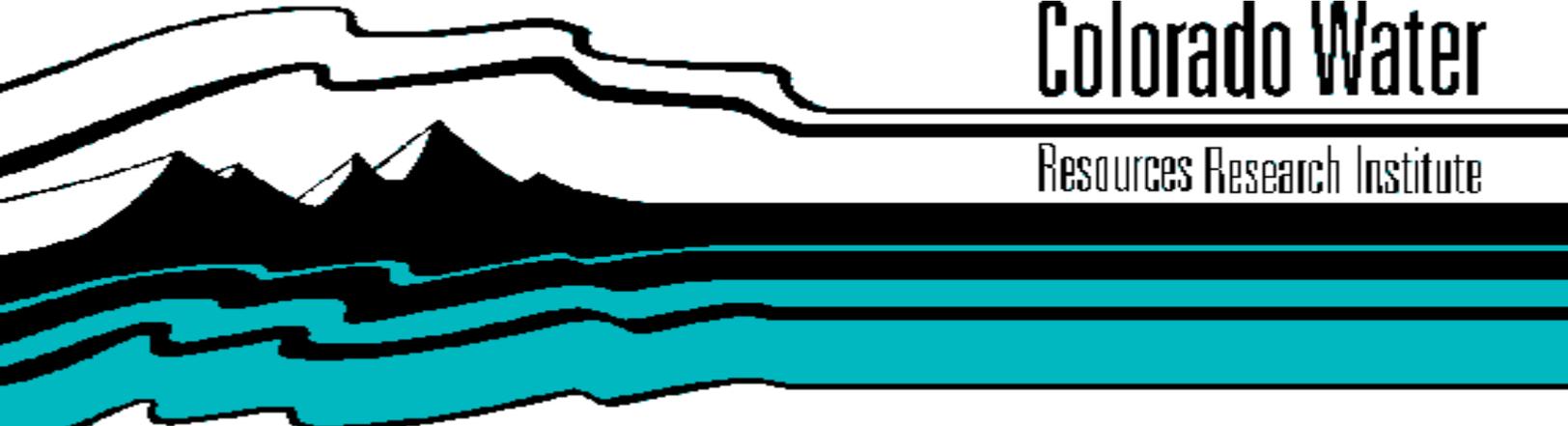


**IRRIGATION WATER CONSERVATION: OPPORTUNITIES
AND LIMITATIONS IN COLORADO-A REPORT OF THE
AGRICULTURAL WATER CONSERVATION TASK FORCE**

by

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Irrigation Water Conservation: Opportunities and Limitations in Colorado

A report of the Agricultural Water Conservation Task Force

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Summary

The Agricultural Water Conservation Task Force was assembled by the Colorado Water Resources Research Institute to consider issues related to irrigation water conservation in Colorado. The overall objective of the task force was to provide information describing the nature of irrigation water use in relation to other uses and the implications of various conservation strategies. The group, which was composed of academic faculty from Colorado State University and representatives of water agencies from throughout the state, assembled relevant information and conducted monthly discussion sessions in the process of producing a thorough report. The resulting document presents the findings of this task force and attempts to clarify the complex issues involved. It should not be interpreted as a legal document or an endorsement of specific public policy recommendations.

Water use in Colorado is structured within the institutional framework of the prior appropriation doctrine, which serves as the legal basis for water rights administration. Under the priority system, the timing of the appropriation determines the user's priority to apply surface and tributary ground water to beneficial use. The prior appropriation system also allows for the permanent transfer of water rights between different users and uses, subject to the protection of other water right holders.

Water rights are quantified based on the rate of diversion from the stream system or the volume stored. The consumptive use portion of a water right is specifically defined as water that is no longer available within a stream or aquifer system after it has been applied to beneficial use. For crop production systems, plant transpiration and evaporation from soil and crop surfaces accounts for almost all the water that is consumptively used. With most irrigation water distribution and application systems, some water is applied in excess of the soil water holding capacity and actual use. The excess water either percolates through the soil and becomes ground water that reenters the stream or river or flows overland through surface channels or drainages to the stream or river. These returning waters, which are in excess of water actually used or held in storage within the crop root zone, are called return flows.

Beneficial uses of return flows from irrigation result in an increase in the overall efficiency of agricultural water use in several of Colorado's river basins. They allow for multiple uses of water within basin systems and increase the water supply for downstream users in the latter part of the irrigation season. In some instances, the benefit of greater water use efficiency derived from return flows can be partially offset by degradation of water quality resulting from repeated use of the same water.

In Colorado, irrigation water use (measured as withdrawals and deliveries) accounts for more than 90% of total used for all purposes on a state-wide basis. Although irrigation water use comprises a much lower percentage of total use in the South Platte and Arkansas basins, where population densities are greater and water use by the municipal and industrial sectors is greater, it accounts for more than all other uses combined.

The sources of water used for irrigation vary among the state's major river basins. Within the South Platte and Arkansas basins, most of the irrigation water demand is furnished by diversion of streamflow and ground water pumping from shallow alluvial aquifers. Segments of the eastern plains overlie nontributary deep aquifers that are part of the larger ground water system known as the Ogallala Aquifer. This nontributary ground water is the source of most of the irrigation water applied to crops in these areas. Irrigation water supplies in the Rio Grande basin are obtained from direct surface diversions and pumping from unconfined and confined ground water aquifers. Throughout most of the Colorado River tributary basin and the North Platte River basin, surface water diversion is the primary source of irrigation water.

Under present conditions, conservation largely occurs through changes in operations or adoption of conservation practices by individual operators. These decisions occur in response to varying combinations of institutional and economic factors that exist within any given region or basin. In areas where irrigation water is obtained by pumping from deep ground water aquifers, economic incentives for water conservation exist because practices that result in increased application efficiency can frequently be justified on the basis of decreased pumping costs. In addition, institutional incentives in the form of restrictions on the rate of aquifer depletion encourage the adoption of irrigation water conservation practices. In the alluvial watershed basins where water is obtained from surface diversions or shallow aquifers, incentives for adopting practices that decrease nonbeneficial consumptive use or result in saved water are somewhat limited unless the water conserved can be used to extend supplies under the terms of an existing water-right decree. The Colorado River Basin Salinity Control Act and its amendments is an example of an institutional initiative that provides economic incentives for water conservation. The intent is to reduce salt loading in the Colorado River by providing cost-share funds for irrigation system improvements that allow for decreased surface water diversions.

The implications of irrigation water conservation are an important consideration, especially in watershed basins where water is derived from surface diversions or shallow alluvial aquifers. Under these conditions, wide-scale adoption of conservation practices designed to increase diversion efficiencies has the potential of altering basin hydrology by reducing the magnitude of return flows. Conversely, the implications of agricultural water conservation in areas of the eastern plains, where deep aquifers are the source of irrigation water, are largely positive because of the overall effect of prolonging the usable life of the aquifer and, thus, the economic viability of the region. Because of variation in potential impacts of irrigation water conservation, the task force concluded that policy initiatives designed to implement conservation should be based on how water is used at the basin level rather than the individual farm level. Also, impacts of water conservation strategies on interstate compact obligations must be considered.

Introduction

The availability and distribution of water are the primary determinants of the character of all natural ecosystems and all modern economies. Society is dependent upon a plentiful supply of water for municipal, recreational, agricultural, and industrial uses. Today's delivery systems provide such easy access to water that most people take it for granted. This is true even in Colorado, a state where water is generally considered the most precious natural resource.

Like other western states, Colorado's settlement and subsequent economic progress was possible only through the development of water resources from surface waters and underground aquifers. Surface water supplies developed from natural streams represent the largest source of fresh water supplies. Although the eastern plains and western plateau regions are semiarid, the central mountains collect an abundance of precipitation in the form of snow during the winter and early spring. This water feeds four of the West's major river systems; the Platte, Arkansas, Rio Grande, and Colorado. Mining and agriculture interests were the first to develop water resources from these stream systems. In recent decades, industrial expansion in the form of manufacturing and development of fossil fuels has occurred. Although growth in these activities has placed minimal direct demands on water resources, the increase in population accompanying industrial growth has produced significant increases in the water requirements of municipalities, particularly those on the eastern front range. Future increases in demand are anticipated from continued population growth and federal mandates for threatened and endangered species habitat and improved water quality.

There is increasing concern about how future demands for water can be met, given that some watersheds are already over appropriated and that the constraints on development of large-scale storage projects are significant. Historically, agriculture has used the vast majority of Colorado's developed water resources. This is still true even though transfers of water from agricultural to urban uses have been employed extensively in recent years to satisfy demand caused by rising population. Irrigation agriculture continues to be the focal point of discussion on sources of water to meet growing demands. Calls for conservation have come from several sources, apparently prompted by assumptions that the magnitude of agricultural water use is associated with inherent inefficiencies in current use and that minimal efforts toward conservation could yield the water required for alternative uses.

Task Force Approach

The Colorado Water Resources Research Institute assembled a task force to study issues relating to the question of whether efforts to conserve agricultural water could solve problems associated with alternative demands without adversely affecting agricultural production or existing delivery systems and users. This Agricultural Water Conservation Task Force was composed of members of the academic community and representatives of various water agencies from throughout the state. The Task Force conducted monthly deliberative sessions during the period from September, 1994 to July, 1995. It took the approach of first defining the institutional and physical realities that govern the use of water and assembled information on the major water features of the state and characteristics of water use. Once this was completed, they considered potential strategies for accomplishing agricultural water conservation and the implications of these different strategies.

Characteristics of use and strategies and implications of conservation were first considered on a state-wide basis. The Task Force then considered these topics on a regional basis. For the purposes of this report, six different water basins were defined based on regional and hydrological characteristics (Fig. 1). In most cases, the regions were designated along the lines of watershed basins. The High Plains deep aquifer basin, however, was identified as a separate basin because of its unique hydrology and characteristics in comparison to the South Platte and Arkansas watershed basins.

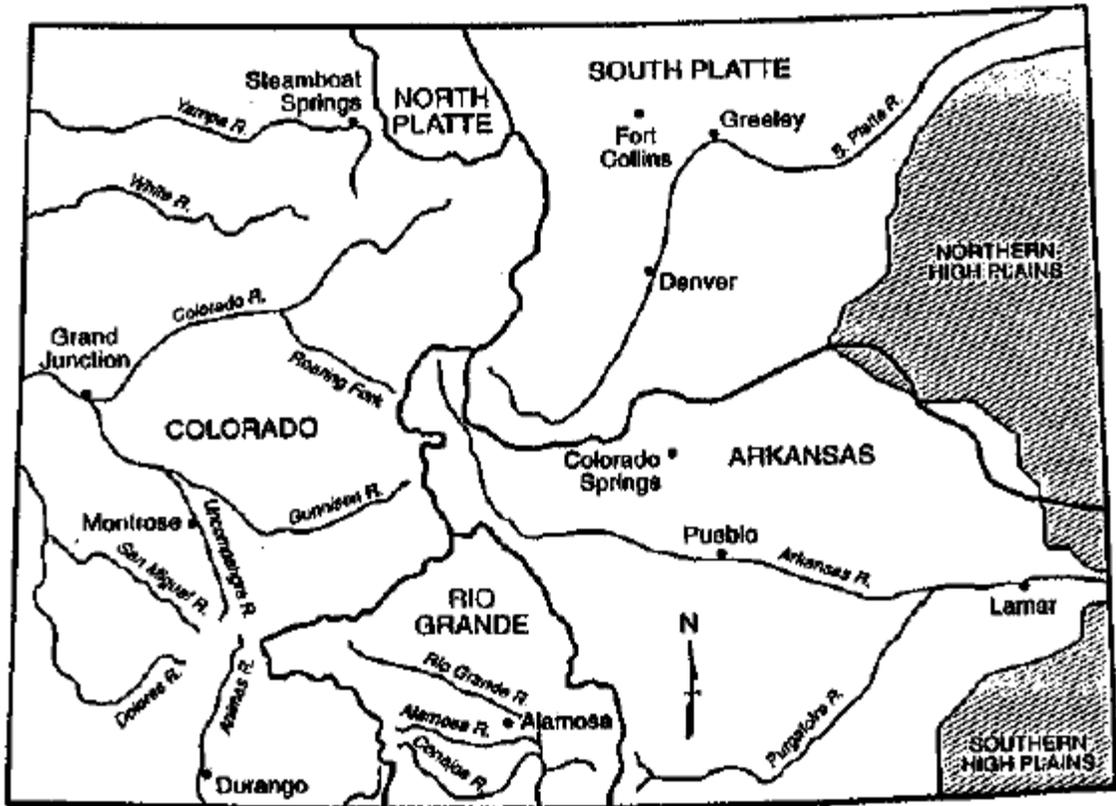


Fig. 1. Regional watershed and deep aquifer basins defined by Task Force.

Institutional Structures Governing Colorado Water Use Institutions

Society has rules, either explicit or implicit, to allocate all resources among competing uses. These rules regulate the use of the resource. The nature of the rules can vary from a simple tradition that has been followed for years, to strict legal definition and enforcement. As resources become more scarce, more formal rules are established.

In general, the formal rules are defined in statutes or laws that specify various rights and responsibilities concerning resource use. Clear and enforceable rights are important for the efficient allocation of any resource. The decision to make a capital investment is based on expectations about the future. The existence of rules that define an enforceable right adds certainty to the planning process, allowing all parties to act more consistently based on a reasonable expectancy of future outcomes.

The characteristics of water resources make the definition of the associated rules and rights more difficult than for most other resources. Surface water is a fugitive "flow" resource where the quantity available varies significantly over time and location. The introduction of storage facilities allows this fugitive flow to be converted into a "stock" resource. This, however, can impact others who have a right to the flow. Ground water has its own characteristics in that the quantities available and properties of the resource are not easily observed, including interrelationships with surface water. Consequently, special rules have evolved to specify the rights associated with water resources. The following presentation provides a brief overview of the evolution and basic principles of water law in the western United States. More detailed discussion on these topics can be found elsewhere (see for example Getches, 1990; Moses, 1986; El Ashry and Gibbons, 1988).

Water rights in the United States originally were based on the riparian doctrine because of the climate and geography of the areas settled earliest. In the east, rainfall is generally abundant, and the landscape is permeated with brooks, streams, and rivers. According to riparian law, water rights are accorded to owners of land bordering water bodies. Water use by all riparian landowners within a particular stream system is restricted to reasonable use, and all owners share in shortages. Place of use is generally restricted to the watershed within which the natural water body exists, which is usually lands bordering the stream. The riparian doctrine still serves as the basis for water allocation in most states east of the hundredth meridian.

As people moved west, new situations were encountered where the riparian doctrine did not adequately address the allocation of water use. Mining was one of the first enterprises in the West requiring large-scale development of water resources. Water was used for processing the ore in placer mining operations. In most cases, the water was diverted and applied to uses located away from the stream. Because the demand for water in this setting could quickly outstrip the quantity provided by a local stream, a new system had to be devised to allocate the right to use the water. This was the origin of the prior appropriation doctrine.

