Basin Planning and Management: Water Quantity and Quality

Edited by
David K. Mueller

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BASIN PLANNING & MANAGEMENT: WATER QUANTITY AND QUALITY

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Edited by
David K. Mueller
U.S. Geological Survey
Lakewood, Colorado

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Colorado Water Resources Research Institute
Colorado State University
Fort Collins, Colorado 80523

Robert Ward, director

Preface

Historically, water resources studies and management strategies, both governmental and private, have been narrowly focused on specific projects or problems. Such studies and strategies are adequate as long as water supplies are abundant and water quality is generally good. However, as water development increases toward capacity and the impact on water quality become more wide-spread, a broader approach to planning and management is necessary.

Since passage of the National Environmental Policy Act, planners of large-scale water projects have been forced to consider wide-ranging impacts to other water users and to the environment. In some cases, these impacts must be considered on a river-basin, or watershed, scale. More recently, congress has mandated the U.S. Geological Survey to investigate water-quality conditions and trends in 60 major river and ground-water basins throughout the country, including 3 in Colorado. The basin, therefore, is the fundamental area to be considered in water resources planning and management.

Other factors are contributing to the need for basin-scale planning and management in Colorado. The public is increasingly aware of the interrelation of water management to fish and wildlife, recreation, and wilderness values. Concern for impacts on these values often extends throughout a river basin where particular management strategies are being planned or implemented. Also, nearly complete appropriation of water supplies has resulted in new approaches to acquire water rights. These approaches require consideration of basin-wide water availability and interactions between surface-water and ground-water basins.

The 1993 Basin Planning and Management symposium was organized by the Colorado Section of the American Water Resources Association (AWRA) to provide water-resources professionals with a means to exchange information on all aspects of basin-scale water supply and water quality. AWRA is dedicated to the advancement of interdisciplinary water-resources research, planning and management. Therefore, AWRA has a unique capability to facilitate communication among professional in various fields and positions.

These proceedings summarize presentations made at the symposium. The authors include economists, engineers, hydrologists, and lawyers. Their affiliations include city, state, and federal agencies; colleges and universities; and private consulting companies. Some individual articles are about basin-scale studies; other articles are grouped to bring together several aspects of water-resources planning and management into a basin-scale framework. Articles cover 3 major river basins in Colorado (the South Platte, the Arkansas and the Colorado), as well as ground-water management, non-point source pollution, and non-structural alternatives to water-supply development. Overall, the articles are an indication of the types of water-resources issues in Colorado that are being addressed on the scale of river and ground-water basins.

I would like to thank the AWRA-Colorado Section board of directors and planning committee for their support and help in organizing the symposium. In particular I am grateful to Jerry Kenny, co-chairman of the symposium, for the significant amount of time and effort he devoted toward making the symposium a success. I also appreciate of the assistance of Robert Ward and the staff of the Colorado Water Resources Research Institute for publication of these proceedings.

Dave Mueller
Lakewood, Colorado

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WATER EXCHANGES:
A NEW FRACAS EAST OF THE DIVIDE

Michael D. ("Sandy") White
White & Jankowski
511 16th Street
Denver, Colorado 80202

One of the few politically correct options for development of future front-range municipal water supplies is an "exchange." Indeed, this correctness seems to be traditional as well, since exchanges have long been thought to be an inherent aspect of Colorado's revered water policy of "maximum utilization." The result is that eastern slope exchanges have proliferated madly over the last few years and continue to do so at a quickening pace. Administration of those exchanges, however, is in its infancy. The relationship between exchanges, not to mention the incestuous relationship between exchanges and augmentation plans, is not well understood. While exchanges associated with discrete projects have been and continue to be extraordinarily valuable, the time has come to examine carefully the exchange mechanism and to evaluate its proper role in future water resources management and development, with special emphasis on water quality concerns. While having some statutory guidance and an increasing amount of case law for assistance, those of us who deal with exchanges professionally are pretty much on our own when it comes to specifics. We are making it up as we go along. This paper is nothing more than a tentative summary of where we stand.

An exchange is a simple sounding swap -- a word understood to represent a straight-forward concept. In practice, however, exchanges are fraught with remarkable difficulties. It did not used to be so. When "exchanges" first came on the Colorado scene, well before the turn of the century, they *were* simple. In order to divert or store water "by exchange," an upstream junior water right owner simply needed to make sure that downstream seniors were kept whole, that they received a specifically designated substitute supply of water sufficient to satisfy their senior water rights. Typically, the upstream junior controlled a reservoir from which releases of substitute supply could be conveniently made for the seniors' benefit. For the better part of this century, such exchanges were routine -- carried on under the administrative supervision of the chief of Colorado water police, the State Engineer.

During at least the last twenty years, however, the practice of exchange has taken on new dimensions. Instead of exchanges using storage releases to satisfy senior direct flow rights, exchanges now appear in every conceivable combination of direct flow and storage. Instead of operating primarily upstream-to-downstream, exchanges now also operate downstream-to-upstream and "around the horn." Finally, exchanges have an entirely new flavor, that of an appropriative water right. No longer are exchanges merely administratively approved conveniences. Instead, exchange priorities are confirmed by Water Court decree and may operate only if in priority. In combination with their kid sisters (plans for augmentation), exchanges have come to dominate Water Court activity, providing some of its most entertaining (and expensive) moments. While exchanges may provide *the only* practicable way to increase the beneficial use of water in an over-appropriated stream system, it is a serious mistake to assume that exchanges are the simple creatures of old.

Exchanges and Political Correctness

On the first business day of this year, water gurus, gadflies, and groupies (together with some genuinely pleasant and respectable folk) gathered for the 1993 (i.e. the first) Annual Water Convention, organized by Ken Salazar, Executive Director of the Department of Natural Resources. The purpose of this rendezvous was to "share information and ideas on current efforts and options for assuring future front range water supplies in the post-Two Forks era." A lively time was had by all, during which the importance of exchanges was emphasized time after time.

Although congenially snubbed by the Governor, who said not a thing about them, exchanges were a centerpiece of discussions by municipal providers, those actually responsible for providing drinking water supplies to the public. The Governor was followed by Thornton's Mayor, Margaret Carpenter. As an example of successful front-range municipal cooperation, she described the "Cosmic Agreement" on Clear Creek water quality which led to the decreed "Cosmic Exchange." The exchange was designed to protect Standley Lake Reservoir (part of Thornton's, Westminster's and Northglenn's raw water systems) from Coors' and Golden's effluent, while maintaining everyone's water right yields. When Standley is being filled in the winter from Clear Creek by diversions through the Croke Canal, the effluent will be discharged downstream and temporarily stored in other facilities. During the non-Croke season, i.e. during the summer, releases from those facilities will constitute substitute supplies to seniors in exchange for equivalent upstream diversions into Standley, i.e. diversions to replace the volume formerly provided by the Coors and Golden effluent. Regarding municipal water conservation, Mayor Carpenter also referred to exchanges as being effective vehicles for increasing the beneficial use of the same amount of water, particularly when they are based on municipal-agricultural cooperation.

Lee Rozaklis' speech, derived from a Hydrosphere report, explored institutional arrangements and water right manipulation techniques which might increase the effectiveness of front-range municipal water systems. After pointing out that the potential shortfall for those systems has been estimated to be as high as 98,000 acre-feet in 2010 and 163,000 acre-feet in the year 2035, Lee mentioned several techniques which might bear additional study, including cooperative exchanges between municipal and agricultural users. While the northern front range has a substantial surplus of water which is quite attractive to hard-pressed municipal users in and around metro Denver, Rozaklis suggested that unnecessary dry up of irrigated lands could be avoided by cooperative techniques such as exchanges, made possible by the lesser water quality requirements of normal agriculture. As a result, municipalities by exchange could divert agricultural water rights, providing a substitute supply primarily of treated municipal effluent.

While these arrangements have been frequently called "effluent exchanges," that is no longer the politically correct terminology. "First Use Agreements" is the preferred term locally, while "physical solution" is the more regional descriptor. Globally, the concept is consistent with the transition from a "cowboy-throughput economy" to a "spaceship" earth economy. Regardless of the name, Rozaklis was quick to point out that complexity and difficulty could be anticipated to accompany the technique.

Nevertheless, potential developments such as the "Barr Lake Plan," hold promise and should be investigated to determine their value as a municipal first use scheme, with particular attention being paid to a variety of issues, including: [1] availability of substitute supplies, [2] competing senior exchanges, and [3] water quality constraints, both those resulting on the river and relating to the substitute supply.

Energized by discussions at the convention, the State lost no time in taking action. Two weeks after the convention the Colorado Water Conservation Board was asked to pay for a more comprehensive study of several projects, including the Barr Lake Exchange. Only three days later on January 21, 1993, the Board agreed. If the General Assembly is compliant, the "Barr Lake Exchange" along with two non-exchange projects will be the subject of a $450,000 state-funded study. In contrast to the tens of millions of pre-construction dollars spent on other similar exchanges, one must question the significance of the state's effort.

History of the Dreaded Exchange in Colorado

Before examining the Barr Lake Exchange, as well as other contemporary and proposed exchanges, we should be familiar with the expanding history of exchanges in Colorado where they are now said to be "common." Colorado's General Assembly was slow to focus specifically on exchanges, waiting almost twenty years after establishing procedures for water right adjudication and administration. In the meantime, as early as 1893, water users had discovered the utility of exchanges which were eventually protected by the Colorado Supreme Court, in the absence of unlawful injury and without benefit of statute. Nevertheless, for about 100 years courts were without jurisdiction to decree exchange priorities in general adjudication proceedings.

The 1897 Act

Exchanges were first addressed legislatively in 1897 when the General Assembly specifically authorized the exchange of imported water for an equivalent amount of native water and provided for exchanges between reservoirs and ditches. Apparently reflecting then prevailing practices on the Poudre, those provisions remain virtually unchanged today.

The 1899 Act

Two years later, in 1899 and as part of establishing a procedure for changing points of diversion of decreed rights, "owners of ditches and water rights" on the same stream were empowered "to exchange with, and loan to, each other, for a limited time, the water to which each may be entitled . . . ." This provision has been said to authorize the practice of rotation or doubling up of water and also remains on the books today. Shortly thereafter, in a 1905 opinion resolving a case from the Arkansas River, the Supreme Court held that the statute applied to "exchanges and loans of water for irrigation purposes only," that exchanges and loans might be made only in the absence of injury to other water rights, and that the burden of demonstrating the lack of injury rested squarely on those making the exchange.

The Legislative Doldrums, Courts Step In -- 1899-1969

Following the 1897 and 1899 Acts, the General Assembly did nothing about exchanges for seventy years. During that time, however, the courts addressed them in a variety of ways, including: requiring junior priority owners in a reservoir to provide a substitute supply as well as substitute delivery facilities to a senior in the same reservoir whose rights were adversely affected by the operation of the junior priorities; protecting a water commissioner from being required "to correlate or compile for [the operator of an exchange] the exchange and storage records" which he maintained; protecting an internal system of exchanges within a ditch system; regarding diligence in the appropriation of water rights on separate tributaries for different projects, holding that their eventual cooperative uses in exchanges was an insufficient basis for crediting work on one project to another; recognizing that exchange itself formed the basis of beneficial use for which a priority could be awarded; vacating an injunction against the enforcement of State Engineer groundwater regulations for the South Platte which, inter alia, provided for the replacement of well depletions by exchange; entering declaratory judgments regarding the validity of exchange agreements; preventing the further proliferation of *pro se* lawsuits arising out of a plethora of water right disputes, including the exchange of gunfire; disapproving the use of water salvaged by phreatophyte eradication as a source of substitute supply in an exchange said to be free of the river's call; protecting an exchange from injury in a change proceeding for other water rights; including exchanges within the "right of disposition" of imported water; adjudicating storage rights based on reservoir fillings by exchange; extending the broad protections of "inquiry notice" to exchange applications; holding not only that the operation of an exchange, pursuant to an agreement with a reservoir operator, could be the basis of a second filling decree in the reservoir by the beneficiary of the exchange but also that the negotiation, execution, and payment under that agreement constituted the specific overt act necessary to establish the appropriation of the refill right; and requiring the satisfaction of contractual requirements for permission to implement exchanges as a condition precedent to seeking their adjudication.

The 1969 Act

In 1969, as part of a massive revision and restatement of Colorado water law, the legislature made some significant strides in the substantive law of exchanges. Although the State Engineer has always had broad supervisory powers over the distribution of Colorado water and enforcement of its water laws, the considerable authority he exercised over exchanges was largely inherent in his larger duties. In 1969, the State Engineer's authority over exchanges was either enlarged or simply made specific, depending on one's point of view. He was authorized to allow out-of-priority upstream storage, subject to later release for the benefit of unsatisfied downstream seniors -- the most notable examples being the "Gentlemen's Agreement on the South Platte" and "top to bottom" administration of Poudre basin reservoirs. Under this provision the engineer's latitude in administration was later judicially protected even to the extent of requiring that the State and Division Engineers be notified in advance of a non-simultaneous exchange, particularly when the substitute supply was in the form of an entry in an "owe-the-river" account. In the same bill, a broad spectrum of exchanges (providing a "substituted supply of water") were specifically authorized, apparently without requiring the permission of downstream seniors, and courts were given jurisdiction to confirm the exchange, jurisdiction which previously had been technically lacking but sometimes simply assumed. Encouraging the exercise of exchanges "to the fullest extent possible" and denominating an exchange as an "appropriative right" which might be adjudicated, the legislature nevertheless required that substituted water "shall be of a quality and continuity to meet the requirements of use to which the senior appropriation has normally been put," although the Colorado Supreme Court later opined that the substituted water may be devoid of formerly beneficial silt. Further recognizing the potential of exchanges, the legislature contemplated their use in connection with imported or foreign water in a provision which has been interpreted as requiring no change decree for the water rights producing the foreign substitute supply.

Also in 1969 the General Assembly enacted a substantial change in water right adjudication and administration procedures, commonly referred to as S.B. 81, the "Water Right Determination and Administration Act of 1969," or as simply the "'69 Act." Exchanges were included in the 1969 Act, only insofar as they were part of a "plan for augmentation." While the legal and practical distinction between exchanges and plans for augmentation is obscure, one dealt with elsewhere in this paper, what S.B. 81 made clear was that, once an exchange became part of an augmentation plan, the exchange would be reviewed by the Water Court, using a standard of non-injury and imposing terms and conditions required to prevent that injury. The substitute supply of an exchange incorporated in an augmentation plan apparently had to meet slightly different standards than an exchange which stood alone. In 1969, however, it was not entirely clear from the statutory language that an exchange could be the sole subject of a Water Court application to obtain a priority.

1981 Amendments

In 1981, the ability to adjudicate exchanges was made certain. "Approval of proposed or existing exchange of water" was expressly included in the matters for which Water Court applications could be made. Furthermore, although exchanges had been considered to be appropriative water rights at least since 1969, subject to the legal requirements for the initiation of an appropriation, operating exchanges were allowed to be decreed with their original "priority date." The effect of the 1981 legislation, clarifying the distinctive nature of an exchange, was several-fold. In appropriating stand-alone exchanges (i.e. a priority to use the "exchange potential" through an exchange reach), one must be concerned about establishing both the elements of an appropriation and the historically-required absence of injury resulting from the exchange. There is, however, no mandatory retained jurisdiction in the Water Court to review future injury, that protection falling to the State and Division Engineer. Finally, municipal and, presumably, irrigation return flows may be used as a substitute supply.

1989 Amendments

In 1989 came yet other substantive legislative pronouncements concerning substitute supplies for gravel pit evaporation as well as exchanges by districts and political subdivisions. Regarding the calculation of substitute supplies for gravel pit evaporation, no replacement is required for exchanges operating by mid-1989 and historic depletions from the original vegetation need not be included in the substitute supplies for subsequent exchanges. Conservancy and conservation districts, together with other public entities, now may enter into exchanges even beyond district boundaries. In 1993, legislation was introduced (although not yet acted upon) which would remove many of the limitations imposed in 1969 on stand-alone exchanges.

Bean Counting

It is difficult to measure the importance of today's exchanges. From a subjective standpoint, they are surely important -- virtually every significant front-range water system employs them. Easily found hard data, tabulations and Water Court resumes, are obviously incomplete or can be summarized only at the certain risk of misinterpretation. Having said that, several conclusions can nevertheless be safely made. First, exchanges are a front-range phenomenon for the most part. Second, the recorded history of exchanges has been relatively recent.

<u>Tabulated Exchanges</u>

As of July, 1992, the State and Division Engineers have tabulated 601 decreed exchanges. Of those, approximately 98% (589) are on the eastern slope, with the vast majority (557) located in the South Platte drainage (Water Division 1), a few (32) in the Arkansas drainage (Water Division 2), and none in the San Luis Valley (Water Division 3). Of the eastern slope exchanges, the overwhelming majority, 96% on the South Platte and 100% on the Arkansas, were adjudicated after 1970 under S.B. 81 (1969). If anything, the tabulated number of exchanges substantially understate the number of documented exchanges. For example, those decreed exchanges which take place entirely within a ditch system do not appear to be tabulated. Exchanges which have not been decreed, but have been administratively approved by the State Engineer as substitute supply plans, are clearly missing. Finally, decreed exchanges which are difficult or impossible to tabulate have been ignored. For example, the tabulation does not list the "grand-daddy of all exchanges" on the Poudre, decreed in 1978 based on an application filed by the Cache la Poudre Water Users Association, along with many of its member companies as well as Fort Collins and Greeley. This decree lists over 1200 exchanges and purports to reserve them a place on the priority list as of at least 1975. Nevertheless, there is insufficient information in the decree, e.g. flow rates or locations, to allow it to be accurately tabulated.

According to the tabulation, the earliest decreed exchange appropriation in the South Platte basin was 1902 and the earliest exchange adjudication was 1926, the average dates falling in 1977 and 1983, respectively. On the Arkansas, the first exchange appropriation was in 1866, the same exchange which was first adjudicated in 1974 -- the same year in which the second exchange was appropriated. By contrast, on the western slope, although there are far fewer (12) tabulated exchanges, 3 in Division 4 (Gunnison River) and 9 in Division 5 (Colorado River), half of those were adjudicated prior to S.B. 81, all of those being in Division 5.

<u>Exchanges in the Resumes</u>

Following the creation of the divisional Water Courts in 1969, approximately 230 applications involving exchanges had been filed on the South Platte and Arkansas (Divisions 1 and 2) by the end of 1992. As might be expected a large majority of those applications (162 or 71%) were filed on the South Platte, with 67 (29%) filed on the Arkansas. After a tentative start, exchange application activity picked up in the mid-1970's and, shortly thereafter, reached its zenith on the South Platte in 1978 and 1980 when over 20 such applications were filed each year. On the Arkansas, the flood of exchange-related applications was slower to come. The peak of applications in Division 2 came during 1983 and 1985, each with 10 applications. Since those heydays, application activity has leveled off with roughly 7-9 applications per year in Division 1 and about half that on the Arkansas.

State Engineer Review of Substitute Supply Plans

The Water Court, of course, is not an essential stop for aspiring exchangers. Whether the court is involved or not, the State Engineer is responsible for exchange supervision under C.R.S. §37-80-120. His review of substitute supply plans has increased dramatically in recent years, from a fairly constant annual level of 35 to 55 plans during 1984-88, to approximately 100 and 200 in 1989 and 1990, respectively. Indeed, many of engineer-approved exchanges never see the steps of the water courthouse, e.g. the major substitute supply plan of GASP.

Tabulated Plans for Augmentation

Because of the close kinship between exchanges and augmentation plans, it is interesting to compare their relative progress in the Water Court. Of course, being a creature of S.B. 81, augmentation plans (at least by that name) were not adjudicated before 1969. Nevertheless, adjudication of augmentation plans has been an important source of business for the Water Courts. By 1992 and with the exception of Division 6 (the Yampa River), the State and Division Engineers had tabulated 733 decreed augmentation plans, roughly 20% more than decreed exchanges. Of the augmentation plans, approximately 70% (521) were in eastern slope drainages (as opposed to 98% of exchanges). On the eastern slope the vast majority of augmentation plans (90%, 472 plans) are located in the South Platte drainage, as compared with 95% of eastern slope exchanges. Virtually all of the other eastern slope augmentation plans are in the Arkansas drainage, with only one being tabulated for the Rio Grande.

Counting Angels -- exchange v. augmentation plan

Since 1969 and certainly since 1981, an important question has been quietly nagging many in the water business who deal with water transactions: Is there really a difference between an exchange and an augmentation plan? Although discussing the question invites derision similar to that encountered during angel counts on pin heads, the potential consequences of being involved in an exchange plan as opposed to an augmentation plan are significant enough to justify a passing examination of their differences. In sum, whether a plan is one of augmentation or is one of exchange is probably resolved simply by its name. That denomination, however, determines important results, including: whether the plan is reviewed by the State Engineer, the Water Court, or both; if reviewed by the Water Court, whether a period of retained jurisdiction must be imposed; and, whether the plan will be administered within and be protected by the priority system.

Increasing the water available -- the statutory definition

Unlike an exchange, a plan for augmentation has been defined by statute as "a detailed program to increase the supply of water available for beneficial use in a Division or portion thereof." Although that increase may be accomplished in a number of ways, the essence of an augmentation plan is that it must "increase the water available for beneficial use."

It is also that increase, said the Colorado Supreme Court in 1991, which distinguishes an exchange from an augmentation plan. In *Florence v. Pueblo* the court gave some pointers along these lines when dealing with Pueblo's exchange based on a substitute supply attributable to imported water. The majority, after noting that the legislature clearly intended that an exchange could be either independent from or part of an augmentation plan, suggested that an exchange stood alone if it "is not part of 'a detailed program to increase the supply of water available . . . .'" In this case, Pueblo "increased its water supply by more efficiently controlling its foreign water supply. This is an appropriate use of foreign water and does not constitute a plan for augmentation." Justice Erickson's concurring opinion, after noting that (unlike an augmentation plan) an exchange may be operated without judicial approval and, if decreed, will have a priority, takes the same tack as the majority: "The exchange project allows Pueblo to increase the efficiency of its transbasin diversions and does not create any net increase in water usage in the Arkansas River Basin."

After reading all this, one wonders whether there ever could be an augmentation plan, increasing the supply of water. There may be no answer! Consider the court's 1976 opinion in *Kelly Ranch v. Southeastern Colorado Water Conservancy District*. There one learns, "new water need not be injected to give life and validity to a plan for augmentation." The end result, apparently, is that the statutory definition of augmentation plans (increase in water available) simply is of no value and we must look elsewhere for the keys by which to distinguish an exchange.

Practical Distinctions

If there is no conceptual definition allowing differentiation between exchanges and augmentation plans, perhaps we have a situation akin to pornography -- something difficult to define but easy to recognize. As with pornography, of course, that easy recognition is highly individualistic. An informal survey of several experienced water lawyers and engineers, asked to describe the differences between the two types of plans, disclosed almost as many practical definitions of and distinctions as there were respondents. No two of them saw these plans in precisely the same light. Most, however, were willing to identify certain characteristics which *tended* (in their personal views) to identify one type of plan or to distinguish one type from the other. Those characteristics are summarized in Table 1, below.

TABLE 1

Exchanges v. Augmentation Plans
(subjective impressions)

Characteristic	Exchange	Augmentation	Comment
Addnl water reqd?	No	No	
Must be decreed?	No	Yes	
Right to do what?	Deplete stream	No net depletion	
	Use water repl	Use water repl	
Priority date?	Yes	No	
Retained jurisd?	Discretionary	Yes	
Subst. supply			
std?	Yes	Yes	Different for quality
location?	Downstream	Upstream	Generally
Diversion/storage			
location?	Upstream	Downstream	
Depletion location?	Exch Reach	Varies	
GW component?	No?	Usually	Remember GASP
Approp reqmts?	Yes	No	1st step, can & will, etc.
What appropriated?	Exch Pot	-	
Administration	Acctg/Priority	Acctg	
Out-of-priority opn?	No/Yes	Yes	Exch: yes, beyond reach
Relation back?	Maybe	N/A	
Diligence reqd?	Yes	No	
No-Injury std?	Yes	Yes	
Sr call reqd?	Yes?	No?	Reusable water
Simultaneous opn?	No	Yes	
Surface stream involv?	Usually	Sometimes	
Water rt reqd for opn?	Yes	No	
Live stream req'd	Yes?	Sometimes	To prevent injury

Practical Conclusions

What does this confusion or blurring between the two types of plans mean to the water professional? Caution is required! First, because there is no reliable definition, whatever the plan is named ("exchange" or "augmentation") will follow it for the remainder of its life. As a result, when christening one of these creatures, consider carefully the consequences of that choice of names. Second, there is a frequent tendency to take a belt-and-suspenders approach, calling a plan both one of exchange and one of augmentation. The most prevalent example being that suggested by the statute, "plan for augmentation, including exchange." Since the two types of plans have conflicting attributes, combining them may be quite dangerous and will at least tempt the spirit of unforeseen consequences. Finally, all bets may be off when it comes to early plans, especially augmentation plans. When the Water Courts were first groping their way through the maze of S.B. 81 and faced new mechanisms like augmentation plans, decrees were issued for plans which bear virtually no resemblance to those decreed today. For example, the Cache la Poudre Water Users Association's augmentation plan admittedly provides neither new water nor replacement water. Instead, wells covered by the plan are considered alternate points of diversion for undiverted surface water rights, regardless of whether those rights are in priority or whether water is physically available in the stream at their headgates. That augmentation plan has no decreed priority, yet the plan has a substantial impact on stream flows in decreed exchange reaches. How will the eventual conflicts be resolved?

