, water users in the South Platte Division were able to move from a prisoner's dilemma game to an assurance problem game. Creating the "critical mass" of coordinated efforts required adequate information and monitoring rules to raise the perceived benefits of coordination. It also required more flexibility than a strict interpretation of the prior appropriation doctrine would have allowed for groundwater users to be able to continue pumping. Water users in the Arkansas basin, however, have only recently moved to an assurance problem game that has characterized the South Platte, resulting in less long-term success in maintaining the balance of the ground and surface water system.

What explains the persistence of the prisoner's dilemma game structure in the Arkansas basin compared to the South Platte when they both had the chance to devise basin-level rules? First, Arkansas basin users were not subject to the same degree of monitoring and expectations of enforcement of rules. The lack of monitoring and enforcement suggests that groundwater appropriators were engaging in a game at another level with the Division Engineers. The well owners had established credible threats, through court cases, that reduced the payoff the state received from enforcing rules. The court rulings also demonstrated that the Division Engineer was not collecting the type of information needed to demonstrate to the court that the rules were fair and adequate. Finally, the focus in the Arkansas basin on the three-day pumping rule, rather than on encouraging flexible augmentation plans, suggests that these rules did not raise the costs of coordinating in the same way that the South Platte rules did.

Finally, while the use of coordinated water resource management in Colorado shows how water users can resolve appropriation dilemmas to a certain degree, the system is certainly not perfect. The analysis showed that they have not been able to move to a rule-ordered game that provides more assurance of coordinated action. The difficulty in moving to a rule-ordered game could be tied to the fact that too much flexibility is provided to groundwater users in the temporary augmentation plans and replacement plans. Also, surface water users still operate under fairly rigid rules that provide less flexibility than groundwater users on when they can appropriate, where, and how much. Surface water users' role in coordinated management comes about through leases to well owners for their surface supplies. At the larger system level, the prior appropriation doctrine does not provide the flexibility needed to make full use of coordinated management. Presumably, surface water users could take advantage of exchanging surface water for some of the extensive supplies of groundwater in times of drought; or by participating more fully in recharge projects to store water for future use. Examining the potential for improved water management through different institutional arrangements governing surface flows is an important next step in explaining the link between rules and management outcomes in Colorado's watersheds.

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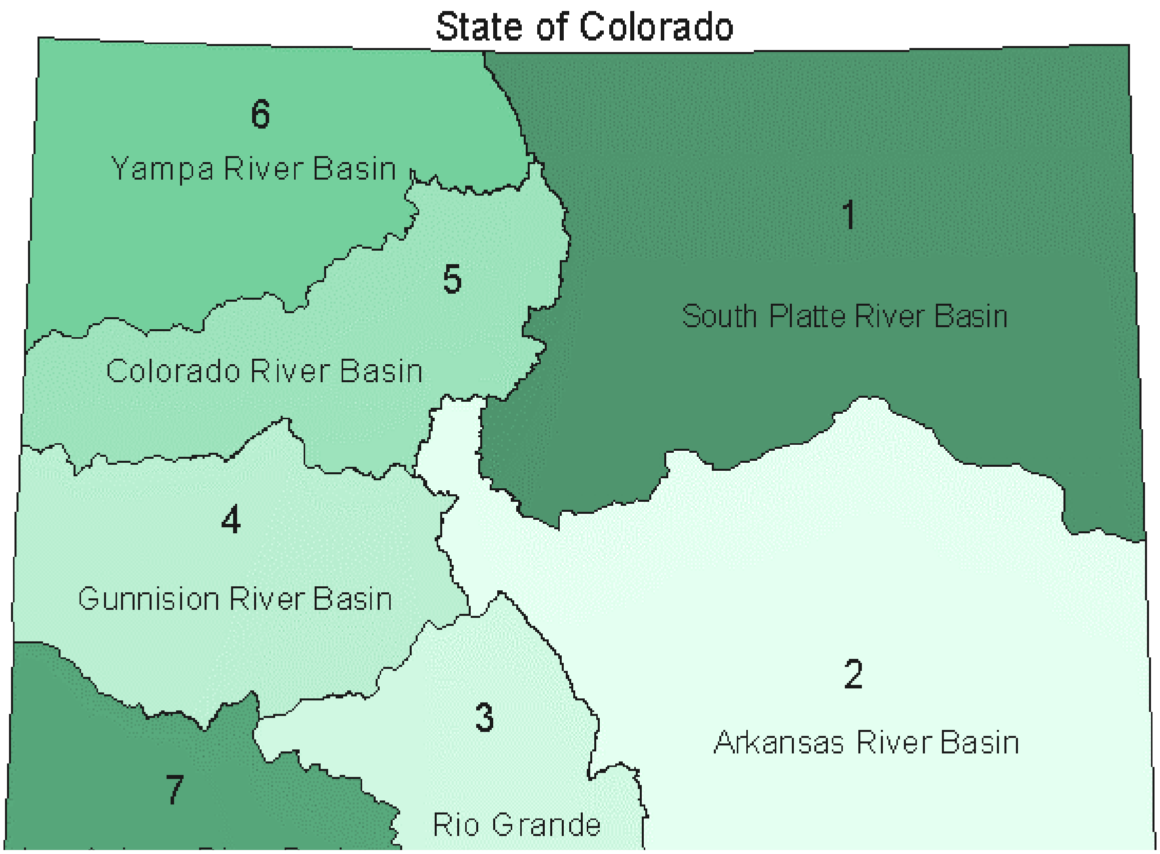
Appendix A: State of Colorado Watershed Divisions