The prior appropriation system of water allocation originally developed within the mining camps and was similar to the practice of filing mining claims. In the early history of mining, the first person to occupy and work a site established a legal claim to the mining rights on that site. Likewise, the first person to put water to a productive use established the highest priority for water use from a given stream system. If the water supply was limited, the earliest (most senior) appropriators had a right to claim their entire allocation of water for beneficial use while those with later (more junior) appropriations received only what remained. This principle, which has come to be commonly referred to as "first in time, first in right," became the basis for water rights administration in much of the western United States. Although the principles of the prior appropriation doctrine originally applied to water used for mining, they were quickly adapted to use in appropriating water rights for irrigation and other beneficial uses as the west was settled.

Prior appropriation doctrine principles grew from local customs rather than established law. The doctrine was so widely accepted in the newly settled regions of the West that it was gradually adopted by various state courts and was incorporated into state statutes. The Federal government formally recognized the concept of prior appropriation in mining legislation passed in 1866 and 1870 and in the Desert Land Act of 1877.

Water Rights in Colorado

Colorado became the first state to formally adopt the doctrine of prior appropriation as the guiding principle for water rights administration with the inclusion of the doctrine in the Colorado Constitution in 1876. This doctrine was adopted subsequently in various forms by eight other western states (Alaska, Arizona, Idaho, Montana, Nevada, New Mexico, Utah, and Wyoming) as the primary legal system for administering water rights. Some states originally adopted the riparian doctrine and subsequently converted to some form of prior appropriation; thus, both riparian and appropriative water rights are recognized. This hybrid doctrine (also called the "California doctrine") is used in California, Kansas, Mississippi, Nebraska, North Dakota, Oklahoma, Oregon, South Dakota, Texas, and Washington. Riparian principles are used to regulate water rights in most of the remaining states.

The Colorado system of the prior appropriation doctrine is reliant upon the legal ownership of water rights. A water right is based on diverting a given quantity of water at a specified site under a specified priority and applying the diverted water at an identified location for a defined purpose. Water rights can be owned by individuals and a variety of entities including municipalities, water and sanitation districts, ditch companies, and state and federal agencies.

To establish, or appropriate a water right in Colorado, water must be used for beneficial purposes. Beneficial use is defined in the Colorado statutes as "the use of that amount of water that is reasonable and

appropriate under reasonably efficient practices to accomplish without waste the purpose for which the appropriation is lawfully made..." (Colorado Revised Statutes, Section 37-92-103(4)). Water rights in Colorado are used for a multitude of beneficial uses including but not limited to municipal, domestic, industrial, recreational, environmental, and agricultural purposes. The use of water for the preservation of the natural environment to a reasonable degree is considered a beneficial use, but the legal right to use water for this purpose is held exclusively by the State of Colorado.

The prior appropriation doctrine also embodies the "use it or lose it" principle. Again this concept has its roots in mining history. Mining claims were valid only as long as the site was worked productively. If mining activity ceased, the claim was considered abandoned. Therefore, a new claim to mining rights could be established on the same site. Similarly for water rights, if appropriated water ceases to be applied to a beneficial use for an extended period of time (10 years), the right to that quantity of water may be declared abandoned. The water then remains in the stream to be appropriated by another individual or entity under a junior water right.

Not all water in Colorado is associated with a particular water right. In some areas of the state, unappropriated water is available for appropriation and beneficial use. Water is also consumed for purposes that are not considered beneficial. These nonbeneficial uses include riparian vegetation such as cottonwoods and willows, and evaporation from waterways, lakes, streams, and wetlands.

Water rights in Colorado are adjudicated by the Colorado judicial system and administered by the State Engineer, who also serves as Director of the Division of Water Resources, Colorado Department of Natural Resources. A district court judge is designated as a water judge in each of seven water divisions in the state, and has jurisdiction to preside over water matters in the division water court. The water courts determine water right quantities and priorities, consider changes in water rights, interpret water right claims, and issue legal decrees permitting the use of water.

The State Engineer is charged with administering and distributing the waters of the state. This officer has general supervisory control over measurement, record-keeping, and regulating the distribution of the waters of the state. The State Engineer is responsible for administering the orders and decrees of the water court system. This consists of providing for delivery of the court-decreed quantity of water to water right holders at the proper location and time according to priority.

The principles of the prior appropriation doctrine applied first to surface waters but not to ground water because little was known at the time of their adoption about interrelationships between surface waters in streams and underlying ground water. Also, little use was made of ground water resources prior to 1940. As the hydrology of stream systems became better understood, the legal framework for ground water regulation evolved. In Colorado, legislation passed during recent years has resulted in a highly structured

system of managing these waters. Where ground water use is determined to have an impact on surface stream flows that are appropriated, the ground water and the associated surface stream flows are administered jointly as one stream system under the principles of the prior appropriation doctrine.

Water rights can be absolute or conditional. Absolute rights have been perfected by placing all or a portion of the decreed amount of water to beneficial use, have undergone the scrutiny of the water court, and have been given a priority date based on the date of the initiation of the appropriation process. A conditional right is a water right for which the applicant has asked the water court to reserve a quantity and priority date based on the applicant's demonstrated intent to appropriate the water for a specified beneficial use, but the right has not yet been perfected because no beneficial use has been made of the water. Continued diligence toward the perfection of a conditional right is essential, because without this continued diligence, the conditional right will be declared abandoned by the water court.

Water rights are quantified based on the rate of diversion (cubic feet per second) or volume stored (acre-feet). However, the amount of water yielded from a water right is affected by the availability of water in any given year. If water supply is limiting, the water right holders that are junior or of a lower priority may not receive their entire allocation of water. The value of a water right, therefore, is depends on its priority.

Changing Water Rights

The prior appropriation system in Colorado allows water rights to be transferred or changed, subject to certain procedures and restrictions imposed by the water courts and the State Engineer's office. Water right transfers or changes can be temporary or permanent, and can involve changes in use, timing, amount, and location of either diversion or use. Proposed changes in water use that deviate from the original water right decree require water court approval prior to implementation. Changes in water use that do not violate the original terms and conditions of the water right decree can usually be implemented without court review, but may be subject to review by the State Engineer.

The permanent transfer of water rights between different users and uses is permitted subject to the protection of other water right holders. Water right changes cannot have a detrimental impact on other vested or decreed water rights. When a change in use is proposed, other water users are protected from injury by terms and conditions that are imposed by the water court and contained in the decree for the water right change. These terms and conditions are necessary to maintain stream conditions that were present at the time other vested water rights were established. This "no-injury" rule is defined and enforced by the water courts. The State Engineer is then responsible for implementing the actions specified by the courts after a change of water right is decreed. The quantity of water that can be transferred is generally based on the amount of water previously consumed by the water user. This approach protects other water users on a

system by maintaining both surface and ground water availability because water that was consumed was not available for use by other water users prior to the proposed transfer or change.

The no-injury rule is applicable whether a proposed transfer is temporary or permanent. Temporary transfers can take the form of exchanges of water between water right holders that are mutually beneficial, or temporary use contracts that effectively lease water to other users during critical time periods. For example, temporary transfers can be helpful for cities that have acquired surplus supplies of water for future population growth, but would like to lease the water to other users for income purposes, until such time as the water is needed by the cities. Temporary changes must be approved by the State Engineer (C.R.S. Section 37-80-120).

There is much discussion regarding the issues associated with agricultural water conservation and the administration of the existing water rights system. The Colorado water rights system provides certainty and protection to water users while allowing for flexibility in changes of use and the transfer of rights. Although the judicial process is viewed by some as an expensive and time-consuming means to resolve water rights issues, the process does allow for other water right holders to act on behalf of and protect their rights, and can be responsive to changing economic and social needs. The adjudication and administration of water rights has evolved over time and will likely continue to do so in the future. The adoption of agricultural water conservation practices by some water users can have serious impacts on other water users and existing stream conditions. This document will attempt to identify some of the key issues that must be addressed as we pursue improvement in on-farm irrigation efficiencies.

Technical Elements of Agricultural Water Use in Colorado

Consumptive Use

The consumptive use portion of a water right is specifically defined as water that is no longer available within a stream or aquifer system because it has been evaporated, transpired by plants, incorporated into products or crops, consumed by people or livestock, or otherwise removed from the water supply. For crop production systems, plant transpiration and evaporation from soil and crop surfaces accounts for almost all the water that is consumptively used. These combined evaporative and transpiration losses are referred to collectively as evapotranspiration and abbreviated as ET. Evapotranspiration losses generally are assumed to be equivalent to beneficial consumptive water use in irrigated cropping systems. The consumptive use portion of a water right is rarely as much as the amount of water that a water right is allowed to divert for a given beneficial use. This is a significant source of confusion and contention in quantifying a water right.

With most irrigation water distribution and application systems, some water is applied in excess of the soil water holding capacity and actual use. The excess water either percolates through the soil and becomes ground water that reenters the stream or river or flows overland through surface channels or drainages to the stream or river. These returning waters, which are in excess of water actually used or held in storage within the crop root zone, are called return flows.

Return flows are typically available for appropriation by downstream water users. When a water right is transferred to another use, water laws in most western states, including Colorado, dictate that the change in conditions resulting from a transfer (i.e., point of diversion and quantity of water diverted, for example) must not and shall not injure other vested or decreed water rights not directly involved in the transaction. This is generally interpreted to mean that only the amount of water actually consumed – the consumptive use – under a historical set of conditions and practices, can be sold or transferred and that return flows are maintained. It is difficult, costly, and time consuming to determine consumptive use with complete accuracy; therefore, engineering estimates are generally used to establish the terms and conditions to be included in the change decree resulting from a transfer of use. Such estimates are based on historical experience with long-used crop varieties and irrigation technologies under historic hydrologic conditions and may or may not be good estimates for a specific operation.

Irrigation Efficiency

Many definitions of irrigation efficiency have been developed and used as measures of irrigation performance. The common factor in all these definitions is that they involve the ratio of water quantity

consumptively used or stored for later use to the quantity delivered.

The general engineering definition of efficiency is an output divided by an input, both of the same character. If the difference between the output and input is not reusable, such as heat generated from an engine, then this difference constitutes a loss to the process or system. The term irrigation efficiency describes a ratio between water quantities, and inherently implies that water not consumed by the crop is lost. However, in irrigation, "nonconsumed" water (water not stored in the root zone) is not always lost to the system. In fact, much of the water not directly consumed by the crop returns to the stream system as return flows. Thus, irrigation efficiency values for individual operations can be misleading because they do not account for water that eventually becomes available to other downstream users in a river basin.

In Colorado, the historical efficiencies of irrigation systems are taken into account by the legal system. A reasonable amount of over irrigation due to unavoidable losses associated with a particular irrigation system is considered a beneficial use. The water required to satisfy the consumptive use needs and also to account for these losses is generally referred to as the duty of water for a given irrigation system.

Return flows are also important because there is a time lag between an irrigation event and the time that the return flow water reaches the stream and is available for subsequent diversion and beneficial use. This time lag can range from a few hours to several months depending on whether it is surface or ground water return flow and the characteristics of the river basin and its soils. Early research by the Colorado State University Agricultural Experiment Station documented that return flows resulting from irrigation greatly increased late-season streamflows in the South Platte basin (Parshall, 1922). The historical record prior to irrigation indicates that streams in eastern Colorado were likely ephemeral in many years (Werner, 1993).

In the Arkansas, South Platte, and Rio Grande basins, the apparent inefficiency of individual irrigation systems creates water storage in a shallow aquifer within the river basin. The additional inflow to the stream from this aquifer increases the water supply for downstream users in the latter part of the irrigation season. Without this temporary ground water storage, natural high levels of river flows in the early part of the growing season would flow downstream and be unavailable for later use.

Degradation of water quality resulting from repeated use of the same water is of concern also. In river basins where return flows are used several times, concentration of suspended solids and dissolved salts increase downstream. This problem is more severe in some basins than others because of natural salt-bearing soil layers.

The traditional irrigation efficiency term describes the overall performance of an irrigation system in delivering water to the crop root zone of an individual farm or field without considering the reuse of return flows. For example, if a 60% efficiency is obtained by an irrigation system on a particular field, it doesn't necessarily mean that 40% of the water delivered to this field is lost to the system. It means that only 60% of

the water diverted from the source and applied to the field is stored in the root zone or used beneficially to satisfy crop requirements. The other 40% may return to the stream or ground water and become available for another user. Thus, in river basins, irrigation efficiencies of individual fields may be low, but the overall water use efficiency of the basin can be high.

The efficiency of various irrigation practices is also important where water is pumped from deep ground water aquifers, but different factors must be considered. In these systems inefficient irrigation results in substantial water loss to the aquifer because the time it takes the deep percolated return flows to reach the ground water aquifer is too long for this water to be considered reusable. In addition, the energy needed to pump the additional water can represent a significant cost to the overall production system.

Water Conservation Terminology

Salvaged water and saved water are terms that refer to a fraction of a diverter's water supply that becomes available as a result of conservation practices or water system improvements. Water salvaged or reclaimed from a nonbeneficial loss of water diverted under a valid water right is called salvaged water. Such losses could include evaporation, transpiration, or seepage that does not return to the stream or aquifer system upon which other water rights depend. Evaporation and transpiration losses are common in open, unlined ditches, which are widely used to convey water for irrigation. Replacing an open ditch with underground pipe would result in conserving water by eliminating evaporation from the open ditch and transpiration from weedy plants or trees growing along the ditch. Some of the seepage from canals returns to the stream or aquifer system as return flow, and is then available for diversion by other water rights. However, this is not always the case. Using underground pipe can eliminate losses of seepage water that would not otherwise return to the stream system. In this example the water conserved would be considered salvaged water because the water conserved would not, under pre-conservation conditions, have been available for diversion and beneficial use by other water users. The owner of salvaged water may elect to change its use, irrigate additional acreage, or store it to cover seasonal shortages but, as a prerequisite, must prove in water court that any changes will not injure other water users.

Return-flow water that is conserved through more efficient diversion and application of a diverted water right is called saved water. If, in the example given above, installation of underground pipe prevented losses of seepage water or other return flow that normally would have returned to the stream or aquifer system upon which other water users are dependent for their supply, the water conserved would be considered saved water. Saved water can be applied to beneficial use by the original diverter to eliminate or reduce periods of shortage, subject to terms of the original water-right decree, but may not be sold or transferred to new uses that are outside the terms of the original water right.

Conservation practices can impact a watershed differently depending on whether the water derived is salvaged water or saved water. Water conserved as salvaged water can potentially increase the amount of water available for alternative uses without adversely affecting other water rights. Water conserved as saved water may decrease the total amount of water available for alternative uses. If the original diverter can make beneficial use of the saved water during periods of shortage in accordance with the terms of the existing decree, the diverter's total seasonal consumptive use will increase. If the saved water becomes available to junior water right holders, those junior users will divert or consume part or all of it.

Salvaged water belongs to the owner of the water right, and can be transferred to new uses, subject to water court approval of a change in water rights. Saved water falls into two categories: 1.) if the owner of the

water right is able to use the saved water to fill shortages under the terms of the water right decree and does not increase the decreed irrigated acreage or apply the water to new uses, the saved water remains under the owner's control; and 2.) if the owner of the water right is not able to use the saved water to fill shortages for the original decreed purposes, the saved water automatically becomes part of the stream system and available for diversion by other holders of water rights upstream or downstream.