The Contemporary Exchange

Today's exchanges are so diverse that they cannot be easily summarized. No attempt to put them in discrete categories will be completely accurate. Nevertheless there are two categories which are helpful repositories of most exchanges -- the "river" exchange and the "intra-ditch" exchange, sometimes simply "ditch" exchange. River exchanges involve the release of a substitute supply to satisfy water rights held by seniors on the river, thereby allowing juniors to divert or store water. Intra-ditch exchanges usually are accomplished along the ditch, away from the river and below the ditch's headgate, by withdrawals from the ditch followed by the delivery of a substitute supply to the ditch.

River Exchanges

Although the earliest reported exchange case deals with an intra-ditch exchange, the vast majority of early exchanges were operated on a river or stream, particularly one with major tributaries. For example, Denver's deliveries of west slope water through the Roberts Tunnel are made to the North Fork of the South Platte. Since the North Fork joins the South Platte below some of Denver's reservoirs, it was physically impractical to store the imported water in those reservoirs. Nevertheless, those flows are frequently used to fill the reservoirs by exchange. The imported water is allowed to flow down the South Platte as a substitute supply for seniors diverting below the North Fork confluence. In exchange, equivalent amounts of native South Platte water is stored in those reservoirs.

Intra-Ditch Exchanges

The modern, politically correct intra-ditch exchange is essentially a device developed by municipalities in cooperation with major agricultural ditch companies. While there is some dispute over the concept's origination, the first widely publicized intra-ditch exchange was the Northglenn-FRICO-Standley exchange, circa 1976. With some variation, most subsequent exchanges have followed the Northglenn pattern. The prerequisite for the intra-ditch exchange seems to be an agreement with the ditch company, without which some courts refuse to adjudicate the exchange. Under that agreement, the municipality withdraws water from the ditch and replaces it with water derived from its treated effluent or from another source. In virtually all instances, the substitute supply is water of lesser quality than the water withdrawn by the municipality. There is usually something more in the deal for the ditch company than reduced water quality. First, the company typically establishes minimum quality standards which the substitute water must meet, thereby insuring that the water will be of sufficient quality for continued irrigation under the ditch. Second, the company gets a bonus -- money, extra water, or both. In the Northglenn exchange, for example, the city's substitute supply was 110% of the water withdrawn. Municipal intra-ditch exchanges are currently being operated by the cities of Westminster, Thornton, Denver, and Lafayette, among others, in cooperation with a variety of agricultural ditch companies. These exchanges may be found, *inter alia*, on: the Burlington Ditch, used primarily by shareholders of the Burlington and Wellington companies and FRICO irrigators within the Henrylyn Irrigation District; the Lower Clear Creek Ditch; the Lower Boulder Ditch; Baseline Reservoir; and the Signal Ditch.

Combination Exchanges

Many interesting exchanges, including some of the more controversial exchanges proposed today, are combinations -- containing elements of both the river and the intra-ditch exchanges. This, however, is not a new concept. It has been practiced in many of Colorado's river basins for years. By the turn of the century on the Poudre, for example, combination exchanges were commonplace. As one travels east, down the Poudre, a series of major canals divert from the north side and then roughly parallel one another as they carry water for irrigation of lands far from the river. In general, the senior priorities are located downstream and, by mid-to-late summer, would call out the upstream juniors when water is most needed for irrigation. To avoid curtailment from those calls, the junior canals instituted exchanges. During periods of high river flow, when there was no call or an even more junior call, the upstream companies would store water in reservoirs beneath their canals. When river flows dropped and calls were placed by the downstream senior companies, reservoir releases delivered to their canals would provide substitute supplies for the seniors and the upstream juniors could continue to divert. Many of those arrangements appear to be described in the decree for the Grand-Daddy of All Exchanges, described above.

Administration of Exchanges

With the proliferation of exchanges, administration is becoming increasingly complex. Before the 1969 Act, administration was handled either by water commissioners who monitored *ad hoc* river and combination exchanges or through the State Engineer who annually reviewed and approved substitute supply plans.

Volume and complexity

Compounded by the mushrooming population of augmentation plans, the difficulties of administering newly decreed exchanges are staggering. By way of illustration, administrative nightmares for a Division Engineer's staff that is already overloaded arise from the decretal quantifications, the complexity of decrees, complex accounting and delinquent reporting by exchangers (not to mention computer software incompatibility), the timing of substitute supplies, notification of and monitoring of exchanges by the water commissioner. As one senior administrative official recently put it, we have reached "water commissioner overload."

The character-of-exchange rule

At a time when the origination and classification of water (e.g. native, reusable, imported, non-tributary) has assumed great importance, an administrative rule has developed to simplify the tracking of various classes of water as they go through exchanges. The rule is that water which is diverted by exchange takes on the character of the substitute supply. For example, if the substitute supply is reusable, so is the water diverted by exchange and conversely. The character-of-exchange rule was born of necessity, again apparently on the Poudre. Imported CBT water is stored by the Northern Colorado Water Conservancy District in Horsetooth Reservoir near Fort Collins and released into the Poudre for the benefit of the District's allottees. A major allotment holder, the North Poudre Irrigation Company, diverts from the Poudre at a point upstream from the Horsetooth discharge. In order to obtain its CBT water, North Poudre diverts native water in the amounts of downstream releases of CBT water. The North Poudre diversions, while actually native water, are accorded the character of CBT water for administrative purposes.

Common decree provisions

While exchange decree provisions vary widely from case to case as a function of the energy and nature of the opponents, there are a number of terms and conditions which can usually be found in any exchange decree:

+ Adequacy of Substitute Supply. The court either delegates to the State Engineer or reserves to itself continued supervision of the quantity, quality, and timing of the substitute supply as may be required by the appropriate statutory provision, C.R.S. §37-80-120(3) or 37-92-305(5).

+ Operation with Downstream Call. Normally, an exchange is allowed to operate only when a downstream senior is calling for water. This limitation is inapplicable under certain circumstances, e.g. where the exchange utilizes reusable water or where the exchange is made to keep the call off the river.

+ Live Stream. Unless the Division Engineer determines there will be no injury as a result, exchanges are normally allowed to operate only when there is a "live stream," i.e. a discernable surface flow throughout the exchange reach -- the stream segment between the point where the substitute supply is introduced and where water is diverted by exchange.

+ Administration. With few exceptions, no exchange may be operated without prior notification of the Division Engineer. He, in turn, is responsible for determining and supervising various operational issues such as the amount of transit losses and the time at which the substitute supply has been provided and the exchange diversions may begin.

+ Accounting. While accounting forms are not usually incorporated in an exchange decree, it typically requires that the forms and methodology be acceptable to the Division Engineer before operation of the exchange. Not only must the exchanger periodically report accounting information to the Division Engineer, frequently on a daily basis, he and sometimes other parties are often entitled to real time access to the exchanger's computer data.

+ Exchange season. The period during which an exchange may operate is dictated by the availability of substitute supply. If that supply is derived from the retirement of irrigation water rights, exchange operation can be expected to be limited to the irrigation season. If, however, there is no seasonal limitation on the substitute supply, e.g. storage releases, no such limitation will be imposed on the exchange.

+ Decreed use of substitute supply. Where native water is to be used as substitute supply, consistent with the character-of-exchange rule, courts normally require that the substitute supply's underlying water rights be decreed for the same use as is intended for the water to be diverted by exchange. If that is not the case at the time of the exchange adjudication, the decree will require it to be so before the exchange is operated.

+ Intervening Seniors. The exchange will not be allowed to operate so long as water rights senior to the exchange and diverting within the exchange reach are unsatisfied.

+ Water Quality Monitoring. Particularly in those heavily contested cases involving intra-ditch exchanges, an applicant should be prepared to consider a water quality monitoring program directed at the substitute supply.

Pending Exchanges

An examination of three prospective municipal effluent exchanges, each at different stages of adjudication and development, is helpful in understanding exchange operations as well as the issues which arise during their development and adjudication. The exchanges associated with the Thornton Northern Project are in the midst of adjudication, trial having been completed and the court's ruling expected soon. The NCWCD's South Platte Water Conservation Project was announced late last year. Because Water

Court applications for this projects' water rights were filed only recently, in December 1992, no significant action has been taken by the court. The Barr Lake Exchange, one to be studied by the state, has not yet been the subject of Water Court applications. All three projects are combination exchanges, incorporating various attributes of both river exchanges and intra-ditch exchanges. All are to be carried out with the cooperation of the ditch companies involved or, presumably, without resort to condemnation by the participating municipalities.

The Thornton Northern Project

In 1985 and 1986, Thornton acquired over 100 farms (21,000 acres) under the Larimer County Canal in Larimer and Weld counties, along with the farms' water rights. Those included slightly less than half of the shares of the Water Supply and Storage Company which operates the canal. In general, as part of a larger project, Thornton appropriated two major exchanges and applied to have them decreed by the Water Court in late 1986. Before the Water Court were also an application to change the WSSC shares for use in Thornton and an application to confirm junior appropriations from the river.

The two exchanges, one a river exchange and one an intra-ditch exchange, have substantially different but interrelated and overlapping functions. The river exchange is to provide diversions to Thornton through the Larimer County Canal when capacity is available and when the city's junior appropriations have been curtailed, to provide water to other users at various points along the Poudre in satisfaction of Thornton's replacement obligations arising under the change application, and to provide the basis for diversions at various pump stations associated with the ditch exchange. Equivalent amounts of substitute supply will be provided to downstream seniors by deliveries from the South Platte at its confluence with the Poudre, based on the addition of water to the South Platte by Thornton far upstream, including significant amounts of its treated effluent discharged at Metro.

Pursuant to an agreement with the company, Thornton's ditch exchange will be phased in incrementally over the last two phases of the project. After the temporary dry-up of most of the Thornton farms has been completed, the city will begin exchanging against the remaining water in the Larimer County Canal under "first use agreements," approved by the company for negotiation with remaining shareholders, or under an additional umbrella agreement with the company itself. In the last phase of the project, Thornton will exchange against its own share water, as well, returning to the ditch 100% of its historical supply and allowing the Thornton farms' return to irrigation. The substitute supply for the ditch exchange will, for the most part, be pumped from stations on the Poudre and on the South Platte near its confluence with the Poudre. After diversion at the pump stations and any necessary treatment, the substitute supply will be delivered by pipeline to the Larimer County Canal. The water delivered must meet 47 water quality standards (fishable and swimmable) pursuant to Thornton's agreement with the company.

To date, Thornton has expended over $80,000,000 on its project for which construction costs are expected to be approximately $450,000,000. The consolidated Water Court applications have been tried and closing statements have been made. Although over 100 statements of opposition were filed, by the conclusion of trial Thornton had resolved the concerns of all but 13 objectors. The matter remains under consideration by the court which is expected to rule in the near future on various legal issues. Following that ruling, conferences are anticipated to develop a decree which conforms to those legal rulings. A final decree is not expected until later this year.

The NCWCD's South Platte Water Conservation Project

The Northern Colorado Water Conservancy District, one of the most vocal objectors to the Thornton Northern Project, has recently filed a similar project of its own. Based on a nifty pamphlet distributed by the District and entitled *South Platte Water Conservation Project*, unappropriated Poudre and South Platte water (yes, everyone agrees that there is quite a bit) will be pumped from the South Platte at a location adjacent to one of Thornton's pumping stations for its ditch exchange. From the District's pumping station, water is to be routed by pipeline to various participating canals and surface reservoirs as well as to a ground water recharge facility.

If direct canal or surface reservoir deliveries are made, river exchanges may result from correspondingly reduced headgate diversions by those canals, thereby allowing others to make upstream diversions or storage by exchange. If water is stored pursuant to the recharge program, it will be later withdrawn through wells and delivered to the canals allowing river exchanges to operate. As currently fashioned, the District's project is a true combination exchange, melding the characteristics of both river and intra-ditch exchanges. Applications for the adjudication of the project water rights were filed on December 23, 1992. As the adjudication progresses and publicity increases, new facets of the project will undoubtedly be revealed, including its cost and the compensation to be paid to participating ditch companies. If nothing more comes of this project, we will forever remain indebted to the District. It has spawned yet another synonym for exchange, "repositioning" of water.

The Barr Lake Exchange

In late 1990, the Barr Lake Exchange was unveiled by its sponsor, Third Creek Corporation. Based on information contained in a proposed exchange plan, dated October 26, 1990, South Platte water which is now diverted by the Burlington Ditch for storage in Barr Lake by FRICO and the Burlington Company will, instead, be diverted or stored upstream for unspecified municipal use. Following the first use of that water, it is to be transported in the form of treated effluent to the new Denver Airport. There, the water will be treated further, discharged to Third Creek, where it will be intercepted by the Burlington Ditch and conveyed into Barr Lake from which it will resume its historical use as irrigation water. Because of storage available at Barr Lake, the exchange (treated effluent for irrigation water) need not be simultaneous and the volume of water available to users under Barr Lake will remain the same as it was historically. The two companies are to receive at least $47,000,000 and their shareholders, at least $10,000 per share. Third Creek Associates will receive 6% of gross revenues, a percentage that converts to between $6,000,000 and $31,000,000. Nevertheless, the plan "passes through a minimum of 85% of the increased value attributable to the [original irrigation] water right to the Barr Lake shareholders and the Companies, while also allowing the shareholders to retain their water for continued agricultural use."

There are admittedly obstacles to Barr Lake Exchange, particularly since other municipalities have already been active on the South Platte within the proposed exchange reach and on the Burlington Ditch itself. These types of issues certainly are neither novel nor insurmountable. Nevertheless, their resolution is anticipated to require the expenditure of up to $12,000,000. Illustrative of the wrinkles frequently found in these combination exchanges, the issues include: [1] resolution of concerns arising out of a 1921 operating agreement between the companies and Henrylyn Irrigation District which shares the Barr Lake facilities; [2] resolution of matters arising under a 1981 agreement between the companies and Thornton for an intra-ditch exchange on the Burlington, an exchange which has been subsequently decreed by the Water Court; [3] resolution of concerns arising out of a similar agreement between the companies and South Adams Water and Sanitation District, an agreement which was also decreed with provision restricting treated effluent in the ditch; [4] resolution of an agreement with Denver, which pumps to the Burlington and exchanges Burlington water upstream; [5] accommodating existing decreed river exchanges against the Burlington Ditch operated by Denver, Mission Viejo, and Englewood, all within the proposed exchange reach on the Platte; [6] accommodation of yet undecreed exchanges, with priority dates senior to the Barr Lake Exchange, and with applications currently pending in the Water Court; [7] approval of the exchange plans by the companies major shareholders, including the Henrylyn District and the City of Brighton.

Based on the foregoing, it is easy to see why Thornton and the Northern Colorado Water Conservancy District initiated their projects on ditch systems and in stream reaches which are relatively free of the pre-existing competition faced by the Barr Lake Exchange. Nevertheless, there is an important issue common to all three exchanges, the quality of the substitute supply.

The Crunch of the Moment -- Water Quality

All three of the major pending exchanges (Barr Lake, Thornton, and NCWCD) face significant concerns about water quality. Indeed, that issue seems to be the most visible and contentious one for proponents of any exchange in which municipal effluent is included within the substitute supply being provided to irrigators. Historically, irrigated agriculture considered even untreated municipal effluent to represent a beneficial opportunity, not a serious problem. Because of extensive municipal effluent discharges into front-range rivers, there long has been a substantial indirect reuse of that effluent (albeit diluted) for irrigation, without any adverse affects. Municipalities were of the view that, although sources of drinking water supplies needed to be of the highest quality, irrigated agriculture could operate quite comfortably with water of lesser quality including conventionally treated effluent. Consequently, a municipality's treated effluent plus some boot (cash or additional water) would be serendipitiously exchanged for agricultural water suitable for municipal drinking water supplies.

Things have changed. Nowadays, when treated effluent is to be discharged directly to a ditch or when an intra-ditch exchange becomes controversial for whatever reason, the quality of the substitute supply becomes a *cause celebre*. The irrigators, together with their camp followers, ask why the municipality is simply transferring its water quality problems to agriculture, at a time of its economic distress. Suspicious of the farmers' new-found desire to grow crops sensitive to water quality, the municipality cannot help but wonder whether it is being viewed simply as a sugar daddy in hard times.

Substitute Supply Standards

While exchanges must operate so as to not injure other vested water rights, there are special statutory standards for substitute supply. Those standards are slightly, but significantly, different for stand-alone exchanges as opposed to exchanges which are incorporated within a plan for augmentation. Substitute supplies for all exchanges are governed by C.R.S. §37-80-120(3) which requires "substituted water" to "be of a *quality* and continuity to meet the requirements of use to which the senior appropriation has normally been put." Exchanges included in augmentation plans, however, are governed also by C.R.S. 37-92-305(5) which provides, "substituted water shall be of a *quality* and quantity so as to meet the requirements for which the water of the senior appropriator has normally been used." The first provision, applicable to both kinds of exchanges, concentrates on the normal uses made of water as envisioned by the senior appropriation, i.e. the beneficial uses for which the appropriation was made. The second provision, applicable to only exchanges which are part of an augmentation plan, focuses on the actual use of the water which has been made by the senior appropriator, regardless of whether that use was the subject of his appropriation. These standards are applied by the State Engineer when approving substitute supply plans or administering decreed exchanges and by the Water Court in the adjudication of exchanges.

The State Engineer's Regulations

Superimposed on the specific quality requirements for substitute supply are water quality standards and classifications for state waters adopted by the Water Quality Control Commission as well as the Water Quality Control Division's issuance and enforcement of permits for point source discharges, all pursuant to the state's Water Quality Control Act. To preclude ugly confrontations on the quality v. quantity battlefield, the Act includes §104, requiring that the Act not be interpreted so as to: [1] "supersede, abrogate, or impair" water rights, [2] "to cause or result in material injury to water rights," or [3] allow "minimum stream flows or minimum water levels in any lakes or impoundments." In 1989's S.B. 181, the General Assembly amended the WQCA to clarify the duties of the WQCC, WQCD and various "implementive agencies," including the State Engineer, in adopting and enforcing water quality standards and classifications. On August 30, 1990, the State Engineer together with the WQCC and WQCD executed a Memorandum of Agreement concerning the relationship of their water quality responsibilities. In February, 1992, after extensive public hearings, he issued his "Senate Bill 89-181 Rules" which became effective on March 30, 1992, and were accompanied by an explanatory "Statement of Basis and Purpose."

Approaches to Meeting Substitute Supply Standards

There are several ways in which the suitability of substitute supplies are evaluated by the State Engineer and the Water Court. Needless to say, such decisions are made on an *ad hoc* basis, with few firm rules of thumb resulting.

The State Engineer

Pursuant to his S.B. 181 Rules, the State Engineer will conduct water quality review of all exchanges, including both those which are submitted to him for approval or renewal as well as those contained in applications to the Water Court, except for "contract exchanges" which do not involve discharges to "state waters," defined under the Water Quality Control act to exclude "water withdrawn until use." In its narrowest sense, this would exclude State Engineer review of intra-ditch exchanges. Exchanges where substitute supply is provided pursuant to a discharge permit will nevertheless be reviewed by the State Engineer to determine whether the senior appropriations requirements of use have been met. Exchanges which have been previously decreed "shall not be affected by [the rules] except to the extent consistent with retained jurisdiction provisions in such decrees, or water quality obligations of the State Engineer's Office pursuant to such decrees." Bear in mind, the purpose of the rules is to insure compliance with water quality standards and classifications for state waters adopted by the Water Quality Control Commission as well as the Water Quality Control Division's issuance and enforcement of permits for point source discharges. In addition, the State Engineer is required under C.R.S. §37-80-120(3) to insure that "substituted water" is of "a *quality* and continuity to meet the requirements of use to which the senior appropriation has normally been put."

For non-decreed exchanges submitted to him for approval, the State Engineer will consider water quality standards and/or classifications in determining whether the quality of the substitute supply meets the requirements of the senior appropriator. Identifying the "senior appropriator" may well be the trickiest part of this analysis. The Statement of Basis and Purpose defines that appropriator as "any downstream water user receiving the substituted supply and senior to the [exchange] who could potentially be the senior 'calling' right on the river, based upon historic call records and/or diversion records." Obviously, the identity of that right will vary throughout the year. In general, the quality of the substitute supply will be evaluated through use of a mass balance and mixing zone approach and will be measured at or near its point of discharge to eliminate downstream degradation which is beyond the control of the exchanger. Under circumstances where that may be inappropriate, such as where dilutive effects of river flow may repair inadequacies in the substitute supply, the State Engineer may evaluate its quality at a point closer to the senior appropriator -- an effort which may require substantially more data to be provided by the exchanger. As evidence that substitute supplies meet the quality requirements, the State Engineer may accept water discharged pursuant to a discharge permit, surface water left in the stream by foregoing diversion, surface water immediately returned to the stream after diversion, and water from any stream designated by the WQCC as "high quality."

Regarding exchanges for which applications have been made to the Water Court, the State Engineer evaluates the substitute supply as described above and may, for water quality reasons, file a statement of opposition, protest, or motion to intervene.

The Water Courts

The Water Courts have taken several approaches to insure compliance with the appropriate statutory standard for the quality of substitute supply. Frequently, the court simply orders that the exchanger will insure that substitute supply will meet the standard and that the State Engineer will make sure it does. At other times, through retained jurisdiction, the court itself is available to review complaints about the substitute supply -- sometimes only to review the State Engineer's action in that regard. In extreme situations, such as Golden's attempt to get exchange credit for discharging its effluent through the Croke Canal into Standley Lake Reservoir (the then major raw water source for Westminster and Thornton), the court will find that the substitute supply cannot meet the statutory standard(s) and refuse to adjudicate an exchange priority.

How good is good enough for irrigated agriculture

Whether scientific fact or political hype, the quality of water suitable for agriculture has become an overriding issue for intra-ditch exchanges. As explained by the Barr Lake proposed exchange plan:

> There is a growing awareness that quality which was assumed to be acceptable for agricultural use may have risks which were not previously recognized, and that secondary treated effluent is not suitable for all agricultural uses. * * * Water treated [by facilities such as those planned at the new airport] has met the strictest California and Arizona standards for use on raw edible vegetables intended for human consumption. These standards are substantially higher than those currently existing in Colorado.

Similar concerns exist in the NCWCD and Thornton exchanges. The District's brochure indicates that water diverted from the South Platte for direct exchange with Poudre ditches will be of a quality suitable for agriculture. If it doesn't happen to be, it will be treated prior to the exchange. The District, however, wasn't nearly so sanguine about the substitute supply in the Thornton ditch exchange on the Larimer County Canal -- although it is the same water, diverted within a few yards of the District's diversion, and is treated if necessary. This kind of ambivalence leads most municipalities to be highly skeptical of the claims that conventionally treated effluent, particularly after it travels some sixty miles in an open river, having been diverted and rediverted many times, will not be suitable for irrigation use.

Most recent water quality concerns seem to be based on recent regulations adopted in California and Arizona, but not in Colorado. Those regulations are related to the direct application of treated effluent, i.e. where the effluent travels by pipe all the way from the waste water treatment plant to the point of irrigation application. In California, for example, restrictive standards have been established for reclaimed water in only "direct beneficial use," defined as "the use of reclaimed water which has been transported from the point of production to the point of use without an intervening discharge to waters of the State." The Arizona rules establish standards for "reclaimed wastewater" which is "reused," being defined as "the use of reclaimed wastewater transported from the point of treatment to the point of use without an intervening discharge to the surface waters of the State for which water quality standards have been established." While Colorado has adopted no similar rule or standard, a draft policy statement is being developed by the WQCD for "Slow-Rate Land Application of Treated Wastewater." It, too, addresses only "reclaimed water," being that which is used for irrigation without ever having been discharged to a stream. The water quality parameters which attracts the greatest attention in effluent reuse is fecal coliform. California and Arizona, for example, allow virtually no fecal coliform (no more than approximately 2 CFU/100ml) in the *direct* reuse of treated effluent for the irrigation of crops which will be eaten raw. The concern, of course, is with human-related fecals.

