Challenges of governing groundwater in U.S. western states

Edella Schlager

Abstract Over the last several decades, water users in the western United States have increasingly turned to groundwater resources to support economic development, but few institutional arrangements were in place to govern groundwater use. Over time, numerous groundwater problems have emerged. Two closely related explanations for this are explored. Surface water sources were the first to be developed, and institutional arrangements to allocate surface water were the first to be devised. These arrangements are not particularly well suited for governing groundwater. Furthermore, the physical differences between rivers and aquifers lead to differences in the development of each type of water, and in production and organization costs. Groundwater development involves low upfront production costs, which individual water users can cover. Once groundwater users have individually invested in productive activities problems emerge, such as declining water tables. Thus, unlike surface water users, groundwater users are faced with devising institutional arrangements to coordinate their water uses after they have invested in and developed productive economic activities. Most western states regulate pumping, although groundwater users, in general, resist pumping limits. The discussion concludes with proposals for modifying the prior appropriation doctrine to better accommodate the active management of groundwater basins for long-term sustainability.

Résumé Sur les dernières decades, les utilisateurs d'eau dans l'Ouest des Etats-Unis se sont tournés en nombre croissant vers les ressources en eau souterraine, pour supporter le développement économique, mais plusieurs arrangements institutionnels ont été mis en place pour gouverner l'usage de l'eau souterraine. Au fil du temps, plusieurs problèmes relatifs aux eaux souterraines sont apparus. Deux proches explications proches pour ceux-ci ont été explorées. Les ressources d'eau de surface ont été les premières à être développées, et les arrangements institutionnels pour l'allocation des eaux de surface ont été les premiers à être divisés. Ces arrangements ne conviennent pas particulièrement bien aux autorités des eaux souterraines. De plus, les différences physiques entre les rivières et les aquifères ont mené à des différences dans le développement de chaque type d'eau, et dans la production et l'organisation des coûts. Le développement de l'eau souterraine nécessite des lois sur les cots de production que chaque utilisateur de l'eau peut couvrir. Dés lors que les utilisateurs de l'eau souterraine ont individuellement investi dans des activités productrice, des problèmes émergent, tels que la baisse des niveaux d'eau. Ainsi, comme pour les utilisateurs d'eau de surface, les utilisateurs d'eau souterraine sont confrontés à la conception des arrangements constitutionnels pour coordonner l'utilisation qu'ils font de l'eau, après avoir inventés et développés leurs activité économique productive. La plus part des états de l'Ouest régulent le pompage, bien qu'en général l'utilisation des eaux souterraines, en général, résiste aux limites de pompage. La discussion conclut sur des propositions permettant de modifier la doctrine d'appropriation, pour ainsi mieux accommoder la gestion active des bassins d'eau souterraine à une durabilité sur le long terme.

Resumen En las últimas décadas los usuarios de agua del occidente de Estados Unidos se han vuelto ascendentemente hacia los recursos de agua subterránea para apoyar el desarrollo económico, aunque pocos convenios institucionales estaban disponibles para regular el uso del agua subterránea. Con el tiempo han emergido numerosos problemas de agua subterránea. Se exploran dos explicaciones estrechamente relacionadas para estos problemas. Las fuentes de agua superficial fueron las primeras en ser desarrolladas y los convenios institucionales para distribuir el agua superficial fueron los primeros en ser concebidos. Estos convenios no están bien adaptados para la gobernabilidad del agua subterránea. Además, las diferencias físicas entre ríos y acuíferos lleva a diferencias en el desarrollo de cada tipo de agua, y en la producción y costos de organización. El desarrollo del agua subterránea involucra costos iniciales de producción bajos que los usuarios

Received: 25 October 2005 / Accepted: 2 November 2005
Published online: 21 February 2006

E. Schlager (✉)
School of Public Administration and Policy,
University of Arizona
Tucson AZ 85721,
USA
e-mail: eschlager@eller.arizona.edu
Tel.: 520-621-5840

 DOI 10.1007/s10040-005-0012-1

individuales de agua pueden cubrir. Media vez los usuarios de agua subterránea han invertido individualmente en actividades productivas emergen problemas tal como niveles de agua descendentes. De este modo, a diferencia de usuarios de agua superficial, los usuarios de agua subterránea se enfrentan con el reto de diseñar convenios institucionales para coordinar sus usos del agua después de que han invertido y desarrollado actividades económicas productivas. La mayoría de estados del occidente regulan el bombeo aunque los usuarios de agua subterránea, en general, se resisten a los límites de bombeo. La discusión concluye con propuestas para modificar la doctrina de apropiación anterior para una mejor adaptación de la gestión activa de las cuencas de agua subterránea para sostenibilidad a largo plazo.

Keywords Legislation · Groundwater development · Groundwater/surface-water relations · Western United States

Introduction

Over the last several decades, water users in the western United States (U.S.) have increasingly turned to groundwater resources to support agriculture, enhance economic expansion, and spur urban growth.[1] For instance, between 1985 and 2000 groundwater use in the U.S. increased by 14% (Hutson et al. 2004). Of the groundwater used in the U.S., the western states consume two thirds of it (Hutson et al. 2004). And, among western states, more than two thirds of all groundwater withdrawn is for agricultural purposes (Hutson et al. 2004). As groundwater use intensifies, many western states are experiencing a variety of groundwater problems and conflicts, ranging from steeply declining water tables, land subsidence, the destruction of riparian habitat, and water quality problems, to intense conflicts among groundwater and surface water users (Glennon 2003).

Western states, however, have not been particularly successful in devising institutional arrangements to resolve groundwater problems and conflicts for a number of reasons. Surface water sources were the first to be developed, and institutional arrangements to allocate surface water were the first to be devised. While these arrangements are well suited for governing surface water, they are not particularly well suited for governing groundwater. Consequently, it is no simple matter to incorporate groundwater into surface water property rights and regulatory arrangements, as most western states have attempted to do.[2] Furthermore, the effort to apply surface water law to aquifers is made even more difficult because of the process that typically unfolds in developing groundwater resources. Groundwater development involves relatively low production costs, including wells, pumping equipment, and nearby distribution systems that entities and individuals can finance, which leads to the rapid development of aquifers. Only after groundwater users invest in groundwater production for their individual or local purposes do problems emerge that require institutional arrangements to resolve. Developing institutional arrangements after water users are firmly entrenched in specific water uses may be a difficult and costly undertaking.