From the Colorado Department of Natural Resources Homepage (1999) http://www.dnr.state.co.us/water/divisions/

Appendix B: 1998 Recharge Operations in District One (Ft. Morgan) of the South Platte Basin Division

Managing Org	Project	Other Participants	Av AF Stored/Yr	Total AF Stored
Bijou Irrigation District				
	Bijou Ditch/Canal		4,189	58,650
	Bijou Recharge Pond 1		846	12,696
	Bijou Recharge Pond 2		307	4,600
	Bijou Creek		4,108	45,192
	Kiowa Creek Recharge	Central CO Water Conservancy District	3,456	51,833
	Milliron Draw Recharge Area	Central CO Water Conservancy District	581	8,722
	Goedert Recharge Area	1 landowner	1,350	2,699
	Lost Creek West Pond	Equus Farms	942	11,302
	Lost Creek East Pond	Equus Farms	843	10,117
Fort Morgan Irrigation District				
	Dagenhart/Lundock Recharge Area		77	851
	Fort Morgan Canal		4,049	76,937
	Badger Creek		3,613	65,037
	Charles Henry Pond	1 landowner	761	9,888
	Bolinger Recharge Area	City of Brush; Ducks Unlimited; CO Division of Wildlife	2,267	43,078
	Public Service Pond	Fort Morgan Irrigation District; Public Service of Colorado	387	5,809
	DT Ranch Recharge	DT Ranch	82	247
	South Side Lateral Recharge	2 landowners	529	1,057
	Reed Recharge Ponds	Fort Morgan Ditch Company	1,207	1,207
Lower Platte & Beaver Canal Company				
	Lower Platte & Beaver Ditch		2,534	17,740
	Daily Recharge Area		737	5,899
	Emerson Lake/Seaman	1 landowner	543	8,148
	Wind Recharge Pond		259	4,915
Upper Platte & Beaver Canal Company				
	Upper Platte & Beaver Ditch/North Ditch		706	9,880
	Beaver Creek/South Ditch		572	6,867
	Kemble Recharge Area		1,156	15,028
	Clark Recharge Area		1,898	11,385
	Dagenhart Recharge Area		376	1,879
Pioneer Water and Irrigation Company				
	Pioneer Ditch		2,382	33,345
	Woodward West Lake		808	11,305
	Woodward East Lake		1,487	20,818
	Peterson Recharge Area		362	2,899
Riverside Irrigation Company				
	Riverside Reservoir Recharge		2,538	25,380
	Goodrich Farms Recharge Area	Goodrich Farms	2,769	41,542
	Antelope Draw Recharge	Farmers State Bank	2,704	27,042
	Headley Recharge	Farmers State Bank of Brush	2,700	16,198
	National Farms Ponds	National Hog Farms	2,814	25,322
	Equus/Riverside Ponds	Equus Farms, Inc	2,211	58,634
	Sublette Recharge Ponds	Sublette Water Co.	10,010	150,152
		Total	**69,160**	**904,300**

Appendix C:

Augmentation & Recharge Deliveries in South Platte and Arkansas Basins 1994-1998*			
	South Platte Basin	**Arkansas Basin**	**State Total****
1994			
Augmentation	95,042	8,317	108,500
Recharge	68,997	0	80,762
1995			
Augmentation	85,235	1,675	98,054
Recharge	90,141	0	105,031
1996			
Augmentation	101,864	1,865	108,712
Recharge	98,783	1,484	129,492
1997			
Augmentation	51,563	18,374	79,591
Recharge	104,672	2,128	134,801
1998			
Augmentation	66,924	2,892	74,283
Recharge	104,656	2,638	114,503
Totals	**867,877**	**39,373**	**1,033,729**
* Data from: State of Colorado Division of Water Resources "1998 Cumulative Yearly Statistics of the Division of Water Resources"			
**State Total includes quantities from Divisions 3, 4, and 7, which are not represented in this chart. No recharge or augmentation deliveries occur in Divisions 5 and 6.			

Appendix D

Summary of Arkansas Basin 1998 Replacement Plans in Acre Feet*					
Applicant	**Wells Covered**	**No. of Wells Pumping**	**Estimated Pumping**	**Estimated Replacements**	**% Replacement of Total Pumping**
Arkansas Ground Water Users	464.0	375.0	24,825.0	9,187.0	37%
Chico Basin/ CO State Land Board	16.0	16.0	19.0	1.2	6%
CWPDA	790.0	676.0	48,200.0	17,112.0	36%
Energy Fuels Coal	1.0	1.0	35.0	2.8	8%
FNMC Water Group	31.0	30.0	1,105.0	288.0	26%
Fort Lyon Well Users Association	69.0	53.0	4,750.0	936.0	20%
Fountain Valley School	1.0	1.0	74.0	67.5	91%
K5 Farms/ Sundance Investments	6.0	1.0	108.0	73.0	68%
LAWMA	584.0	517.0	103,811.0	19,934.0	19%
McComber Family	2.0	2.0	63.0	16.0	25%
Mount Massive Golf	1.0	1.0	27.0	22.8	84%
City of Pueblo	3.0	2.0	92.0	83.1	90%
Upper Arkansas Water Conservancy District	15.0	12.0	201.0	71.2	35%
Vineland Well & Pump Users Assoc.	4.0	3.0	241.0	68.0	28%
Total	**1,987.0**	**1,690.0**	**183,551.0**	**47,862.6**	**26%**
* From Bagenstos (1998), "Summary of 1998 Replacement Plans", Division 2 State Engineers Office					