There is a very important distinction, however, between *direct* reuse of treated effluent and its *indirect* use after it has been discharged to a stream. Transportation down the river for significant distances, diversions from and subterranean return flows to the river, and low flow conditions where the effluent moves through the alluvium, tend to eliminate or substantially reduce quality-related problems associated with the effluent. At some point, the dangers wane to insignificance or disappear altogether. As a result, no governmental standards have been adopted, anywhere, which impose the same restrictions on *indirect* reuse of effluent as have been imposed by California and Arizona on *direct* reuse. Indeed, the California and Arizona standard would be "virtually unattainable in any of Colorado's subalpine streams without additional treatment." Not surprisingly, Colorado stream standards for agriculture include no standard for fecal coliforms. The EPA has established a standard 200 CFU/100ml where human contact is anticipated and 1000 CFU/100ml where it is not. The UN's Food and Agriculture Organization as well as the World Health Organization also recommends 1000 CFU/100ml, primarily because there is no epidemiological basis for a lower standard. The Colorado Agricultural Experiment Station concludes, "Since farm workers are subject to frequent exposure to water during the irrigation process, a 1000 CFU/100ml standard seems a reasonable standard for agricultural diversions." Even that standard could not be met by the water diverted by many Colorado ditches.

The upshot of all this is that water quality will play a major role in any municipal-agricultural cooperation in the realm of exchanges, particularly intra-ditch exchanges. Emotions tend to run high, as might be expected considering effluent's raw material. Where exchanges contemplate *direct* reuse of treated effluent, one can expect the courts and the State Engineer to apply quite strict water quality standards perhpas as low as (2 CFU/100ml) to the substitute supply. On the other hand, based on agriculture's experience in this and other states, where the reuse is *indirect* far less stringent requirements can be anticipated, something in the 1000 CFU/100ml range. After all, as was stated in *A-B Cattle Co*, in determining the acceptability of a substitute, a "balancing of interests is required."

What about intervening polluters on the river

The most interesting water quality issue for river exchanges involves intervening polluters, usually municipalities who discharge effluent within the exchange reach. They do so quite lawfully, pursuant to discharge permits issued by the WQCD and within the effluent limitations contained in the permits. Those effluent limitations, however, are derived in part based on the dilutive effect of the stream flow. The higher the flow, the more relaxed the limitation. If a river exchange reduces that flow, however, the effluent limitations may be made more stringent upon permit renewal. More stringent limitations may substantially increase effluent treatment costs. Is this the type of injury which must be prevented by the Water Court in an exchange adjudication?

This issue has been addressed twice concerning Pueblo's Arkansas River exchange, once in the Division 2 Water Court and once by the Colorado Supreme Court in *Florence*. In order to avoid increased waste water treatment costs, the Water Court expressly required a minimum flow past a municipal effluent outfall in order to protect the effluent limitations in the discharge permit. That requirement was not appealed. Nevertheless, the Supreme Court noted it. The same issue is now before the Division 1 Water Court in the Thornton Northern Project adjudication, where Kodak and Fort Collins have objected to river depletions based on the *Florence* dicta. Everyone looks forward to the resolution of this issue, once it is fully argued, especially in light of the provisions of §104 of the Water Quality Control Act, discussed above.

Conclusion

Because important issues must be addressed within the subject of exchanges, now is not the time for stridency. Indeed it is hard to write or say anything about intra-ditch exchanges without being accused of being an apologist for one interest or another. More importantly, it is essential for public officials with policy-making responsibilities to carry a bit of good-faith skepticism about the universal utility of exchanges. They are not a quick fix. Handled badly, they are a recipe for future disaster. Used wisely, they have an important role to play in achieving that maximum utilization which is the essential goal of Colorado water management and policy.

ARE WATER MARKETS EFFICIENT?: EVIDENCE FROM CLEAR CREEK AND SOUTH PARK

Mark Griffin Smith
Assistant Professor of Economics
Colorado College
Colorado Springs, Colorado 80903

Abstract

Market efficiency presupposes a number of conditions, one of which is that market prices reflect value. The value of a water right is related to attributes of that right including, the appropriation date (reliability), point of diversion (location and possible third part effects of use or transfer) and current use restrictions. In an efficient market, these attributes should statistically account for the variation in prices among water rights. In inefficient markets, this relationship between attributes and price should have little explanatory power. Inefficient markets are caused by a number of factors including transaction costs, asymmetrical information and unequal bargaining power between buyer and seller.

This study examines two distinctly different water markets. The market for mutual ditch company shares on Clear Creek is the most active water market in Colorado in which hundreds of transactions have been made. In South Park, water was sold off the ranches in less than thirty large and complex transactions. The empirical evidence shows that whereas Clear Creek has an efficient market, prices for South Park water rights are erratic.

Introduction

Surface water sources in the State of Colorado east of the Rockies are scarce. For some time they have been completely appropriated; this means that under the state's water law based on the doctrine of prior appropriation, someone has a claim on every drop of water that flows east from the Rockies down the South Platte or Arkansas Rivers. Given this situation only two options exist for those that need water - build new storage or buy water from existing users. The storage option is increasingly unattractive. New storage reservoirs on the east slope can only capture irregular peak flows during the spring runoff as the remainder of the flows have already been appropriated by other users. Furthermore, new reservoirs are environmentally damaging, hence unpopular and thus difficult to build. The only option that remains is to reallocate water amongst existing users. In Colorado this has been accomplished effectively through sales of water rights on the market.

Water markets have existed in Colorado for some time. Anderson (1961) reports that farmers within the same mutual ditch company have rented and traded water between themselves for over eighty years. What is new in the last twenty years is the entry of cities into the water market to purchase agricultural water for transfer into municipal, commercial and industrial uses. The result of these sales is the wholesale reallocation of water away from agriculture to the cities and from one region to another.

Colorado's eastern slope has one of the most active water markets in the United States. While much has been written about the water market within the Northern Water Conservancy District in northeastern Colorado (Saliba, 1987; Crouter, 1985) the southern Front Range has received much less attention. Northeastern Colorado's water market attracts much interest because of the relative ease that shares of the federally funded Colorado-Big Thompson Project are exchanged among farmers and between farmers and cities. The exchange of water rights along the southern Front Range is more complex. The objective of this paper is to describe the structure and character of this market along the southern Front Range.

The Setting

The southern Front Range of Colorado extends 110 miles from Denver in the north to Pueblo in the south. Collectively the Front Range and a number of other mountain ranges make up the Colorado Rockies. Here at the base of the mountains, where the high plains meet the Rockies, lie the cities of Pueblo, Colorado Springs and the Denver metropolitan area. Metro Denver includes the cities of Denver, Aurora, Lakewood, Thornton, Golden, Arvada, Westminster, North Glenn and Littleton as well as many other smaller communities.

During the 1970's and early 1980's the cities along the Front Range experienced a period of rapid economic growth and a concomitant influx of people. The factors generating this growth included energy development in western Colorado, increased defense spending and the relocation of a number of federal agencies to a major federal center in Denver. In 1982 the collapse of oil prices led to an end of much of the energy exploration in the state and a much less rapid rate of growth (Colorado Department of Local Affairs, 1989).

More people means greater demand for water. The cities set out to accommodate growth by procuring new water supplies to meet the rising demand. The two major surface water sources in the region are the South Platte and Arkansas Rivers. The South Platte flows from the northern end of the Front Range, through the Denver area across the farmlands of northeastern Colorado and on into Nebraska. The Arkansas runs south-east out of the Rockies, truncating the Front Range at Pueblo, passing through the agriculturally productive lower Arkansas Valley and into Kansas. The average annual flow of the South Platte measured upstream of Denver is 122,000 acre-feet/year (U.S.G.S., 1988), while the average annual flow of the Arkansas measured upstream of Pueblo is 595,000 acre-feet/year (U.S.G.S., 1988). In addition to these two major rivers Clear Creek and the tributaries of Fountain Creek are also an important sources of water to cities in the Denver metro area and Colorado Springs, respectively. Clear Creek joins the South Platte in Denver with an average annual flow of 142,000 acre-feet/year (U.S.G.S., 1988) Fountain Creek flows through Colorado Springs with an average annual flow of 46,950 acre-feet/year (U.S.G.S., 1988) and joins the Arkansas near Pueblo.

The South Platte is the historical source of water for the city of Denver and those cities in the Denver Metropolitan area served by the Denver Water Board. Most of the cities in the metropolitan area with the exception of Aurora buy some of their water from the Denver Water Board. Denver began developing reservoirs along the South Platte upstream of the city in the late 1800's. By the late 1920's the city had out grown the resources of the South Platte and began to look over the mountains for new sources. The 1930's saw Denver's first transmountain diversion. This transmountain diversion and subsequent diversions from the tributaries of the Colorado continue to generate controversy within the state and sharp division between the east and west slopes.

Clear Creek which flows into the South Platte in Denver supplies water to the cities of Golden, Arvada, Westminster and Thornton. Each of these cities also purchase water from the Denver Water Board. Aurora located to the southeast of Denver is the only city within the metropolitan area which is completely independent of the Denver Water Board. Aurora has a storage reservoir on the South Platte that it jointly owns with the city of Thornton. Aurora also owns reservoir capacity on the Arkansas River which it can convey to the South Platte river basin through a system jointly owned with the city of Colorado Springs.

Colorado Springs developed its original water supply from the tributaries of Fountain Creek. As the city grew, the city decided to develop storage on the Arkansas itself. Joining first with Aurora, a system was developed to pump water from high upstream on the Arkansas to the South Platte then by conduit to Colorado Springs. Later the city joined in the Frying-Pan Arkansas Project with the Southeastern Colorado Water Conservancy District to transfer water from a tributary of the Colorado across the mountains to the Arkansas. This water can be stored in either the Twin Lakes Reservoir or a hundred miles downstream in the Pueblo Reservoir just upstream of the city of Pueblo. Water can then be pumped from the Pueblo Reservoir to Colorado Springs through a conduit running parallel to Fountain Creek (Bostrum, 1989). Pueblo is the only major city along the Arkansas and is thus in the advantageous position of being able to take water directly from the river although it does own storage in both the Twin Lakes and Pueblo Reservoirs (O'Hara, 1989).

The Buyers

Who the buyers are for any particular water right is largely determined by a city's ability to capture, store and convey the water to its customers. All buyers are not equal with respect to their capacity to use water emanating from different sources. New storage and conveyance structures built to use new sources are expensive. At present cities are looking for rights that can be used without investing in either new storage reservoirs or conveyance systems.

While Denver is the largest city along the Front Range with the most extensive conveyance and storage system, it has been one of the least active players in the water market over the last twenty years. There are two reasons for this. Denver has enough water to meet the needs of the city and county of Denver. The city has also been trying to develop the Two Forks Project to meet both its long term needs and the more immediate needs of communities it serves. Thus Denver's recent effort has been directed toward developing new storage rather than acquiring agricultural water. Furthermore, the Denver Water Board reasons that the future of Denver is linked to the future of the state as a whole. The short-sighted acquisition of agricultural water will, in the long run, undermine the economy of the region (Ruetz, 1989). Should Denver change its policy and choose to enter the water market, its existing conveyance and shortage system would allow it to make use of water rights along the South Platte as well as transmountain water from tributaries of the Colorado.

The two most active players in the water market in the Denver metropolitan area are the cities of Aurora and Thornton. Aurora and Thornton jointly own a reservoir on the South Platte upstream of Denver and have used this reservoir for the storage of many of the agricultural water rights they have purchased on the South Platte. Beyond the South Platte, these cities have reached in opposite directions to acquire additional water rights. Aurora takes water from the Arkansas River through the pipeline that is jointly owned with Colorado Springs. Taking advantage of this investment, Aurora has purchased water rights from the Twin Lakes Irrigation Company and the Colorado Canal Company on the Arkansas. While Aurora has gone south, Thornton has gone north and west. Thornton has gone north to purchase water from the Cache la Poudre River and west for rights on Clear Creek.

Golden, Arvada and Westminster are also purchasing water rights on Clear Creek. The Clear Creek market is distinct from the South Platte market although it is actually tributary to the South Platte. These small cities along Clear Creek (Golden, Arvada, Westminster) have no existing storage capacity on the South Platte or means of conveying water from the South Platte. Therefore they are left with two alternatives; competing with each other for scarce supplies along Clear Creek or buying water from Denver at a time when Denver is seen as an increasingly unreliable supplier. The price of rights along Clear Creek reflects the heavy competition for these rights. Price differentials between Clear Creek and South Platte rights on an acre foot basis are between six and eight thousand dollars (McLemore, 1989).

Colorado Springs can capture water from Fountain Creek and directly from the Arkansas. The city has purchased water rights from both Twin Lakes and the Colorado Canal Company on the Arkansas.

Pueblo has a unique status in the Front Range water market as a relatively small city sitting alone on the region's largest river. Pueblo's situation allows it to pick up small quantities of water from water rights from irrigation ditches near Pueblo as these opportunities come along. These sales are too small to attract interest from more distant buyers (O'Hara, 1989).

Types of Sales

Two principal types of sales make up the major water transfers from farmers to the cities within the region, water rights transfers and shares in mutual ditch companies.

A water rights transfer is the sale of a water right from one party to another. Water in Colorado is a usufactory right meaning the right is to use of the water, not to the water itself. Ownership of the water itself is vested in the public, although "the right to divert the unappropriated waters of any natural stream to beneficial uses shall never be denied" (Article XVI, Section 6, Constitution of the State of Colorado). A water right is the right to divert water to a "beneficial use". Title to water can be freely transferred from one party to another and need not be attached to land.

The major area of water rights transfer activity within the southern Front Range region has been the sale of water rights from ranches along the South Fork of the South Platte upstream of Denver in an area know as South Park to the Denver area cities. These sales began in the late 1960's and are continuing up to the present. Since 1967, 93% of the original water rights along the south fork of the south Platte in South Park have been sold to the metro area (BBC, 1987). These rights have been conveyed through twenty-five separate sales of ranch water rights. Most of the sales have involve the sale of the water alone, but some have also included land.

The second way to buy water is to buy shares in a mutual ditch company. These ditch companies were originally founded to manage the irrigation ditches that convey water to their members. As members withdraw from farming or ranching they are free to sell their shares. Anyone is free to buy these shares as long as they can demonstrate a beneficial use for the water. Shares cannot be bought and held for speculation.

Market activity along Clear Creek is solely for shares in the mutual ditch companies that have rights along the Creek. The other major transfers are the purchases of Twin Lakes and Colorado Canal shares by both Aurora and Colorado Springs.

Water Right Attributes

Water rights have a number of attributes that determine their value in the market. These are: priority date, adjudication date, source, location and type of use.

Water law as practiced in the State of Colorado is perhaps the purest expression of the doctrine of prior appropriation in the West. The basic tenet of prior appropriation is, "first in time, first in right". The first person to divert water from a stream and put that water to beneficial use has a superior claim to the flows from that stream to all subsequent or "junior" appropriators. The law establishes a queue whereby the first or most senior appropriator receives his or her full right from the stream before any junior appropriator. If there is not enough water in the stream, junior appropriators are simply "called out"; they are told to shut off their diversions to meet the requirements of those holding senior rights. The order in the queue is established by the date that water was first diverted and put to beneficial use, the priority date. Records of the priority dates are maintained in the State Engineer's Office. A senior right on the heavily appropriated South Platte has a priority date earlier 1870 (Curry, 1989).

Periodically the courts adjudicate a river. The purpose of an adjudication is to grant court approval to all water rights established prior to the adjudication. All diverters who have established their diversions prior to the adjudication process must file evidence of such with the court. If a diverter fails to do so, his or her right will become junior to the date of adjudication. While priority is the primary determinant of the position of the right in the queue, purchasers of water rights need to be certain that their priority was in fact approved in the earliest adjudication subsequent to their original appropriation.

Given the uncertainty of natural streamflows, the more senior the water right, the more valuable it is as a more senior right is more reliable. "Free river" conditions are increasingly rare on both the South Platte and the Arkansas. A "free river" is one on which all rights receive water. Purchasers of water rights are only interested in senior rights although most ranch transfers will include both junior and senior rights. Junior rights have little value.

The second major factor affecting the reliability of a water right is its source. The source of a surface water right can vary between an ephemeral stream to a major river such as the South Platte or Arkansas. The value of a water right on a perennial stream is higher than one on an intermittent or ephemeral stream for two reasons. First, the larger the stream, the more likely it is that your right will receive water. There is simply more water to divide amongst right holders. Second, the perennial stream will run all summer. The South Platte itself will still have water in August when many of its tributaries have dried up after the spring melt-off. The longer the stream runs, the more water you get.

The location of the diversion along the river is a fourth important attribute of a water right. Every water right includes a description of the exact location of the point of diversion. The right is the right to divert water at that location and that location alone. If the right is sold, the point of diversion must be changed unless the buyer intends to use the water at the same location which is generally not the case. To change the point of diversion, the applicant must file for a change of diversion with the court and have that change approved. The importance of location arises from the fact that it is in general much easier to move the point of diversion downstream than it is to move it upstream. Moving the point of diversion downstream simply means leaving the water in the river a while longer until it gets to the new diversion. The court will normally reduce the amount of the right by some small amount as a "charge to the river" for losses due to evaporation and, in the case of effluent streams, seepage. Other water rights are not affected. On the other hand, if I try to move the point of diversion upstream, I will reduce flows to diverters between the new and the old points of diversion. These diverters will most often file protests against my change in diversion increasing both the time and transactions cost associated with my purchase of the right. For this reason, there have been very few purchases of water rights downstream of Denver for use by the upstream communities (McLemore, 1989).

The final attribute of a water right that is important in determining its value is its historic use. The water rights transfers along the Front Range have been from farms or ranches to the cities. The historic use of the water has been for irrigation and for irrigation only. The city as buyer must file with the court to change the type of use from agricultural to domestic uses. In a few cases such as the sale of shares by the Colorado Canal Company on the Arkansas, the seller has gone to the courts to change the type of use before looking for sellers (Bostrum, 1989). This reduced the uncertainty to the eventual buyers, Aurora and Colorado Springs, as to whether the change would be granted.

Legal Constraints

The role of the courts in the transfer process is to assure against negative third party effects. Application for a change in a water right must be publicly announced. Anyone who feels that they may be injured by the proposed change can file a petition of protest with the court. The issues under dispute between the applicant and the protestants are resolved under the legal process in the same manner as other civil proceedings with the exception that trials take place before a district court judge who has a special appointment to the water court.

Third party effects from water transfers arise from the fact water is used and reused many times before leaving the state. Downstream diverters have the right to return flows from upstream water users.

If these return flows are diminished by any change in the water right, the downstream diverter has cause for legal action and protection from any action that would diminish his or her right.

A decree must be obtained from the court in order for a water right to be legally transferred from one owner to another. In the decree the new owner or applicant will request a change in the type of use and the point of diversion. These changes have been described above. The applicant may also request a change from a direct flow right to a storage right or for a change from the right to divert during the irrigation season to a year round diversion right.

Water rights that were originally obtained for agricultural use allow a farmer to divert water during the irrigation season which extends from 150 to 180 days depending upon the length of the growing season. Water may not be diverted during the winter months unless one also owns a right to these winter flows. Many agricultural water rights including all of the ranch transfers from South Park were originally direct flow rights, that is the right to divert water directly from the river when it is available. These flows had to be applied directly to the land and could not be stored. The demand for domestic water is more evenly distributed throughout the year. Therefore cities that acquire agricultural rights will generally request that the new decree allow them either to store the water in a reservoir or to spread their diversions over twelve months rather than seven to better match the seasonal distribution of domestic demand.

The court must also determine the amount of water that the buyer will be allowed to divert. This determination will be based on the historic consumptive use of the previous owner and the effects of proposed changes on downstream rights holders. The court determines consumptive use by reviewing the both the type of crop and cropping patterns that were historically practiced by the seller. The consumptive use of water is higher where a farmer harvests three cuttings of alfalfa than where one cutting of hay was harvested each year. The court recognizes this difference and protects the downstream diverters by assuring return flows by limiting to historic consumptive use the amount that can be diverted under the change in right.

Water transfers not only affect water users but also land owners. When water is transferred out of agriculture to domestic use, previously irrigated land is allowed to dry up. Wind and soil erosion may result from the loss of vegetation. Nuisance grasses takeover abandoned fields then invade adjacent fields. In most cases native grasses cannot reestablish themselves because of increased soil salinity. The State of Colorado recognizes the potential injury to adjacent landowners and has therefore required buyers to revegetate dried up land. In a recent decision the court ruled in favor of a group of plaintiffs asserting that the revegetation efforts of the buyer had been inadequate (Denver Post, 1989)

The objective of the court in water rights proceedings is to protect the interests of third parties who might otherwise be injured by the transaction. The free market fails to protect third parties in situations in which actions cause negative externalities (Just et al., 1982). While there is a clear need for a process to protect third parties, this protection comes at considerable expense and delay for the buyer and introduces an element of uncertainly into the transaction.

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WATER EFFICIENCY AS A COST-EFFECTIVE SUPPLY OPTION

Scott Chaplin and Jim Dyer
Rocky Mountain Institute
Water Program
1739 Snowmass Creek Road
Snowmass, Colorado 81654-9199

Introduction

Traditionally, in an effort to meet a growing demand for water, utilities have only considered supply-side options such as dams, canals, and treatment plant expansions. Now, however, as the costs of obtaining water and of treating water and wastewater rise, demand-side approaches which use less water more efficiently to deliver unchanged or improved services are increasingly proving to be the most economical way of meeting increased water demand. Sometimes called conservation or demand management, the technologies and methods for increasing water use efficiency have improved dramatically in recent years.

Indeed, with the passage last year of the National Plumbing Efficiency Standards, it is clear that water efficiency will become increasingly important. Under this new legislation, the maximum water use allowed for any showerhead or faucet manufactured in the United States after January 1, 1994 will be 2.5 gallons per minute and the maximum for toilets will be 1.6 gallons per flush.

In addition, the Federal government may soon require minimum levels of efficiency efforts, such as the California Best Management Practices, before allocating funding for future water supply projects. Therefore, it is now becoming incumbent on water utility managers to take demand side management seriously. This new push by the Federal government will best meet the long term interests of taxpayers, utilities, the environment, as well as commercial, residential, agricultural, and industrial waters users. Communities across the United States have experienced water savings of 20, 30, 40 percent, and even more through the implementation of cost-effective water efficiency programs. At RMI we have compiled over 80 case studies which document these levels of savings and the other benefits of water efficiency.

This paper describes Rocky Mountain Institute's least-cost planning method, provides illustrative case studies of successful efficiency programs, and discusses some of the problems and promises associated with implementing efficiency programs. The focus throughout is on municipal water efficiency.

End Use/Least-Cost Planning

Water providers routinely consider a community's long- and short-term goals and needs, compare various alternatives for achieving the stated objectives, and choose the approaches that meet those needs at the least cost. Communities often do not need more raw water, they simply need more of the services water provides. Customers want to have clean hands, dishes, and clothes, to maintain a beautiful yard, to cool industrial machinery, and to receive other amenities that water provides. They don t care whether they use more or less water, as long as they get the desired services, what we call end-use, with the quality and reliability they want. The end-use/least cost planning method compares supply options on an equal ground with efficiency measures. This approach may require a shift in thinking for some water utilities. Using the Lawrence Berkeley Laboratory method of calculating the levelized cost of saved resources, we can place on a dollar value on the quantity of water that is saved through efficiency projects and use this number to compare efficiency with the cost of new supply projects. Whereas water supplied by a new dam or desalination plant may cost between $500 and $2,000 per acre-foot, municipal water efficiency (better showerheads, toilets, etc.) can provide water for $50 to $200 per acre-foot and lead to many additional benefits.[1]

Benefits of Water Efficiency

For water providers, efficiency programs are generally faster, easier, and cheaper to bring on line than traditional supply-side programs such as dams and canals. Since efficiency does not require a large, irreversible commitment of money to build large storage and diversion projects, these programs reduce the financial risk of miscalculating demand far into the future. Also, efficiency programs can be implemented incrementally as needed, thus lowering the costs of the program by spreading them over a period of years. This shortens payback periods, and reduces the need for large up-front loans. Although water rates may sometimes need to be increased to make up for lowered sales, overall costs to the utility will also decrease due to lower costs of providing water services. Implementing an efficiency program can also help reduce the uncertainty of demand forecasts.

For water and wastewater treatment providers, water efficiency programs can defer, if not eliminate, the need for expensive water and wastewater treatment plant expansions. Also, there is a potential to reduce operating costs because of reduced energy and chemical use, equipment down-sizing, shorter operation time, and increased effectiveness of the treatment process. Efficient water use can reduce both overall base demand and peak demand. As more stringent drinking water and wastewater standards require the removal of more contaminants, the cost of treating water and wastewater will increase significantly, adding further to potential savings from having to treat less water.

More efficient use can also improve water quality in areas where groundwater overpumping is drawing brine, or pollution from landfills and toxic-waste sites in to public water supplies. For example, heavy groundwater pumping in Fresno, California pulled groundwater contaminated with dibromochloropropane, an agricultural chemical, toward city wellfields. After shutting down 35 wells, the city began efforts to reduce water demand and thus prevent contamination of the city s other wells. The Water Conservation Board proposed a program to retrofit 81,000 single-family homes with water meters, and is requiring the use of 1.6 gallon-per-flush toilets and 1.0 gallon-per-flush urinals (where used) in all new construction. In addition, Fresno plans to retrofit 125,000 single-family and multifamily homes with water-efficient showerheads and other retrofit devices.[2]

[1]These costs are "levelized" to spread the capital and operating costs of each option over its lifetime.