Overview of Colorado Water Use

Characterization of water use in Colorado is difficult because of variation that exists in sources of supply, the array of end uses from region to region, delivery systems used, and the methods used in accounting for use. The State Engineer administers and records diversions in each of the seven water divisions in the state on a continuing basis. Values for water deliveries provided by this effort are based on actual records from various diversion points. Table 1 provides a summary of water deliveries for the 1992 and 1993 water years for the entire state. For this water accounting system, a water year begins on November 1 of the prior calendar year and ends on October 31.

The various categories describe either diversions for specific end uses or types of entities diverting water. The data do not account fully for irrigation use because complete records are not kept on the amount of final end-use for water diverted originally to storage and subsequently released for irrigation. For the 1992 and 1993 water years, direct irrigation diversions were 75% of the state-wide total, and do not include the amount of irrigation water released from storage. Municipal water diversions, which reflect a large proportion of urban water demand, averaged only 3.9% of total water withdrawals.

Table 1. Water deliveries for various uses in Colorado during the 1992 and 1993 water years.

Type of diversion	1992	1993
	----- acre-feet -----	
Irrigation	10,319,942	11,370,700
Storage	2,056,468	2,376,508
Municipal	571,628	562,527
Commercial	33,529	26,245
Domestic	14,117	28,443
Stock	133,523	167,762
Industrial	204,843	194,247
Recreation	8,989	14,407
Fish	143,157	367,467
Augmentation	82,887	99,392
Recharge	99,770	94,991

A detailed analysis of state water use under 1985 conditions was conducted by the U.S. Geological Survey as a part of its water-use monitoring program. The work was conducted in cooperation with the Colorado Division of Water Resources, Office of the State Engineer, and the results were reported on both a county and hydrologic subregion basis (Litke and Appel, 1989). The regional watershed boundaries the Task Force selected for its analysis of agricultural water conservation are generally consistent with the hydrologic subdivisions used in the USGS study. In addition to the data for withdrawals and deliveries from surface systems, the USGS analysis included estimates of ground water use from confined aquifers.

The data presented here (Table 2) were modified from the actual values compiled in the USGS report by first removing the withdrawals given for hydroelectric power and then reporting water use for various categories on a percentage rather than an absolute basis. Hydroelectric power withdrawals were eliminated because no consumptive use is associated with this category of use and the general assumption that water used for power generation is generally devoted to some other end use in the stream system before it leaves the state. The categories given for various end uses differ in some cases from those used by the State Engineer. Municipal use includes water used by hotels, motels, office buildings, restaurants and other commercial facilities including civilian and military institutions, and all water used for household purposes (inside and outside) in both rural and urban areas. The industrial use category included water used for manufacturing and processing of products such as foods, beverages, steel, machinery, chemicals, and paper. Other uses included water used for the extraction of minerals, coal, crude petroleum, and natural gas; generation of thermoelectric power; and water withdrawn by public supply systems but not delivered to commercial, domestic, industrial, or power users. Uses not incorporated in the study included water use by fish hatcheries, second-source domestic use, reservoir evaporation, water used in augmentation plans, and certain instream uses such as habitat protection and recreation.

Withdrawals and deliveries for irrigation were greater than 90% of totals used for all purposes on a state-wide basis (Table 2). Variation in irrigation water use among the different basins is directly related to population density. Irrigation water use comprises a much lower percentage of total use in the South Platte and Arkansas basins, where population densities are greater and water use by the municipal and industrial sectors is greater, than in other basins. The high proportion of irrigation water use in Colorado is comparable to that for other western states where significant irrigation development has occurred (El-Ashry and Gibbons, 1988).

Table 2. Percentages of total water withdrawals and deliveries for various purposes in different Colorado basins. Data based on conditions observed in 1985.

End-use category	South Platte	Arkansas	Rio Grande	Colorado	North Platte	High Plains	Entire State
	----- % of total use -----						
Municipal	12.9	5.1	0.4	1.2	0.1	0.8	4.4
Industrial	1.8	3.8	<0.1	<0.1	<0.1	<0.1	1.0
Irrigation	80.2	84.6	99.4	97.0	98.1	98.0	91.6
Livestock	0.4	0.3	0.1	0.5	1.6	0.8	0.4
Other	4.8	6.2	0.1	1.2	0.1	0.4	2.6

Source: Litke and Appel, 1989

Water Use - South Platte River Basin

Water Features and Basin Hydrology

The major water features of the South Platte River basin are indicated in Fig. 2. The South Platte River originates in the mountains of central Colorado and flows about 450 miles northeast across the Great Plains to the confluence with the North Platte River at North Platte, Nebraska. The basin encompasses 19,020 square miles within Colorado, with elevations ranging from 3,500 feet in Julesburg at the state line to 14,000 feet in the headwaters area. Climate in the basin is characterized by wide temperature ranges and irregular seasonal and annual precipitation. Precipitation in the mountains averages 40 inches annually, while in contrast, precipitation on the plains east of Denver ranges from 12 to 16 inches a year.

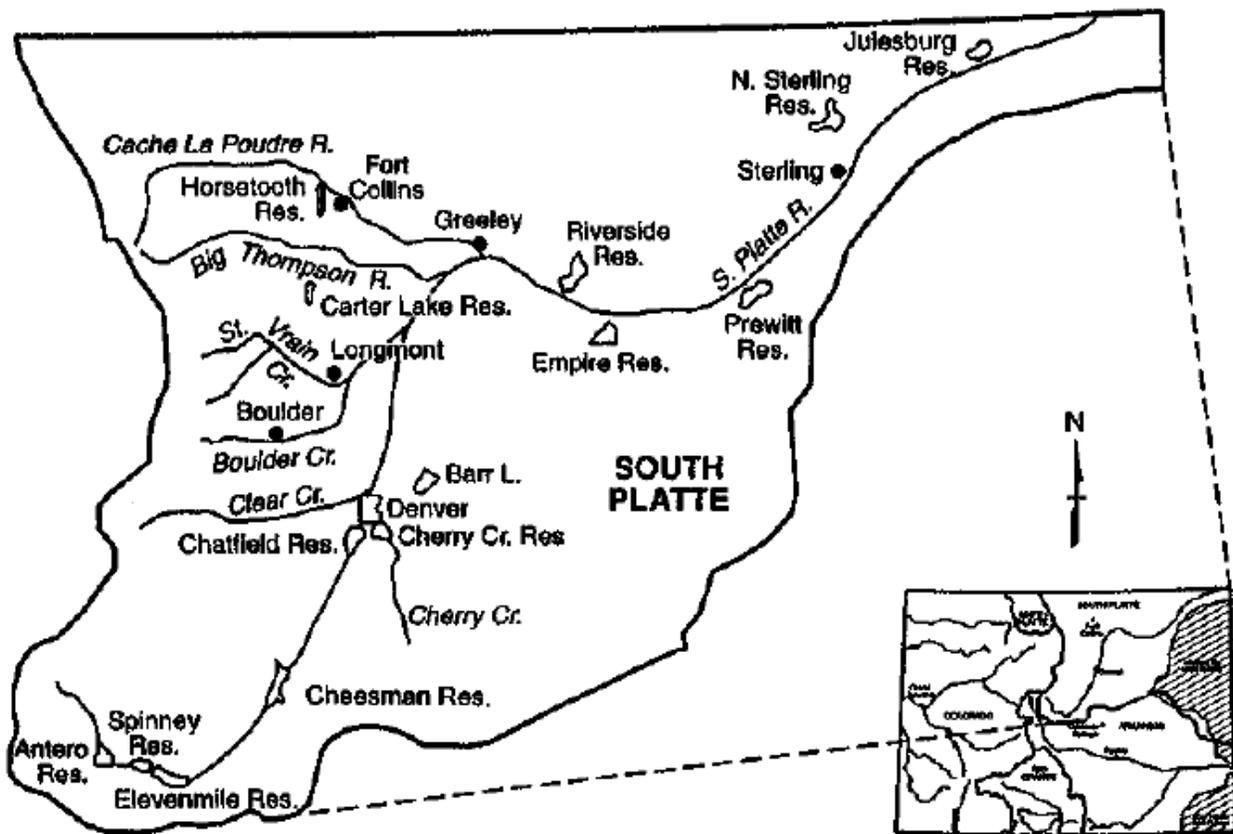


Fig. 2. Water features of the South Platte River basin in Colorado.

Major tributaries to the South Platte include Cherry Creek, Clear Creek, Boulder Creek, the St. Vrain River, the Big Thompson River, and the Cache la Poudre River. Flows on the river reach their maximum at Kersey, and although there are no major perennial tributaries downstream of this point, several plains tributaries contribute significant quantities of water to the South Platte system during periods of high rainfall. There are approximately 370 reservoirs in the basin with capacities in excess of 500 acre-feet, and a collective storage volume of 2.2 million acre-feet. The major instream reservoirs on the main stem are Antero, Spinney, Eleven Mile, Cheesman, and Chatfield. The major storage facilities that exist on offstream sites or on tributaries are Cherry Creek Reservoir, Barr Lake, Carter Lake, Horsetooth Reservoir, Riverside Reservoir, Empire Reservoir, Prewitt Reservoir, North Sterling Reservoir, and Julesburg Reservoir.

The South Platte River is a headwaters system, therefore there are no significant surface water inflows from upstream river systems, with the exception of interbasin transfers from west of the Continental Divide. Native water basin yields are estimated to be 1.44 million acre-feet annually, with average annual water imports of 400,000 acre-feet. Average annual surface water flows leaving the state at Julesburg are 393,000 acre-feet, with annual ground water outflow from the alluvial aquifer averaging 15,000 acre-feet.

In addition to surface water, ground water is used extensively throughout the basin for irrigation, municipal, domestic, and industrial water supplies, and livestock. It is available from alluvial aquifers in stream valleys, consolidated aquifer systems underlying the plains, and fractured systems of the metamorphic and granite rocks of the front range. Wells completed in the alluvial aquifer system provide high yields, whereas wells completed in fractured rock in the mountains produce low yields. The two primary aquifer systems in the basin are the South Platte alluvial aquifer, and the Denver Basin aquifer. The Denver Basin aquifer is composed of four major bedrock aquifers.

The alluvial aquifer system is recharged by infiltration of seepage from streams, reservoirs, and ditches, and by deep percolation of precipitation and applied irrigation water. The direction of ground water flow is normally toward the river from recharge sites. Irrigation return flows in the form of both surface and ground water contribute to streamflow. Ground water levels within the alluvial system can decline during the year because of pumping for irrigation; however, these declines are not a significant problem within the South Platte alluvial system. Approximately 680,000 acre-feet of ground water was withdrawn from the alluvial aquifer for irrigation purposes in 1993.

Ground water discharge from the alluvial aquifer to the river in the South Platte system is variable from one location to another and is related to saturated thickness and ground water level of the alluvial aquifer. Comparisons of estimated basin inflows and water diversions indicate that water diversions and withdrawals greatly exceed the total amount of water available. Thus, a significant portion of the irrigation water demand

in the system is satisfied by return flows.

Water Quality

Water quality issues in the basin include point and nonpoint source urban and mine drainage pollutants, salt accumulation on lower basin irrigated lands, elevated levels of nutrients and total dissolved solids in surface water and the alluvial aquifer, and localized areas of high nitrogen concentrations in the ground water in the central portion of the basin. Metals contamination resulting from historic mining activities is observed in several headwater streams. The problem is especially apparent in Clear Creek from Idaho Springs to the South Platte. Water quality in the main stem of the South Platte River and its tributaries to the north is degraded significantly when it reaches the plains by discharges from municipal waste treatment facilities and urban runoff. Water in stream reaches immediately below these urban-industrial corridors often fails to meet the state's water quality standards for dissolved oxygen, fecal coliform bacteria, ammonia, and phosphorus. Quality improves in the main stem farther downstream because of irrigation diversions, which tend to consume nitrogen and phosphorus, and dilution effects from incoming streams draining less urbanized areas of the northern front range.

The use of ground water return flows for irrigation in the lower basin contributes to higher dissolved solids concentrations and can affect stream water quality, especially during low-flow conditions. Dissolved-solids concentrations of the return flows are increased because of the concentrating effects of consumptive use losses through evapotranspiration, dissolution of soil minerals, and their association with a variety of agricultural chemicals. Median dissolved-solids concentration in surface water within the basin increases in a downstream direction from 395 mg/L at Denver to 1,550 mg/L near Julesburg (Dennehy et al., 1993).

Contaminants in alluvial ground water of the basin occur largely as a result of agricultural activities and municipal and industrial wastewater discharges. The most serious problem is high nitrate concentrations, which are occasionally above the EPA safe drinking water standard of 10 mg/L. The highest levels in the shallow alluvial aquifer are observed near Greeley. The major source of ground water nitrate contamination in this area is manure generated by concentrated animal feeding operations and applied to surrounding fields. Farther downstream, both manure and agricultural fertilizers are believed to be the primary sources of nitrates in groundwater. Median dissolved-solids concentration from recent surveys of ground water from the South Platte alluvial aquifer was about 1,000 mg/L (USGS, 1988).

Distribution of Water Use

A more complete description of water use in the South Platte River basin was compiled previously by Caulfield et al. (1987). The major characteristics of water use in the basin are provided in the following summary. Division I of the Colorado State Engineer's office administers over 542 major irrigation diversions, 4500 major direct flow rights, and 1200 major storage rights in the South Platte Basin. Water is used for a variety of purposes including irrigation, municipal, industrial/commercial, recreation, and environmental uses.

Agricultural land use is distributed throughout the basin. Most of the agricultural land is cropland and pasture, with small areas designated as confined feeding operations. The cropland consists of 40% irrigated land and 60% dryland farming. Most of the irrigated land is located within a triangle formed by the cities of Boulder, Fort Collins, and Greeley, and along the main stem of the South Platte River. Total irrigated acreage in the basin in 1992 was approximately 730,700 acres, based on county agriculture census data. The primary crops grown in the basin are corn for grain and silage, perennial forages, small grains, sugar beets, wheat, dry beans, sunflowers, and some vegetables. The types of irrigation practices used are flood, furrow, and sprinkler irrigation systems. Farming operations located adjacent to surface water supplies use primarily surface irrigation methods, although the use of sprinkler systems tapping the alluvial aquifer are becoming more common.

Interstate Compact Considerations

Use of South Platte River water is subject to the restrictions set forth in the South Platte Compact signed by Colorado and Nebraska in 1923. The compact stipulates that between October 15 and April 1, Colorado has full use of all flow within its boundaries, except for one proposed canal beginning near Ovid, and flowing into Nebraska. Between April 1 and October 15, Colorado can divert water with a priority junior to June 14, 1897 downstream of the Washington-Logan county line only if the mean daily flow at the interstate station at Julesburg is greater than 120 cfs. Colorado water rights senior to that date can continue to divert water if flows are less than 120 cfs.

Average annual total flow leaving the state at Julesburg is 387,000 acre-feet (Ugland et al., 1994). During the month of August, flows leaving the state average 153 cfs, exceeding the compact requirement by only 33 cfs. In years when supplies are low, compact requirements often restrict the junior water rights on the river in late summer months. This results in limited direct-flow diversion potential for all but the most senior users on the lower end of the system. In fact, most ditch systems on the lower end of the system with rights junior to the compact have been abandoned.