The following section provides a brief history of surface water development in the western U.S. and an explanation of the ‘prior appropriation doctrine’—the body of laws that govern the allocation and use of surface water. Next, the structure and function of groundwater basins and how groundwater resources have been developed are examined. As western states attempt to address emerging or expanding groundwater issues, many have extended the reach of the prior appropriation doctrine, as it applies to surface water, to also govern groundwater, and the problems created are examined. The problems vary by groundwater setting. Groundwater basins that are not hydrologically connected to surface water sources are subject to being mined, whereas groundwater basins that are hydrologically connected to surface water sources may be arbitrarily foreclosed to active use because of the legal rights of surface water users. The paper concludes with proposals for modestly modifying the prior appropriation doctrine to better accommodate and promote the active management of groundwater basins for long-term sustainability.

Surface water development and governance

One of the defining features of the western U.S. is its aridity. In an arid environment, water is often diverted from streams and transported, sometimes great distances, to mines, farms, cities, and towns. Developing surface water supplies requires two intensive collective efforts. First, it is costly to plan, build, and maintain a surface water transport project. Production costs entail building diversion structures, a distribution system, and perhaps storage reservoirs to control water supplies and delivery, which may involve a network of pipes and residential hookups for municipal uses or field outlets and channels for irrigation purposes. The costs for such systems are typically borne by municipality and water agencies, or commercial organizations rather than individuals. Administrative costs, including developing information about the physical setting, negotiating over the location and design of the water system, organizing labor, and monitoring and enforcing agreements, are significant. Furthermore, considerable effort and attention must be paid to maintaining operational and management standards. Developing and modifying water schedules; devising, adopting, and modifying water allocation rules; monitoring allocations and enforcing rules; and system maintenance are all ongoing costs that must be met to realize the benefits of the surface water system. Before irrigators are likely to enjoy water flowing into their fields, they (often in conjunction with government agencies) must

[1] For the purposes of this paper the western states are Arizona, California, Colorado, Idaho, Kansas, Montana, Nebraska, Nevada, New Mexico, North Dakota, Oklahoma, Oregon, South Dakota, Texas, Utah, Washington, and Wyoming

[2] For a more general argument concerning the conflict between property regimes and ecosystem governance in the U.S. see Klug (2002).

 DOI 10.1007/s10040-005-0012-1

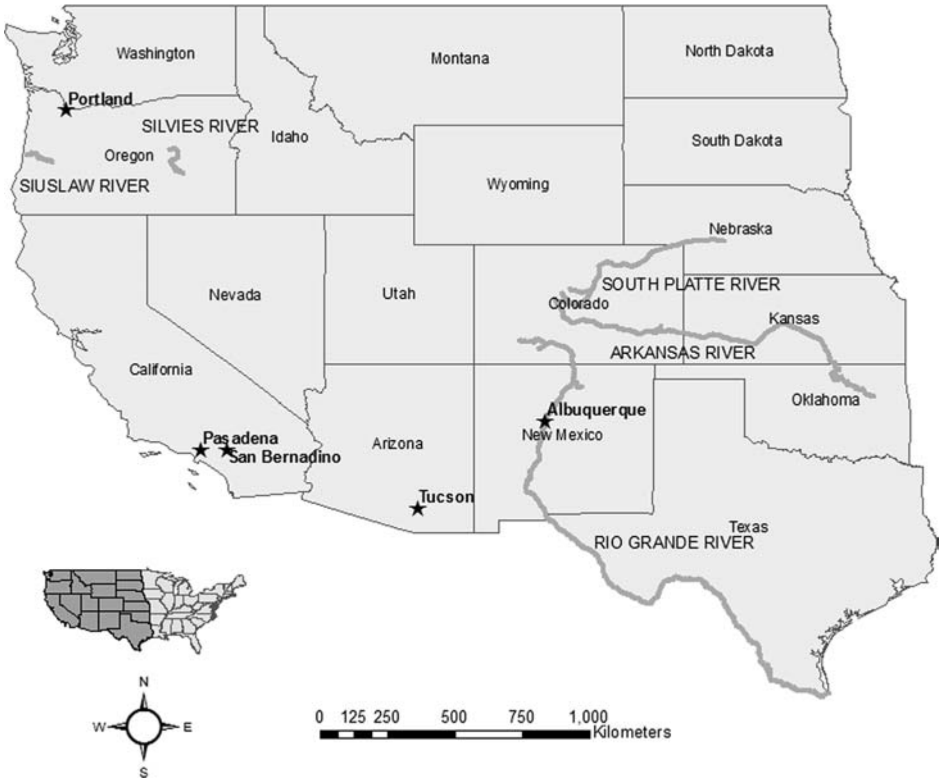

Fig. 1 Map of the western western U.S. (Source: U.S. National Hydrography Dataset)

make significant upfront investments to construct the water system and establish operational criteria.

Second, and just as important, is ensuring that there is water available in the stream to be diverted to the water project. Projects, depending on size and scope, may take years, even decades, to complete. It is unlikely that people will engage in such undertakings unless they can reasonably expect that the water that they intend to divert will actually be available and not just at completion of the project, but over the project's lifetime. This requires developing and administering a surface water law system capable of allocating, modifying, monitoring, and enforcing water rights across thousands of water users spread over hundreds of square miles of a watershed. This entails a collective effort of substantial proportions.

Map of the western U.S. [computer map] 1:50,000,000 meters. U.S. National Hydrography Dataset. University of Arizona: Tucson, AZ. 2005. Using ArcGIS. Version 8.3. Redlands, CA: Environmental Systems Research Institute, 1992–2005.

Developing organizations and crafting water laws evolved in tandem (Pisani 1996; Brown 2003). As people pooled their capital and labor through various administrative mechanisms, they demanded more secure water rights to protect their investments. For instance, irrigation colonies were among the earliest settlements in Colorado. For a fee, a family would receive a town plot, a farm plot, and a portion of water to irrigate the farm plot (Abbott et al. 1994). The colonies would use the fees to build diversion works and canals. The first colony was considered a success. With success came imitation, and a number of other irrigation colonies were formed (Mehls 1984). One located itself upstream of the original colony and diverted water that the first colony relied upon. Intense conflict erupted as irrigators threatened to destroy canals and diversion structures. A compromise was eventually reached where water would be allocated on a first in time, first in right basis (Abbott et al. 1994).