At the residential level, a Consumer Reports article reports potential water and sewer savings ranging from $15 per year in Dayton, Ohio, to $62 per year in Houston, Texas, with the installation of an ultra-low-flush toilet.[3] The use of water-efficient showerheads and faucet aerators can lead to savings annual savings of $26 to $170 annually per household, primarily from reduced water-heating needs. The payback period for these devices from energy savings alone is generally six months to one year. In addition, retrofitting a household with efficient showerheads and aerators can save up to 15,000 gallons of water per year, and displace annual emissions of up to 1,800 pounds of carbon dioxide, 3 pounds of nitrogen oxides, and up to 6.6 pounds of sulfur dioxide.[4]

Successful Efficiency Programs

The most common efficiency improvements now in use include utility-based measures such as rate structure changes, metering, and leak detection and repair programs, as well as customer-based efficiency measures including indoor fixture retrofits, fixture replacement, and outdoor watering efficiency improvements. Reclamation and reuse are also now playing an integral role in many programs. Although not in widespread use, graywater and rainwater collection systems are becoming increasingly popular.

Utility-Based Measures

Metering - No efficiency program can expect to make significant headway if customers are not billed according to use. Under New York City's Universal Metering Program, savings of 10% to 30% per building are expected.[5] Denver's savings from the recent completion of its metering program may not be as high due the already high level of consumer awareness.

Rate Structure Changes - Increasingly, communities are revising their rate structures to signal that future supply will cost more than present supply, and that peak supply costs more than base supply. The most effective rate structures are "increasing block" structures, as opposed to flat or declining block rates. Under these rate structures, a relatively low rate, sometimes called a "lifeline" rate, is charged for a quantity of water calculated to meet the basic needs of low-income customers. Beyond that quantity, higher rates are charged according to set intervals. Some communities, such as Santa Barbara, California, also apply a peak-season surcharge, particularly to the higher-level blocks, in the summer months, when outdoor watering creates especially high peak-demand water-treatment costs.

Leak Detection and Repair - Despite high initial costs, leak detection and repair programs are proving to be cost effective for many water suppliers, especially those with old, deteriorating systems.[6] In 1988, the Boston Water and Sewer Commission found and repaired 888 leaks wasting 11.55 million gallons per day. In 1989, they detected over 400 more leaks, most of which were repaired by January 1990, saving an additional 7.16 million gallons a day.[7]

Customer-Based Efficiency Measures

Demand can be significantly reduced by efficiency improvements on the customer side of the meter. Examples of these measures include installing water-efficient household fixtures, fixing leaky toilets and faucets, making outdoor watering more efficient, installing water-efficient landscaping, repairing leaks, and correcting wasteful water habits.

Indoor Water Use - The greatest long-term reliable savings for indoor water use will come from installing water-efficient fixtures in new construction and replacing conventional fixtures in existing construction. For the average homeowner, this could lead to a reduction in water use of 35% or more. In addition to designing programs for the residential sector, efficiency efforts should include hotels, motels, schools, civic buildings, and businesses. Significant savings are also available in the industrial sector through the recycling of water and redesign of certain systems.

Just as a utility's leak detection and repair program should focus on fixing the largest leaks first, efficiency programs aimed at the customer side of the meter will have the greatest effect when focused on those customers that have the highest potential to save. At RMI we are calling this precision guided efficiency. Efficiency programs should target retrofit programs towards customers who have a high number of users per fixture and/or the most inefficient fixtures. For example, retrofitting toilets in crowded public housing units will save substantially larger quantities of water than retrofitting the same number of toilets in a high-income neighborhood. Similarly, retrofitting bathrooms in any institution or public facility would yield similar results. Precision guided efficiency programs also consider the marginal cost of water delivery in a utility s service area and on peak demand. Thus, to maximize the savings to the utility, efficiency programs should concentrate on areas where delivery costs are the highest and times when use is the largest.

Below are two examples of successful targeted programs:

- In Calvert County, Maryland, the Water Conservation Office retrofitted a senior citizens center with 1.6 gallon-per-flush toilets in order to free up sewer capacity to build 50 more apartments. Before the retrofit, the center was using 5,045 gallons per day. One year after the retrofit, it was down to 2,137 gallons per day. The cost of the program was $16,000. It would otherwise have cost $135,000 to secure the water and sewer rights to build the 50 apartments.[8]

- At Edinboro University in Pennsylvania, a campus-wide program retrofitted dormitories with low-flow showerheads, faucet aerators, and other retrofit devices. The savings achieved were approximately 11 million gallons of water per year, roughly 20% of the previous use. Utility costs -- water, sewer, and energy -- were reduced by $52,000 per year, at a total cost for the efficiency program, including labor, of $11,000.[9]

After analyzing dozens of efficiency programs around the country, RMI has calculated that the cost of saved water from a residential showerhead and faucet aerator retrofit program will range from $43 to $120 per acre-foot saved.[10] For a toilet retrofit program the cost of saved water will be between $200 and $250 per acre-foot saved. These figures are dwarfed by the cost of new supplies of water and, in many cases, the current cost of water supplies. The Two Forks dam that was proposed several years ago, for example, would have supplied water at a cost of over $700 per acre-foot.[11] The average retail price for residential customers in the United States is over $500 per acre-foot. High tech water supply alternatives, such as desalination plants, supply water at a cost of $2,000 per acre-foot or more.

Outdoor Water Use - The savings potential from improved efficiency in outdoor water use will vary greatly from one region to the next. The largest outdoor savings result from installing water-efficient landscaping in new construction, or changing existing landscaping to less water-demanding landscaping. As with indoor water use, a precision guided approach will lead to the most cost effective savings. Thus, utilities will do well by focusing on the largest outdoor water users. Brown and Caldwell performed outdoor water use audits for 29 companies in San Jose, California and found that total irrigation water could be reduced 32 to 74%, with no decrease in the appearance of the landscape or health of the plants.[12]

New Developments

Water reclamation and reuse have also led to significant increases in overall water efficiency in some areas. Because of the diminishing quality of high-quality water in the area, the city of St. Petersburg has developed a dual distribution system to use reclaimed water for domestic (non-potable) needs. An average of 18-20 mgd of reclaimed water is used primarily for irrigation with a few (> 3) million gallons per day used to provide cooling within the system. About 1/3 of the water needed by the city (62 mgd) is supplied by reclaimed water. The development of this system should eliminate the need for exploration for new water sources and expansion of water facilities until 2030 - 2050.[13]

Beyond the widely-used water saving devices, several other technologies should not be over looked, including rainwater collection systems and graywater systems, which can also reduce outdoor water use. Graywater systems divert shower, sink, and other wash water from the sewer for use in toilets and for landscaping. Such technologies are generally more expensive initially and also require more maintenance than conventional systems, but may provide long term savings. The State of California has passed legislation allowing the use of graywater for subsurface irrigation. Rainwater collection systems and cisterns, which were once commonplace in the United States, can supply water for cleaning, toilet flushing, landscaping, gardening, and in some cases, potable uses.[14]

Implementing Efficiency Programs

Techniques for implementing efficiency measures range from basic methods such as ordinances, standards, giveaways, rebates, loans, surcharges, hookup fees, and public education to the more advanced techniques such as limited-use contracts, transferable savings, competitive bidding, water and energy utility partnerships, and water service companies. Many of these techniques are particularly effective when applied to new construction or remodeling projects. Most successful water efficiency programs incorporate many of these techniques in an integrated and targeted manner to maximize their effectiveness.

Ordinances and Standards - An essential part of any successful efficiency program is the setting of standards for the "best available technologies." Ordinances and standards should require these technologies in all new construction and renovations. The new Federal standards for water-efficient fixtures include toilets using 1.6 or gallons per flush or less, urinals using 1.0 gallons per flush or less, showerheads with flows of 2.5 gallons per minute or less, kitchen faucets with flows of 2.5 gallons per minute or less, and bathroom faucets with flows of 2.0 gallons per minute or less. Some officials on the Federal level would like to see the standard for showerheads lowered to 1.5 gallons-per-minute. We believe that this would be a mistake at this time, however, since some of the models available delivery inferior showers and lower customer satisfaction could lead to lower implementation rates. Nevertheless, standards should be written to encourage technical innovation and alternative technologies that "beat the standards," such as effective 0.8 gallon-per-flush toilets, 1.5 gallon-per-minute showerheads, composting toilets, and graywater systems.

Hookup Fees for New Construction - In North Marin County, California, townhouse or condominium builders who limit their per-unit turf area to 400 square feet or 20% of the total landscaped area, whichever is less, will receive a $190 discount on the per-unit hookup fee. Turf areas of 200 square feet or less will earn the builder of an apartment a hookup fee discount of $95. These voluntary turf limits amounted to a 40% reduction in the turf area previously seen in the area for this type of new construction, corresponding roughly to a 16% reduction in water use for townhouse units and about 8% for apartments. In the second and third years of the program, more than 95% of the new apartments, townhouses, and condominiums built in the area qualified for the credits.[15]

Giveaways and Rebates - Many communities have had considerable success with giveaway programs involving high-efficiency showerheads and faucets. In addition, a growing number of communities are using ultra-low-flush toilet rebate programs, ranging from $50 to $100 per toilet installed, including Goleta and Santa Monica, California, Glendale and Tucson, Arizona, and Denver, Colorado.

Education, Information, and Promotion - While education programs targeted towards individual customers are certainly useful, education can also be valuable for equipment distributors, design professionals, builders, landscape professionals, and plumbers who may be unfamiliar with water-efficient products and techniques. In many areas it is important to have educational materials available in English and Spanish.

Advanced Methods - Several innovative techniques are available for saving water, many of which have long been used to reduce energy demand. These techniques include transferable savings, competitive bidding, limited-use contracts, water and energy utility partnerships, and the use of water service companies. Transferable savings schemes usually require new users to secure their own water supply by saving as much or more than they will require from the existing demand base thus eliminating for the utility the burden of securing new supplies. Under competitive bidding, utilities set a savings goal and allow outside entities to bid against one another to meet the goals with whatever cost-effective methods they may devise. Limited-use contracts can be effective in both reducing overall demand and in reducing peak demand. Water and energy utility partnerships help distribute the costs and benefits of retrofit programs among several interested parties. Finally, water service companies are now installing water-efficient technologies and fixing leaks for their customers in exchange for a share of the cost savings.

Conclusion

With forward-thinking leadership on the national level, even before the last election, a greater emphasis has been placed on the efficient use of resources. The most significant contributions to the field of efficiency, however, have not come from the top, but rather from hundreds of communities that are making sound economic decisions by investing in relatively low-cost efficiency programs instead of expensive new supply projects.

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IMPLEMENTING IRRIGATION EFFICIENCY: THE ENERGY SAVINGS INCENTIVE

Richard Pinkham
Rocky Mountain Institute
Water and Agriculture Programs[1]

Introduction

Efficient use of water in irrigation is increasingly important throughout the western United States. Desired crop yields can be obtained using less water, and saved water can be applied to additional fields, sold to other users, or devoted to environmental needs and enhancement. Irrigation efficiency may reduce groundwater overdraft, helping perpetuate the agricultural future of some regions. Reduced water applications can also reduce leaching of salts and agricultural chemicals, thereby maintaining or enhancing surface and groundwater quality.

These benefits of efficient irrigation are well-known. So too are the many technologies and practices that can increase on-farm water efficiency. As with any good idea, the critical question in irrigation efficiency is how to implement it. How can farmers be motivated to change equipment and management techniques?

Wherever water is pumped, rather than moved by gravity, cutting the cost of energy use can be an important motivation for implementing water-efficient irrigation technologies and practices. Even where water itself has a zero or low price, irrigation efficiency may provide economic payoffs by reducing the pumping costs to move water to farms, to distribute water to fields, and to pressurize water application systems. These energy savings can be significant for individual farmers and for water providers. They have also become important to energy utilities, many of which, as this paper will show, are developing innovative programs to work with farmers and water districts.

Energy Efficiency and Water Efficiency - the Connection

Reducing the amount of energy used to move a given quantity of water by properly sizing pumps and mainlines, using the most efficient pumps available, and maintaining them well is often recognized as important to improving farmers' bottom lines and energy utilities' supply positions. Pumping energy can also be saved by reducing the amount of water used in irrigation the less water pumped, the more energy saved. Thus, energy efficiency in irrigation is not just a matter of improving pumping plant efficiency; it can often be linked to water efficiency.

[1]The author thanks Colin Laird, previously of RMI, for initial research and preparation of the PG&E and BPA case studies, first published in "Feedback and Irrigation Efficiency," Water Efficiency Implementation Report #4, Rocky Mountain Institute, 1739 Snowmass Creek Road, Snowmass CO 81654, (303)927-3851.

A variety of energy savings incentives and implementation techniques are available to encourage adoption of water-efficient irrigation. Opportunities are available to individual irrigators, water providers, and energy utilities:

- Individual irrigators can change water management practices or invest in new technologies on their own initiative or with agency assistance - in order to reduce their energy bills. Savvy farmers are taking such steps already.

- Irrigation water suppliers with an interest in stretching supplies, protecting water rights, or cutting costs can motivate farmers to implement new techniques and technologies by pointing out the energy cost savings farmers will obtain. The suppliers can disseminate information on efficient irrigation, provide on-farm technical assistance, and provide a variety of financial incentives to farmers.

- Energy utilities pursuing demand-side management strategies can obtain "new energy supplies" by reducing energy use in irrigation systems. Innovative energy utilities are implementing water efficiency programs for agricultural customers and forging partnerships with irrigation water suppliers to pool finances and management skills, resulting in significant savings in water, energy, and money.

Some Innovative Programs

Because of their direct interest in energy conservation, energy utilities are the most obvious candidates for developing programs that result in water savings through concern for energy efficiency. Often energy utilities will collaborate with water providers and agricultural organizations in order to most effectively reach farmers.

In Colorado, a cooperative effort of the Western Area Power Administration, the Colorado State Soil Conservation Board, the Colorado Office of Energy Conservation, and the U.S. Soil Conservation Service supports three pump testing and irrigation efficiency teams. In addition to pump efficiency tests, these teams help farmers with soil moisture monitoring, conservation tillage, conversion to LEPA systems, and other measures that can save both water and energy.

Energy utilities in other regions are establishing programs that seek to save energy by increasing irrigation water efficiency. Irrigation water providers, agricultural officials, and resource analysts in Colorado and elsewhere can benefit from the experiences of energy utilities active in irrigation water management. Rocky Mountain Institute's survey of innovative programs is now in progress. Two of the most interesting programs found so far are those run by Pacific Gas & Electric and Bonneville Power Administration.

Pacific Gas & Electric (PG&E) - San Francisco, California[2]--To help reduce energy use, PG&E has in place a rebate program of up to $100,000 per account per year for its commercial, industrial, and agricultural energy users. Although energy savings are the focus of the program, PG&E recognizes the relationship between water and energy use in irrigated agriculture, and is rewarding the use of energy-efficient practices and technologies that also save water. Thus, in addition to rebates for retrofitting or adjusting their pumps (rebate based on horsepower and annual energy use), and for low-pressure sprinkler nozzles (506/nozzle), farmers can receive rebates for water-saving equipment such as time clocks with battery or springwound back-up ($50/time clock), and for surge valves ($450). Besides these standardized rebates, PG&E also has a customized rebate program for especially large systems, or those with special savings opportunities.

In recent years, the popularity of the program has increased partly because of California's drought and reduced allocations from state and federal water projects. Aside from the drought, one of the keys to the success of this program has been the enthusiasm of the PG&E representatives, who have established long-standing relationships with area farmers.

PG&E also has a pump testing program and an irrigation system survey program. In this latter program, PG&E representatives analyze a farmer's irrigation system water and energy use and make recommendations on reducing water applications through better irrigation scheduling and changes in equipment.

Currently, PG&E is exploring possible partnerships with several water and energy agencies interested in sharing the costs of providing water and energy efficiency programs in agriculture.

Bonneville Power Administration - Walla Walla, Washington[3]--WaterWise is a program developed by the Bonneville Power Administration (BPA) to provide farmers with incentives to adopt energy-efficient and water-efficient irrigation practices and technologies. Bonneville has developed the program over the last decade to save energy by assisting local energy utilities in Washington, Oregon, Montana, Idaho, Wyoming, Utah, Nevada, and California with programs to reach irrigators of all sizes.

The WaterWise program includes pump testing, system evaluations, hardware retrofits, water management, on-farm computer support to quantify water and energy savings, and a low-tech management project. It also makes use of the Bureau of Reclamation's computerized weather information system, AgriMet. Bonneville supports technical assistance programs for participating utilities run through state offices in Idaho, Oregon, Washington, and Montana.

Beginning in 1991, Bonneville and the Northwest Irrigation Utilities sponsored an irrigation management pilot program of the Central Electric Co-op in Redmond, Oregon.[4] The aim was to quantify potential energy and water savings, reach small and medium-sized irrigators in the area, and test the voluntary adoption of conservation measures after an educational visit. Bonneville was interested in the pilot program because it required minimum investment and offered the potential of substantial savings.

The pilot project took a simple, low-tech, hands-on, technical assistance approach to the farmers. It offered basic water management assistance by teaching area farmers soil moisture monitoring and other conservation techniques. A follow-up survey showed that most of the suggested efficiency improvements were voluntarily implemented by farmers after the initial visit. Results from the first two years of the project indicate savings in energy and water of 10-20% easily achievable, and 30-40% in some instances.

The "low-tech" approach succeeded because of its simplicity and the skill of the field representative, a retired county extension agent, who had an established reputation in the area. Local farmers trusted his criticisms and the improvements he suggested for their irrigation practices. The Co-op believes this kind of local connection is so valuable that, as it expands its program, it wants to train locals rather than import experts to help farmers become more efficient. BPA is now working to make available a similar program to all utilities participating in the WaterWise program.ConclusionEnergy utilities pursuing demand-side management strategies have an important stake in reducing the amount of water farmers pump to irrigate crops. A number of energy utilities throughout the West are putting in place programs to assist farmers in irrigating more efficiently, and are often working cooperatively with water providers and agricultural organizations. The lessons learned from these programs can help energy utilities and water providers improve existing water efficiency implementation programs and put new ones in place. A Rocky Mountain Institute publication presenting case studies of the most innovative and successful programs will be available by late spring of 1993.

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[2]Mark Backus, Pacific Gas & Electric, 123 Mission St., Rm. 2459, San Francisco CA 94106, (415) 973-2461.

[3]Thomas R. Osborn, Bonneville Power Administration, 101 Poplar, Walla Walla WA 99362, (509) 522-6262.

[4]Vern Rice, Energy Specialist, Central Electric Co-op, Box 846, 2098 N. Hwy. 97, Redmond OR 97756-0187, (503) 548-2144. Walt Trimmer, Irrigation Specialist, Northwest Irrigation Utilities, 2830 N.W. Kings Blvd., Suite 102, Corvallis OR 97330, (503) 754-2819.

SOUTH PLATTE RIVER BASIN WATER-SUPPLY AND WATER-QUALITY STUDIES

ANALYSIS OF NUTRIENT, SEDIMENT, AND PESTICIDE DATA FROM THE SOUTH PLATTE RIVER BASIN, WATER YEARS 1980-92

Kevin F. Dennehy
U.S. Geological Survey
Lakewood, Colorado 80225

The South Platte River basin was one of the first 20 study units selected in 1991 for investigation under the U.S. Geological Survey's National Water-Quality Assessment (NAWQA) program. One of the first major components of the South Platte study was a compilation, screening and interpretation of available nutrient, sediment, and pesticide data from surface- and ground-water stations in the basin. The retrospective analyses of existing water-quality data will provide an historical perspective on the water quality in the South Platte River basin, strengths and weaknesses of available information, and implications for water-quality issues, study priorities, and study design.

The South Platte River basin drains about 24,300 square miles in parts of three States, Colorado (79 percent), Nebraska (15 percent), and Wyoming (6 percent). The majority of the basin population (approximately 2 million) is concentrated along the Front Range urban corridor in Colorado. The South Platte River originates in the Rocky mountains of central Colorado and flows about 450 miles northeast across the Great Plains where it joins the North Platte River at North Platte, Nebraska. Average annual precipitation varies greatly between the mountains and the plains. In the mountains, precipitation ranges from 7 to 60 inches, while in the plains average annual precipitation ranges from about 12 to 16 inches. The South Platte River flows from its headwaters along the Continental Divide through urban areas and onto the agricultural areas in the plains. The river is highly regulated along its entire length. Large quantities of water are diverted to ditches and reservoirs. Flows in the river, especially during fall and winter (low flow), are maintained by ground-water return flows from agricultural lands while during spring and summer (high flow) flows are dominated by snowmelt runoff and irrigation.

Three aquifer systems were examined in this study: South Platte alluvial system, High Plains aquifer, and the Denver Basin aquifer system (Dawson, Denver, Arapahoe, and Laramie-Fox Hills).

Most of the data analyzed were collected by the U.S. Geological Survey and the U.S. Environmental Protection Agency. Additional surface-water data were collected by the Denver Regional Council of Governments (DRCOG) and the Metropolitan Waste Water Reclamation District (MWWRD). Supplemental ground-water data were included in the analysis from the North Front Range Water Quality Planning Association (NFRPA). After initial compilation of data from many sites, available data from 63 surface-water sampling sites and 110 wells were determined suitable for the intended purposes. The quantity of data available for these sites varied among the groups of constituents and media examined. For example, in surface water, more than 2,500 samples were analyzed for nutrients, 457 samples were analyzed for suspended sediment and 559 samples were analyzed for pesticides. With respect to ground-water, 410 samples were analyzed for nutrients and 20 samples were analyzed for pesticides. All the available data that were used were in machine-readable format.

The nutrients examined included: total nitrogen, dissolved organic nitrogen plus ammonia, dissolved nitrite, dissolved nitrite plus nitrate, total phosphorus, dissolved phosphorus, and dissolved orthophosphate. Sediment constituents examined were total suspended-sediment concentration and total suspended particle size. Pesticides examined include the following compound classes: organochlorine, organophosphorus, triazine and other nitrogen-containing compounds, carbamates, and chlorophenoxy acid compounds.

The median concentration of dissolved nitrite plus nitrate, as nitrogen, in surface water ranged from less than 0.01 to 4.8 mg/L and the median concentration of total phosphorus ranged from 0.01 to 2.55 mg/L. Point sources in urban areas, particularly waste water treatment plants (WWTP), showed an increase in nitrogen and phosphorus concentrations downstream of their discharges. There were no measurable increases in nitrogen and phosphorus species in agricultural areas in the lower part of the basin. Major tributaries showed similar increases in nitrogen and phosphorus through Front Range urban areas (WWTP discharges) to their confluence with the South Platte river. Most nutrient concentrations exhibited no temporal trends; however, flow-adjusted concentrations of organic nitrogen plus ammonia and dissolved phosphorus increased slightly over time downstream from Littleton, Colorado and Loveland, Colorado, respectively. Furthermore, concentrations of dissolved nitrite plus nitrate, dissolved ammonia, and dissolved phosphorus in agricultural and mixed agricultural/urban land use areas were significantly higher during low-flow season (fall-winter) than at other times in the year. These higher concentrations probably reflect the input of ground-water return flows that were not diluted with high surface-water flows during this period of the year.

Estimated annual nutrient loads were calculated for selected sites in the basin. Generally, organic nitrogen composed most of the nitrogen load at urban sites whereas nitrate composed most of the load at agricultural sites. Data were insufficient to calculate loads for many parts of the basin and also were difficult to interpret because of the complex water management practices. Surface water discharge, concentrations of dissolved nitrite plus nitrate and dissolved phosphorus decreased along the South Platte River from Kersey, Colorado to North Platte, Nebraska.

Nutrient concentrations in ground-water samples varied by aquifer, land use, and well type. No seasonal trend was observed. Concentrations of dissolved nitrite plus nitrate and dissolved ammonia were highest in the South Platte alluvial aquifer where the majority of the total ground-water samples were collected. The median concentration of dissolved organic nitrogen plus ammonia, dissolved nitrite, and dissolved nitrite plus nitrate in the alluvial aquifer were much higher than for any of the other aquifers. Organic nitrogen plus ammonia concentrations were highest in irrigation wells. Observation wells completed in the alluvial aquifer in rangeland areas had more than twice the median nitrite plus nitrate concentration than similar wells in agricultural land use areas. Only concentrations of nitrite plus nitrate indicated a trend with depth in the South Platte alluvial aquifer; concentrations decreased with increasing depth.

Overall, there is a lack of sediment data within the basin. Only four sediment sample sites were available along the South Platte River for analysis, but at least those sites were fairly well distributed areally. Tributaries to the South Platte River had little or no spatial coverage. The temporal distribution of sediment data was highly variable, with some sites sampled intensively for short periods, whereas other sites were sampled irregularly. Only the four main stem sites had an adequate distribution of samples by deciles of flow. Suspended sediment was not sampled frequently enough to enable analysis of loads, concentration trends, or particle-size trends. Three out of the four main stem sites are located in the agricultural land use areas, therefore more samples were collected in that land use area than in any other. Generally, suspended sediment concentrations increased from the foothills of the Rocky Mountains to the confluence with the North Platte River in Nebraska. However, at a number of sites along the South Platte

River, the flow is diverted to reservoirs and ditches. This reduces the flow in the river, enabling large quantities of sediment to be deposited at these sites. It is clear that diversions affect or control much of the streamflow and sediment transport along the river. Suspended sediment concentrations in the South Platte basin were much higher in agricultural areas than National Water Summary averages and much lower for rangeland areas. Suspended-sediment concentrations varied by month; most were transported by snowmelt runoff.