Potential/Future Alternative Demands for Water

Water in the South Platte Basin has historically been developed and dominated by irrigated agriculture use. However, recent population growth on the front range, combined with emerging water demands for fish and wildlife habitat and recreation, is resulting in a gradual reallocation of water away from agriculture. The reallocation of agricultural water is evidenced by the fact that the Front Range experienced an 8% decline in irrigated acreage between 1978 and 1992, or a loss of 57,000 acres. In addition, 67 agricultural-to-municipal change of use cases were filed with the Division I Water Court between 1977 and 1991. These 67 applications sought to transfer a total of 768 water rights originally decreed to agricultural use. In addition, agricultural water allotments for Colorado-Big Thompson Project water have declined over the last 20 years, while those for municipal water use have increased.

Fish and wildlife habitat maintenance has emerged as a relatively recent demand for water in the basin. Demands for water for fish, maintenance of riparian zones for wildlife habitat, and recovery of declining native and threatened and endangered species are increasing. Recreational demand is also increasing because of increasing population in the basin and the growing popularity of water-based recreation.

Climate in the basin is characterized by wide temperature ranges and irregular seasonal and annual precipitation. Mean annual precipitation in the mountains averages 40 inches, whereas, precipitation on the plains can average less than 10 inches a year.

The major tributaries downstream of Pueblo Reservoir are Fountain Creek, Purgatoire River, St. Charles River, Huerfano River, Apishapa River, Muddy Creek, and Big Sandy Creek. Primary reservoirs include Turquoise Lake, Twin Lakes Reservoir, Clear Creek Reservoir, Pueblo Reservoir, Adobe Creek Reservoir, Trinidad Reservoir, John Martin Reservoir, and the Great Plains Reservoir System.

The Arkansas River basin produces an average annual yield of 884,000 acre-feet of native supply. This is supplemented with imports from the Colorado River basin, which totaled 132,870 acre-feet in 1993. Average total basin surface water outflow at the Colorado-Kansas state line was 142,200 acre-feet annually during the period from 1951 to 1993 (Ugland et al., 1994).

Ground water is also used extensively in the basin for irrigation, municipal, livestock, and domestic water supplies. It is derived primarily from the basin-fill aquifer in the upper basin and the adjacent alluvial aquifer along most of the river course. The alluvial aquifer system is recharged by infiltration from streams, reservoirs, and ditches and by percolation of precipitation and applied irrigation water. The direction of ground water flow is toward the river from the recharge areas, thereby contributing to streamflow. Between 1978 and 1985, approximately 183,000 acre-feet was pumped annually from the main stem alluvial aquifer.

As with the South Platte Basin, surface water and ground water are closely interrelated, resulting in conjunctive water use practices. Based on a comparison of estimated basin inflows to water diverted in the basin, water is reused approximately 1.8 times prior to discharge at the state line. This estimate is based on 1993 total diversions of 1.87 million acre-feet divided by total basin inflows of 884,000 of native water and imported water of 132,870 acre-feet. The resulting ratio of 1.8 indicates that water diversions in the system exceed the total amount of surface water available to the system.

Water Quality

Water quality assessments of the Arkansas River basin have been recently summarized by the U. S. Geological Survey (Middelburg, 1993) and the Colorado Department of Public Health and Environment (CDPHE, 1994). Water quality in the upper reaches of the Arkansas and its tributaries has been impacted significantly by mining activity. Concentrations of metals above water quality standards are consistently found in the main stem of the Arkansas from Leadville to Pueblo Reservoir and along Fourmile Creek, which drains the Cripple Creek mining district. Elevated levels of metals have also been observed in the headwaters of the Purgatoire and Huerfano Rivers and in Fountain Creek above Colorado Springs.

The primary source of contamination from nutrients (ammonia, nitrate, and phosphorus) is municipal

effluent. Levels of nutrients in the lower basin decline with increasing levels of agricultural diversions indicating that agricultural crops serve as a sink for nutrients.

Salinity is a major factor reducing the water quality in the lower reaches of the Arkansas. Dissolved solids increase from approximately 50 mg/L in headwater streams to around 300 mg/L above Pueblo Reservoir. Median concentrations below Pueblo Reservoir were around 2,800 mg/L during the 1987 to 1989 sampling period (Middelburg, 1993). Mass balance studies conducted in the lower reaches of the main stem indicate that the major factor accounting for increased salinity levels in the lower Arkansas River is consumptive use in the basin (Cain, 1985).

Ground water in the alluvial aquifer has been degraded somewhat by nitrate and increased concentrations of salts (CDPHE, 1994). During the 1994 monitoring period, 14% (19 of 139) of the wells sampled contained nitrate levels above the EPA drinking water standard. The median level of dissolved solids was 2,400 mg/L. Although traces of pesticides were found in 19% of the monitoring wells, none of the wells sampled contained levels in excess of drinking water standards.

Distribution of Water Use

The major use of water in the basin is crop irrigation. Agricultural land is located primarily in the lower portion of the basin, below Pueblo Reservoir. Pueblo Reservoir and John Martin Reservoir control streamflow in the lower reaches. Both reservoirs store water during the winter and during flood periods for later release. In addition, Pueblo Reservoir is used for storage of water diverted into the Arkansas River from the Colorado River Basin as part of the Fryingpan-Arkansas Project.

According to the 1992 Federal agriculture census, there are approximately 440,200 acres of irrigated land in the Arkansas River Basin. Diversion of streamflow and ground water pumping are required to sustain agricultural production because of low annual precipitation levels. Most of the irrigated land is therefore located along the main stem of the Arkansas River and its tributaries. Primary crops include hay, corn, wheat, beans, and vegetables.

Other water uses in the basin include municipal demand and recreational activities such as rafting and fishing. Cities such as Pueblo and Colorado Springs account for increasing water demands, and upstream uses such as rafting are growing.

Interstate Compact Considerations

The Arkansas River Compact was ratified by the states of Colorado and Kansas and the U.S. Congress in 1948. The general principle of apportionment underlying the compact is a division of the benefits of reservoir storage on the basis of percentage shares of stored and flowing waters. Colorado is apportioned 60% of the water subject to the compact, and Kansas is apportioned 40%. Total surface water outflow to Kansas during water year 1993 was 110,400 acre-feet (Ugland et al., 1994).

The Arkansas River Compact is currently the subject of federal judicial review. In July of 1994, the U.S. Supreme Court Special Master, Arthur L. Littleworth, delivered a final recommendation in the case of Kansas v. Colorado, indicating that irrigation well development in Colorado occurring after ratification of the Arkansas River Compact resulted in a violation of the Compact. In response to the ruling, the State Engineer promulgated rules governing the measurement of tributary ground water diversions located in the Arkansas River Basin. The State Engineer's office is currently working to implement the new rules, as well as enforce the existing requirements of the Arkansas Rules and Regulations Governing the Use of Ground Water established by the Colorado Ground Water Commission. In May, 1995 the U.S. Supreme Court affirmed all of the recommendations of the Special Master. Phase II of the litigation, which will consider compensation to Kansas, is pending.

In September of 1995 the State Engineer promulgated amended rules and regulations concerning the use of tributary ground water. These rules require replacement of depletions to usable state line flow by post-compact well owners and the replacement of out of priority depletions to holders of senior surface water rights by all wells.

Water Use - San Luis Valley/Rio Grande Basin

Water Features and Basin Hydrology

The Rio Grande tributary basin drains a large area in the south-central region of Colorado. The major water features of this basin are noted in Fig. 4. The San Luis Valley, which is the dominant geographic feature of this region, extends about 100 miles from Poncha Pass near the northeast corner of Saguache County, Colorado, to a point about 16 miles south of the Colorado-New Mexico state line. The Valley's total area is 3,125 square miles, of which about 3,000 are in Colorado. Population centers include Alamosa, Del Norte, Saguache, San Luis, Monte Vista, Center, LaJara and Antonito. The topography of the Valley is generally flat except for the San Luis Hills and a few other small areas. The average elevation is about 7,700 feet. Bounding the Valley on the west are the San Juan Mountains and on the east the Sangre de Cristo Mountains.

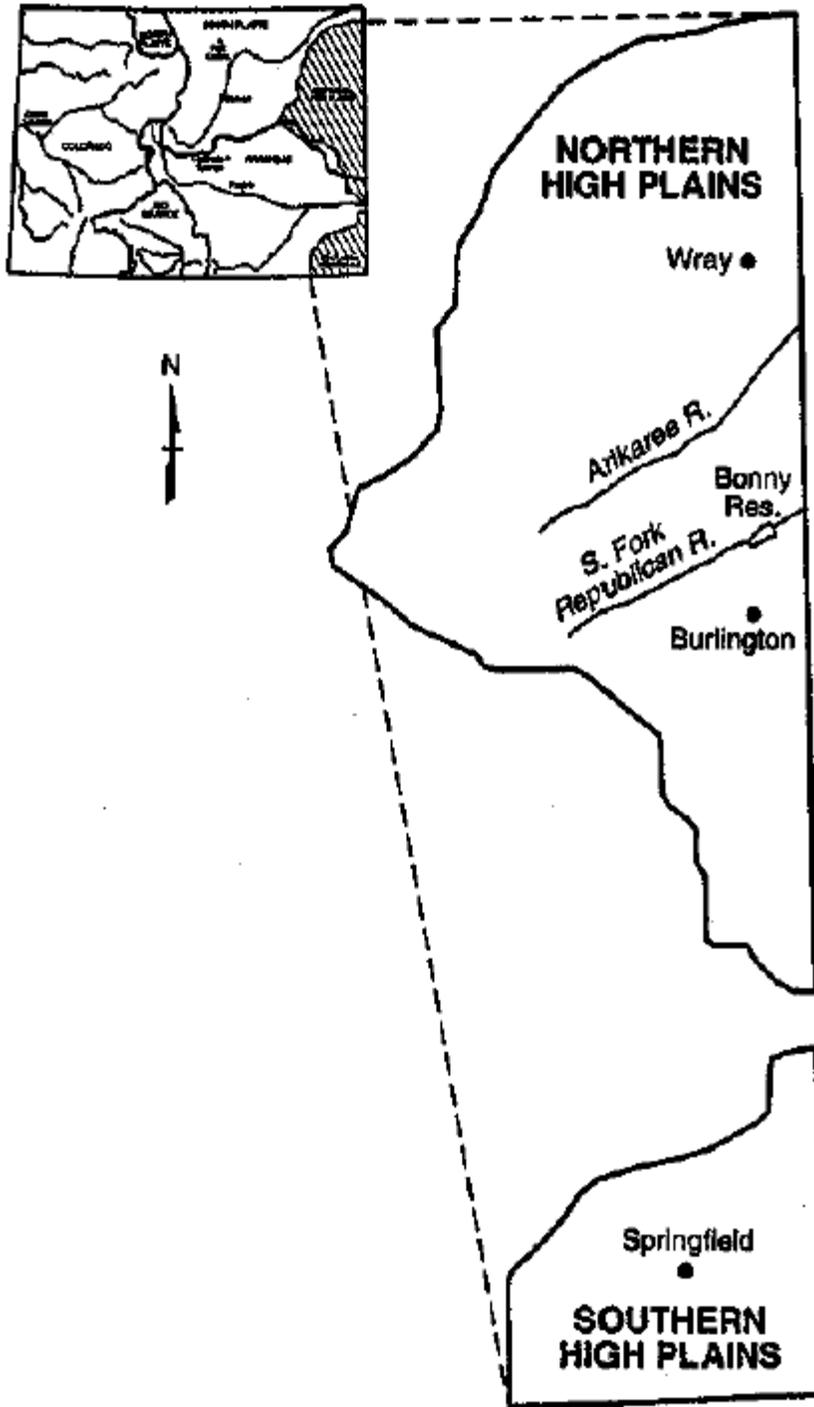


Fig. 4. Water features of the Rio Grande basin in Colorado.

Most of the valley floor is bordered by alluvial fans deposited by streams originating in the mountains. Most of the streamflow is derived from snowmelt originating in the mountains. The northern half of the San Luis Valley is internally drained and is referred to as the Closed Basin. The lowest part of this area is known locally as the "sump." The remainder of the Valley is drained by the Rio Grande and its tributaries. Major rivers are the Rio Grande, Conejos, and Alamosa Rivers; major reservoirs include the Rio Grande Reservoir, La Jara Reservoir, Platoro Reservoir, Continental Reservoir, Santa Maria Reservoir, Mountain Home Reservoir, Smith Reservoir, Sanchez Reservoir and Terrace Reservoir.

Total annual water supply to the San Luis Valley averages 1.65 million acre-feet, with about 3,000 to 5,000 acre-feet imported into the Valley on an annual basis (Colorado State Water Plan, 1974). Average Rio Grande outflow to New Mexico was 325,000 acre-feet annually during period from 1931 to 1993 (Ugland et al., 1994). Total surface water diversions in water year 1993 were 1,582,876 acre-feet.

Ground water in the San Luis Valley is obtained from unconfined and confined aquifers. The aquifers are separated by a series of clay formations 10 to 80 feet thick throughout much of the central and northern parts of the Valley at depths ranging from 80 to 100 feet. In the southwestern part of the Valley, lava flows and tuffs from the San Juan mountains dip eastward under the valley floor and restrict the vertical movement of ground water. Because of the nature of the confining layers, it is difficult to differentiate between unconfined and confined aquifers except on a local basis. Shallow unconfined ground water occurs almost everywhere in the valley and extends 50 to 200 feet beneath the land surface. The depth to water in the San Luis Valley is less than 12 feet except along edges and in most of Costilla county. Recharge to the unconfined aquifer in portions of the Valley is derived primarily from infiltration of applied irrigation water and leakage from canals and ditches. However, in the intensively farmed area north of the Rio Grande surface diversions are used almost exclusively for recharge in that area of the Closed Basin. Many irrigation diversions occur by pumping of wells to supply center pivot sprinklers.

A ground water divide caused by recharge from canal leakage and applied irrigation water occurs north of and parallel to the Rio Grande. Ground water south of the divide moves toward the Rio Grande, whereas ground water north of the divide flows into the Closed Basin, where water is consumed by evapotranspiration. This closed basin area north of the Rio Grande receives surface water diverted from the Rio Grande as well as runoff from tributary streams, but irrigation return flows do not return directly to the river because of the ground water divide. Ground water levels in the closed basin are relatively stable, but are subject to decline if pumping exceeds recharge during drought periods. A portion of southeastern Saguache County, near the Bureau of Reclamation Closed Basin Project perimeter, is currently experiencing declining ground water levels.

Water Quality

Surface water quality in the Rio Grande Basin was recently evaluated through a basin-wide water quality assessment program conducted by the Water Quality Control Division of the Colorado Department of Public Health and Environment (CDPHE). Monitoring occurred during the calendar year of 1992, and results were reported in 1994 (CDPHE, 1994). Excessive levels of trace metals are found in some streams in the basin and have been attributed to historic and more recent mining activities as well as localized naturally occurring geologic conditions. Streams affected include Willow Creek near Creede, the Alamosa River (including Terrace Reservoir) and several of its tributaries in the southwestern portion of the basin, and Kerber Creek and its tributaries in the northern part of the Closed Basin. Salinity is not a problem in surface waters in this basin. The 1992 monitoring program results indicated that total dissolved solids rose to a level of approximately 270 mg/L (85th percentile value) in lower-elevation stream reaches. Recent surveys of ground water quality indicated nitrate levels in excess of drinking water standards (10 mg/L) in 14% of domestic wells sampled. Pesticide contamination of ground water above the drinking water standard was observed in only one of 93 wells sampled (CDPHE, 1994).