As water rights became more secure, people designed and implemented more complex and powerful administrative structures to pool financial and other resources in order to build larger surface water projects. Initially, private investments in colonies, ditch companies, water companies, and mining companies fueled the construction of water projects. However, different governance forms, including special districts and municipal governments, rapidly began to take over water development activities. In most western states, these new forms of organization, particularly water districts and irrigation districts, became popular at the end of the 19th century and early 20th century. As the federal government began funding and building large surface water projects, states created additional special districts to operate the projects upon completion. These public sector entities had much broader powers than private companies. They could tax, place liens (rights over another's property) on crops and farmland, exercise powers of eminent domain (state control over a property) to condemn or confiscate water rights and land, and develop and hold water rights. In return for such broad powers, they were required to attend to public goods and benefits (such as flood control) that private companies often ignored. The public entities also invested in activities that spurred economic growth, such as reclaiming land by draining wetlands (Bastasch 1998). As these more powerful and sophisticated organizations

 DOI 10.1007/s10040-005-0012-1

encountered water availability and security issues, water rights systems were adapted to resolve those issues.

The doctrine adopted by all western states was the prior appropriation doctrine, as defined earlier. It is really a doctrine of “first come, first served”. Priority is the defining feature of the prior appropriation system. Appropriators are allocated water based on when they first began appropriating water. In an arid environment in which rainfall is limited and rivers and streams are relatively few and modest in size compared with the eastern U.S., the flows of rivers and streams can rapidly be reduced to a trickle, and water users can easily interfere with each other’s diversions. Priority provides certainty of water rights. Rights holders do not have to fear that new water users can undermine their water rights. New users have to wait to take water until users with more senior rights have been satisfied. In addition, priority favors early arrivals because water scarcity is not equally shared; rather it falls upon newer water users. In times of shortage, if all water users were to share equally in reductions, no one would receive sufficient water to serve their purposes. Instead, it is better that at least some be served (Vranesh 1987). The prior appropriation doctrine was firmly established in the west when many states were still territories. It was written into state constitutions upon statehood, and it has been upheld by state supreme courts under challenge.[3]

Administering water based on priority has led to concepts such as “regulating” a river and placing a “call” on the river. If river flows are inadequate to satisfy senior appropriators, they may “call” to have their rights satisfied. The state water administrator then regulates the river, ordering junior diverters to cease until senior rights holders are satisfied. It is not unusual for rivers to have calls on them year around. For instance, the Arkansas River in southeastern Colorado usually has a year-around call. In the spring, summer, and fall, irrigators are calling for their water rights; while for the rest of the year, owners and operators of storage reservoirs are calling for their storage rights to be satisfied. Rarely are post-1900 water rights developed in priority or in line to be satisfied (Blomquist et al. 2004). The Arkansas River is regulated year around. Many other rivers are regulated for a portion of the year; the intensity with which they are regulated depends on the number of water rights allocated, precipitation during the year, and so forth. For instance, Bastasch (1998) examined the 1995 water year in Oregon. In eastern Oregon, which is the driest area of the state, a call went on the Silvies River in February and only appropriators with rights dating to 1885 or earlier had their rights fully satisfied. However, in western Oregon, which is wetter, a call did not go on the Siuslaw River until October and only appropriators with rights dating to 1977 or earlier had their rights fully satisfied. Thus, in 1995, the Silvies River was “regulated” back to 1885, whereas the Siuslaw River was “regulated” back to 1977.

While priority protects earlier appropriations from later ones, the superior right of senior appropriators is not absolute. Senior appropriators are restrained from using their water rights in ways that harm junior appropriators. Diversions by junior appropriators may be stopped only if such action provides water to senior appropriators at a time and place that they can put it to use. If shutting off diversions by junior appropriators does not make water available to senior appropriators in a timely manner, then junior appropriators can continue to divert water.[4] Furthermore, senior rights holders are allowed to change the uses of their water right, say from crop irrigation to municipal water supply, and their point of diversion, if no injury results to others. In practice, the “no injury rule” means that only the portion of the water right that is consumed is transferable. The portion that was never diverted or that returned to the river has almost certainly been diverted by others, and those diversions must be protected. Junior water rights holders have reasonable expectations to stream conditions as they existed at the time that they initiated appropriations (Vranesh 1987).

It is important to note that the concepts of priority, call, futile call, and no injury are based on and receive their meaning from a particular physical environment—finite and variable flows of water in above ground channels that are replenished from year to year, see Table 1. A “call” on a river implies that there is insufficient water for all water rights to be satisfied, at least for a period of time, depending on demand and moisture. During a relatively wet year, more water rights tend to be satisfied than for a drier year. Thus, most water rights holders expect to have their water allocations withheld sometimes. Additionally, if shutting down a diversion by a junior appropriator does not make more water available to a senior appropriator during a period of time when the water is needed, the junior appropriator can continue the water use. Surface water moves rapidly within streambeds, quantity varies considerably from month to month and year to year, and volumes are measured in terms of seconds and minutes. Correspondingly, the concepts constituting the prior appropriation doctrine are based on short time periods. Whether these concepts have the same meaning in environmental settings that involve much longer time frames and much less variability in water, such as groundwater basins, is questionable, as will be discussed below.

[3] The argument that the prior appropriation system is best suited for an arid environment is most clearly explicated in Dunbar (1983). Pisani (1996) takes exception to it. While Pisani agrees that aridity played a central role in the development and adoption of the prior appropriation doctrine, he argues that alternative water law systems were present, such as the riparian doctrine and Mexican and Spanish water laws and practices. The prior appropriation system succeeded over other systems for a variety of economic reasons. For instance, in the 19th century beliefs in the power of free enterprise and private property as the best means of meeting people’s needs prevailed. Less consideration was given to community needs, such as assuring that all members were given equal access to a water supply. As Pisani (1996:23) concludes: “The pursuit of wealth took precedence. Enterprise triumphed over equity”.

[4] This practice is known as the ‘futile call’ (Tarlock et al. 2002:184).

 DOI 10.1007/s10040-005-0012-1

Table 1 Characteristics of surface water and groundwater

	Surface water	Groundwater
Characteristics		
Location	Well defined, above ground channels	Under ground basins
Visibility	Easily visible	Not visible without special, technical equipment and expertise
Seasonal availability	Highly variable, but easily ascertained flow patterns	Little variability
Amount of withdrawal	Restricted to annual supplies	Exceed annual recharge for considerable length of time
Evaporation	May be considerable	Little
Effects of withdrawals on flows	Reduction apparent in days or weeks	Reduction may not be apparent for months or years

Groundwater development and governance

The development of groundwater resources and their use occurs within an institutional setting largely designed to allocate, divert, distribute, and beneficially use large volumes of surface water. Developing and carefully managing aquifer systems present substantially different advantages and challenges compared to surface water. Many of the advantages and challenges spring from the structure and function of aquifers (see Table 1). The fundamental premise is that a groundwater basin provides a source of water and a valuable location for storage of that water. Groundwater storage alone is a highly prized function that can compensate for the limitations and shortcomings of surface water systems (Blomquist et al. 2004). For instance, unlike surface water, groundwater is not subject to the same evaporative processes as surface water, nor is it quickly transported. It remains available year around and during droughts. It can be tapped close to its place of use avoiding the cost of developing extensive distribution systems. It is less exposed to contaminants from land and air. Furthermore, a groundwater basin buffers peak, seasonal, and drought water demands. In addition, the storage may be actively used and managed to store surplus surface water supplies for later use when needed. Actively using the basin storage capacity is more economical than building surface water storage (Blomquist et al. 2004).