Pesticide data were available from 30 surface-water sites in the basin between 1980-92. However, approximately half of those sites are limited to 4 specific locations in the basin. Pesticide data for surface-water sites in the basin are limited by the number of analyses per station, the distribution of analyses by compound class and land use, the distribution of analyses throughout the year, the distribution of analyses by decile of flow, and the number of analyses for the most heavily applied pesticides. Pesticide data in ground-water are available from 20 wells in the basin, none of which had more than one analysis. The areal distribution of wells is poor; most samples were collected from observation wells screened in the alluvium that underlies agricultural areas.

Most of the pesticide concentrations were less than laboratory reported detection limits. Generally, percent detections was highest for range and agricultural areas, somewhat lower for urban land use areas, and zero percent for forest land-use areas. Concentrations of 2,4-D decreased as discharge increased at those wells with sufficient concentration and flow data to examine this relation. Concentrations of CDPA, triazines, and other nitrogen-containing compounds were detected in ground-water; all detectable concentrations for atrazine and its metabolites were from wells in agricultural land-use areas.

STREAM STANDARDS AND IMPROVEMENTS STUDIES

Todd L. Harris
Department of Laboratory Services
Metro Wastewater Reclamation District
Denver, Colorado

Metro Wastewater Reclamation District (Metro) is facing a series of difficult decisions concerning wastewater treatment options needed to meet existing stream standards for Segment 15 of the South Platte River. Presently, dissolved oxygen (D.O.) concentrations below stream standards occur at night during late summer, low flow conditions. Based on results from a water quality model (Segment 15 Water Quality Model) for the segment, increased expenditures for facility improvements (concrete, steel and increased overhead, and maintenance) in the form of additional Nitrification/Denitrification facilities for the complex will not alleviate the problems of dissolved oxygen levels below standards. Metro, therefore, has committed over $1,500,000 to complete stream standards and improvement studies along Segment 15 of the South Platte River. These studies include investigating the possibility of site specific stream standards and possible D.O. enhancing channel improvements. The District is conducting laboratory and field studies to monitor the influence of its discharge on the South Platte River, and to gather sufficient in^_formation so that decisions can be made on how to achieve required levels of water quality, meet appropriate standards, and protect the valuable resources of the South Platte basin most effectively.

These studies are not exclusively an engineering evaluation on how to best treat wastewater. They are a combination of biological, engineering, chemical, geological, modeling, and mapping studies which look at non-traditional means of solving Metro's problems. These studies explore the surface water resources, ground water resources, and terrestrial resources.

Studies of Surface Water

During the low flow summer months, almost the entire flow of the South Platte up^_stream of Metro's discharge is diverted for agricultural use. Most of the surface water in the South Platte immediately below Metro consists of discharge from the Central Facility. The quality and quantity of these waters are greatly influenced by Metro's discharge. Evaluation of this surface water resource has included studies on rearation rates, diffusion rates, community metabolism, sediment oxygen demand, time of travel, phased water quality monitoring, diel dissolved oxygen variation, flow rates, and toxicity testing.

Reaeration rate studies using argon and krypton gases and a rhodamine dye tracer were done. The studies demonstrated that the ability of the river to rearate itself is severely hampered by slack water conditions behind structures built for irrigation withdrawal and utility protection. The drop structures themselves, significantly increase oxygen in the surface water. The amount of rearation due to flow over these structures is now known. These measurements will be utilized to determine if indeed, with similar channel modifications, the South Platte can rearate itself.

Diffusion rate studies have demonstrated oxygen diffusion across the surface of a High Plains River is not easily measured. Diffusion techniques must be modified to take into account not only the rapidly moving water in the channel, but also, the quiescent shallows and secondary reaches. Diffusion was best measured by krypton gas loss over the various segments rather than by the conventional floating dome method.

Measurements of community metabolism demonstrated that dissolved oxygen levels in the South Platte during low flow and moderate water temperatures are driven by a hydroponic plant and bacteria community. This community is capable of super-saturating the water during the daylight hours and demanding most of the oxygen through respiration at night. These results were verified by diel dissolved oxygen studies which show that the dissolved oxygen levels of the South Platte rise and fall with the sun.

Flow rates studies utilizing dye tracers demonstrated that the flow of the South Platte River is directly proportional to Metro's discharge. Metro's influence is seen as far as twenty five miles downstream although the flow regime is no longer dominated by the discharge, but by groundwater, tributaries, and irrigation re^_turn flow.

Toxicity testing (WET testing) of the effluent has demonstrated that the effluent itself is not toxic to the sensitive Ceriodaphnia dubia or the fathead minnow. Chemical parameters measured with time of travel studies demonstrate that ultimate CBOD, NH3, and Organic N all decline downstream from Metro, and that nitrate levels show a marked increase.

Studies of Fishery Resources

Data also have been collected on the fisheries resources of the South Platte River. D.O. criteria are based primarily on fish response and sensitivity. If it can be demonstrated the fish will not be impacted by the D.O. levels currently present in Segment 15, a lower site specific D.O. standard may be justified. The distribution and abundance of twenty-three species of fish occurring in this segment have been charted. Fish habitat has been measured and mapped from Metro to Fort Lupton. Habitat Suitability Indices have been determined for 11 species, commonly occurring in this reach. These Habitat Suitability Indices demonstrate that there is poor habitat present for most warm water game fish species and that the river (regardless of Metro's discharges) is best suited for species such as Cyprinus carpio (carp) and Catostomus commersoni (white suckers).

Fish studies demonstrated that the greatest numbers and kinds of fish inhabit the pools (which also had the lowest D.O. measured). The abundance of fish present was not adversely affected by Metro's discharge as the greatest number and most species were collected in the pools closest to the plant.

In conjunction with field studies of fish distribution, abundance, and habitat, studies are being conducted at the University of Wyoming's Red Buttes Laboratory. These studies will determine at what D.O. levels chronic or toxic effects might occur to fish species which presently live or may have historically lived in Segment 15. In these studies, dissolved oxygen is being regulated to simulate a diel variation. Seven species of fish are being tested at oxygen levels that mimic or go below those levels found under the most extreme conditions in the river. Acute and chronic studies are being conducted on adult and larval life stages. Studies conducted to date have not demonstrated any acute toxicity.

Studies of Groundwater Quality and Quantity

Because the river changes as it flows, the effects of both the quality and quantity of groundwater seepage into Segment 15 were studied. These studies demonstrated that Segment 15 of the South Platte River is a gaining stream and the rate of groundwater recharge is correlated to Metro's discharge. Water quality measurements demonstrated the groundwater recharge to the river was nearly devoid of oxygen and contributed to an oxygen deficit. Downstream groundwaters were also shown to be higher in nitrates than surface waters.

As an interesting sidelight, these studies revealed there was a very active hyporheic zone beneath the channel of the South Platte. There was active movement of water in and out of this hyporheic zone. As oxygen rich waters were filtered through this zone they were stripped of oxygen. Qualitative studies are currently underway to determine if the mechanism of oxygen depletion within this zone is carbonaceous or nitrogenous oxygen demand.

Studies of Terrestrial Flora and Fauna

Because Metro's decisions have basin-wide implications, the terrestrial flora and fauna are also being studied through wetlands evaluations, endangered species surveys, and evaluation of migratory waterfowl and other birds of federal importance. One alternative currently under investigation to improve water quality to meet D.O. standards involves adding low drop structures and removing high diversion dams in order to increase the rearation of the river. Before these alternatives can be assessed, the value of the present river corridor must be known. Wetland habitats have been measured and mapped from Metro to the Fulton ditch headgate structure (4.6 miles). These wetlands were delineated in anticipation of need of a 404 Permit from the Army Corps of Engineers which would be required before any construction activities are proposed on the river. If modifications of the river channel must occur in order to meet stream standards, then the value of and effect of such modifications on the river corridor must be known.

Potential alternatives to improve river water quality which involve stream modifications and construction activities, also require that endangered species as well as endangered species habitat be surveyed. A small flowering plant of the orchid family, Spiranthes diluvialis (a ladies' tress), may occur in the riparian reaches of the South Platte below Metro. A survey for this plant will be made during late July and August to determine if it is present. If it is present, the effect of various construction alternatives on populations would need to be assessed.

Studies also have been completed on waterfowl use of the South Platte River below Metro. Over 12,000 ducks of 14 species have been counted in the 4.6 miles of river below Metro's outfall. Some of the fourteen species enumerated comprise the largest overwintering populations on the Central Flyway this far north. The value of this resource, as well as its contribution to the "urban environment", must be considered when determining the best alternatives which will meet D.O. standards. A bicycle path follows the South Platte from near Chatfield Reservoir to more than five miles north of Metro. Large numbers of bird watchers utilize this path to observe the overwintering populations of migratory waterfowl. Questions on how valuable these birds are in comparison to the fish of the South Platte must be answered based on the results of these surveys. Another aspect being evaluated is the effect of this many ducks on the water quality and nutrient load of the river.

Other studies are being carried out by Metro to establish design criteria and evaluate physical alternatives (river channel modifications) which would enable Metro to achieve stream standards. Most of the data from the studies described in this paper are being incorporated into the Segment 15 Water Quality Model which will be used to evaluate all design alternatives. Once the data are collected and model simulations for the different alternatives have been obtained, the alternatives will be rated. Each alternative will be evaluated on whether the river meets stream standards throughout the segment. In addition, such factors as implementability, reliability, environmental compatibility, cost, and public support will be used to determine the most feasible/effective alternative.

The results of these studies demonstrate the exceedingly complex biological, chemical, physical and sociological interactions that take place in dealing with the South Platte. The results emphasize the multitude of variables that must be examined in order to provide the data to best make decisions that will protect and enhance the South Platte River's valuable resources in the most effective manner.

STRATEGIES FOR WATER SUPPLY MANAGEMENT FOR USERS IN THE SOUTH PLATTE RIVER BASIN

Evan Ela
Thornton Water Resources Department

Water users in the South Platte River basin have found benefit in developing new strategies for the management of their water supplies. The new strategies have resulted from certain observed trends in the physical and legal hydrologic systems. A primary trend observed in the physical system is increasing urbanization resulting, in some cases, in higher flood peaks of lower quality water, a longer season of subsurface return flow, greater augmentation of depletions, a reduced senior demand and increased importation of water supplies. Legal trends have been toward stricter decree conditions and have resulted in innovative approaches to efficient use such as exchange, reuse, conservation and groundwater recharge.

Several strategies have been developed by municipal and industrial suppliers in the northern Denver metro area to cope with these hydrologic trends. For example, off-stream storage reservoirs which utilize abandoned gravel pits have become common. Appropriative rights of exchange and junior water rights have been obtained by numerous entities, establishing a secondary priority system that manages competition for exchange opportunities and temporary flood peaks. Several contractual operating agreements provide for innovative ways to manage supply quality and quantity. The possibilities for additional agreements are almost limitless. And finally, a special type of operating agreement known as an interruptable irrigation supply is being considered where it can be easily implemented within the constraints of existing water law. In sum, the most promising new strategies feature cooperation among formerly competitive water users and a more efficient management of water resources within the river basin.

CITY OF GREELEY: WATER SUPPLY PLANNING AND MANAGEMENT FOR DROUGHTS

Jerry Kenny
Managing Engineer
Boyle Engineering Corporation
Lakewood, Colorado

David Frick
Vice President of Engineering
Resource Consultants and Engineers
Fort Collins, Colorado

Sam Bryson
Senior Water Resource Engineer
Resource Consultants and Engineers
Fort Collins, Colorado

Nancy Munns
Water Resource Manager
City of Greeley
Greeley, Colorado

Abstract

Reliability is a key requirement for all municipal water systems. In the arid west, droughts are a recurring phenomenon that can have devastating effects on communities if adequate preparations have not been made. Greeley, Colorado was interested in testing the reliability of its system by investigating the yield of existing water rights and water supply facilities under severe drought conditions. Located in northeastern Colorado, Greeley draws its water supply from three different river basins: the Cache la Poudre River, the Big Thompson River, and the Colorado River through the Colorado-Big Thompson and Windy Gap Projects. While these sources were considered to be adequate to supply the city's water needs, a study was needed to evaluate the potential yields from all available sources during a severe drought and confirm their adequacy. To accomplish this goal, a joint stochastic analysis of the three basins was performed to develop design droughts, and a model of the supply system was developed to assess the performance of the water supply system under the design drought conditions. The stochastic analysis generated 10,000 years of streamflow data for each basin, from which drought sequences representing 20-, 50-, and a 100-year droughts were selected. A MODSIM network model of the Cache la Poudre and Big Thompson basins was developed to evaluate the potential yield available to the city during the selected drought sequences under a range of operational alternatives. The model has been transferred to the City of Greeley and will be a useful tool in future water supply planning.

NON-POINT SOURCE POLLUTION MONITORING AND REMEDIATION

EVALUATION OF HEAVY METAL RETENTION BY A WETLAND: SUGARLOAF GULCH, LAKE COUNTY, COLORADO

Chris Rowe
Department of Earth Resources
Colorado State University
Fort Collins, Colorado

Since the 1860's mining of sulfide-ore deposits near Leadville, Colorado, has yielded profitable quantities of gold, silver, copper, lead, zinc, iron, and bismuth (Tweto, 1968). Metals are released from mines and mine tailings when exposed to oxygen and water. Also formed in the reaction is hydrogen ions, thus lowering the pH, which in turn helps to release more metals. The solubility of many metals in aqueous systems depends on their redox potential and pH of the solution (Hemond and Benoit, 1988). Water flowing from abandoned mines and tailings creates low pH and metals in solution known as acid mine drainage (AMD).

In the past, mining and mineral processing operations were conducted without adequate concern for human health and Earth's resources (Perry and Klienmann, 1991). This lack of environmental controls caused the a significant contribution of dissolved cadmium, cooper, iron, manganese, and zinc into the Arkansas River (Moran and Wentz, 1974). The water quality impacts from this AMD can be especially devastating (Cohen and Gorman 1991). AMD impacts on aquatic life are the most serious of all nonpoint source impacts in Colorado (Parsons, 1989). Presently, there is extensive research regarding passive mine drainage treatment systems (PMDTS) for AMD (Hammer, 1989, Guertin et. al., 1985, Weider et. al., 1990). An area that has received considerable interest for PMDTS is wetlands, both natural and constructed (Walton-Day, 1990, Chalfont, 1992).

Wetlands are usually considered to act as sinks for metals (Giblin 1985). However saturation of the sorption and biological uptake sites in wetlands by metals may occur, causing the wetland to be ineffective (Weider, 1990). One experimental constructed wetland reached saturation with respect to iron within 39 days, with the inflow and outflow iron concentrations being equal (Wieder et al, 1990). This suggests that wetlands impacted by AMD act as a sink for metals for only a limited amount of time. Results vary widely on the effectiveness of metal retention by wetlands. Values ranging from 0% of lead passing through to 100% of zinc have been reported (Giblin, 1985). Many factors such as percent organic matter, microbial activity, and hydraulic retention time appear to be at work. Results vary in the degree of retention of metals from AMD impacted wetlands (Guertin et. al., 1985).

One way in which metals are removed may be sorption directly onto sediments (Weider et. al., 1990). Most metals are sorbed more effectively by organic matter than by mineral soils (Vestergaard, 1979). Since wetland soils are usually rich in organic matter, they may be well suited to remove metals from AMD (Hemond and Benoit, 1988). Few data are available regarding metals accumulation in the organic substrate of wetlands (Weider et al., 1990).

A hypothesis is that wetlands may lessen the effects of acid deposition by reducing nitrate and sulfate, resulting in net alkalinity production in the wetland (Hemond and Benoit, 1988). Reducing environments that would lead to alkalinity production exist in the anoxic environment of most wetlands. The resulting increase in pH will also help in the sorption of metals to organic matter (Hemond and Benoit 1988).

Lake County, Colorado has an extensive AMD problem. With wetlands possibly acting to remediate the AMD, it is logical to study them further. This study was developed to assess metal retention in an AMD impacted wetland in Lake County, Colorado. This study will also determine the possible mechanisms involved.

Acidic metal laden water flows into a wetland in Sugarloaf Gulch from two abandoned mine adits. All the waste rock is in three tailing piles which sit within the wetland. Adit discharges, precipitation, and ground water percolate through the tailings then enter the wetland. One small channel begins below the main tailing pile and runs into Lake Fork. Water flows at or near the ground surface throughout the wetland. The surrounding geology is granitic with porphyritic intrusions. The wetland substrate is gravel outwash several meters thick overlain by approximately half a meter of gleyed clay with approximately ten centimeters of peat at the surface. The slope varies between one and five degrees. *Carex* is the dominant vegetation with some willow and *juncus* present.

Thirty surface and subsurface sample sites were established throughout the wetland. Water samples were collected from July 1992 through October 1992. Related physical parameters that were measured included discharge, hydraulic conductivity, electrical conductivity, pH, and temperature. An unimpacted wetland was sampled just west of the study site to establish base line conditions. All samples were filtered through a 0.45 micron filter and acidified to a pH of 2.0, then run through an inductively coupled plasma (ICP) spectrophotometer for metal analysis. These metal concentrations were then multiplied by the stream discharges to determine a metal flux. This mass balance approach was implemented to determine metal fluxes entering and exiting the wetland.

Metal concentrations in the surface water are high for several metals. The highest concentrations were those seeping out of the largest tailing pile. Although not associated with either mine adit the average concentration of iron was 11.7 mg/L, for manganese 69.5 mg/L, and for aluminum 4.6 mg/L. the Dinero Tunnel, the largest surface contributor of water, had average concentrations of zinc at 8.9 mg/L, manganese at 36.9 mg/L, and aluminum at 0.7 mg/L. A spring that drains into the wetland approximately 400 meters from the Dinero Tunnel had average aluminum concentrations of 5.6 mg/L, and average zinc concentrations of 5.9 mg/L. As the channel exists the wetland and drains into Lake Fork the concentrations remained similarly high. Average manganese concentrations were at 32.2 mg/L, zinc at 6.6 mg/L, and aluminum at 1.1 mg/L.

Preliminary mass balance result suggest that metal loads of surface waters decrease as they pass through the wetland. Loads to the ground water have not been calculated yet. As the surface waters travel through a series of four small beaver ponds it appears that there is some movement of surface waters to ground water. Channel discharges decrease as it travel through the ponds by as much as 50%. If output load calculations were made with input discharge values, the metal loads exiting the wetland would still have decreased by 18-84% over the input loads. The difference in loads between the input and output was significant in almost all cases. Iron loads were changed an average of 400%, with average loads exciting the wetland at 0.8 kg/day. Manganese showed the smallest change with a 95% change, with an average input load 4.8 kg/day and an average output load of 9.5 kg/day.

The mass balance method suggests that the wetland is improving water quality. However remember that discharges were constant, and metal concentrations were these also similar during the sample period.

It should be noted that these are preliminary results and ground water analysis may influence the total load calculations. Further work includes subjecting soil samples to a series of extractions to determine how tightly the metals are held. Along with this is determine the percent organic matter and particle size analysis.

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IMPACTS OF A NATURAL WETLAND ON TOTAL-PHOSPHORUS LOADS DOWNSTREAM FROM A WASTEWATER TREATMENT PLANT

James R. Kunkel and Timothy D. Steele
Advanced Sciences, Inc.
405 Urban Street, Suite 401
Lakewood, Colorado 80228-1236

Introduction

The treatment of domestic wastewater to obtain an effluent total-phosphorus concentration acceptable to regulators frequently requires using advanced wastewater treatment (AWT) technologies such as chemical-physical treatment, rapid infiltration basins, constructed wetlands, or land application systems. The design and construction costs of such systems may range from a few hundred thousand dollars to over one million dollars for even the smallest wastewater treatment facilities serving only several hundred to one thousand persons. Moreover, annual operation and maintenance costs may range from several tens of thousands of dollars per year to many tens of thousands of dollars per year. The per-connection cost for design and construction may be as high as $10,000, with annual operation and maintenance costs per connection of over $50. These costs are over and above those for operation and maintenance of conventional wastewater treatment facilities and include the costs for phosphorus treatment only. Many smaller water-and-sanitation or special districts cannot afford such costs. As an example of the natural-wetland total-phosphorus treatment process, this paper considers measured streamflow and water-quality data for several months in 1990 and 1992 to assess the performance of natural wetlands in removing total phosphorus downstream from a relatively small (65,000 gallons per day) wastewater treatment plant.

The Perry Park Water and Sanitation District's Waucondah Wastewater Treatment Facility discharges to Bear Creek about 0.4 miles (mi) downstream from Waucondah Lake (Figure 1). The Treatment Facility consists of primary and secondary treatment with the following processes: bar screen, primary clarifier, rotating biological contactors, secondary clarifier, chlorination, and chlorine contact basin. The existing Treatment Facility is designed for an average daily flow of 0.32 million gallons per day (mgd), but currently has only about 312 units, comprising about 780 residents, connected to it. The future number of total units is estimated to be about 1,300, serving a projected resident population of between 3,900 and 4,000 people (Richard P. Arber Associates, Inc., 1990).

Effluent discharge and water-quality data obtained from the District indicates that the average daily discharge during the period January 1987 through December 1990 from the Treatment Facility was about 63,000 gallons per day (gpd), or about 0.1 cubic feet per second (cfs). Total-phosphorus concentrations in the effluent from the Treatment Facility over the same time period averaged about 6.8 milligrams per liter (mg/L). The Colorado Department of Health (CDH) has instructed the District to design, construct and operate an AWT facility to remove enough total phosphorus from the effluent of the Waucondah Wastewater Treatment Facility to attain a concentration in the effluent of 0.2 mg/L averaged over a 30-day period (CDH, 1991). The design and construction costs of AWT alternatives have been estimated to be between $404,000 and $979,000 (Richard P. Arber Associates, Inc., 1991). Operation-and-maintenance costs of the proposed AWT facility alternatives were estimated to range between $18,000 and $58,000 per year. These annual costs are in addition to the costs to operate the existing Treatment Facility. Because of these large costs and the small population base of sewer connections to pay for them, the District sought relief from the 0.2 mg/L total-phosphorus concentration limit presently stipulated by the CDH for the Waucondah Wastewater Treatment Facility effluent.

Background and Existing Data

The Chatfield Basin Authority and Perry Park Water and Sanitation District collected intermittent streamflow and water-quality data on Bear Creek upstream from the Treatment Facility (Site 6 on Figure 1), between August 1986 and August 1987, September through December 1990, and March through August 1992 (ASI, 1991a; 1991b; 1992; 1993). The Authority and the District also collected streamflow and water-quality data on Bear Creek downstream from the Treatment Facility (Site 6A on Figure 1) and downstream from the confluence of Bear Creek and West Plum Creek (Site 6B on Figure 1) for the September-through-December 1990 period and the March-through-August 1992 period (ASI, 1991b; 1992). Streamflow and water-quality data at the three in-stream flow sites (6, 6A, and 6B) and the Treatment Facility effluent are available concurrently only for eight samples collected during the September-through-December 1990 period and five samples collected during the March-through-August 1992 period. These 13 samples form the basis for the analyses of total phosphorus presented below. An additional five samples were collected in 1992 at site 6C on Bear Creek upstream from the confluence with West Plum Creek. These five samples were used to the assess the predictive capability of a phosphorus-balance method for estimating in-stream total-phosphorus loads on Bear Creek. The data used in this paper are not presented here but are part of the public record for the Chatfield Basin Authority (ASI, 1991a; 1991b; 1993).

Total Phosphorus in Bear Creek and West Plum Creek

Total-phosphorus loads in Bear Creek and West Plum Creek, based upon data collected during the September-through-December 1990 and March-through-August 1992 periods, were analyzed to assess the historical wetlands uptake downstream from the Waucondah Wastewater Treatment Facility. These fall, early winter, and spring/summer data should represent a reasonable assessment of total-phosphorus removals, based upon the 13 concurrent data points available during this period. The results of the phosphorus-balance analysis are summarized in Table 1.

For the period of record analyzed, total-phosphorus concentrations in Bear Creek just downstream from Waucondah Lake and upstream from the Waucondah Wastewater Treatment Facility (Site 6 on Figure 1) averaged about 0.14 mg/L. with an average load of about 0.59 pounds per day (lbs/d) for the 15 samples given in Table 1. Total-phosphorus concentrations and discharge from the Waucondah Wastewater Treatment Facility for the period analyzed were obtained from the District (Table 1). The total-phosphorus concentration for this period averaged about 7.0 mg/L, and the discharge averaged about 0.09 cfs. The resulting average total-phosphorus load discharged to Bear Creek by the Treatment Facility for this period was about 3.5 lbs/d. Because total-phosphorus and discharge data are reported only monthly at the Treatment Facility, it was assumed that these values were relatively constant throughout a given month and could occur on any given day during that month.