Distribution and Characteristics of Water Use

The predominant use of surface and ground water in the Valley is crop irrigation. Estimated ground and surface water withdrawals in 1985 were 455,000 and 1,400,000 acre-feet, respectively (Litke and Appel, 1989). Approximately 450,000 acres of irrigated land exists in the basin (USDC, 1994). Average annual precipitation ranges from 7 to 10 inches, with more than half the precipitation occurring between July and September. The short growing season limits the types of crops that can be grown to primarily barley, oats, spring wheat, perennial forage legumes and grasses, potatoes, and other vegetables.

Irrigation practices in the Valley vary according to water source (surface or ground water), soil conditions, topography, and types of crops grown. Traditional surface irrigation methods such as flood, furrow, and wild flood irrigation are used in areas that are supplied primarily by surface water. These areas include agricultural land near all stream systems in the Valley. Many farmers throughout the Valley have been converting to sprinkler systems and rely upon a combination of surface and tributary ground water supplies. As of 1996, about 2,130 sprinkler systems were in place, irrigating 257,000 acres.

Irrigation efficiencies in the Valley are relatively high because of the large number of sprinkler systems in use. There are, however, localized situations, such as flood-irrigated native hay meadows, where efficiencies may be less than optimum.

The San Luis Valley is home to the Bureau of Reclamation's Closed Basin Project. The project's purpose is to salvage unconfined ground water in the sump area of the Closed Basin that would otherwise be lost to nonbeneficial evapotranspiration. The salvaged water is delivered through a 42-mile conveyance

channel to the Rio Grande to assist Colorado in meeting its commitment under the Rio Grande Compact of 1939. Constructed in stages, the project was initiated in 1972 with congressional approval of Public Law 92-514, and completed in 1994. The Project also provides for the delivery of mitigation water to the Alamosa National Wildlife Refuge and Blanca Wildlife Habitat Area, and stabilization of San Luis Lake.

The Closed Basin Project has not yet pumped more than 37,000 acre-feet in any calendar year, even though the designed pumping capacity is 104,830 acre-feet. Adequate precipitation in the San Luis Valley and northern New Mexico, as well as adequate storage in Elephant Butte Reservoir, have reduced recent needs for Closed Basin Project water.

Interstate Compact Considerations

Water allocation in the San Luis Valley is governed by the restrictions set forth in the 1939 Rio Grande Compact, ratified by Colorado, New Mexico, and Texas. The compact sets forth Colorado's obligations, requiring, in each calendar year, a certain amount of water to flow to New Mexico based on index quantities at upper basin stations. Discharge quantities are set for the Conejos River and Rio Grande. The compact regulates the accumulation of credits and debits by stating that no annual debit nor accrued debit, shall exceed 100,000 acre-feet, and that no annual credit shall exceed 150,000 acre-feet. Administration of the compact can result in the curtailment of surface water diversions on the Rio Grande and the Conejos during the irrigation season, resulting in supply deficiencies for irrigators.

Water users in the San Luis Valley began supplementing their limited surface water sources with artesian ground water withdrawals early this century. Because surface water diversions and tributary groundwater withdrawals are interrelated, and the requirements set forth in the Rio Grande compact had to be met, new ground water appropriations had to be limited. In 1981, the State Engineer's Office stopped permitting shallow aquifer well permits in the Closed Basin in order to enhance the stabilization of withdrawals and recharge in the Closed Basin. In addition, since the early 1970s deep, confined-aquifer well permits have not been issued and new tributary ground water appropriations have not been allowed.

Potential/Future Alternative Demands for Water

The San Luis Valley overlies large amounts of ground water. Ground water can be found near the valley surface, and at great depths. Various entities have expressed interest in developing and transferring this source of water from the Valley to other locations such as the Denver-metro area. A recent development proposal went as far as the Colorado Supreme Court before being abandoned after the Court found that water was not available for the plan as proposed.

The whitewater rafting industry and water-short communities in New Mexico are placing increasing

demands on water from the Rio Grande basin in Colorado. Although no purchase and transfer arrangements are currently in place, the potential exists under current state statutes. Other demands for water include recreational activities, possible endangered species needs downstream, and ongoing agricultural requirements in a water-short system.

Water Use - Colorado River Tributary Basin

Water Features and Basin Hydrology

The Colorado River basin drains a vast area of 242,000 square miles, one-twelfth of the land area of the continental U.S., and includes parts of seven different states. Topography ranges from high mountains in the upper reaches of the basin to desert land as the river enters Mexico. The upper basin is commonly divided into three major sub-basins, each of which is fed by tributary streams that originate in Colorado. The major water features of each of the three sub-basins are noted in Fig 5.

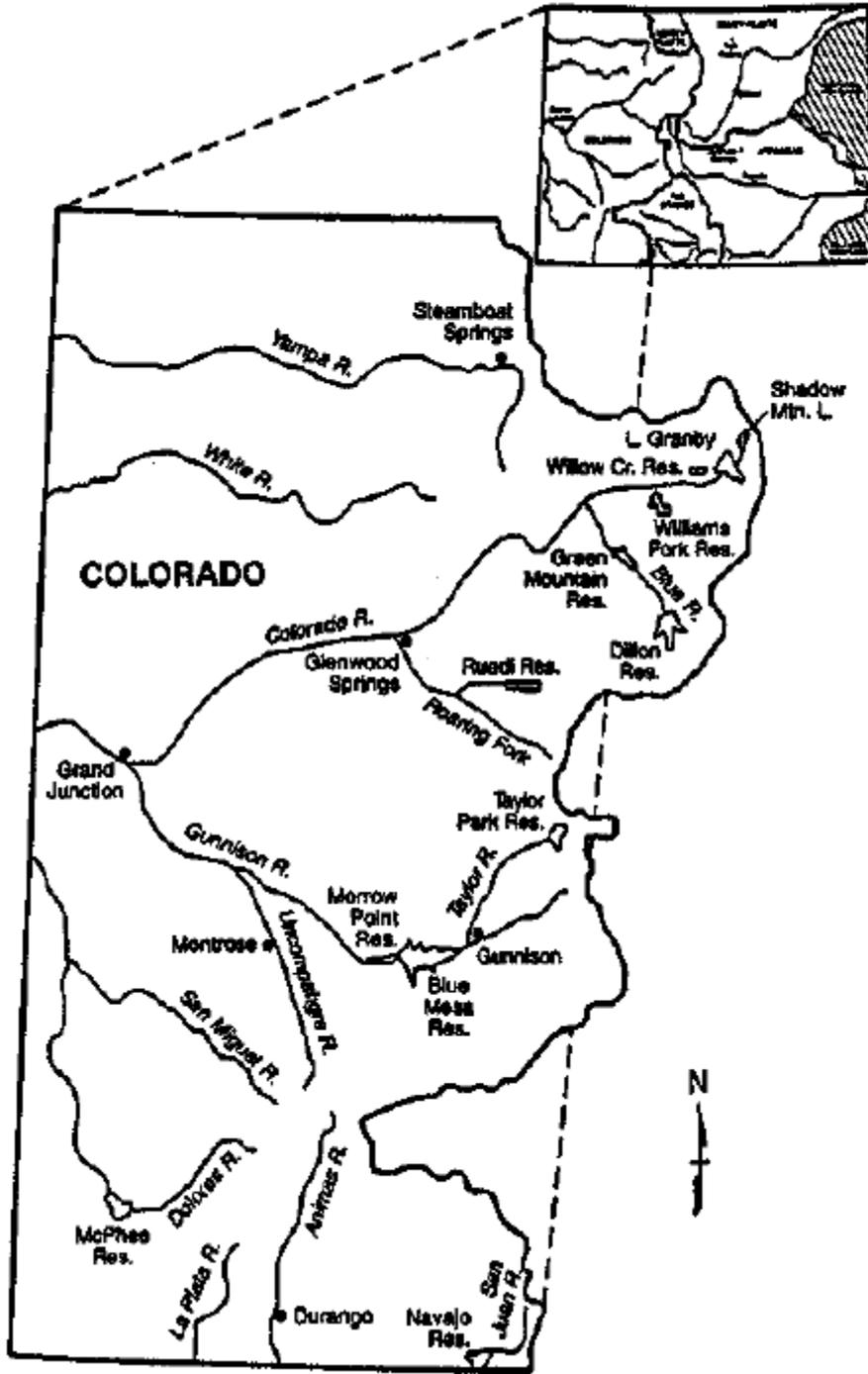


Fig. 5 Water features of the Colorado River tributary basin in Colorado.

The Yampa and White rivers in northwestern Colorado are part of the Green River sub-basin. The main stem sub-basin includes the Colorado River and its major tributaries, the Gunnison and Dolores rivers. The San Juan, Animas, and La Plata rivers are part of the third major sub-basin. These three sub-basins drain a total area of approximately 38,000 square miles within Colorado.

The Colorado River basin is sparsely populated, with an average population density of 9.32 people per square mile. Agriculture is the primary economic enterprise throughout most of the region. The basin contains several reservoirs that store water for use within the basin and for transmountain diversions. The major structures are the Aspinall Unit (Blue Mesa, Morrow Point, and Crystal reservoirs), Taylor Park Reservoir, and Ridgeway Reservoir on the Gunnison; Green Mountain, Ruedi, Dillon, and Williams Fork reservoirs and the Colorado-Big Thompson Project (Granby, Shadow Mountain, and Willow Creek reservoirs) on the main stem and its tributaries; McPhee Reservoir on the Dolores; and Navajo Reservoir on the San Juan. The total amount of water exported from the basin to the eastern side of the continental divide averages approximately 510,000 acre-feet annually and includes diversions from reservoirs and water collected by high-elevation ditches near the divide.

Water Quality

Overall water quality in this basin is the best in the state (CDPHE, 1994). The upper reaches of several tributaries in the basin contain elevated concentrations of metals as a result of mining activity during the late 1800s and early 1900s. In most cases, remediation efforts have been implemented.

Several of the streams in the basin flow through lands overlying saline geologic formations and, thus, are affected by salinity. Although the salinity levels are generally below drinking water standards, salinity of streams draining the basin has been of concern and is relevant to the topic of agricultural water conservation. The salinity of streams and reservoirs in the portions of the Colorado River basin is caused by salt loading from various sources and consumptive use of water, which decreases the dilution of saline inflows to the river systems. Natural sources of salt loading account for almost half (47%) the salinity in the Colorado River system (USDI, 1993). The major natural sources include saline springs, erosion of saline geologic formations, and runoff. Irrigated agriculture's contribution to salinity is estimated at 37% and arises from consumptive use of water by crop plants and evaporation and the leaching of salts contained in saline soils underlying conveyance structures and croplands. In Colorado, salinity of surface waters in the Colorado River basin varies greatly depending on presence of upstream sources of salt loading and native streamflows. Values of minimum, maximum, and mean flow-weighted average annual salinity at various monitoring locations in the Colorado basin since 1941 are presented in Table 3. Salt concentrations in the Yampa and San Juan are generally low because they drain high-elevation areas that are high in average

annual precipitation. Salinity of the Colorado River increases incrementally with salt loading from hot springs in the Glenwood Springs area and return flows from irrigation along the lower Gunnison and in the Grand Valley. The high concentrations of salt found in the Dolores River originate primarily from ground water saturated with salt from a collapsed salt dome that surfaces in the river in the Paradox Valley.

Table 3. Minimum, maximum, and mean flow-weighted average annual salinity of water from streams in the Colorado River basin.

River/Tributary	Location	Minimum	Maximum	Mean
		----- mg L ⁻¹ -----		
Yampa	Near Maybell, CO	112	281	154
White	Near Watson, UT	252	792	440
Colorado	Near Glenwood Springs, CO	223	855	393
	Near Cameo, CO	327	1,132	526
	Near Cisco, UT	372	1,871	679
Gunnison	Near Grand Junction, CO	331	1,114	606
Dolores	Near Cisco, UT	269	4,947	831
San Juan	Near Archuleta, NM	133	264	180

Source: US Dept. of Interior, 1993

Distribution of Water Use

According to Colorado Division of Water Resources statistics, an area of 1,060,000 acres is irrigated. The array of crops grown under irrigation varies significantly within the region. In the Green and San Juan sub-basins, the irrigated acreage is almost entirely devoted to hay and pasture crops. The same is true for the upper reaches of the main stem of the Colorado and Gunnison drainages. Within these areas, most of the irrigated land is adjacent to streams, so irrigation water is diverted directly onto the land with a minimum of conveyance losses, and return flows are not delayed. In the lower reaches of all the major main-stem tributaries, forages are still the predominant irrigated crops, but grains are noticeably more important and occupy between 10 and 20% of the total irrigated acreage. Water delivery systems in most of these lower tributary areas are designed to irrigate land remote to the tributary sources, resulting in longer conveyance distances, greater conveyance losses, and delayed return flows.

Irrigation expansion in most of the Colorado River basin has been negligible for the past several decades, with the exception of the lands under the Dolores Project. This project will bring an additional 28,000 acres under irrigation and provide supplemental irrigation water for 26,000 acres currently being irrigated.

The average annual undepleted, unregulated water yield of this basin is 10.7 million acre-feet, which is approximately 75% of the water yield of the entire upper Colorado basin. The total annual consumptive use in the basin averages 2.3 million acre-feet (USGS, 1989). Average annual withdrawals from the basin for transmountain diversions to the eastern front range are approximately 510,000 acre-feet. Approximately 95% of the total diversions in the basin are used for irrigation. The consumptive water use by irrigation is greater than 95% of the total consumptive use in the basin (USGS, 1989).

Consumptive water use by forages, the dominant crops throughout this basin, varies with the type of forage crop grown and climate. Climatic variability within the Colorado basin is significant largely because of the variation in elevation. Precise values for seasonal consumptive use by forage crops have not been determined, but estimates based on general climatic trends (day-length and average temperatures) are available (SCS, 1978). For pasture grasses, these estimates range from 13.5 inches of consumptive use at higher elevations to 35 inches at the lowest elevation sites near Grand Junction. Similar estimates for alfalfa seasonal use range from 13 to 40 inches at high- and low-elevation sites, respectively.

Interstate Compact Considerations

Water use in the Colorado River basin is subject to two interstate compact agreements. The Colorado River Compact allocated the water resources to the seven states drained by the river and its tributaries. A second compact divides water among the five states occurring within the region defined as the Upper Basin.

The Colorado River Compact partitions the water in the entire basin between the Upper and Lower basins, with the dividing point defined as Lee Ferry, Arizona. Thus, the Lower Basin includes Arizona, California, and Nevada and portions of Utah and New Mexico drained by streams tributary to the Colorado River below Lee Ferry. The Upper Basin includes Colorado, Wyoming, Utah, and New Mexico and portions of Arizona drained by streams tributary above Lee Ferry. The provisions of the compact limit the Upper Basin to 7.5 million acre-feet of consumptive use per year; limit the Lower Basin to 7.5 million acre-feet of consumptive use per year, plus an additional 1.0 million acre-feet of consumptive use per year; require the Upper Basin to deliver at least 7.5 million acre-feet over any ten-year period; and require both basins to share equally in any Mexico delivery requirements. A treaty between the U.S. and Mexico requires delivery of 1.5 million acre-feet annually if this quantity is not met by surplus flows above the apportionments made in the compact. The compact was ratified in 1923 by all participating states except

Arizona. Arizona finally ratified the provisions in 1944.