For all of their beneficial features, groundwater basins are, nonetheless, difficult to govern because of information deficits. Identifying and mapping the boundaries and the various aquifers within a basin is a time consuming and expensive process, not to mention the time and cost involved to develop complex hydrological models to explain the dynamics of water resources inflows to and outflows from the basin. Often, such costly studies are undertaken only after serious problems emerge (Bastasch 1998). Such information deficits create considerable uncertainty concerning the effects of pumping. Groundwater users cannot easily determine the effects of their pumping on one another, on the aquifer, or on surface stream flows. Consequently, they are reluctant to reduce or cease pumping when called upon to do so, especially if large amounts of water remain in storage.

Given the structure and functioning of groundwater basins, it is not surprising that the groundwater development path has varied considerably from that of surface water. Groundwater development unfolds rapidly once a minimum level of technology and energy become widely available (Shah 1993). Historically, in most western states, access to groundwater basins was minimally restricted, with land ownership or leasing the only requirement for access. For instance, in 1940, in the Arkansas River Basin in southeastern Colorado, an estimated 40 irrigation wells were in operation. By 1972, 1,477 wells were in use (MacDonnell 1988). Currently, there are over 5,450 permitted wells (Colorado Geological Survey 2003).

Groundwater is widely used because of its high value. It may be the only source of irrigation water for some farmers. For other farmers, groundwater may be more reliable, timely, and adequate than the water they receive from canal systems; thus, they invest in wells as a source of supplemental water. For other farmers, groundwater may be more "convenient" and cost effective, at least in terms of labor, than canal water. Center pivot irrigation systems allow one person to irrigate up to 810 ha of land (Ashley and Smith 1999). Some cities rely on groundwater as their only source of supply; other cities too have begun to use groundwater. For some of the same reasons as farmers, it may be the only water source available to service new residential subdivisions. In many instances, cities are turning to groundwater because of its quality. As federal drinking water regulations become more restrictive, switching to groundwater is more cost effective than modifying or building new treatment facilities (Bastasch 1998).

Compared to surface water, groundwater development entails substantially lower upfront administration and construction costs, which may be borne by a single individual, family, or entity. Contract administration costs are also low. Farmers and cities need not organize, bargain, and negotiate over the development of groundwater systems or search for the means to pay for such systems.

Ease of development and a lack of information and understanding of an "invisible" resource have led to over utilization of many groundwater basins. Unlike the surface water settings in which water conflicts emerged almost immediately and threatened to discourage investment and economic development, groundwater problems emerged after people invested considerable sums of capital. In the case of surface water, considerable fortunes could be made only if a secure water rights system could be developed and

 DOI 10.1007/s10040-005-0012-1

administered. In the case of groundwater, considerable resources were invested and fortunes made before developing a water rights system that protects existing users became pressing. Across the West, cities and industries thrived on groundwater, and vast expanses of land were irrigated through groundwater. Farmers in southern California cultivated oranges using groundwater. The southern California cities of Pasadena and San Bernardino depended on groundwater to serve their citizens, so much so that by 1937, Pasadena filed a lawsuit to try to protect its dwindling groundwater supplies from new users (Dunbar 1977; Blomquist 1992). The desert cities of Arizona required groundwater to thrive. Until recently, Tucson, Arizona was the largest city in the U.S. entirely dependent on groundwater.

The rapid development of groundwater did not occur in an open access or institution-free setting, but it did occur in a setting that placed few limits on groundwater use. Before adopting groundwater codes in response to intense conflict, many western states recognized some variant of the "reasonable use" doctrine, sometimes also known as the American doctrine (Ashley and Smith 1999). The reasonable use doctrine allows landowners overlying a groundwater basin to pump as much water as they can put to reasonable use on their land. The reasonable use requirement was intended to limit the waste of water, not the pumping of water. The only use considered unreasonable was any non-overlying use that interfered with other well pumpers (Gould 1990). The reasonable use doctrine does not prevent or resolve disputes among overlying landowners where well interference or overdrafting of the basin has occurred. As long as an overlying well owner makes reasonable use of the water, that owner is not liable for interference that affects another well. Furthermore, well owners may pump "until they can no longer afford the cost of ever greater pumping depths or until the aquifer is exhausted" (Gould 1990).

States did not anticipate and attempt to avoid the numerous conflicts that have occurred under the reasonable use doctrine due to accelerated groundwater development. Rather, state governments responded to crises, and substantial crises have motivated state legislatures to act as needed. In the late 1920s, New Mexico was one of the first states to attempt to move beyond the reasonable use doctrine to protect threatened artesian basins in the southeastern part of the state (Clark 1987). A neighbor state, Arizona, was one of the last to act. Arizona did not pass a groundwater code until 1980, and this occurred mostly in response to a federal government threat to withhold a long desired and much coveted major surface water project (Blomquist et al. 2004).

In adopting groundwater codes, the approach that most western states took was to extend the prior appropriation doctrine to cover groundwater.[5] Beginning with New Mexico in 1931 and ending with Montana in 1961, groundwater in most western states was governed by the prior appropriation system. Existing wells were given priority dates, new wells were allowed only with permits granted by state water agencies, and state water agencies could refuse to issue permits in over-appropriated aquifers (Dunbar 1977). States extended the priority system to groundwater because it was a familiar and well-accepted set of institutional arrangements that they believed would allow them to satisfactorily regulate groundwater use, just as it allowed them to regulate surface water use. Later, as the hydrologic connections between ground and surface waters became better understood, legal scholars heralded the application of a single body of law to integrate ground and surface water uses, with little consideration given to the applicability of a priority system to aquifers (Grant 1987).

The application of the prior appropriation doctrine to groundwater basins has produced diametrically opposite results depending on the groundwater setting. In the case of groundwater basins not hydrologically connected to a surface water source, otherwise known as non-tributary groundwater basins, the prior appropriation doctrine has not stopped or prevented groundwater mining. In the case of groundwater basins hydrologically connected to surface water sources, or tributary groundwater, effects have been mixed. It has had the desirable effect of protecting surface water flows from pumping because surface water rights holders are invariably senior to well pumpers. However, in protecting the surface water flows used by senior appropriators, it has had the unintended effect of forgoing the use of considerable amounts of groundwater. In both groundwater settings, the prior appropriation doctrine has not resolved intense conflict between groundwater and surface water users, or adequately recognized or encouraged the management and use of groundwater basin storage.