During the assessment period, water-quality data were collected in Bear Creek downstream from the Treatment Facility at the culvert leaving the pond into which the effluent is discharged (Site 6A on Figure 1 and Table 1). From the available data summarized in Table 1, the concentration of total phosphorus in Bear Creek at this point averaged about 1.1 mg/L. The streamflow at Site 6B was estimated by summing the measured streamflow at Site 6 and the average monthly discharge measured at the Treatment Facility. The resulting average total-phosphorus load at Site 6A was 3.5 lbs/d for the period, substantially higher than the Bear Creek total-phosphorus loads upstream from the Treatment Facility effluent discharge as would be expected. This total-phosphorus load averaging 3.5 lbs/d is identical to the 3.5 lbs/d discharged by the Treatment Facility about 0.1 mi upstream. This is because much of the total phosphorus discharged by the Treatment Facility is in a dissolved form. The man-made pond just downstream from the treatment facility is most effective in removing phosphorus adsorbed onto settleable solids and, therefore, does not greatly reduce the total-phosphorous load if it is primarily dissolved.

Water-quality and streamflow data collected during the analysis period in West Plum Creek downstream from confluence with Bear Creek (Site 6B), are shown in Table 1. Total-phosphorus concentrations at Site 6B for this period averaged about 0.07 mg/L, and total-phosphorus loads for the period averaged about 2.1 lbs/d. This total-phosphorus load represents the combined load from Bear Creek and from West Plum Creek. In order to estimate how much of this total-phosphorus load may have come from Bear Creek required calculations, based upon several assumptions, as described below.

Analysis of Total Phosphorus Removal by the Bear Creek Wetlands

To estimate the streamflow in Bear Creek just upstream from its confluence with West Plum Creek (Site 6C, where no streamflow data are available, on Figure 1), it was assumed that Site 6C had the same streamflow as Site 6A upstream. The streamflow in West Plum Creek just upstream from its confluence with Bear Creek (hypothetical Site 6D) was calculated by subtracting the streamflow at Site 6C from the measured streamflow at Site 6B. The resulting calculated streamflow in West Plum Creek is shown in Table 1, which also summarizes the calculations of total-phosphorus loads for all sites.

No known data on total-phosphorus concentrations exist for West Plum Creek upstream from its confluence with Bear Creek (Site 6D). For purposes of this current analysis, we have assumed that the total-phosphorus concentration in West Plum Creek at Site 6D is 0.02 mg/L for all streamflows analyzed during the period, except for the April 9, 1992 analysis which assumed a concentration the same as Site 6B. This assumption is based upon a 0.02 mg/L detection limit, historical data at Site 6 in Bear Creek, and consideration of total-phosphorus concentration data at other locations in the Chatfield Reservoir basin. This assumption should provide a worst-case removal-rate analysis for the Bear Creek data. Table 1 shows the estimated total-phosphorus loads for West Plum Creek, based upon these assumptions.

The total-phosphorus loads for Bear Creek at Site 6C, upstream from its confluence with West Plum Creek, were calculated by subtracting the loads in West Plum Creek upstream from Site 6B from the measured loads at Site 6B. The total-phosphorus loads at Site 6C are shown in Table 1. The resulting estimates of total-phosphorus concentrations at Site 6C were calculated from the loads and streamflow at the site. Analysis of the resulting calculated total-phosphorus loads at Site 6C indicates that an average of 1.2 lbs/d was discharged by Bear Creek into West Plum Creek for available discrete samples during the period analyzed. The average calculated total-phosphorous concentration at Site 6C for this period is about 0.18 mg/L, which is less than the proposed total-phosphorus discharge standard of 0.20 mg/L for the Waucondah Wastewater Treatment Facility.

This reduction in Bear Creek total-phosphorus loads from an average of 3.5 lbs/d at Site 6A to 1.3 lbs/d at Site 6C represents a 63 percent removal by the 2.3 mi of ponds and wetlands in Bear Creek. This removal percentage is on the upper end of reported total-phosphorus removals in wetlands (EPA, 1976 and 1988; Herron, 1990). One reason for this relatively large total-phosphorus removal rate may be as follows. For the period analyzed, the streamflows were generally low, providing the opportunity for water to come in contact with the Bear Creek sediments and plant roots. Another reason for the seemingly high total-phosphorus removal rates is that the EPA-reported removal efficiencies are for free-water surface systems of relatively short distances (less than several hundred feet). Also, a 2.3 mi stream reach, such as Bear Creek downstream from the Treatment Facility, could result in much larger total-phosphorus removals. Therefore, if the effluent-discharge compliance point for the Waucondah Wastewater Treatment Facility were moved downstream in Bear Creek to it confluence with West Plum Creek, the approximately 2.3 mi of wetlands in Bear Creek would be considered in the observed reduction of total-phosphorus concentrations to acceptable levels.

Future population growth within the District should result in increases in the total-phosphorus loads discharged to Bear Creek by the Treatment Facility, assuming the associated total-phosphorus concentrations do not decrease. The ability of the 2.3 mi of wetlands to continue assimilating total phosphorus over the long term, or to assimilate increased phosphorus loads presently is unknown. We judge that the 2.3 mi of wetlands downstream form the Treatment Facility should be able to assimilate phosphorus, even if the loads due to increased sewer connections in the District increase. Monitoring of the performance of the ponds/wetlands system would help to confirm continued benefits of the phosphorus-assimilative capacity downstream from the Treatment Facility and to assess if this assimilation occurs over a wider range of streamflows and weather conditions, as well as over the long term.

During the period March-through-August 1992, the Perry Part Water and Sanitation District monitored total-phosphorus concentrations at Sites 6, 6A, 6B, and 6C. Only five of the samples collected could be compared to the calculated removals shown in Table 1. Results of this comparison are as follows:

Date	Predicted TP Concentration (mg/L)	Measured TP Concentration (mg/L)
4/09/92	0.16	0.15
4/21/92	0.15	0.18
5/06/92	<0.02	<0.02
6/10/92	0.26	0.10
7/07/92	0.10	<0.02

The average percent difference in the predicted versus the measured total phosphorus for the above five measurements was about 26 percent. This percentage is considered to be reasonable. Therefore, based upon this case study, the use of natural wetlands to remove total phosphorus downstream from a wastewater treatment facility appears to be possible and the prediction of such removals using a simple phosphorus balance also appears to be possible. This natural removal mechanism may provide financial relied to smaller water and sanitation or special districts which are being required by regulatory agencies to construct and to operate costly AWT facilities for removal of total phosphorus.

Summary and Conclusions

Short-term benefits of this phosphorus-assimilative assessment resulted in an approved compliance-schedule extension granted by the CDH (1992a). In conjunction with available basinwide monitoring data (ASI, 1991a; 1991b; 1992; 1993) and development of a non-point source plan (WCC, 1992), the total-phosphorus wastewater-effluent discharge target concentration was modified from 0.2 mg/L to 1.0 mg/L (CDH, 1992b), thereby enabling relatively small dischargers to streams in the Chatfield basin to apply more flexibility in implementing cost-effective wastewater treatment.

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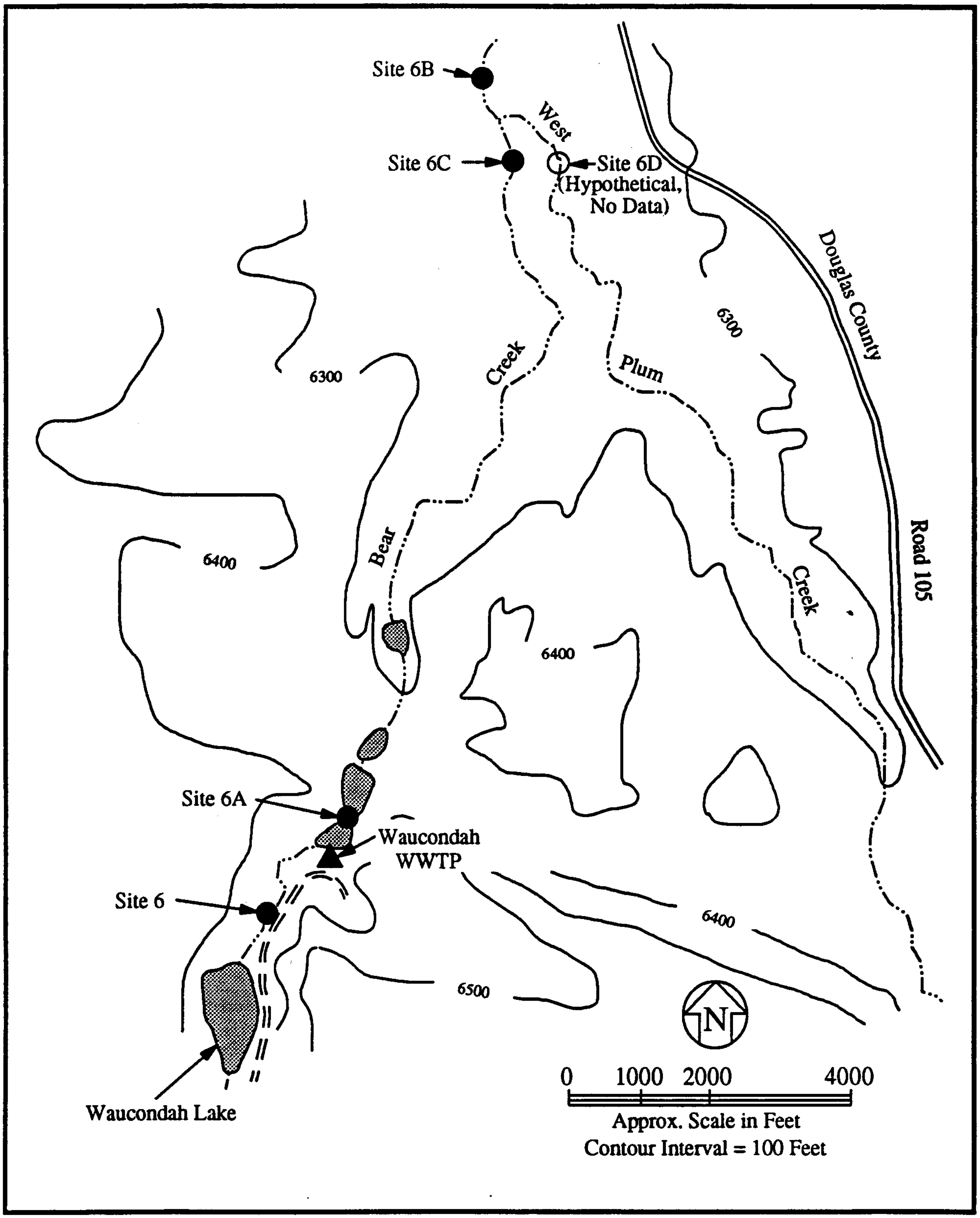
Table 1
Total Phosphourus Load Calculations, Bear Creek/West Plum Creek System

DATE	Site 6[1] INSTANTANEOUS STREAM FLOW (CFS)	Site 6[1] PHOSPHORUS, TOTAL (MG/L AS P)	Site 6[1] PHOSPHORUS, TOTAL (LBS/D AS P)	Site WWTP[1] INSTANTANEOUS STREAM FLOW (CFS)	Site WWTP[1] PHOSPHORUS, TOTAL (MG/L AS P)	Site WWTP[1] PHOSPHORUS, TOTAL (LBS/D AS P)	Site 6A[1] INSTANTANEOUS STREAM FLOW (CFS)	Site 6A[1] PHOSPHORUS, TOTAL (MG/L AS P)	Site 6A[1] PHOSPHORUS, TOTAL (LBS/D AS P)
04-Sep-90	0.35	0.04	0.08	0.08	8.12	3.50	0.43	0.95	2.20
18-Sep-90	0.21	0.03	0.03	0.08	8.12	3.50	0.29	1.34	2.09
02-Oct-90	0.20	0.05	0.05	0.09	7.93	3.85	0.29	2.32	3.63
16-Oct-90	0.28	0.04	0.06	0.09	7.93	3.85	0.37	2.68	5.34
30-Oct-90	0.28	0.04	0.06	0.09	7.93	3.85	0.37	3.10	6.18
13-Nov-90	0.28	0.01	0.02	0.09	7.44	3.61	0.37	1.61	3.21
28-Nov-90	0.33	0.05	0.09	0.09	7.44	3.61	0.42	0.87	1.97
11-Dec-90	0.24	0.05	0.06	0.08	6.24	2.69	0.32	0.80	1.38
24-Apr-92	1.40	0.01	0.08	0.11	7.82	4.64	1.51	0.31	2.52
09-Apr-92	8.70	0.08	3.75	0.09	5.66	2.74	8.79	0.13	6.16
21-Apr-92	12.00	0.01	0.65	0.10	5.66	3.05	12.10	0.16	10.43
06-May-92	8.70	0.01	0.47	0.10	6.58	3.55	8.80	0.01	0.47
21-May-92	0.07	1.45	0.55	0.10	6.58	3.55	0.17	1.34	1.23
10-Jun-92	3.50	0.15	2.83	0.09	4.75	2.30	3.59	0.30	5.80
07-Jul-92	0.47	0.01	0.03	0.11	6.83	4.05	0.58	0.07	0.22
TOTALS			8.80			52.32			52.84
AVERAGES	2.47	0.14	0.59	0.09	7.00	3.49	2.56	1.07	3.52

DATE	Site 6B[1] INSTANTANEOUS STREAM FLOW (CFS)	Site 6B[1] PHOSPHORUS, TOTAL (MG/L AS P)	Site 6B[1] PHOSPHORUS, TOTAL (LBS/D AS P)	West Plum Creek (Hypothetical Site 6D)[1] INSTANTANEOUS STREAM FLOW (CFS)	West Plum Creek (Hypothetical Site 6D)[1] PHOSPHORUS, TOTAL (MG/L AS P)	West Plum Creek (Hypothetical Site 6D)[1] PHOSPHORUS, TOTAL (LBS/D AS P)	Site 6C[1] INSTANTANEOUS STREAM FLOW (CFS)	Site 6C[1] PHOSPHORUS, TOTAL (MG/L AS P)	Site 6C[1] PHOSPHORUS, TOTAL (LBS/D AS P)
04-Sep-90	1.6	0.05	0.43	1.20	0.02	0.13	0.43	0.13	0.30
18-Sep-90	1.9	0.03	0.31	1.60	0.02	0.17	0.29	0.09	0.13
02-Oct-90	2.2	0.05	0.59	1.90	0.02	0.20	0.29	0.25	0.39
16-Oct-90	2.6	0.03	0.42	2.20	0.02	0.24	0.37	0.09	0.18
30-Oct-90	2.6	0.05	0.70	2.20	0.02	0.24	0.37	0.23	0.46
13-Nov-90	2.7	0.05	0.73	2.30	0.02	0.25	0.37	0.24	0.48
28-Nov-90	2.8	0.09	1.36	2.40	0.02	0.26	0.42	0.49	1.10
11-Dec-90	2.3	0.04	0.50	2.00	0.02	0.22	0.32	0.16	0.28
24-Apr-92									
09-Apr-92	10	0.16	8.62	8.49	0.16	7.32	1.51	0.16	1.30
21-Apr-92	14.9	0.09	7.23	2.8	0.02	0.30	8.79	0.15	6.92
06-May-92	16	0.01	0.86	7.2	0.02	0.78	12.10	0.02	0.09
21-May-92									
10-Jun-92	4.7	0.20	5.07	1.12	0.02	0.12	3.59	0.26	4.94
07-Jul-92	1.2	0.06	0.39	0.58	0.02	0.06	0.58	0.10	0.33
TOTALS			27.20			10.28			16.91
AVERAGES	2.27	0.07	2.09	2.77	0.03	0.79	2.26	0.18	1.30

1) See Figure 1 for location.



Location Map, Bear Creek/West Plum Creek Monitoring Sites

STORMWATER-NPDES MONITORING PROGRAM AT THE ROCKY FLATS PLANT NEAR DENVER, COLORADO

Timothy D. Steele and James R. Kunkel
Advanced Sciences, Inc.
and
Robert E. Fiehweg, EG&G Rocky Flats, Inc.

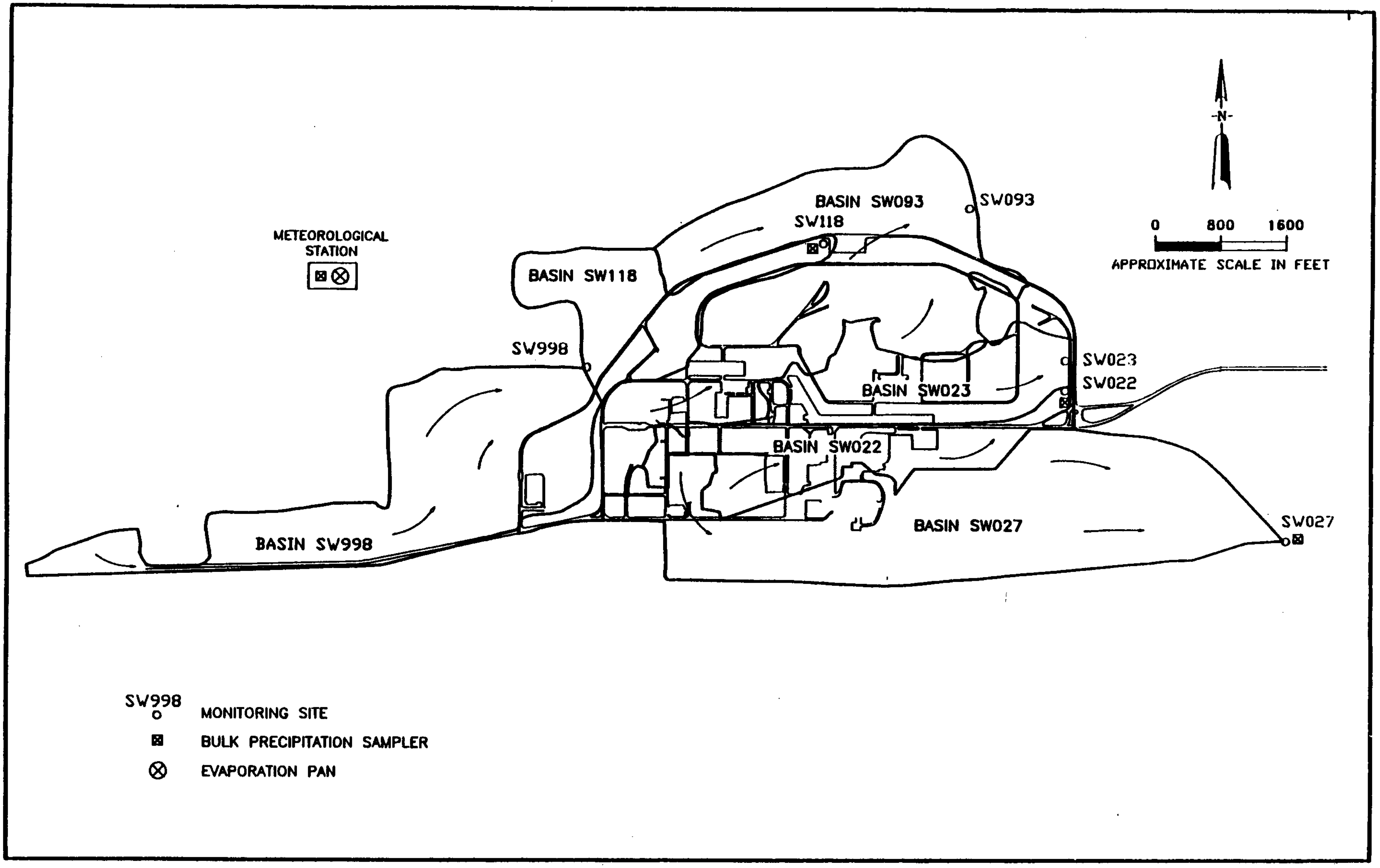
Introduction

In October 1991, a comprehensive monitoring program associated with the U.S. Environmental Protection Agency's (EPA's) stormwater NPDES permit-application program (EPA, 1990; 1991) was implemented by Advanced Sciences, Inc. (ASI) on behalf of EG&G Rocky Flats, Inc., for characterizing storm-runoff/high-flow events discharging in streams and channels draining from the Rocky Flats Plant's (RFP's) core area and nearby buffer zone. Event sampling had been conducted previously at five surface-water monitoring sites beginning in July 1990 for a non-point source assessment study (ASI, 1991a). Field-instrumentation upgrades and a sixth monitoring-site installation were completed during October 1991. A dual system of automatic samplers connected to a stage-recording data-logger/pressure-transducer component provided a means of obtaining more detailed sample coverage during the initial part of event hydrographs. Discrete samples at a given surface-water site were composited by discharge-weighting, based upon flows associated with these samples. In this manner, event-mean concentrations for indicator water-quality variables of interest (generally, aggregate radionuclide measurements of gross alpha and gross beta and selected trace metals) were obtained for sampled events at a given site. Reporting of sitewide and offsite surface-water monitoring is provided in an annual report series (see, for example, EG&G Rocky Flats, Inc., 1992).

This paper highlights results of this stormwater NPDES permit-application monitoring program (ASI, 1991b; 1992; 1993). Over a 15-month monitoring period, 32 events were sampled at various surface-water and/or bulk-precipitation sites included in the monitoring network. Evaluation has been made of the effectiveness of obtaining comprehensive hydrograph coverage for a number of storm-runoff/high-flow events as well as in obtaining data over a range of hydrologic conditions and time of year. Examples of event-sample coverage are provided, as well as an assessment of resultant event-generated water-quality data. During the 15-month monitoring period, a total of 116 storm-runoff/high-flow samples (32 events) and 19 bulk-precipitation samples were collected.

Approaches

The following design components for a stormwater-NPDES water-quantity and water-quality monitoring program were implemented. Five monitoring sites (SW022, SW023, SW027, SW093, and SW118, Figure 1) included in EG&G's non-point source assessment program (ASI, 1991a) were upgraded with field instrumentation for recording continuous flow stage and automatic sampling of storm events. A sixth monitoring site (SW998, Figure 1) was instrumented in a manner identical to the five upgraded sites and were included in order to obtain better definition of non-point source runoff in the northern and western parts of the RFP Controlled Area and in limited parts of the RFP buffer zone. As shown on



STORMWATER NPDES MONITORING-SITE LOCATION MAP

FF10-1.DWG

Figure 1

Figure 1, the six monitoring sites measure runoff from about 840 acres, or virtually 100 percent of the developed part of the Controlled Area and parts of the West and East Buffer Zones. Specific detailed descriptions of the field instrumentation are included in ASI (1992; 1993).

Rainfall data also were collected to support this study. Rainfall data from the EG&G-operated meteorological station in the West Buffer Zone or from a tipping-bucket rain-gage located near site SW022 (Figure 1) were available for concurrent time periods with the measured flows in the storm-drainage system. The relationship of rainfall data to the measured storm runoff at the six monitoring sites gave an indication of whether and when significant non-rainfall water may be entering the storm-drainage system. The rainfall data also indicated whether or not a given storm could be considered as a "representative storm" for collection of NPDES water-quality samples, as defined by 40 CFR 122.26 or as instructed by EG&G staff later during execution of the monitoring program.

Because of potentially limited sample volumes from the automatic sampler at each site, the large volumes of water required for analysis of the chemical constituents specified by 40 CFR 122.26, and the goal to characterize the "first-flush" effect for storm hydrographs, two samplers were installed at each of the monitoring sites, except site SW998, in October 1991. Both samplers were actuated by the data logger alarm feature. The primary sampler samples from the beginning of the storm runoff at preset time intervals until the data logger goes out of alarm or all 24 bottles in the sampler are filled. The secondary sampler takes samples from the beginning of the storm runoff at 1.5-minute intervals until the data logger goes out of alarm or all 24 sample bottles are filled. The purpose of the secondary sampler is to provide a sample of the "first flush" from the basin occurring within the first 30 minutes of storm runoff. In mid-November 1992, the paired "first-flush" samplers were removed, and an additional paired sampler was installed at site SW998.

In addition, supplemental field monitoring was implemented, using bulk-precipitation (wetfall/dryfall) samplers and an evaporation pan. The purpose of the bulk-precipitation samplers was to sample both wetfall and dryfall. Dryfall consists of suspended particulates carried by the wind. These particulates tend to be deposited in the funnel of the bulk-precipitation sampler and then are "washed" into the sampler by wetfall (precipitation). Because some contaminants are adsorbed onto dust particulates, the bulk-precipitation sampler should give an indication of wind-blow transport of contaminants settling out of the air column at a specific point. The data collected by the bulk-precipitation samplers gave an indication of the transport of contaminants downwind at the RFP. These bulk-precipitation samplers were located at the existing EG&G meteorological station in the West Buffer Zone (usually upwind of the RFP Controlled Area) and at sites SW022, SW027 and SW118 (all generally downwind from the RFP Controlled Area) (Figure 1). The evaporation pan was located at the existing EG&G-operated meteorological station. Resultant precipitation and evaporation data are reported in ASI (1992; 1993, Appendix C).