Upper Basin water is allocated among states within this region by the 1948 Upper Basin Compact. According to this agreement, the amount of water available in any given year is divided among these states as follows: Colorado, 51.75%; Utah, 23%; Wyoming, 14%; New Mexico, 11.25%; and Arizona; a fixed quantity of 50,000 acre-feet annually.

The net effect of the agreements as described in the 1970 Long Range Reservoir Operating Criteria result in a Colorado entitlement of approximately 3.1 million acre-feet per year. This total is conditional based on several factors including long term hydrology, the total water yield in any given year, and current interpretation of the Law of the Colorado River, which requires the Upper Basin states to deliver one-half of the Mexican treaty obligation. Historically, Colorado has used less than the share of water to which it is entitled by the compact agreements. Estimates vary as to how much water remains to be developed, but state officials indicate that development necessary to accommodate at least an additional 450,000 acre-feet of consumptive use would be allowable. Some of this could occur through projects already in place.

Potential/Future Alternative Demands for Water

Demand for water originating in the Colorado River Basin will likely increase in the future. Urban growth along the eastern front range is a substantial consideration, and some of this demand can be met by existing pipeline structures if adequate supplies are available. Recreational demands, including snowmaking for ski resorts and instream flows for rafting and game and native fish habitat are expected to increase. In recent years, the U.S. Fish and Wildlife Service has determined that a 15-mile reach of the Colorado River between the diversion structure of the Grand Valley Irrigation Company and the confluence of the Gunnison and Colorado Rivers is critical habitat to four native species declared endangered under the Endangered Species Act; the Colorado squawfish, humpback chub, razorback sucker, and bonytail chub. Additional instream flows, enough to obtain year-round minimum flows within this "critical reach" of 810 to 7,260 cfs, are being sought to achieve recovery of these species.

Additional demand for water supplies is based on water quality considerations. Salinity problems on the Colorado River are intensified by increased diversions of agricultural water in the Grand Valley as well as low flows caused by increased upstream diversions.

Water Use - North Platte River Basin

Water Features

The North Platte River originates in the north-central Colorado mountains and flows about 45 miles north through Jackson County into Wyoming (Fig. 6). The river drains a high mountain park of approximately 1500 square miles known as North Park. Total annual inflow to the basin averaged 433,000 acre-feet between 1976 and 1993, consisting primarily of mountain snowpack melt.

Primary tributaries to the North Platte in Colorado include the Canadian River, Michigan Creek, Illinois Creek, and Grizzly Creek. A major tributary to the North Platte, the Laramie River, flows into the North Platte in Wyoming. Major reservoirs in North Park include Walden Reservoir, MacFarlane Reservoir, Lake John, and Meadow Creek Reservoir.

Portions of the flows from the North Platte and Laramie Rivers are exported eastward into the South Platte drainage. Exports in 1993 were 5,892 and 19,455 acre-feet of North Platte and Laramie River water, respectively, to the Poudre River in the South Platte Basin. Total North Platte flows leaving the state in 1993 and entering Wyoming were 156,658 acre-feet.

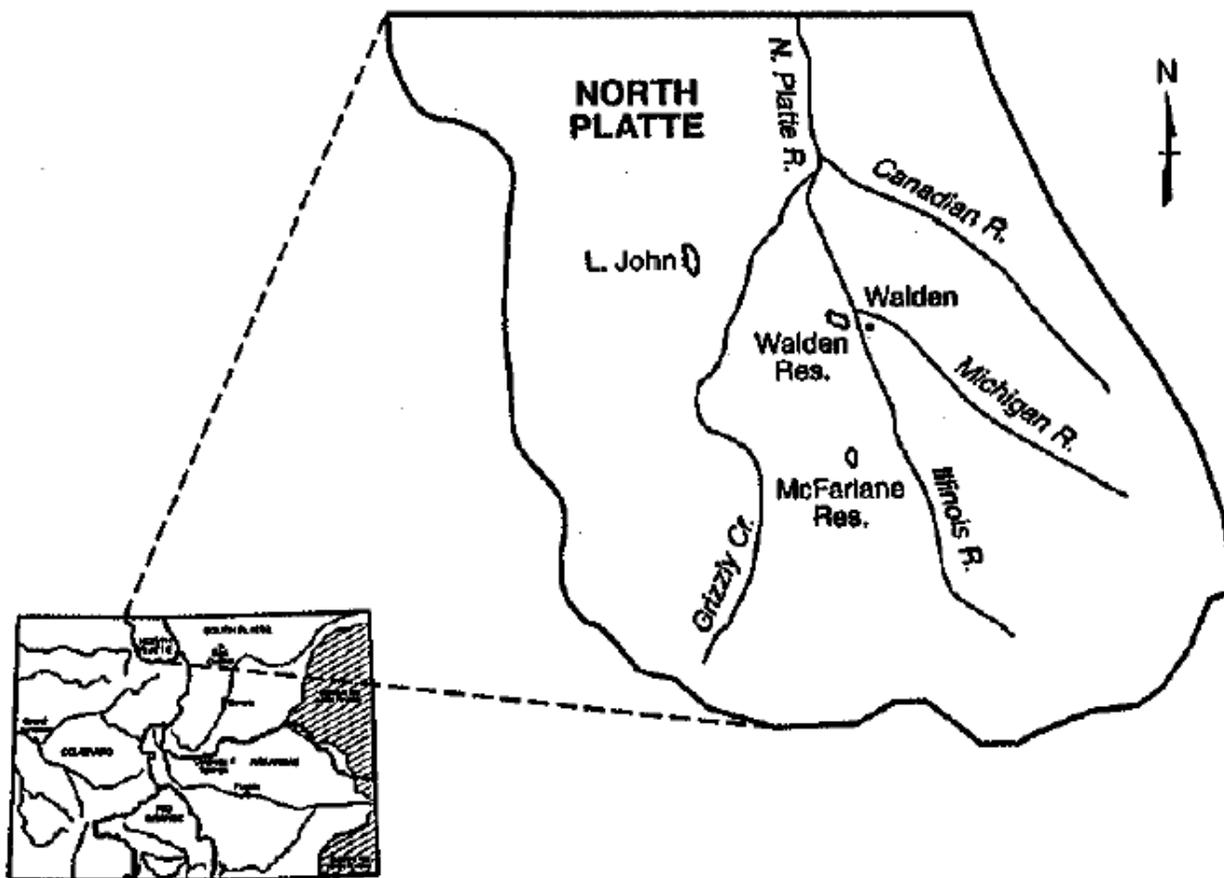


Fig. 6. Water features of the North Platte River basin in Colorado.

Distribution of Water Use

Surface water in the basin is used primarily by local ranches for irrigation of grasses harvested for the production of hay. Although there are no significant ground water withdrawals for agricultural or other uses in the basin, delayed return flows from surface irrigation maintain river flows during the latter portion of the irrigation season. Irrigation practices consist primarily of direct flow diversion and flood application to fields. Irrigation in North Park is constrained by low water availability late in the growing season because of limited storage capacity and the rapid nature of snowpack runoff. No significant water quality problems exist currently in the basin (CDPHE, 1994).

Approximately 114,000 acres in North Park were irrigated by North Platte River water in 1993, a decrease from previous highs of almost 130,000 acres in the mid-1970's. The total quantity of water diverted for irrigation in 1993 in District 47 was 535,342 acre-feet, while consumptive use in that year was 88,182 acre-feet. An additional 9,523 acre-feet was diverted for storage purposes.

Federal Decree Considerations

In 1954, the U.S. Supreme Court divided the water of the North Platte River among the states of Colorado, Wyoming, and Nebraska. Under the decision, Colorado may irrigate up to 145,000 acres of land in Jackson County (North Park) during any one irrigation season and may store up to 17,000 acre-feet of water for irrigation purposes during any given water year. Under the litigation decision, Colorado may also export up to 60,000 acre-feet of water in any period of ten consecutive years from the North Platte River to the South Platte River basin. Current levels of storage and export to the South Platte basin are well below the quantities allowed under decree.

Also affecting water use in the area adjacent to North Park are the requirements set forth by the U.S. Supreme Court in its decision regarding the Wyoming v. Colorado litigation, settled in 1957. The Supreme Court's decision allocated to Colorado users the right to divert from the Laramie River and its tributaries 49,375 acre-feet of water in each calendar year. Only 29,500 acre-feet of such water may be used within the drainage basin of the Laramie River and 19,875 acre-feet can be diverted for use outside the Laramie River Basin. Wyoming water users have the right to divert and use all water remaining in the Laramie River and its tributaries after Colorado's diversions.

Potential/Future Alternative Demands for Water

Irrigated acreage is decreasing in the basin because of the low economic returns from traditional hay production operations in this area. In 1954, the Supreme Court established a cap of 145,000 acres available for irrigation, however, only 114,000 acres are irrigated currently. Even with recent declines in irrigated

acreage, ranchers are subject to limited water late in the growing season due to rapid spring runoff and limited storage capacity.

Primary sources of economic revenue include the sale of grass hay to Front Range interests, timber production, recreation and tourism, and livestock production. Future demands for irrigation water are expected to follow current trends because of interstate litigation constraints, the limited number of operators in the area, and commodity prices. Municipal demand is also likely to remain stable, while recreation and tourism-related water uses are likely to remain stable or increase in response to increased population on the northern Front Range.

Water Use - High Plains Deep Aquifer Basins

Water Features and Basin Hydrology

The Northern High Plains and Southern High Plains deep aquifer basins refer to the regions of eastern Colorado that overlie portions of the ground water system known as the Ogallala Aquifer. These two deep aquifer basins include about 12,000 square miles of land area and all or parts of 15 counties (Fig. 7). The entire Ogallala Aquifer underlies portions of South Dakota, Nebraska, Wyoming, Kansas, New Mexico, Oklahoma, and Texas.

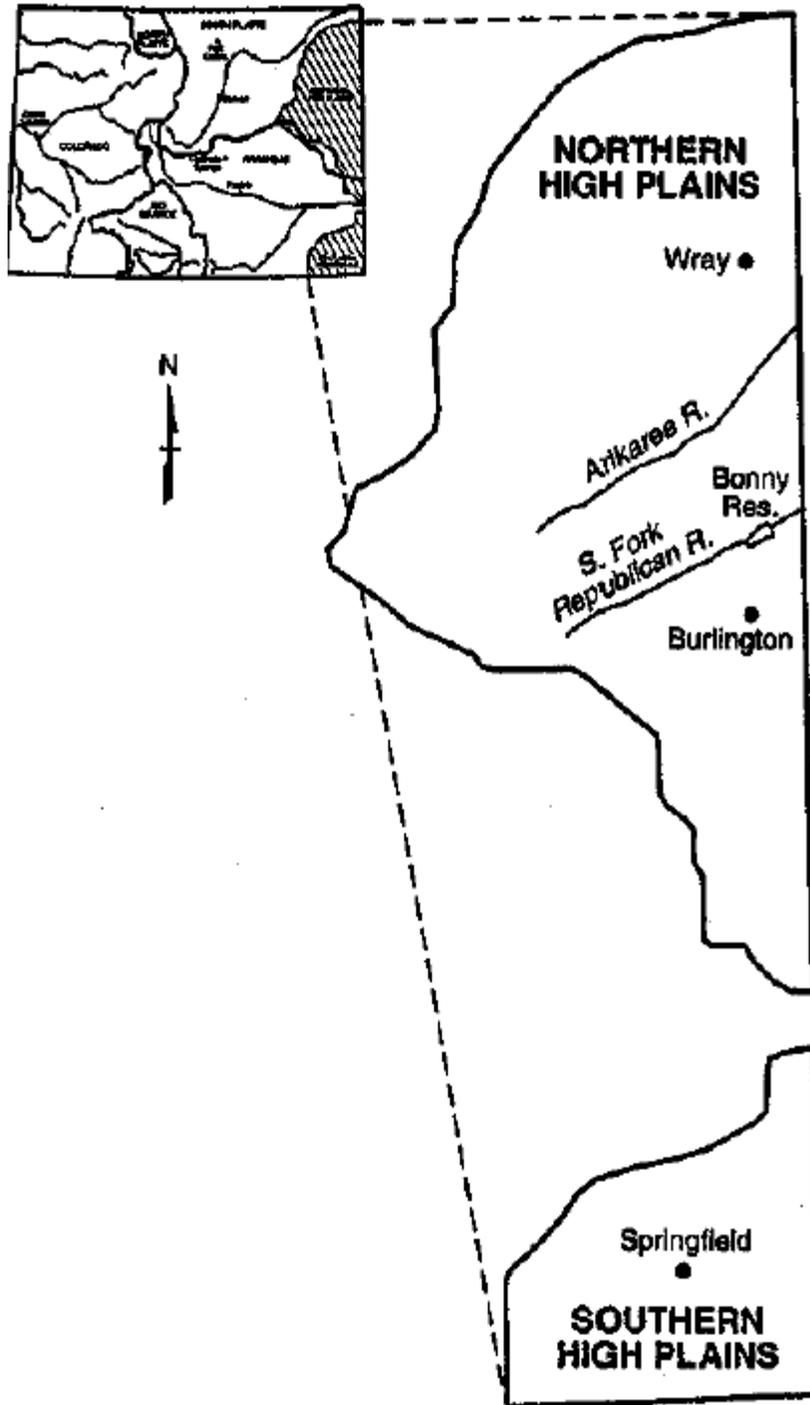


Fig. 7. Water features of the Northern and Southern High Plains deep aquifer basins.

The deep aquifer basins are separated by Big Sandy Creek and the Arkansas River. The Northern High Plains basin is the largest part, and is located northeast of Big Sandy Creek and centers around Yuma County. The Southern High Plains basin is south of the Arkansas River in the southeast corner of the state. The northern section has an area of about 9,000 square miles, and the southern section includes 2,800 square miles. The primary population centers are Wray, Burlington, Cheyenne Wells, Akron, and Springfield.

Surface water systems in the basins include the Arikaree, Republican, Smoky Hill, and Cimarron Rivers. Some ground water flow contributes to the lower Republican and Arikaree Rivers, but the major portion of discharge is underflow to Nebraska and Kansas. Therefore, the aquifer underneath Northern and Southern High Plains basins are considered distinct from local surface water systems and are regulated as nontributary ground water. The Republican and Arikaree Rivers are subject to the Republican River Compact, which limits Colorado to 54,000 acre-feet of consumptive use annually.

In a few places the aquifer is more than 400 feet thick, but more typically it ranges in thickness from 150-300 feet. From one-third to three-fourths of the porous material within the formation is saturated with ground water. Of the normal annual precipitation (15-18 inches) in the region, probably not more than an inch reaches the aquifer. Although the aquifer is recharged by precipitation, natural discharge and pumping now substantially exceed the natural recharge from precipitation.

The northern portion of the aquifer contained an estimated 118 million acre-feet of ground water in 1965. Since that time, approximately 17 million acre-feet have been withdrawn from the aquifer. The current withdrawals by approximately 4,400 large-capacity wells result in an estimated water-level decline of one foot per year.