Non-tributary groundwater basins and prior appropriation

The prior appropriation doctrine, as conceived and administered, was not designed to conserve water, rather it was designed to encourage the diversion and use of water. Such use has dewatered streams and rivers and harmed aquatic life and riparian habitat (Pisani 1996). Applying the prior appropriation doctrine to groundwater basins also encourages the development of the water and has resulted in groundwater mining. For instance, Colorado applies the prior appropriation doctrine to some non-tributary groundwater basins called "designated" basins (Bryner and Purcell 2003). Such basins are governed under the Ground Water Management Act of 1965. That act applied the priority doctrine to groundwater uses in designated basins and granted the Colorado Ground Water Commission broad powers to regulate those uses.[6]

[5] Five of the seventeen western states do not govern groundwater under the prior appropriation. They are Arizona, California, Nebraska, Oklahoma, and Texas. Of the five, Nebraska recognizes the hydrologic connection between ground and surface water and attempts to coordinate the management of the two types of water.

[6] In Colorado, monitoring of water rights largely falls on water users either requesting state water officials to shut down junior users or using courts to bring lawsuits. Measuring of actual water use usually does not occur unless a change or transfer of water rights occurs.

DOI 10.1007/s10040-005-0012-1

In general, a priority system works differently when applied to a groundwater basin than when applied to a surface water source. For surface water, priority works to adjust surface water appropriations within a water year in response to fluctuating flows so that senior rights are protected. In a groundwater setting, priority acts to limit the number of well permits issued to protect existing users (Gould 1990). It does not act to prevent water table declines. All western states that apply the prior appropriation doctrine to groundwater, including Colorado, allow for "reasonable" declines in water tables. What constitutes a reasonable decline has not been defined in statute. It is left up to state courts to determine on a case-by-case basis (Grant 1987).

In Colorado, in times of substantial shortage, the Colorado Commission could assert its authority to prohibit issuance of additional permits and could prohibit pumping of junior wells so that owners of senior wells can continue to appropriate water (Fischer and Ray 1978). Even though a number of the designated basins are experiencing long-term water level declines (McGuire et al. 2003), the Commission has been reluctant to exercise its powers. In part, there are no alternative sources of water for farmers in these basins. In addition, the effect of shutting down junior wells is unclear. Shutting down junior wells may not have a noticeable effect on senior wells for months or even a year or more. Finally, even though water levels are declining, the basins hold a considerable amount of water, and shutting down junior wells directly contradicts the state's desire to develop and use water resources. What the Commission has done, in the most heavily used designated basin, is adopt more strict criteria for issuing well permits, particularly if the well is to supply sub-divisions of single family homes (Upper Black Squirrel Creek Groundwater Management District 2001).

Oregon, like Colorado, also governs non-tributary groundwater under the prior appropriation doctrine (Bryner and Purcell 2003). Like Colorado, the Oregon Water Resources Department issues a groundwater permit unless there would be injury to other rights or to the public interest (Bastasch 1998). In determining whether there would be injury to other rights or the public interest, the department checks existing laws. For instance, the Oregon legislature has prohibited appropriation in some areas to preserve municipal supplies (Bastasch 1998). Also, the department determines whether water is available to be appropriated. If the department determines that the appropriation of groundwater by all water rights in an aquifer "exceeds the average annual recharge or results in further depletion of already over-appropriated surface waters" it may deny a permit (Bastasch 1998). As Bastasch (1998) notes, in practice, the Oregon Water Resources Department has issued groundwater permits on a routine basis, in part because the department is required to do so unless it can demonstrate harm, and in part because the department does not have adequate data (e.g., recharge rates, actual pumping versus permitted pumping, etc.) or a comprehensive understanding of its groundwater basins. Consequently, a number of groundwater basins in Oregon have been over permitted.[7] The Oregon Water Resources Commission develops policy and oversees the Water Resources Department and is authorized to designate critical basins. Once a basin is designated as critical, the Oregon Commission is granted considerable authority to regulate groundwater, including prohibiting additional permits, limiting the amount of water that may be pumped annually from the basin, and even reducing existing water rights (Bastasch 1998). Such designations are strongly resisted by water users and may take a decade or more to go into effect as water users contest critical designations in court. As Bastasch (1998) explains, "When data are sufficient to trigger groundwater controls, the damage has usually already been done and communities are heavily invested in the customary level of (over-) use. And the controls are so unpopular and fiercely resisted that the state no longer considers them a practical management alternative".

For instance, in the Willamette Basin, which underlies the most heavily populated areas of Oregon, ranging from Portland to Eugene, the Water Resources Commission has managed to declare one unit within the basin as a critical groundwater area. Such a designation has had the effect of reducing groundwater pumping by 50% and preventing the issuance of new water rights (Oregon Water Resources Department 2002). The report does not comment on whether water levels have stabilized. Another aquifer within the basin has been designated as closed to any further water development. No new water rights will be permitted (Oregon Water Resources Department 2002). A more common mechanism for governing pumpage is to issue conditioned permits. A permit may require a well owner to install a measuring device and annually report water use and levels. If water levels fall below a designated point, the well owner may be required to reduce pumping (Oregon Water Resources Department 2002). As the Oregon Water Resources Department (2002) notes, "Beyond these designated areas, groundwater supply issues continue to develop in aquifers within the Willamette Basin. However, it may be many years before the Water Resources Department develops the scientific data and analysis needed to support further restrictive classifications or withdrawals."

Oregon is struggling to sustainably manage groundwater basins in the most heavily developed and developing areas of the state. The administrative tools that the Water Resources Commission has to work with are reactive. These tools are employed after groundwater problems have been identified. In most cases, the actions taken have slowed the rate of groundwater mining, but have generally not arrested it. Well owners and landowners resist such restrictions because they have few or no alternative sources of water. Furthermore, such restrictions threaten future economic growth and development (Oregon Water Resources Department 2003).

[7] As Bastasch (1998:60) explains, "The prime directive is to issue a water right unless there is injury to other rights or the public interest. Contrast this with a more conservative approach—arguably one more appropriate for allocating a limited public resource—which would be to deny applications unless it can be shown that no harm would result to other rights or the public interest."