The suite of chemical constituents analyzed for storm-runoff/high-flow event and bulk-precipitation samples included the total-analyte-list (TAL) metals (Al, Sb, As, Ba, Be, Cd, Ca, Ce, Cr, Co, Cu, Fe, Pb, Li, Mg, Mn, Mo, Ni, K, Se, Ag, Na, Sr, Th, Sn, Va, and Zn). For event samples, analyses were performed for selected anions and other constituents (alkalinity, Cl, F, pH, SO_4, dissolved solids, and suspended solids), and selected nutrient species (NO_2/NO_3-nitrogen, ammonia-nitrogen, and total phosphorus). Additionally, each of the event automatic-sampler bottles collected by the automatic samplers were field-tested for pH, specific conductance (SC) and water temperature. Field measurements also were made on composited samples. Grab samples, as well as a few samples collected late during the monitoring period that were not submitted for laboratory analyses, were field-tested for pH, SC, water temperature, and dissolved oxygen (ASI, 1993, Table 4). Detailed results of laboratory analyses and field measurements are compiled in ASI (1992; 1993, Tables A-1 through A-4).

Results

Non-Stormwater Discharges - Only two (SW023 and SW093) of the six monitoring sites have exhibited continuous flows during the monitoring period. A preliminary analysis of the runoff and water-quality data collected to date indicates several patterns of interest. The runoff at sites SW022, SW027, SW118, and SW998 showed intermittent characteristics, that is, the flows decreased to zero after a rainstorm. On the other hand, the runoff at sites SW023 and SW093 exhibited perennial (continuous-flow) characteristics; that is, the flows decreased after a rainstorm but did not cease entirely. This indicates that either ground water or some other discharge from the RFP (such as leaks in water lines or sanitary sewer lines) may be the primary source causing continuous flows at these two sites. Event hydrographs for sites SW023 and SW093 (ASI, 1992, Figure 7), indicate that flow continues at some low level even after many days of no rainfall. Comparison of daily precipitation data with measured daily discharge data indicate intermittent occurrences of non-rainfall flows at sites SW023 and SW093 (ASI, 1992; 1993).

Infiltration to the storm-sewer system at site SW023 was estimated by ASI (1991a). The non-rainfall days used for the infiltration analysis included the second day after a recorded daily precipitation up to the next rainfall day. For site SW023, this included about 200 days during the period July 26, 1990 through August 31, 1991 (402 total days with many missing days of data). The longest non-rainfall period within the period of record was 31 days from December 19, 1990 through January 18, 1991. The total measured discharge at site SW023 for the 200 no-rainfall days was about 40.1 acre-feet (ac-ft) or about 13.1 million gallons (MG). On an annualized basis, this flow volume would be about 7.4 MG, or an average of about 0.020 million gallons per day (MGD).

Infiltration to the storm sewer system at site SW093 was estimated for the same 200 non-rainfall days as for site SW023. For site SW093 the total measured discharge for these 200 days was about 101 ac-ft or about 33.1 MG. On an annualized basis, this flow volume would be about 18.8 MG or an average of about 0.052 MGD. Based upon non-precipitation flows at these two sites, the estimates of infiltration to the storm-sewer system are based upon about a one-year intermittent period of record. The total estimated quantity of infiltration at monitoring sites SW023 and SW093 is about 0.072 MGD or 26.2 MG annually. This amount of water was judged to be insignificant (ASI, 1991a).

Stormwater Event-Related Discharges - In general, the observed daily-mean discharges at the six monitoring sites appeared to be in response to storms whose intensity and duration are reflected by the daily precipitation data collected at the EG&G meteorological station located in the West Buffer Zone, approximately 0.5 miles (mi) from the nearest flow-gaging site (SW998) and 2.0 mi from the furthest flow-gaging site (SW027). Preliminary analysis of these precipitation and discharge data indicates that the largest rainstorm during the 15-month monitoring period for which runoff was measured, occurred during August 23 through 25, 1992; this storm had a total 3-day precipitation of 2.50 inches (in). The estimated storm runoff in each case was calculated by summing the daily mean discharges from the storm (less base flow), multiplying this total daily mean discharge by 1.98 to obtain the volume of the storm runoff in ac-ft, and dividing by the drainage area at the site to obtain the depth of runoff in inches from the storm event.

The rainfall-runoff responses for 17 storms during the 15-month monitoring period at the six monitoring sites have been compiled (ASI; 1992; 1993, Table 5). Only rainstorms were considered, because snowmelt runoff is difficult to quantify without data related to air temperature and snowpack conditions. The rainstorm runoff at the six monitoring sites for the 17 storms ranged from zero percent of rainfall at all sites, except SW023 and SW093, to over 100 percent of rainfall at site SW118. The total (including snowmelt) runoff at the six monitoring sites for the October-1991-through-August-1992 period of record, ranged from approximately 20 percent of total precipitation (including snow) at site SW998 to 175 percent of rainfall at site SW118 (with many missing days of runoff). Hurr (1976) found, based upon limited data, that the runoff in the Woman Creek basin (drainage area >1,000 ac) was about 1.4 percent of rainfall. One of the factors contributing to the small percentage of rainfall that ran off in the Woman Creek case by Hurr (1976) was that most of the records that were used to develop the Woman Creek rainfall-runoff relationship resulted from frontal storms with long rainfall durations, rather than thunderstorms whose intensities are much higher. Therefore, it is concluded that the rainfall-runoff relationships presented at the six monitoring sites are reasonable.

Analyses of these results indicated that uneven runoff responses occurred to point-measured precipitation values. This was especially evident for the thunderstorms, typical of the semi-arid environment of the area. Distance from the precipitation measuring point (EG&G's meteorological station) also affects the quality of the rainfall-runoff relationships. The amount of runoff detention also impacts the rainfall-runoff relationships. Many small detention facilities are located at the RFP, consisting of small ponds and depressions, berms around buildings and tanks, and other areas. Runoff collected in these areas is released after the storm events and distort the runoff response to rainfall. The drainage basins in which detention is judged to be largest include monitoring sites SW022, SW023, and SW093.

These analyses also indicated that runoff values (in inches) for some storms were larger than the rainfall values (in inches) measured at the EG&G meteorological station. This might be due to inaccuracies in the flow and rainfall measurements, distance of the meteorological station from the drainage basin, or differences in patterns that thunderstorms track across a given drainage basin. Of the 17 storms, eight had runoff depths higher than rainfall depths for one or more of the drainage basins.

<u>Stormwater Event-Related Samples</u> - Analysis of the available 52 storm-runoff water-quality sample summaries (ASI, 1992, Tables 6 through 11) indicates that at site SW022 the highest trace metal concentration was 60,800 µg/L for iron. Average (4 samples) trace metal concentration for this analyte was 34,430 µg/L. Concentrations of anion, nutrient, and other constituents were within typically acceptable values for storm-runoff water quality. At site SW023, the highest trace-metal concentration was 21,600 µg/L also for iron and the average (11 samples) trace metal concentration for this analyte was approximately 9,570 µg/L. Concentrations of anion, nutrient, and other constituents were within typically acceptable values for storm-runoff water quality. At site SW027, the highest trace-metal concentration was aluminum with a maximum value of 20,200 µg/L and an average value for four storm-event samples of nearly 7,900 µg/L. Other constituent concentrations were generally within acceptable values for storm-runoff water quality. At site SW093, the highest trace-metal concentration also was aluminum with a maximum value of 34,800 µg/L and an average value for six storm-event samples of 13,400 µg/L. Other constituent concentrations were generally within acceptable values for storm-runoff water quality. At site SW118, the highest trace-metal concentration was 23,300 µg/L for iron. Average trace-metal concentration for this analyte was approximately 7,630 µg/L. Concentrations of anion, nutrient, and other constituents were within typically acceptable values for storm-runoff water quality. At site SW998, only one sample has been analyzed to date and indicated relatively low concentrations of trace metals, anions, and nutrient species in the storm runoff.

Climatological and Bulk-Precipitation Data - The observed daily-mean discharges at the six monitoring sites appeared to be in response to storms whose intensity and duration are reflected by the daily precipitation data (ASI, 1992, Appendix C, Tables C-1 and C-2) collected at the EG&G meteorological station located in the West Buffer Zone or at the EG&G tipping bucket rain-gage near site SW022. Preliminary analysis of precipitation recorded at the EG&G meteorological station in the West Buffer Zone and discharge data for the 15-month study period indicate that the largest snow storm for which runoff was measured occurred during March 2 through 9, 1992; this snow storm had a total 8-day precipitation of 2.47 in. The largest rainfall storm for which runoff was measured was the 3-day period between August 23 and 25, 1992, when 2.50 in fell.

A total of 19 bulk-precipitation samples were collected and submitted for selective laboratory analysis. Results of 8 of these 19 sample analyses summarized in ASI (1993; 1993, Table 12) indicate that the maximum trace metal detected in the bulk precipitation was iron, with a maximum concentration of 168 µg/L and an average concentration for six samples of approximately 89 µg/L.

Summary

The following conclusions are made as a result of the preliminary analyses conducted for the stormwater NPDES study:

1) A total of 116 surface-water samples and 19 bulk-precipitation samples have been collected and submitted for selective laboratory chemical analyses for 32 events (storms or otherwise high recorded flows). Of the samples collected, analytical results are available for 52 samples (22 primary composites, 27 secondary composites, and 3 grabs). Of the bulk-precipitation samples collected, analytical results are available for 8 samples.

2) The surface-water samples were analyzed for selective trace metals, anions, and nutrient species. Trace metals having the highest concentrations in the storm-runoff samples were aluminum and iron which exhibited both high concentrations in single composite samples and persistence over many such composite samples. Anion and nutrient species concentrations were at expected storm-runoff levels. Of the 8 bulk precipitation samples analyzed for metals only, none showed unusually high concentrations.

3) For aluminum (Al) and iron (Fe), maximum and average concentrations (units of ug/L) for each monitoring site are as follows (based upon limited analyses received to date):

Site	Al Max	Al Avg	Fe Max	Fe Avg	No./Type
SW022	59,900	34,760	60,800	34,430	4/Composites
SW023	21,400	8,940	21,600	9,570	11/Composites
SW027	20,200	7,880	17,100	6,630	4/Composites
SW093	34,800	13,400	34,300	14,150	6/Composites
SW118	22,300	7,310	23,300	7,630	8/Composites
SW998	--	3,130	--	2,490	1/Grab Sample
Bulk Precip.	149	73	168	89	6/Composites

4) Numerous previous studies have documented physical characteristics and ambient chemical conditions in stream and impoundment sediments in and around the RFP area.

Implementation of the proposed suspended-sediment samplers and additional more-detailed characterization of bottom-sediment chemistry of stream channels and of reservoirs (both on-site and offsite) may be useful in expanding upon available historical data and in refining the assessment of non-point source contributions.

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IMPACTS OF DEVELOPING WATER SUPPLIES IN THE COLORADO RIVER BASIN

WATER QUALITY-QUANTITY CONFLICTS IN DEVELOPING THE REMAINDER OF COLORADO'S COLORADO RIVER ENTITLEMENT

David H. Merritt
Colorado River Water Conservation District

Colorado has developed only about two-thirds of its compact entitlement waters, under the Colorado River Basin Compact and the Upper Colorado River Compact. However, further development of these waters are complicated by many conflicting desires. These include historic transbasin diversion conflicts, general instream flow issues, specific endangered fishes instream flow needs, wetlands issues, and water quality issues of downstream, in-state users.

The issue of the Wolford Mountain-Green Mountain substitution presents a good case study. In order to utilize yield made available by the construction of the Wolford Mountain Project by the Colorado River Water Conservation District, the Denver Water Department has to retain water stored in Lake Dillon, rather than release that water to Green Mountain Reservoir. The Bureau of Reclamation then has to schedule water releases out of Wolford Mountain Reservoir to meet downstream requirements on Green Mountain Reservoir. Entities in the Grand Valley have objected to this, claiming that the change in water quality thus engendered makes the water unsuitable for its historic uses.

A basic precept of the State Constitution is that the right to divert to beneficial uses unappropriated waters of the state shall not be abridged. This is such a strong tenant of Colorado Water Law that when the Colorado Water Quality Control Act was passed in 1975, it contained a specific clause, Section 25-8-104, which stated, in part:

> "(1) No provision of this article shall be interpreted so as to supersede, abrogate, or impair rights to divert and apply water to beneficial uses in accordance with the provisions of sections 5 and 6 of article XVI of the constitution of the state of Colorado, compacts entered into by the state of Colorado, or the provision of articles 80 to 93 of title 37, C.R.S, or Colorado Court determinations with respect to the determination and administration of water rights."

The perceived infringement of the Colorado Water Quality Control Commission and Division on water development activities came to a head in 1988, with the promulgation of the Anti-Degradation Rule. This rule required that the Commission **Designate** stream segments which had water quality better than Table Value Standards in 12 key parameters for Aquatic Life Class 1 and Recreation Class 1 as High Quality II. Degradation of the water quality in these segments would only be allowed if it was demonstrated that it was necessary to support important social and economic development in the area in which the waters were located. There was concern by the water development community that this would be a unacceptably difficult test to overcome.

Also at this time, the natural resource development community was becoming increasingly concerned with overlapping water quality regulations in many of the state agencies. There was a concern that they were being subjected to conflicting regulations, that the regulators were not really communicating with each other, and a desire to have the agencies most knowledgeable in their area more involved in the implementation of the regulations. There was also a concern that the Water Quality Control Commission and the Division were not adequately taking water rights issues into consideration in the development and implementation of regulations. As a counter to this, Senate Bill 89-181 was passed, recognizing the independent water quality authority of a number of state agencies within the Department of Health and the Department of Natural Resources. It required that these agencies develop Memoranda of Understanding with the Colorado Water Quality Control Division, to ensure that there be consistency in enforcement of water quality regulations. And, it also required that the Water Quality Control Commission consult with the Colorado Water Conservation Board and the State Engineer's Office on issues which might impact water rights.

It was the recognition of the independent authority of the State Engineer in water quality matters which has brought to a head the next round of water quality battles. While SB 89-181 explicitly did not enlarge upon any existing authorities, it did shine a light upon the State Engineer's responsibilities in the approval of non-decreed exchanges and substitute supply plans, and in Water Court proceedings pursuant to applications for decreed exchanges and plans for augmentation. As required by SB 89-181, the State Engineer's Office promulgated Rules and Regulations for the Implementation of Subsection 25-8-202(7) on February 4, 1992.

The original intent of the exchange and substitute supply plan statutes were to protect agricultural water supplies in municipal effluent exchanges, thereby ensuring that the water being delivered was still adequate to meet the uses for which it was originally intended. It was not meant as an anti-degradation policy, but was in fact, a recognition of the fact that agriculture water quality requirements are not as stringent as municipal water quality requirements.

We now however are seeing these statutes argued as a anti-degradation requirement, with the contention that any increase in Total Dissolved Solids (TDS) or salinity due to the proposed reservoir substitution represents an injury to the water right, and should not be allowed.

To understand this issue, it is necessary to place it in the context of the Colorado River Basin. In 1974, the seven Basin States of the Colorado River, in response to concerns by the Republic of Mexico, the water users in California and Arizona and under pressure by the Environmental Protection Agency, promulgated Numeric Criteria for Salinity in the Colorado River. These numeric criteria were established at the three mainstem stations on the Lower Colorado, below Hoover Dam, below Parker Dam, and at Imperial Dam. Additionally, in a 1972 minute to the Treaty with Mexico, a differential standard was established, whereby the United States agreed that the water delivered to Mexico be no more than 115 mg/l (+/- 30) greater than the water delivered to the last US user at Imperial Dam.

The numeric criteria which were so established are flow weighted average annual values, representing the quality in 1972 at these three stations. It was also recognized that temporary excursions from these criteria may occur, during periods of below normal flows. These would not be considered to be exceedences of the standards. There was an explicit desire to not establish standards at the state line of each of the basin states, (a proposal of the Environmental Protection Agency), because of the impacts this might have on an individual state's ability to develop its own compact entitlement. Instead, a national program was authorized and implemented through the Bureau of Reclamation and the Soil Conservation Service to identify the most economical alternatives to salt load reduction throughout the entire Basin. These alternatives are being implemented and funded through a combination of direct Federal appropriations, cost share from the Basin Hydro-electric Fund, and local cost share based upon direct benefit (if any) to the local entity.

Current estimates of the economic impacts of increased salinity to the water use in the lower basin range up to $200/acre foot/year of increased consumptive use in the Upper Basin, with costs of salinity control measures at $40 to $75/acre foot/year. Currently, these costs are costs which are borne by the Basin and the Nation as a whole, due to the dispersed nature of the impacts, the large amount of Federal land in the Basin, the international treaty implications, and the importance of the Colorado River to the Region and the Nation. Any requirement for individual new projects to offset the effects of their increased usage within the State would ultimately extend to a requirement to offset the impacts within the basin. This could potentially double the cost of developing new water supplies within Colorado, possibly making that development infeasible. A way must be found through this new water quality dilemma enabling Colorado to assure that in-state uses are protected without sacrificing our ability to develop the balance of our waters.

WATER MANAGEMENT AND ENDANGERED SPECIES PROTECTION IN THE UPPER COLORADO RIVER BASIN

Tom Pitts
Tom Pitts & Associates
Consulting Engineers
Loveland, Colorado

The potential for major conflicts between future water development and protection of four endangered fish species in the Upper Colorado River Basin resulted in a cooperative program to recover the species while water development proceeds. Cooperators include the U.S. Fish and Wildlife Service, Bureau of Reclamation, Western Area Power Administration, States of Colorado, Utah, and Wyoming, environmentalists, and the water development community. The Recovery Program includes protection of habitat under State water law, $3 million per year to fund a variety of recovery activities, and $50 to $75 million in capital projects (water acquisition, fish passages, hatcheries, refugia). Water depletion projects pay a one time depletion charge and receive a no jeopardy opinion under the Endangered Species Act, as the Program and the depletion charge offset jeopardy situations.

The Program is in its fifth year of operation. Emerging issues include flow protection for species vs. compact development, the adequacy of methodologies for fish flow recommendations, conversion of conditional water rights to instream flows, and the need for new approaches to instream flow acquisition and appropriation. Resolution of these issues requires continued efforts and innovation by Program participants. The 15 year program represents the best chance for resolving potential major conflicts between Federal environmental law and water development and management under State water rights systems.

PRACTICAL APPLICATIONS OF INSTREAM FLOWS IN COLORADO

Jay W. Skinner
Senior Water Resource Specialist
Statewide Instream Flow Program Coordinator
Colorado Division of Wildlife

Abstract

Various agencies of the Colorado Department of Natural Resources have sought to utilize the state's Instream Flow and Natural Lake Level Program to protect instream flows in federal permitting and land management activities. Over the past five years, the Colorado Division of Wildlife and the Colorado Water Conservation Board have attempted to have federal agencies such as the Federal Energy Regulatory Commission, the US Forest Service, the US Fish and Wildlife Service, and the Bureau of Land Management endorse the state's program and methodologies to protect instream flow values. This paper will examine four cases where the CWCB's program and/or its methodologies have been utilized, with varying degrees of success, in federal permitting or land management activities. The cases are: a FERC hydropower licensing effort, a USFS special use permit, the proposed Piedra Wilderness Area, and the Colorado River Endangered Fish Program.

Legal and Historical Background

In 1973 the Colorado General Assembly passed a law which for the first time recognized that a beneficial use of water could occur within the stream bed; in other words, a physical diversion from the stream was no longer required for a legal beneficial use. This new law formed the foundation for the Colorado instream flow program. Colorado's instream flow statutes can be found at CRS 37-92-102(3); the original language has been amended three times, in 1981, 1986 and 1987. The key phrases of the statutes are:

- "Further recognizing the need to correlate the activities of mankind with some reasonable preservation of the natural environment, the Colorado water conservation board is vested with the exclusive authority, on behalf of the people of the state of Colorado, to appropriate...such waters of natural streams and lakes as the board determines may be required for minimum stream flows...to preserve the natural environment to a reasonable degree."

- "Prior to the initiation of any such appropriation or acquisition, the board shall request recommendations from the division of wildlife and the division of parks and outdoor recreation."

- "The board also shall request recommendations from the United States Department of Agriculture and the United States Department of the Interior."

- "The board also ma acquire, by grant, purchase, bequest devise, lease, exchange, or other contractual agreement...water, water rights or interests in water..."

- "No other person or entity shall be granted a decree...for instream flows..."

- "The board shall determine that the natural environment will be preserved to a reasonable degree by the water available..., that there is a natural environment that can be preserved to a reasonable degree with the board's water right, if granted, and that such environment can be preserved to a reasonable degree without material injury to water rights."

- "Any appropriation based on water imported from one water division to another shall not...constitute a claim, bar, or use..."

- "Any appropriation shall be subject to existing uses and exchanges...whether or not confirmed by court order or decree."

- "Nothing in this article shall...deprive the people..of those waters available by law or interstate compact."

Since 1973, the Colorado Water Conservation Board (CWCB) has made instream flow appropriations on approximately 1300 stream segments totaling over 7300 miles. In addition, the CWCB holds minimum lake level decrees on 485 natural lakes. According to the Colorado Division of Wildlife's Stream and Lake Database, there are approximately 17,200 miles of intermittent and perennial flowing stream in Colorado and over 1300 natural lakes. With very few exceptions, all of these water rights were based on field data collected by the Colorado Division of Wildlife (CDOW). Based on that field data, the CDOW made flow recommendations to the CWCB for their formal approval and prosecution in water court.

Also in nearly every instance, the CDOW's instream flow recommendations to the CWCB have been based on the amount of water needed to protect a cold water fishery (i.e. salmonid fishes or trout). The CDOW and the CWCB view the presence of a healthy cold water fishery as a good indication or "yardstick" to measure the presence of a "natural environment"; if the CWCB appropriates enough water to protect the fishery, then the rest of the natural environment is also protected. The term "natural environment" was not defined in statute and it has always been the position of the CDOW that this was not an inadvertent omission; if credible scientific evidence can be developed where the CWCB can make the findings required by law ("that a natural environment exists ... and that the natural environment will be protected by the board's water right if granted"), then the CWCB has both the authority and the duty to file for the water needed to carry out their statutory mandate. The selection of the cold water fishery standard was one of convenience; there are about 11,000 miles of cold water streams in Colorado and much is known about the habitat requirements of trout.

The exceptions to the cold water fishery rule are on the eastern plains of Colorado where the CDOW identified critical and unique aquatic ecosystems that are sustained by flowing water and where without the flowing water these unique areas will cease to exist. The CWCB filed for water rights in 1974 and 1975 to preserve the natural environment on the Arikaree River, the North Fork of the Republican River and Chief Creek (all in Yuma County), and on Gageby Creek (in Bent County). The future for the instream flow program lies in the transitional (cool) water streams and in warm water streams where the fish species present include both game and non-game fishes. Some of these species need the protection of an instream flow water right now as their numbers are either unknown or declining and their habitat may be literally drying up.

Practical Applications

The Colorado instream flow program offers many different avenues where almost any instream flow value can be protected and where almost any player can get into the instream flow game. The program is set up to address almost any situation: where a private party or governmental entity may approach the CWCB with a request that an instream flow recommendation be pursued; where a private party or governmental entity may approach the CWCB with water, water rights, or interests in water to lease or donate to the CWCB for instream flow purposes; where a federal agency may seek to utilize the state's instream flow program to accomplish their land or resource management goals rather than pursue a controversial federal water reservation; and where any unique and/or critical instream value can be protected with an instream flow water right. The Colorado instream flow program can be and has been utilized to accomplish each of these goals. The balance of this paper will discuss some examples of the flexibility and applicability of the Colorado program.

FERC Relicensing - Two projects owned and operated by the Public Service Company of Colorado (PSCo) are currently seeking new licenses from the Federal Energy Regulatory Commission (FERC). Both projects are similar in that they both have operated since the early years of the 20th century, both are very small projects when you consider the whole PSCo system, and both have dried up significant reaches of stream for much of every year that they have operated. The Georgetown Project dries up approximately two miles of South Clear Creek and the Salida Project dries up approximately 5 miles of the South Arkansas River and about 0.6 miles of a tributary of the South Arkansas, Fooses Creek.

FERC's position on relicensing has changed; new regulations require FERC to consider both power and non-power resources (environmental concerns). As a result, PSCo has consulted with state and federal resource and land management agencies regarding these projects. The CDOW, the US Forest Service, and the US Fish and Wildlife Service have actively participated in the relicensing process. Since the major issue, as far as the resource agencies were concerned, was instream flows, PSCo's consultant (in close consultation with the resource agencies) conducted instream flow studies on the affected streams. The resource agencies reviewed and commented upon the results of the studies and have spent the better part of the last 18 months trying to negotiate appropriate instream flows with PSCo. While these negotiations are still on-going, it appears that some instream flow bypass will be required in each of the two projects. When that occurs it may be necessary to involve the CWCB's instream flow program to make sure that the water that is bypassed stays in the stream. A bypass is just that, once the water passes the point of bypass it is legally available to the next water right on the stream; the only way to protect water in the stream from diversion in Colorado is through the state's instream flow program.