From 1993 to 1994 the southern aquifer dropped an average of 2 to 5 feet. The area of greatest decline was northeastern Baca County and southeastern Prowers County. A small area northeast of Stonington had a decline of 19.6 feet.

Distribution of Water Use

The primary end-use for ground water from the Ogallala aquifer is irrigated agriculture, with a negligible quantity pumped for municipal-domestic and stock watering purposes. There are approximately 700,000 acres of irrigated farmland within the Northern High Plains basin. Corn is the dominant crop produced; however, significant acreages of sunflowers and alfalfa are also grown. Irrigated acreage within the Southern High Plains basin is estimated to be around 41,000 acres. This is down from 86,000 irrigated acres in 1974 when 880 wells were pumping. Since the 1974 peak there has been a near halt of irrigation well construction. The decline in acreage is due to several factors, including the inability of some portions of the

aquifer to yield sufficient quantities of water for sustained periods of time, and declines in pump efficiency as depths to the pumping level increased. The principal irrigated crops in the Southern High Plains basin are winter wheat, corn, sorghum, and alfalfa.

Institutional and Economic Constraints on Use

Rural electrification beginning in the 1930's and introduction of center pivots in the early 1950's resulted in dramatic increases in ground water use and the mining of nontributary water. Colorado legislation passed in 1957 and 1965 addressed areas of high density well development, primarily in the Ogallala Aquifer region, by establishing a Ground Water Commission. The Commission has approved eight designated ground water basins, including the Northern and Southern High Plains Designated Basins, with a total of 13 management districts, all located in eastern Colorado.

Designated ground water is regulated on the basis of a modified appropriation doctrine. First in time is still "first in right," but only a "reasonable amount" of ground water mining is permitted. The Commission is charged with administering ground water development and pumping within the various designated basins to allow economic development, while minimizing the lowering of aquifer water tables. In 1966, denials of well-permit applications began in heavily pumped areas. The rate of well drilling peaked in 1967 at 471 wells, and declined rapidly thereafter as fewer permits were allowed.

In addition to institutional restrictions, the rate of aquifer mining by irrigation in the deep aquifer basins has decreased because of economic and efficiency factors. The cost of pumping has been a major limiting factor. When energy prices increased rapidly in the 1980's, the number of irrigated acres decreased. As these costs leveled out in the late 1980's, irrigated acreage trended upward. Increased energy costs also affected the price of production inputs such as fertilizer, limiting profit margins for many growers. The aquifer level continues to drop at an average rate of about one foot per year, which is a significant reduction from the 1970 rate of 3 to 5 feet per year. This difference is significant in intensively irrigated areas such as Kit Carson County where estimates indicated that continued rates of decline of 3 to 5 feet would lead to 30 to 50% reduction in saturated aquifer thickness over a 10-year period.

Although the average actual depletion throughout the basin for the past 25 years has been less than 20%, there are significant areas in the Northern High Plains where the depletion has exceeded the allowable 40% in 25 years. In addition to this, in most cases the permitted well capacity already exceeds the allowable depletion criteria. The Commission recently revised its depletion policy to a 40% decline in the water table over a period of 100 years.

Irrigation Water Conservation

Research, product development, and technology improvements occurring over the past several decades have produced a wide range of practices that have the potential of conserving irrigation water. The adoption of the various practices by agricultural producers has been a function of economic and social elements as well as institutional factors. The purpose of this section of the report is to summarize the types of conservation methods available and discuss the issues associated with water conservation practices in general, including the implications of implementing various methods. Terminology used to describe the direct effects of various conservation practices will follow that previously established in the report. As used herein, the term application efficiency refers to the amount of water diverted and applied per unit of irrigated land area.

Irrigation Water Conservation Practices

Types of practices. Decreases in irrigation water use at the individual farm level can be achieved by structural improvements in the application systems or target land, better maintenance of existing irrigation systems, information management techniques, altered tillage and soil management, or changes in the crops grown. In some cases, combinations of these different methodologies are applied in a single setting.

Structural improvements in application systems include practices such as replacing open ditches with underground pipe, lining ditches, use of gated pipe, fitting gated pipe systems with surge-flow devices, conversion from furrow to sprinkler irrigation or drip irrigation, upgrading existing sprinkler systems, and installation of tailwater recovery systems. The primary objective of adopting these practices is to increase application efficiency at the individual farm level. In many instances they also have the potential of decreasing nonbeneficial consumptive use. Similarly, structural land improvements such as construction of conservation bench terraces and land leveling are designed to improve application efficiency and decrease nonbeneficial consumptive use.

Information management and altered tillage and soil management are also practices designed to increase application efficiency at the farm level. Information management usually involves techniques that allow growers to schedule irrigation based on moisture needs of crops. Specific techniques include monitoring soil moisture and maintaining daily records of crop water balance using estimates of consumptive water use from weather data. Conversion to minimum or conservation tillage, use of furrow diking, and practicing more timely fertilization are examples of altered tillage and soil management. Information management techniques can also be used to schedule strategic deficits in water availability during periods when crops are relatively insensitive to soil water deficits. This form of information

management is generally referred to as deficit irrigation, and results in decreases in beneficial consumptive use. Various state and federal agencies have devoted significant research effort in recent years to defining deficit irrigation practices that will allow producers to either avoid or minimize economic and productivity losses. Substantial progress has been made in devising successful strategies, especially with grain crops, in which the fraction of the plant harvested for sale or direct end-use is only a fraction of biological yield.

Changes in cropping patterns also can result in decreases in beneficial consumptive water use. Examples of specific changes include reducing acreages of irrigated crops, switching entirely to dryland crops, and switching to crops with lower seasonal consumptive use.

Some conservation measures can be implemented at the system level to improve overall application efficiency within a basin and, in some cases, decrease nonbeneficial consumptive use. For example, some segments of conveyance canals maintained by irrigation companies in the Grand Valley have been lined to reduce seepage losses and decrease nonbeneficial consumptive water use by weedy plant communities along these canals. Further savings have been proposed for other delivery systems in the Grand Valley by the use of structural alterations in canals that will result in increased application efficiencies.

Incentives for adopting water conservation measures. Incentives for adopting water conservation practices vary regionally. In those areas pumping from deep ground water aquifers, economic incentives for water conservation exist because practices that result in increased application efficiency can frequently be justified on the basis of decreased pumping costs. In addition, institutional incentives in the form of restrictions on the rate of aquifer depletion encourage the adoption of irrigation water conservation practices.

In the alluvial watershed basins where water is obtained from surface diversions or shallow aquifers, incentives for adopting practices that decrease consumptive use or result in saved water are somewhat limited unless the water conserved can be used to extend supplies under the terms of an existing water-right decree. In some situations other direct economic benefits can be realized from the adoption of water conservation measures. Examples include savings from reduced power costs associated with pumping and revenue derived from marketing the conserved water on the rental or sales market. Economic benefits are difficult to project on general basis because the large number of variables involved requires that potential gains have to be evaluated on a case-by-case basis.

If the goal is to recover salvaged water for some other beneficial use, incentives for conservation are generally assumed to be limited because of the amounts of water available from changes in practices or potential institutional, statutory, and economic barriers to transfer of use. In the case of water conserved by reducing nonbeneficial consumptive use, the amount of water involved is likely to be so small that the economic incentive for any single operator is minimal. Of the management practices mentioned previously,

only those involving changes in cropping patterns could result in salvaging significant quantities of water by decreasing beneficial consumptive use. The changes in cropping practices involved, however, are substantial, and economic barriers to this transition in cropping can be significant. For example, shifts from feed crops (corn or alfalfa) to melons in the Arkansas River basin can result in significant water salvage because of the seasonal consumptive use of melons is much lower than that of either corn or alfalfa. However, this type of cropping change involves making wholesale modifications in farm operations and entering a more dynamic marketing environment. Thus, this change in cropping practices is not likely to occur on a widespread basis. Economic barriers to salvaging water through changing cropping practices can be overcome with transition from irrigated to dryland farming upon the sale and transfer of agricultural water to urban use. This type of transition has occurred on relatively large acreages of formerly irrigated land in the South Platte and Arkansas River basins.

The existence of economic incentives for surface water users to implement practices that result in more efficient diversion depends on the disposition of the resulting saved water. Growers are free to retain control of this water if the accrued savings can be used to extend supplies under the terms of the existing decree. In many cases, irrigators are short of water for a portion of the growing season, so there is an economic incentive to use the saved water to fill shortages. If, however, the grower is unable to use the saved water in this manner, the saved water automatically becomes part of the stream system and available to other users.

The incentives for adopting deficit irrigation practices are lacking, partly because of institutional barriers to transfer of a portion of the historic consumptive use within any given decree. These barriers include problems with quantifying the portion of the historic consumptive use to be transferred and administering the resulting change. One alternative to permanent transfers of a portion of consumptive use is dry-year option contracts between agricultural and municipal users. Under these arrangements, agricultural users would be paid to fallow land during short-term periods when supplies fall far short of total demands within the basin.

Issues Associated with Irrigation Water Conservation

General implications of water conservation practices. In watershed basins where water is derived from surface diversions or shallow alluvial aquifers, the adoption of conservation practices that decrease either nonbeneficial or beneficial consumptive use will have minimal effect on hydrology at the basin level, because return flows are not affected. There is concern that decreases in nonbeneficial consumptive use could threaten wetlands created by long-term irrigation.

Within any given basin, wide-scale adoption of conservation practices designed to increase diversion efficiencies has the potential of altering basin hydrology by reducing the magnitude of return flows. In areas where return flows fulfill a portion of irrigation demands, their importance is measured not only in magnitude, but also in timing. A significant fraction of the return flows from irrigation are delayed in their return to the stream system because the pathway is via porous soil media within the alluvial aquifer, which restricts the rate of water flow. On a basin-wide scale discharges from the alluvial aquifer increase late-season streamflows, which can meet irrigation demands for extended periods after peak runoff from snowmelt. The system, in effect, functions in the same manner as a reservoir, with diversions in excess of consumptive use contributing to storage and return flows functioning as releases.

Changes in irrigation practices at the basin level that would significantly increase diversion efficiencies could negatively impact water users who depend on these return flows. In the South Platte, Arkansas, and Rio Grande basins, irrigation diversions greatly exceed streamflows, which demonstrates the dependence of downstream users on return flows and is evidence of a relatively high level of water use efficiency within the basin. Reduced return flows are not a concern in the lower reaches of some watersheds where there is no downstream dependence on these return flows if interstate compact issues are not limiting.

Another likely effect of basin-wide increases in diversion efficiency is increased consumptive irrigation water use. This would occur as a consequence of irrigators using the savings from more efficient diversions to fill shortages within their decrees. Increased consumptive use would affect basin hydrology and eventually result in reduced return flows.

Large-scale transfers of water from irrigation to alternative uses causes a transition from irrigated to rainfed (dryland) agriculture. In many cases, this can cause decreased land values because of limited alternative land uses, greater potential for soil erosion, and unreliability of dryland cropping practices because of limited and variable natural precipitation (Sutherland and Knapp, 1988). If annual precipitation levels and soils are favorable, dryland cropping practices can be successful even though productivity levels are greatly reduced. In many cases, precipitation and soils dictate that land must be converted to rangeland to stabilize production and prevent erosion. This requires careful long-term management of revegetation, which is not generally cost-effective. In the past, the unfavorable economic outlook for dryland cropping and rangeland restoration led to land abandonment after water transfers. This has been largely remedied by various combinations of government subsidies supporting land revegetation and water court stipulations requiring restoration. Even with these remedies in place, transfers have a significant negative impact on local economies and public institutions because of decreased economic activity and a lower tax base.

Water quality impacts. Irrigation management that results in return flows has been targeted as an important contributor to water quality problems in watershed basins with significant agricultural development.

Irrigation practices in the Grand Valley and on lands served by the lower Gunnison and its tributaries have been identified as one factor contributing to increased salinity in the Colorado River (USDI, 1993). In response to congressional action to comply with treaty obligations to Mexico, the Bureau of Reclamation has developed and maintained programs to reduce this source of salt loading in recent years.

Nutrient and pesticide loading of surface and alluvial ground water can also arise from irrigation return flows. Although potential nutrient loading from irrigated agriculture and confined animal feeding exceeds that from urban sources in the South Platte basin, nutrient concentrations in surface water are highest immediately downstream of the Denver-Metropolitan area (Litke, 1995). Because of nutrient uptake by crops, irrigation diversions actually decrease nutrient loads in surface water to the extent that the levels of nutrients leaving the basin are lower than total annual inputs from all sources. However, ground water contamination from nutrients and pesticides is apparent in the areas of the South Platte basin where irrigated agriculture is most concentrated (Austin, 1993). Although return flow from irrigation is one factor contributing to contamination, the magnitude of this contribution in relation to other factors is unknown.

Impacts of transfers to instream uses. Another issue involved in considering agricultural water conservation is the fate of the resulting water. Irrigated agriculture is vital to the overall economy of Colorado. If water resulting from conservation is transferred to municipal or industrial uses, this will tend to enhance the value of this renewable resource to the state's economy. In addition, when agricultural water is transferred to the alternative uses indicated above agriculture users are compensated for the loss, since the right to use water is considered a property right. Instream uses proposed for water resulting from agricultural water conservation include recreation and improved habitat for threatened or endangered species. If the conserved water is to be transferred to these uses, the same economic incentives for transfer must exist. In this case, the issue of who pays becomes important. If the water is transferred for the purpose of enhancing the environment, the costs and benefits of such changes in use have to be considered on an individual basis.

Irrigation Water Conservation - South Platte River Basin

Strategies. Irrigators in the South Platte Basin rely on water storage and return flows to provide and maintain water supplies. For example, farmers at the lower end of the system depend on river gains from surface and ground water return flows to maintain river levels late in the season. The amount of reuse in the system indicates that diverters are using return flows as an integral part of water supplies in the basin. Because of this interdependence on surface and ground water, strategies for water conservation must take

into account the downstream dependence on flows returning to the system after upstream use.

The legal requirements affecting the adoption of water conservation measures have developed because of the hydrologic characteristics of the system. Farmers adopting water conservation measures must comply with the provisions set forth in the original water right decree. Farmers seeking to change the use of, or transfer, water obtained using water conservation methods are subject to legal standards regarding water that is saved or salvaged and must avoid injury to other water-right holders.

Strategies currently being used in the basin to improve on-farm efficiencies include both structural improvements in conveyance structures and irrigation systems, use of information management techniques, improved crop management, and changes in crops being grown. These strategies have been adopted on a continual basis in recent history throughout the South Platte basin.

The types of strategies adopted by farmers depend on economic feasibility, topography, soils, type of crop grown, and source of water supply. Surface water users have been adopting practices such as ditch lining and use of gated pipe, while ground water users typically adopt measures that improve the efficiency of their sprinkler systems or other application methods. Adoption of irrigation scheduling practices is used when farmers are able to control the timing of water deliveries.

The primary justification by individual operators for initiating water conservation practices has been to extend supplies within the season or in subsequent seasons by enhancing storage reserves. Because the amount of decreed water rights exceed average annual water supplies in the basin, water shortages are common. These shortages involve lack of sufficient supplies to completely satisfy ET requirements of the acreage and array of crops produced under any given decree for either a portion or an entire growing season. During the early and late periods of the growing season stream flows are often inadequate to meet direct diversion requirements of decrees. In addition, when more than one crop is produced under the same decree, irrigation water is preferentially allocated to the higher value crop, while the lower value crop is maintained under deficit irrigation (i.e., the quantity of irrigation water applied is less than the ET demand of the crop).