 DOI 10.1007/s10040-005-0012-1

The mining of non-tributary groundwater under the prior appropriation doctrine is not unique to Oregon and Colorado; most western states that use the prior appropriation doctrine to govern non-tributary groundwater encounter the same problems in at least some of their basins. Well permits are regularly granted even though the hydrogeology and conditions within a basin are not well understood. This is not unlike what occurred among western states in granting surface water rights. Many western rivers are over-appropriated. More water rights have been granted than water available in a river. This was not viewed as particularly troublesome because of the priority system that protected senior rights holders. Junior rights holders were regularly shut down when water was scarce.[8] Priority does not act to protect senior rights holders in non-tributary basins. Shutting down junior wells may have little effect on water availability for senior wells for months or possibly years. If the latter, it becomes particularly difficult for a state agency to address because the agency is then faced with shutting down a use that has been in place and that people have come to rely upon for a long period of time.

Tributary groundwater basins and prior appropriation

States that apply the prior appropriation doctrine to groundwater recognize the hydrologic connection between groundwater and surface water and attempt to minimize the effects of pumping on stream flows. However, it should be noted that attempts to minimize the effects of pumping on surface water flows is due to historic happenstance. In most western states, surface water was developed before groundwater. Consequently, wells are junior to most surface water diversions (Grant 1987). Surface water flows are protected, not because the prior appropriation doctrine recognizes any intrinsic value of leaving water in streams, but simply because surface water rights are senior to groundwater rights.[9]

How does the prior appropriation doctrine work in relation to tributary groundwater basins? The doctrine has been adapted to accommodate some pumping, while also protecting senior surface water rights holders. The effects of groundwater abstraction on surface water sources may be delayed by days or even years, depending on the distance the well is from the surface water source. For instance, in Colorado, while many wells were installed beginning in the 1950s, notable effects on surface flows did not occur until the 1960s (MacDonnell 1988). Conversely, shutting down wells will not appreciably affect surface water flows for months or years. These delayed effects are not easily handled within the prior appropriation doctrine. For instance, suppose priority is strictly enforced on a river in which water rights issued after 1970 are rarely satisfied. All wells permitted after 1970 would never be allowed to pump, even though groundwater is plentiful. Wells permitted prior to 1970 also present a vexing problem. Even though they may be in priority periodically during a water year, during peak water demand periods, only those with very senior water rights may be in priority and those with junior rights may have their pumping suspended. However, restricting pumping is unlikely to make additional water available to the river in a timely manner to fulfill the senior water rights. In the context of the prior appropriation doctrine, this is known as a futile call, as discussed above. If curtailing or ceasing pumping by junior appropriators does not make additional water available to senior rights holders, then pumping by the junior appropriators should not be restricted. In this case, wells would be allowed to continue to pump. Consequently, even though they are junior appropriators, this practice slowly undercuts the rights of senior surface water rights holders.

This is the precise scenario that occurred in Colorado in the mid-1960s. In 1965, the Colorado legislature passed an act that directed the State Engineer to regulate wells to protect senior appropriators. In 1966, the State Engineer attempted to shut down a series of wells in the Arkansas River Basin (Radosevich et al. 1976). The well owners appealed the decision to the water court; eventually, the case was decided by the Colorado Supreme Court. The well owners made a number of claims; one of them was the "futile call" that protected them from having their wells shut down. The State faced a problem; it wanted to encourage the use of groundwater, but not at the expense of surface water rights holders. In 1969, the legislature acted once again and passed an act to reduce the conflict between surface water and groundwater users. The act provided a mechanism by which junior rights holders could withdraw water out of priority. That is, they would not have to shut down their diversions, even if a senior appropriator "called" for water. This act created the augmentation plan that "provides a highly flexible tool enabling new uses of water without strict regard for the priority system, so long as existing rights are not injuriously affected" (MacDonnell 1988). Junior appropriators, whether of surface water or of tributary groundwater, can protect their diversions from "calls" by senior appropriators by augmenting stream flow. An augmentation plan involves determining the streamflow reduction that could result from groundwater extraction from one or more wells, or other adverse consequences to the river, and then identifying a source of water that will be made available to the river at the time and place of injury to senior

[8] Grant (1987) argues that the practice of issuing water rights in overappropriated water sources reflects a "hunting license" mentality. Appropriators are given permission to hunt for unappropriated water. If they can find none, that is, if in hunting they deprive senior appropriators of water, the priority system will curtail their activities.

[9] In states that do not apply the prior appropriation doctrine to tributary groundwater, intense conflict has emerged around the effects of pumping on surface water flows. Arizona is an extreme example of a state that uses distinct bodies of law and regulation to govern ground and surface water with no legal recognition of the physical connection between the two sources of water (Glennon 2003). Except for a few basins that underlay the most heavily populated areas of the state and are heavily regulated, all other basins remain under the reasonable use doctrine. Under Arizona law surface water rights holders, governed by the appropriation doctrine, have no recourse against well owners who are governed by the reasonable use doctrine (Glennon 2003). Consequently, well owners can and have pumped rivers and streams dry (Glennon 2003).

 DOI 10.1007/s10040-005-0012-1

appropriators. Well owner associations have formed that purchase or lease surface water rights that are placed under the control of the State Engineer's office to be released to rivers and streams when necessary. Irrigation districts and ditch companies have invested in groundwater recharge projects designed to contribute to the available water during the summer irrigation season (Blomquist et al. 2004).

The New Mexico State Engineer has followed the same path as that of Colorado, especially in governing the aquifer tributary to the middle Rio Grande, which is home to 38% of the population of New Mexico (Bartolino and Cole 2002). Beginning in 1956, the State Engineer began conditioning well permits issued in the middle Rio Grande (Jones 2002). Well owners were required to eventually acquire surface water adequate to replace the streamflow reduction to the Rio Grande due to their pumping. The State Engineer took this action because of the rapidly growing population of Albuquerque, a growing irrigated agricultural sector, and the noticeable effects of pumping on surface water flows, which made it difficult for New Mexico to abide by the Rio Grande Compact that required the state to deliver a defined volume of water to Texas each year (Jones 2002). The State Engineer anticipated that, eventually, his office would have to stop issuing new groundwater permits when the effects of well pumping equaled the amount of surface water rights in the basin (Jones 2002). That occurred in 2000 when the middle Rio Grande was closed to new groundwater appropriations (Jones 2002).

Governing tributary groundwater under the prior appropriation doctrine has had the beneficial effect of protecting senior surface rights holders. At least sometimes during the year, water is likely to remain in rivers. Such outcomes are certainly preferred to those that occur in Arizona where well pumping is allowed to completely and permanently dry up rivers and streams. However, governing tributary groundwater under the prior appropriation doctrine is not without consequences. The amount that can be pumped is limited to the amount of surface water available to account for pumping effects. The volume of surface water available for lease or purchase by well owners is considerably less than the volume of water in tributary basins. In addition, the volume of surface water available for lease or purchase is declining. Consequently, significant amounts of groundwater forgo use. The tributary aquifers of the South Platte River in northeastern Colorado are estimated to hold upwards of 8 million acre feet [9,867,912,000 cubic meters] of water (MacDonnell 1988). The tributary aquifers of the Arkansas River in southeastern Colorado are estimated to hold close to two million acre feet [2,466,978,000 cubic meters] of water (Colorado Geological Survey 2003). The latest U.S. Geological Survey study of the middle Rio Grande refuses to estimate the volume of water in the basin citing the uncertainty over data, however, the depth of the most commonly used aquifer extends 608 meters (Bartolino and Cole 2002).

At first glance, forgoing groundwater pumping may not appear problematic. Leaving groundwater in an aquifer is certainly more desirable than mining it or pumping it and drying up a river. Also, it appears reasonable to condition groundwater pumping on the amount of surface water available to account for the effects of pumping on a river. How else can all of the demands on a river be met each year? Furthermore, placing a strict limit on groundwater pumping may force cities to manage and restrict their growth instead of encouraging and promoting growth and the consequent urban sprawl (Lucero and Tarlock 2003).

Such an approach, however, narrowly defines sustainability and ignores the value of groundwater basins, and eliminates numerous opportunities for actively managing and using both the groundwater storage and the water in tributary basins to realize a variety of goals over a longer time frame. For instance, in the midst of a drought, the water requirements of surface water rights holders could be met through groundwater. Thus, the water that they would have otherwise withdrawn remains in the stream and satisfies water needs and demands, such as protecting riparian areas and aquatic life. During wetter years, surface water rights holders would meet their consumptive uses through surface water diversions, reducing pumping from the basin, allowing some replenishment of the basin. In addition, during wetter years, an active basin recharge program would capture and store the surplus surface water to replenish the aquifer and bank water for use during the next drought. Pumping limitations that are based on the amount of surface water available to offset the annual effects of pumping take an overly narrow view of sustainability. Thus, this approach reduces the flexibility and benefits available when basin storage is utilized.

Alternative approaches for governing groundwater

Critics of the prior appropriation doctrine rarely consider the effects of the doctrine on groundwater. Rather, they focus on the negative consequences of the prior appropriation doctrine on surface water sources and uses. The prior appropriation doctrine has been criticized as being inefficient, wasteful, and environmentally destructive (Pisani 1996). It is inefficient because it privileges senior water users who may engage in low value economic activities over junior water users who may be engaged in higher valued activities. It is wasteful because it discourages conservation. Water not used and left in the stream is water that can be appropriated by someone else. Thus, if water rights holders use less water than they are entitled, then that water will eventually be lost to them. It encourages drawing water out of channels; it can even be environmentally destructive when excessive surface water diversions occur.

To correct such excesses, some critics of the prior appropriation doctrine argue that the prior appropriation system should be dispensed with entirely and replaced with a permitting system that is not based on priority. A permitting system would shift the locus of control over water from individual water users to state governments. Under the priority system, a state cannot refuse to issue an individual a water right if there is water available and its use would not unduly interfere with other water users.

 DOI 10.1007/s10040-005-0012-1

Also, once an individual has a water right, it cannot be taken from him as long as he puts the water to a beneficial use. Under a permitting system, states would be allowed to refuse to issue permits, even if water was available, and revise and rescind existing permits in order to realize a broad range of social values, from discouraging certain farming practices to protecting riparian habitat (Pisani 1996).

It is unlikely that any western state is going to entirely replace the prior appropriation doctrine with a permitting system as proposed by Pisani (1996). Many states afford the prior appropriation doctrine constitutional protection. Therefore, for most states, replacing the prior appropriation system would require amending state constitutions. A process to devise a workable and equitable means for reviewing existing water rights and issuing permits based on new understandings of beneficial use would take several decades, if at all, to complete.

Although water rights in the western U.S. are built on the prior appropriation system, this does not mean that sustainable groundwater use and the active management of groundwater storage is impossible. States have demonstrated an ability to modestly modify the prior appropriation doctrine when necessary, and with some additional modification that builds on existing water laws and practices, groundwater could be better governed for long-term sustainability. The following modest proposals relate primarily to tributary groundwater basins. Feasible institutional change often requires that those that would be harmed would also be made whole in some manner, or that the change creates a larger pool of benefits for participants. Actively managing tributary groundwater basins will make more water and more storage available than current practices, which may encourage acceptance of sustainable management approaches. Actively managing non-tributary groundwater for long-term sustainability will be more challenging because individuals and businesses are less willing to substantially reduce groundwater pumping without an alternative source of water made available to them (Blomquist 1992; Shah 1993; Bastasch 1998).

First, priority should be modified so that water rights holders may have their water rights satisfied from a variety of sources. Currently, water rights under the prior appropriation doctrine lock rights holders into specific sources of water to be diverted at specific points. Priority should be modified so that if there is a surface water shortage, surface water rights holders may have their rights satisfied through the pumping of groundwater.[10] Second, at the beginning of a water year for a river basin, an estimate should be made of the surface *and* groundwater available for the year. This would involve measuring snow pack in the mountains (the major source of surface water in the western U.S.) and estimating the amount of surface water in storage and the amount of groundwater available for pumping. Except for groundwater estimates, much of this is already routinely done by the operators of large surface water projects, state departments of water resources, and various federal agencies. Once an estimate is developed, the operators of surface water projects inform their members of the amount of water they are likely to have available to them over the course of a year.

The first two proposals would result in treating groundwater and surface water as a single water source and would direct use to the source that is most abundant. During relatively wet years, surface water would be more heavily used to satisfy short-term demands; it would also be placed in aboveground storage or used for artificial recharge to provide water during drier years. During drier years, stored surface water and groundwater would be more heavily relied on to meet short-term needs. This allows the necessary surface water flows to remain in streams to protect riparian habitat and aquatic life. The priority system would still be used to allocate water. During relatively wet years, more water rights will be satisfied; correspondingly, during relatively drier years, fewer water rights will be satisfied.

Third, groundwater storage must be more actively managed and coordinated among water users. Most western states allow the recharge and recovery of groundwater through carefully regulated permitting processes (Blomquist et al. 2004). That is, states are attempting to encourage water providers to capture and bank surface water for later use. Such laws provide the foundation for actively managed storage in tributary groundwater basins. To make full use of storage, recharge activities will be increasingly important. Close coordination is also necessary to: (1) replenish groundwater storage following dry periods, and (2) optimize groundwater recharge to minimize the effects of groundwater withdrawal on surface watercourses and other eco-hydrologic habitats.