Implications. The adoption of water conservation strategies can impact water availability, local and regional hydrology, and water quality. Water supply deficiencies in the basin are illustrated by individual situations where decrees do not provide adequate supply to complete a crop, and over-appropriation of existing supplies, indicating that demand exceeds supply.

The individual water-short irrigator can improve water use efficiency or seek supplemental supplies such as rental water, or ground water, to ensure an adequate water supply to grow a crop. Water conservation practices can be used to improve water availability for the farmer in a water-short situation, if

the decree requirements are met. More efficient application of water could extend available supplies for crop production, as well as make water available for junior water-right holders that rarely have enough water.

The adoption of water conservation measures can however, reduce return flows to ground water and affect the balance between surface and ground water availability in the system. Surface flow rates could decline because ground water discharge to streams is reduced, and the timing of river flow could be altered by changes in ground water returns. Changes in the return flow regime could also impact ground water levels and pumping costs, instream flows, riparian zone maintenance, and wetlands.

Timing and availability problems stemming from a reduction in return flows would cause a greater dependence on existing water supplies. Reduced return flows that lower ground water levels and reduce instream flows could be addressed using more surface storage capacity to control timing of surface flows, and aquifer recharge to enhance ground water levels. Both options, however, are costly and controversial.

The South Platte conjunctive use system has resulted in several water quality problems in the basin. Over-application of irrigation water can cause leaching of agricultural chemicals to the ground water, and eventual degradation of surface water resources. Application rates that reduce leaching (and return flows) can reduce the transport and concentration of pollutants. If federal legislation is ultimately revised to mandate reductions in nonpoint source pollutants from farming, irrigators in the South Platte Basin could be required to adopt best management practices to control pollutants. Many management practices designed to control nonpoint source pollutants also function as water-saving measures through decreased diversions. The forced adoption of best management practices, while improving water quality, could also impact basin hydrology by altering the return flow regime.

The adoption of water conservation measures in the South Platte Basin is currently occurring on an incremental basis, resulting in improved water availability for individual growers. The potential for widespread adoption exists, but the ramifications of altering the existing hydrologic characteristics of the system must be weighed against any potential benefits.

Irrigation Water Conservation - Arkansas River Basin

Strategies. The Arkansas River basin is similar hydrologically to the South Platte basin. Irrigators in the basin rely on water storage and delayed return flows to maintain river flow and surface water supplies. Current irrigation practices such as flood and furrow irrigation not only provide for immediate crop demands, but also recharge the alluvial aquifer, allowing for ground water pumping as a supplemental source of water. The rate of reuse in the system indicates that diverters are using return flows to further

water supplies in the basin. Because of this interdependence on surface and ground water, farmers considering water conservation measures must account for potential injury to other water users on the system.

Even though Arkansas River Basin irrigators are subject to legal and hydrologic constraints affecting the adoption of water conservation practices, there are situations that are potentially suited to the use of efficiency-improving measures. Typical strategies could include the adoption of management or structural improvements that increase water use efficiency within the stipulations of an existing decree, and extend water supplies, thereby allowing for improved production. If no change or transfer is proposed, and the irrigator does not cause injury to another farmer, then the use of water conservation measures could improve existing operations. Ditch and canal lining, irrigation scheduling, surge irrigation, and the adoption of sprinkler irrigation could be advantageous.

Implications. The use of water conservation measures in the Arkansas River Basin could be beneficial in many respects, if the impacts associated with their use are assessed and evaluated as part of the adoption process. Historic supplies have not been adequate to meet demands for water, resulting in a situation where growers have had to seek supplemental sources. If the use of water conservation measures can improve water supply availability without causing injury to other users, then the result would be improved management. For example, much of the irrigation infrastructure in the Arkansas River basin dates from the previous century and is in need of upgrading. Major canals that are currently unlined support extensive vegetation resulting in significant conveyance losses in the form of nonbeneficial consumptive use. Lands served by structures such as these could benefit from improvements.

The adoption of water conservation measures for the purpose of reducing water quality problems is another example of a potentially beneficial situation. The most significant benefits are likely to come from measures that result in decreased consumptive use. Water conservation measures such as irrigation scheduling could also play a role in meeting Arkansas River Compact obligations, if the benefits outweigh the costs and do not affect usable state line flows.

Water conservation measures, however, can reduce return flows to ground water and affect the balance between surface and ground water availability in the system. Surface flow rates could decline because ground water discharge to streams is reduced, and the timing of river flow could be altered. Timing and availability problems could cause a greater dependence on limited surface water supplies. For example, in the situation of canal lining, canal conveyance losses to ground water can be a significant source of ground water recharge, and may require maintenance of ground water levels through artificial recharge. The losses to ground water recharge and/or streamflow maintenance must be weighed against the benefits associated

with reduced losses to riparian vegetation. Similarly, water quality improvement benefits must also be weighed against possible hydrologic changes.

Irrigation Water Conservation - San Luis Valley/Rio Grande Basin

Strategies. Improvement of on-farm irrigation efficiencies by conversion to sprinkler systems has occurred on a relatively continuous basis over the past 25 years. Just over 50% of the total irrigated acreage is under sprinklers currently, and many growers have adopted irrigation scheduling practices.

Potential strategies for further improvements in efficiency include the adoption of improvements in surface irrigated areas fed by the Alamosa and Conejos tributary systems, where water shortages are common on most farming operations. Ground water pumpers in areas of declining ground water levels should continue to adopt system improvements in order to reduce impacts to the unconfined aquifer.

An additional strategy in the basin is the reduction of incidental loss of water to non-beneficial vegetation and evaporation. Portions of the San Luis Valley overly shallow groundwater formations that are accessed by incidental vegetation not currently deriving economic benefit. Reduction of the water loss associated with non-beneficial vegetation could be beneficial to the Valley in terms of water salvage, but there could be negative impacts to wetlands and wildlife habitat. The Bureau of Reclamation's Closed-Basin Project addresses this concern in one region of the Valley. Evaporation from surface water sources is also considered a non-beneficial loss of water. Surface water system operations could be evaluated to determine the potential for water salvage and related environmental impacts.

Implications. The implications associated with the adoption of efficiency improvement measures in the San Luis Valley vary with the scale to which measures are adopted, the types of measures adopted, and local surface and groundwater conditions. The impacts associated with the adoption of conservation measures can be hydrologic, institutional, environmental, or various combinations of these. Hydrologic and institutional impacts are related to maintenance of the no-injury rule. Implications in the San Luis Valley can be negative or positive, depending on the scenario.

In situations where tributary ground water levels are relatively stable, the adoption of measures such as canal lining and the installation of tailwater recovery systems, could reduce recharge to the aquifer and have a negative impact on local hydrology and environmental resources such as wetlands. Water table levels could drop, raising the cost of pumping, and where excess water returns to surface water systems, stream flow rates and timing could be altered.

Where excess irrigation water can not return to accessible sources such as the tributary aquifer or

surface stream system, conservation measures would be beneficial. Similarly, where irrigators are reliant on confined aquifers, the adoption of efficient practices is likely to prolong the useable life span of the aquifer. The adoption of improvements in surface water systems could be beneficial if injury to other water right holders can be avoided. Injury is likely if ground water levels are impacted by the action, and if surface water availability is reduced.

Additional reductions in nonbeneficial ET beyond those currently realized by the Closed Basin Project could improve net water availability. However, the environmental impacts such as the loss of soil-stabilizing vegetation and possibly wetlands, should be considered.

Irrigation Water Conservation - Colorado River Tributary Basin

Strategies associated with salinity control. Much of the effort in agricultural water conservation in the Colorado River basin has focused on the Grand Valley near Grand Junction, the Uncompahgre Valley of the Gunnison, and McElmo Creek near Cortez. The soils in these areas are of marine origin and contain high quantities of salt. Typical irrigation water delivery systems are long, open, unlined canals supplying water to open unlined laterals for farm delivery. On-farm irrigation systems include graded furrow, sprinkler, and microirrigation systems with field irrigation efficiencies ranging from greater from around 20% to greater than 90%. Deep percolation of water from irrigation ditches and fields leaches salt from the soil profile and underlying shales, producing increased salt loading of the Colorado River.

Congress passed the Colorado River Basin Salinity Control Act of 1974 and 1984 amendments to improve water quality in Lower Basin states and the Republic of Mexico. The act provides cost-share funds for equipment to farmers, engineering and design services from the Natural Resources Conservation Service, and information and education resources from the Cooperative Extension Service. Irrigation system improvements used to reduce salt loading have included incorporation of gated pipe and surge system improvements, installation of drip and microspray systems, installation of underground pipe in place of laterals, and lining of open laterals and ditches. Most improvements are designed to decrease the amount of nonbeneficial consumptive water use and the amount of water leached through the profile. Both factors should result in decreased diversions and, thus, water conservation in the form of both salvaged and saved water. Estimates of eventual salvaged water yields from these activities in the Grand Valley are around 1,000 acre-feet of water annually, while saved water from salinity control activities in this valley are estimated to yield 70,000 acre-feet per year (CWCB, 1992).

Other conservation strategies. Another potential source of conserved water from irrigation operations in

the Grand Valley has been identified. The Grand Valley Project was constructed between 1912 and 1917 by the Bureau of Reclamation, and is currently operated by the Grand Valley Water Users Association (GVWUA) and four irrigation districts. The GVWUA system includes approximately 25,000 of the 70,000 acres irrigated in the Grand Valley. The major conveyance structure for this system is the Government Highline Canal, which delivers water from a diversion structure above the critical 15-mile reach (described above) to crop land near and below Grand Junction. Operation requires that the canal be kept full throughout its 55-mile length to provide sufficient volume and water elevation within the canal for all delivery points. When irrigation demands are less than anticipated, water must be returned to the river through a system of spillways. The Bureau of Reclamation has estimated that approximately 36,000 acre-feet of saved water could be conserved by structural improvements to the Government Highline Canal (CWCB, 1992).

With the exception of cropland in the Dolores, Lower Gunnison, and Uncompahgre basins, most of the irrigated agriculture outside the Grand Valley involves irrigation of pasture and hay crops by direct diversion of stream flows onto adjacent lands. There appears to be little potential for future conservation in these systems because of the lack of benefits from delayed return flows (return flows from these systems are essentially immediate) and the relatively small amounts of consumptive use involved.

Implications. The disposition of potential salvaged and saved water resulting from salinity control and system operation improvements has been the subject of much discussion. A study conducted by the Colorado Water Conservation Board offered four possible scenarios for use of the conserved water. First, there are no institutional barriers to the original appropriators using the salvaged or saved water to relieve shortfalls in current supply during periods of peak irrigation water demand, provided that present irrigated acreage is not expanded. Second, since upstream storage from Green Mountain Reservoir is available and currently meets some of the Grand Valley demand, saved water resulting in reduced diversions could be used by upstream junior users on the main stem of the Colorado River.

A third scenario was projected on the assumption that the right to the saved or salvaged water could be assigned to the original appropriator or the agency investing in conservation measures. This property right could then be leased or transferred to various uses such as the endangered species recovery program in the critical 15-mile reach, upstream junior users, or senior instream flow rights administered by the Colorado Water Conservation Board. The final scenario projected by the Board study was that savings accruing from conservation measures would remain as return flows in the Colorado River below Grand Junction. This assumes that junior claims relying on the return flows exist or that future claims filed for purposes such as a Colorado Water Conservation Board instream flow for endangered species recovery or other downstream

junior use could arise.

Irrigation Water Conservation - North Platte River Basin

Strategies. The irrigators of North Park generally rely on direct diversions from surface water streams, since there are no significant ground water withdrawals for agricultural purposes. The predominant crop grown is grass hay, and the most common type of irrigation practice is wild flooding. Farmers generally flood hay meadows early in the irrigation season, and have limited water supply available in late summer. Lower basin stream flow is maintained by delayed return flows to the system.

Farmland is located adjacent to streams allowing for diversion and immediate return of water applied in excess of field capacity. Adoption of water conservation methods has been minimal because of limited storage capacity in the basin and the low economic value of crops grown. Because the climate and topography of the region limit cropping alternatives, few incentives exist for future conservation efforts.

Implications. The adoption of water conservation measures in North Park could impact the current return flow regime by reducing return flows and instream flow maintenance, and would likely require additional storage so that water could be delivered when crops require it. The potential for increased storage in this basin is minimal in light of the current decree requirements. Further implications include potential conflict over the North Platte decree stipulations, as raised by the state of Nebraska.

The North Platte River is impacted by water quality problems in late summer below Cowdrey because of low flows and associated high temperatures that negatively affect fisheries. Adoption of conservation measures that result in decreased late-season instream flows at the lower end of the system could intensify this problem.

Irrigation Water Conservation - High Plains Deep Aquifer Basins

Strategies and implications. Farmers within the Northern and Southern High Plains basins began improving irrigation efficiencies in the mid-1970's in response to institutional and economic factors restricting the amount of pumping from the aquifer. Many farmers have switched to sprinkler irrigation systems with adaptations such as drop nozzles, low-pressure delivery systems, irrigation scheduling, minimum tillage, and other techniques to improve on-farm efficiency and reduce pumping requirements.

The reduction in rate of aquifer decline concurrent with increased irrigated acreage and well operation indicates an overall improvement in water management in the area. Moreover, the potential for future

savings is significant because changes in on-farm water use resulting from adoption of water-saving methodologies have no impact on other users within the basin. Therefore, unlike other basins, the implications of agricultural water conservation in the region are largely positive because of the overall effect of prolonging the usable life of the aquifer and, thus, the economic viability of the region.

Concluding Statement

The demands on water resources in Colorado continue to grow even though many of the state's streams are over appropriated and some underground aquifers are experiencing net depletion on an annual basis. Irrigation of agricultural lands accounts for more than 90% of the developed water resource withdrawals in the state. The dominant use of water by this sector of the economy has prompted calls by some for increased conservation efforts by agriculture to meet future alternative demands.

Both institutional and hydrologic factors can affect the potential for and effects of agricultural water conservation. Although the institutional barriers to conservation exist for the entire state, the hydrological conditions affecting agricultural water use vary greatly among and within the different basins. A significant proportion of irrigation water rights are dependent on return flows from upstream irrigation diversions in the South Platte, Arkansas, and Rio Grande basins. If water conservation measures that decrease the magnitude of return flows become widely adopted, the existing hydrologic integrity of these basins will be affected. The potential for agricultural water conservation is greater in the Colorado basin, where there is less dependence by irrigation operations on return flows. The High Plains deep aquifer basin is distinct hydrologically from the other basins because the point of use is widely separated from underground water resources. In this region, future agricultural water conservation will depend largely on economic incentives and the need to conform to state regulations designed to limit excessive depletion of the Ogallala aquifer.

The potential for future agricultural water conservation in Colorado varies greatly among regions. More importantly, policy initiatives designed to implement conservation should be based on how water is used at the basin level rather than at the individual farm level. Consideration of the existing structure of water use at the basin level will minimize any negative implications of conservation strategies. Also, impacts of water conservation strategies on interstate compact obligations must be considered.

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