Treating surface water and tributary groundwater as a single source and actively managing the basin storage entails some political risks. For example, the temptation may exist to meet all water uses during dry years and extend water uses during wet years. Unless, over the long-term, limits are placed on the amount of water that may be withdrawn, and the basin is replenished, mining may occur.

Conclusion

The western U.S. is experiencing a number of transformations that raise challenging water issues. First, western states are experiencing rapid population growth. Nevada and Arizona are the two fastest growing states in the U.S. The population of the western U.S. is now largely urban and not rural. Second, the economies of western states are changing. No longer do agriculture and resource extractive industries, such as mining and timber, dominate. Rather, economies have become much more diversified. Third, western lands, forests, lakes, rivers, and mountains are increasingly valued for their recreational opportunities and "wilderness" experiences and not for their ability to produce cattle, minerals, or timber. These transformations are occurring, however, in a context in which agriculture

[10] This practice was allowed for more than a decade by the Colorado State Engineer's Office on the South Platte River. In order to delay the time when a call would go on the river, a well association was allowed to deliver groundwater to one of the most senior surface water rights holders (MacDonnell 1988)

 DOI 10.1007/s10040-005-0012-1

controls and uses 70% of the water in most states. Furthermore, these transformations have occurred at the end of the federal dam building era. Rapidly growing urban populations and the businesses and industries that now compose western economies cannot rely on the federal government to provide them with more water in the manner enjoyed by farmers and ranchers several decades before.

Where will the water come from to serve the western U.S.? It will likely replace the uses heretofore occurring by agriculture, which has relied heavily on surface and groundwater to grow crops in an arid environment (Ashley and Smith 1999). Where will water be stored to provide urban economies with a dependable, stable year-around water supply? The question remains largely unanswered as water providers continue to search and plan for surface water projects, although groundwater basins have begun to play an important role. In terms of water storage, groundwater basins are key to addressing the many water conflicts across the western states. Whether state administrators and water producers are capable of realizing the full potential of groundwater basins for meeting the many new water needs depends largely on their ability to modify and devise institutional arrangements suitable for surface and groundwater as integrated systems rather than just surface water.

References

Abbott C, Leonard SJ, McComb D (1994) Colorado: a history of the centennial state. 3d edn., University Press of Colorado, Niwot, CO

Ashley JS, Smith ZA (1999) Groundwater management in the west, University of Nebraska Press, Lincoln, NE

Bartolino JR, Cole JC (2002) Ground-water resources of the Middle Rio Grande Basin, U.S. Geological Survey Water-Resources Circular 1222, Department of the Interior, Washington, DC

Bastasch R (1998) Waters of Oregon, Oregon State University Press, Corvallis, OR

Blomquist W (1992) Dividing the waters, ICS Press, San Francisco, CA

Blomquist W, Schlager E, Heikkia T (2004) Common waters, diverging streams, Resources for the Future Press, Washington, DC

Brown J (2003) “Whisky’s fer drinkin’ water’s fer fightin’!” is it? Resolving a collective action dilemma in New Mexico. Natural Resources Journal 43:185–221

Bryner G, Purcell E (2003) Groundwater Law Source Book of the Western United States, Natural Resources Law Center, University of Colorado Law School, Boulder, CO

Clark I (1987) Water in New Mexico: a history of its management and use, University of New Mexico Press, Albuquerque, NM

Colorado Geological Survey (2003) Groundwater Atlas Of Colorado, http://geosurvey.state.co.us/wateratlas/

Dunbar RG (1977) The adaptation of groundwater-control institutions to the arid west. Agricultural History 51(4):662–680

Dunbar RG (1983) Forging New Rights in Western Waters, University of Nebraska Press, Lincoln, NE

Fischer WH, Ray SB (1978) A Guide to Colorado Water Law, Colorado State University, Colorado Water Resources Research Institute, Fort Collins, CO

Glennon R (2003) Water Follies, Island Press, Washington, DC

Gould GA (1990) Water rights systems. In: KR Wright, Water rights of the fifty states and territories, Am Water Works Assoc, Denver, CO, pp 6–18

Grant DL (1987) The complexities of managing hydrologically connected surface water and groundwater under the appropriation doctrine. Land and Water Law Review 22(1):63–95

Hutson SS, Barber NL, Kenny JF, Linsey KS, Lumia DS, Maupin MA (2004) Estimated use of water in the United States in 2000, U.S. Geol Surv Circ 1268, Department of the Interior, Washington, DC

Jones CA (2002) The Administration of the Middle Rio Grande Basin: 1956–2002. Nat Resour J 42:939–968

Klug H (2002) Straining the law: conflicting legal premises and the governance of aquatic resources. Soc Nat Resour 15:693–707

Lucero L, Tarlock AD (2003) Water supply and urban growth in New Mexico: same old, same old or a new era? Nat Resour J 43:803–835

MacDonnell L (1988) Colorado’s law of ‘underground water’: a look at the South Platte Basin and beyond. University of Colorado Law Review 59(3):579–625

McGuire VL, Johnson MR, Scheiffer RL, Stanton JS, Sebree SK, Verstreiten IM (2003) Water in storage and approaches to groundwater management. High Plains aquifer, 2000, USGS Circ 1243

Mehls S (1984) The new empire of the Rockies: a history of northeast Colorado, Bureau of Land Management, Denver, CO

Oregon Water Resources Department (2002) Groundwater supplies in the Willamette Basin, Portland, OR

Oregon Water Resources Department (2003) Groundwater supplies in the Umatilla Basin, Portland, OR

Pisani D (1996) Water, land, and law in the west: the limits of public policy 1850–1920, University Press of Kansas, Lawrence, KS

Radosevich GE, Nobe KC, Allardice D, Kirkwood C (1976) Evolution and administration of Colorado water law: 1876–1976, Water Resour Publ, Fort Collins, CO

Shah T (1993) Groundwater markets and irrigation development, Oxford University Press, Oxford

Tarlock AD, Corbridge JN Jr, Getches DH (2002) Water resource management: a casebook in law and public policy, Foundation Press, New York

Upper Black Squirrel Creek Groundwater Management District (2001) Rules and regulations and statement of policy, Colorado Groundwater Commission, Denver, CO

U.S. National Hydrography Dataset, University of Arizona: Tucson, AZ 2005. Map of Western U.S. 1:50,000,000. Using ArcGIS, v.8.3 Redlands, CA: Environmental Systems Research Institute, 1992–2005

Vranesh G (1987) Colorado Water Law, 3 vols. Natural Resources Law Center, Boulder, CO

 DOI 10.1007/s10040-005-0012-1