Colorado Wilderness Areas - Many believe that the reason the federal government was invited to play in the Colorado instream flow game was to offer the federal land management agencies an opportunity to work within Colorado's water right system to accomplish their land management objectives. This, in the opinion of the state's "water community", is far better than the federal government asserting a federal reserved water right. In the 1986 amendments to CRS 37-92-102(3), the agencies of the US Departments of Agriculture and Interior were invited to participate in the state's program. Many believe that the goal was to break the log jam on Colorado wilderness designation. Unfortunately, here we are in 1993 and the Colorado wilderness log jam is still alive and well. This is not to say that the state's program can not and will not ever be utilized to protect wilderness instream flows. The most recent attempts at Colorado wilderness legislation have, to varying degrees, utilized the Colorado instream flow program.

The most recent Colorado wilderness bills have sought to designate as wilderness several areas downstream of both private property and private water rights. In these cases some of Colorado's congressional delegation have tried to use the CWCB's program as a way to see that these wilderness areas are designated while still protecting both the water rights that exist and the future potential to develop water on those upstream areas. As of this writing the jury is still out on Colorado wilderness designation but the potential still exists that the state's instream flow program may be the answer to these "downstream" wilderness areas.

Many of the same water rights issues persist in the designation of wild and scenic rivers in Colorado. In a similar fashion to that described above, the CWCB's instream flow program may hold a relatively easy solution to the designation of wild and scenic rivers in Colorado.

Recovery of the Colorado River Endangered Fish - The Recovery Implementation Program for the Endangered Fish of the Upper Colorado River Basin (RIP) is a multi-party, multi-state, multi-agency effort to recover four endangered fish species while allowing water development in the basin to proceed. One of the major pieces of the foundation of the RIP is the provision of sufficient instream flows to recover the fish. The RIP states that in Colorado, the way that this will be accomplished will be through the CWCB and their instream flow program. The challenge that this aspect of the RIP offers has proven to be quite rigorous.

The problems associated with the study of rare, highly migratory fish in large, turbid rivers are both numerous and complex. The CWCB has requested instream flow recommendations from the US Fish and Wildlife Service (FWS) for the critical habitat reaches for the listed fish. Since the fish are so rare and so mobile, and since the rivers in which they live are so large and turbid, studying these fish is a very difficult task. A large amount of information is needed to gain a general understanding of the four species' habitat requirements and life cycle needs; in other words, at the time that the RIP was initiated very little was known about these fish. After over five years of intense study of the endangered fish, there are still significant information gaps.

The experts feel that several factors have impacted the fish; the Colorado River basin has been forever altered by the activities of mankind. The river's flow, temperature, and sediment regimes have been altered by water development and the river's morphology has been altered by channelization and by the changes in flow and sediment. The flow recommendations that have been submitted by the FWS essentially seek to restore a natural hydrograph in both shape and magnitude recognizing of course the limitations of the existing system (existing senior water rights, large federal water projects, and existing transmountain diversion projects). There continues to be considerable disagreement among the RIP participants over the instream flow recommendations and the methodologies utilized by the field biologists to arrive at the flow recommendations. Whether these flow recommendations are challenged from a technical standpoint in water court remains to be seen.

The CWCB has moved forward on an instream flow appropriation for the 15 miles of the Colorado River just upstream of Grand Junction, Colorado for the months of August, September, and October. The FWS biologists recommended an instream flow of between 700 and 1200 cubic feet per second (cfs) to maintain 90% of the adult Colorado squawfish habitat. The CWCB found that only 581 cfs was available for an instream flow appropriation and have filed for that amount in water court. Additional hydrologic studies and/or water acquisition will be required to increase this instream flow up to the full amount recommended by the FWS.

Instream flow studies and recommendations on other river segments utilized by the endangered fish are on-going and will eventually be transmitted to the CWCB for final action. The jury is still out on the success of the RIP but the Colorado instream flow program is and will continue to be crucial to the program's success.

Other Federal Actions - The Colorado instream flow program has been utilized in the National Environmental Policy Act (NEPA) process as well and with a fair amount of success. In 1986, a series of agreements were signed by the State of Colorado and several ski areas and water providers on the western slope. The most important of these agreements were with Keystone Ski Area, Breckenridge Ski Area, Copper Mountain Ski Area, and the Vail Valley Consolidated Water District. Each of these entities were seeking to contract for water from a federal (Bureau of Reclamation) facility, Green Mountain Reservoir. The water was to be used primarily for snowmaking purposes. All of these water service contracts involved upstream exchanges of water. Snowmaking is a rather unique type of water use in that it occurs during the winter when stream flows are naturally at their lowest and it is a use of water that is 100% consumptive for all practical purposes (the water does return to the stream but not for a long time). The Green Mountain Water Sales Environmental Impact Statement identified these upstream exchanges of water to snowmaking uses as having adverse impacts on the environment. For the water sales to move forward these environmental impacts had to be mitigated. This is where the instream flow program came into play.

The ski areas and the CWCB and the CDOW developed terms and conditions which utilized instream flow amounts (without regard for their water right seniority relative to the ski areas' water rights) as thresholds for mitigation. The agreements differed from one another based on the diversion configuration, the fishery resource, and the habitat conditions. Most of the agreements were sequential in nature in that certain operational or mitigation activities were triggered by different flow amounts. For example, one agreement (Keystone Ski Area) required initial habitat improvement with annual fish stocking requirements along with flow levels which trigger altered diversion rates and curtailment of diversion. Another agreement (Breckenridge Ski Area) sets flows where operational constraints are initiated, where mitigation (fish stocking) is required and where diversions are curtailed. Still another agreement (Vail Valley) required the construction of a small reservoir upstream of the snowmaking diversion to directly replace a portion of the snowmaking diversions.

This is only one example of the Colorado instream flow program's potential to protect instream flow values in the NEPA process. The real advantage to utilizing this approach is that stream ecosystems are protected while water use continues. In many cases, the protection that the stream receives is more than that which the water right priority system would provide while at the same time allowing for sensible water use.

Conclusions

Many feel that the Colorado instream flow program does an adequate job protecting Colorado's streams. The CWCB must balance its duty to encourage water utilization with its duty to protect the natural environment to a reasonable degree. This is not an easy task as water resource issues in Colorado are very volatile and politically charged. The Colorado instream flow program has an unlimited number of tools whereby instream flow values can be protected. The Colorado instream flow law is sufficiently broad that one is only limited by science on one hand and one's imagination on the other.

THE ARKANSAS HEADWATERS RECREATION AREA

A SUCCESS STORY;
THE ARKANSAS HEADWATERS RECREATION

Steve Reese
Colorado Division of Parks and Outdoor Recreation

The Arkansas River is acknowledged as a premier recreation river in the United States. It is one of Colorado's outstanding natural resources.

The Arkansas River from Leadville to Pueblo (148 miles) has international, national, and statewide recognition for whitewater boating, and is also widely known for fishing. Sightseeing is extremely popular, for the Arkansas River lies adjacent to the Collegiate and Sangre de Cristo mountain ranges, in the Royal Gorge, and along Highways 24, 285, and 50, all of which are primary tourism routes in Colorado.

The Arkansas Headwaters Recreation Area (AHRA) is a 2-3 hour drive away from over 2 million Front Range residents. The Arkansas River passes through 4 counties, 6 cities, and several small communities.

Sixty percent of the river here is through private lands, while 30 percent runs through Bureaqu of Land Management lands and 10 percent runs through other agencies.

On the Arkansas boating has increased by an average of 19 percent per year from 1982 to 1990. There is more whitewater boating on the Arkansas River than on any other river in the United States, and more whitewater boating than on all other Colorado rivers combined. There were more than 233,000 visitors who enjoyed a whitewater boating experience in 1992.

Hunting, hiking, fishing, sightseeing, camping, and picnicking have increased dramatically and continue to do so. During the summer of 1992, total visitation was over 388,000.

Tourism and recreation have become leading industries in Colorado. "Peak to peak" the AHRA consists of outstanding resources and recreation opportunities with a very strong regional impact. Total statewide economic impacts of AHRA use are in excess of $30 million annually.

Because of all this, recreation management and resource protection are critical issues, and working in partnership with these communities, landowners, and user groups is essential.

Today, the AHRA is managed jointly by the Colorado Division of Parks (DPOR) and the Bureau of Land Management (BLM). The Arkansas River Recreation Management Plan is in place and is being implemented. As a result, there is now a single entity which is dealing with the entire area as a whole. Issues which have long existed and those which come up daily are now being addressed. Facility improvements and site acquisitions identified as essential are being dealt with.

Locally, regionally, and statewide, the management of the AHRA has significant impacts to area residents, the visitors, the resource, and the state economy.

THE ARKANSAS RIVER: AN ANALYSIS OF RIVER BASED RECREATION ISSUES

Robert B. Naeser
AquaSan Network, Inc.
1101 W. Mineral Ave. Suite 260
Littleton, CO 80120

Abstract

This case study uses two contingent valuation surveys (anglers and private boaters), in conjunction with information about commercial rafting, to evaluate river based recreation on the upper Arkansas River. The primary purpose of this study was to look at the economic impact of the three primary use groups (anglers, private boaters and commercial rafters) on the upper Arkansas River Valley. The commercial rafters had the greatest impact, followed by private boaters and anglers.

Secondarily, the study looked at the various river use issues. The CV surveys provided insight into the opinions of these use groups concerning current river management problems. The majority of respondents believed that commercial rafting on the Arkansas should be limited. They were in favor of a more holistic management style that would improve the experience for all users.

Introduction

The headwaters of the Arkansas River are in the snow-capped peaks of the Collegiate Range near Leadville, Colorado. From there it drops through numerous canyons and high mountain valleys before entering Pueblo Reservoir, 141 miles downstream. The section of the river between Pueblo Reservoir and Leadville is referred to as the upper Arkansas River.

Outstanding kayaking, whitewater rafting and trout fishing are available on this part of the Arkansas River. The upper Arkansas is recognized as one of the premier recreation rivers in the United States and the world. The popular river recreation sections lie within a two to three hour drive for Colorado's tow million plus Front Range residents. The River flows immediately west of Pueblo and an hour southwest of Colorado Springs. Denverites can reach the upper portion of the river within two and one-half hours drive. The close proximity of the river to the metropolitan areas of Denver, Colorado Springs and Pueblo makes for a convenient day, or weekend trip for recreationists living in these areas. They do not have to set aside a large block of time and money to enjoy the river experience.

The increasing popularity of recreation on the Arkansas, and growing off-stream demands, necessitates an economic valuation of Arkansas River recreation. Placing a monetary value on river recreation will provide a gauge from which to measure the value of recreation as compared to the other demands for the river's water.

This study of recreation on the Upper Arkansas River looks at the opinions of the three primary Arkansas River use groups (anglers, private boaters and commercial rafters) concerning current issues facing the river. In addition, the economic impacts that these three use groups have on the communities of the Upper Arkansas River are addressed.

Method

In order to conduct this research, I designed two contingent valuation surveys. The surveys were administered to members of the Colorado Whitewater Association (CWWA) and the Pikes Peak Chapter of Trout Unlimited. The surveys explored what members of these two groups are willing to pay to use the river and their opinions concerning various issues surrounding recreation on the Arkansas. The information on commercial rafting comes from a senior thesis authored by a colleague of mine, Julie M. Johnson.

River Use Issues

The popularity of whitewater boating on the Arkansas River has increased tremendously over the past decade. From 1979 to 1987, total boating use has increased from 22,220 user days (a "user day" is one person engaged in recreation for all or part of a calendar day) to 116,488 user days. Commercial use increased from 18,518 in 1979, to 93,190 in 1987. Private boater use of the Arkansas increased by 629% from 3,704 to 23,298 for the same period. The Arkansas River is expected to reach its maximum carrying capacity within five years.

The increasing number of boats found on the river has caused speculation about the future of recreation on the Arkansas. River users are at odds about how the river should be managed. Several conflicts have arisen between the three groups.

Private Boaters v Commercial Rafters

The private boaters are scared off by the increasing number of commercial rafts in the more popular sections. Bumper to bumper raft traffic, on weekends, decreases the enjoyment of the whitewater experience. The threat of being run over by a raft, not being able to "play" in waves and holes, is driving boaters away from the Arkansas in search of less crowded rivers. The private boater feels like he/she has been squeezed out of certain sections, namely Browns Canyon.

Anglers v Whitewater Boaters

During the summer of 1991, the Arkansas River outfitters asked the Bureau of Reclamation (BuRec) to extend releases from the Twin Lakes dam through August 15, 1991. In a normal season, the flow regime of the Arkansas is such that water levels drop below 400 cfs at the end of July. This flow is too low for commercial operations and their season is finished. The BuRec agreed to this proposal and guaranteed a minimum of 750 cfs through August 15, thereby extending the commercial season by an extra three weeks.

Trout Unlimited opposed flow augmentation on the grounds that it destroys the fish habitat. They sued the BuRec to stop releases from Twin Lakes after August 1. After a number of stays Trout Unlimited won and the water was shutoff at midnight of August 13, 1991. This action heightened the tensions that already existed between anglers and commercial rafters.

In addition to the flow augmentation issues the anglers would like to see all types of whitewater boating limited. The anglers claim that boating scares the fish away and ruins his/her experience. The large number of boats coming down the river interferes with the continuity of the experience. The angler is sometimes forced to stop casting and wait for boats to pass. "It is difficult to enjoy the solitude of the river with screaming hordes passing by, each and every person asking if you've caught anything."

The Economic Impact of Recreation on the Arkansas River

Recreation on the Arkansas provides revenue for the communities situated along the river. In order to determine the value of private whitewater boating and fishing a question was included on the survey asking the average expenditure for one day of Arkansas River recreation. These values for survey respondents were then averaged and multiplied by the total number of users (either anglers or private boaters) for the entire 1991 season. This figure was multiplied by 2.56, which is the travel expenditure multiplier provided by the Colorado Tourism Board, to derive an estimated economic impact to the communities along the river.

The average private boater spends $51.00 per day on an Arkansas River excursion. This average boater makes 6.6 trips per year to the river. In one season they will spend $337.00 on Arkansas River whitewater recreation. From May through September of 1991, 17,764 private boaters (7% of all whitewater trips last season) used the Arkansas River. The direct impact of the money spent by these boater is $905,964.00. When this value is multiplied by 2.56, the total economic benefit from private boating is $2,319,268.00.

The anglers surveyed spent an average of $34.57 per day fishing. Out of that amount approximately $16.84 was spent in the Arkansas River Valley. This amounts to slightly more than half of the daily fishing expenditure being spent in the communities along the Arkansas. In the summer of 1987, the Arkansas River had 23,330 fishing days. For this season anglers had a direct impact of $392,877.00. After multiplying by the recreation multiplier the total economic impact of angling on the upper Arkansas amounts to $1,005,766.00.

The total economic benefit of commercial rafting was obtained by taking the average total per person expenditures for a day of commercial rafting in Colorado and multiplying this figure by the total number of customers guided down the river. For 1991, this figure was $73.98 per day. IN 1986, a Public Information Corporation study generated a figure of $61.50 per day of rafting and this was converted into 1991 dollars to obtain the amount of $73.98. For the 1991 season, 163,047 customers participated in raft trips down the Arkansas for a direct impact of $12,062,957. When this amount is multiplied by 2.56, the total economic impact of commercial rafting is $30,881,170.

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ALTERNATIVES FOR GROUNDWATER BASIN MANAGEMENT

CONJUNCTIVE SURFACE AND GROUND WATER USE THROUGH DEEP BEDROCK AQUIFER INJECTION AND RECOVERY

Bruce A. Lytle[1]
Khanh T. Le[2]
John C. Halepaska[3]

INJECTION/RECOVERY CONCEPT

The Front Range area of Colorado is characterized as a semi-arid region, with less than 15 inches of rainfall on the average per year. The principal water supplies for the Front Range area are provided through surface flows that result from snow melt runoff in the mountains to the west, and from a large bedrock ground water basin along the Front Range, known as the Denver Ground Water Basin. The volume of water available in the surface streams along the Front Range is quite variable on an annual basis due to variability of mountain snowpack. In addition, Denver Basin ground water users, such as the Willows Water District, have experienced the lowering of the potential surface in the Denver Basin aquifers by as much as 30 feet per year.

Most of the use of the surface water supplies and the Denver Ground Water Basin supplies along the Front Range is for municipal use. Due to the semi-arid nature of the region, municipal demands are quite skewed on a monthly basis, characterized by extremely high summertime peak demand periods (Figure 1). Conversely, base flows in the wintertime represent a very small portion of the overall annual municipal demand (Figure 1). Because of these factors, municipal entities are required to provide installed capacity, i.e. wells, treatment plants, pipeline sizing, etc., to meet the peak summertime demands, which results in many of these facilities either being idle, or operating at a reduced capacity, during much of the year.

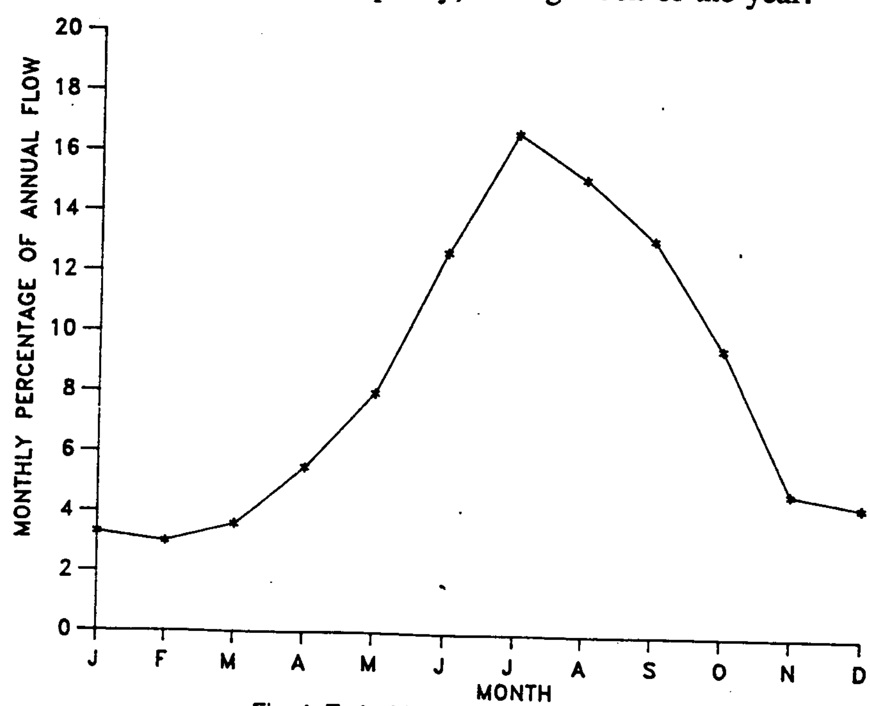

Fig. 1–Typical Monthly Municipal Demands

The concept of injection storage of surface supplies in the bedrock aquifer with subsequent recovery was conceived because (a) excess surface water flows are frequently available during the wintertime months, and early spring months, when municipal water demands are low, (b) municipal wells are idle during the wintertime months, as they are not necessary to meet base water demands, and (c) increased efficiency in use of available surface water supplies slows the depletions on the Denver Basin aquifers.

The concept of deep bedrock aquifer injection storage is that excess surface water supplies can be diverted, treated and injected through existing municipal production wells at times when all of these facilities can handle the excess flows. These supplies would then be stored in the bedrock aquifer until such time as the demand for this water is required, eg. a dry cycle where surface water supplies are limited or during peak demands.

This concept was presented to the United States Bureau of Reclamation as part of the High Plains States Ground Water Demonstration Project and received funding for a 5-year research and development project. The co-sponsors for this project are the Willows Water District (District) and Denver Water, with the District providing the well facility for injection and Denver Water providing the potable surface water supply.

EVALUATION OF TECHNICAL ISSUES

Hydraulics

As part of the Bureau of Reclamation research and development project, Denver Water potable surface water supplies are being injected into an existing District Arapahoe aquifer production well (A-6A), completed to a depth of 1,500 feet, with a production interval of 1,000 to 1,500 feet. A schematic showing the general completion details of the well, including injection piping, is shown in Figure 2. Injection rates to date have ranged from 400 to 600 gallons per minute (gpm), and injection run durations have varied from 1 week to 3 weeks.

The procedure for injection is cyclic whereby, first, surface water is injected for a period of time to evaluate the hydraulic response in the well, i.e. head buildup with time. Then, at various points on the head buildup curve, the injection is stopped, and a pump cycle is conducted to clean the well and aquifer face so that injection efficiency can be maximized. Thereafter, injection recommences and the cyclical process continues. To date, approximately 170 ac-ft of water have been injected into the Arapahoe aquifer and stored with an overall efficiency of 97 percent (total volume of water injected minus total volume of water pumped divided by the total volume of water injected).

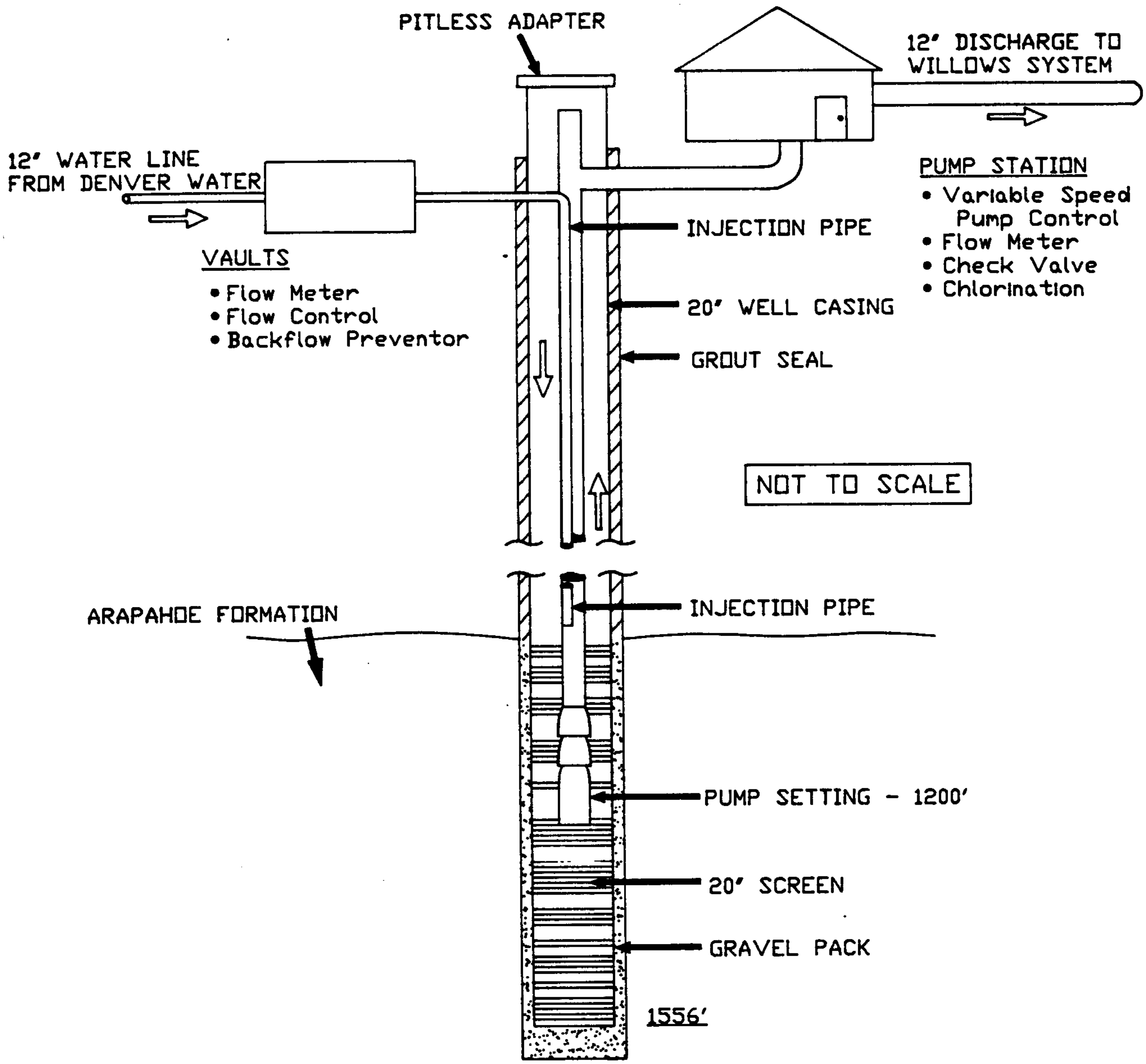

Fig. 2–Well A-6A Injection Well Schematic

During injection, head builds up in the well at a rate greater than would theoretically be expected (Figure 3). This phenomenon may be related to one, or more, factors, including: (a) higher head losses with water flowing out through the screen, (b) fines buildup causing minor plugging of the screen and/or matrix, (c) thermal gradients between the aquifer water and the source water, (d) entrained air in the source water and/or (e) bio-plugging caused by increased biological activity.

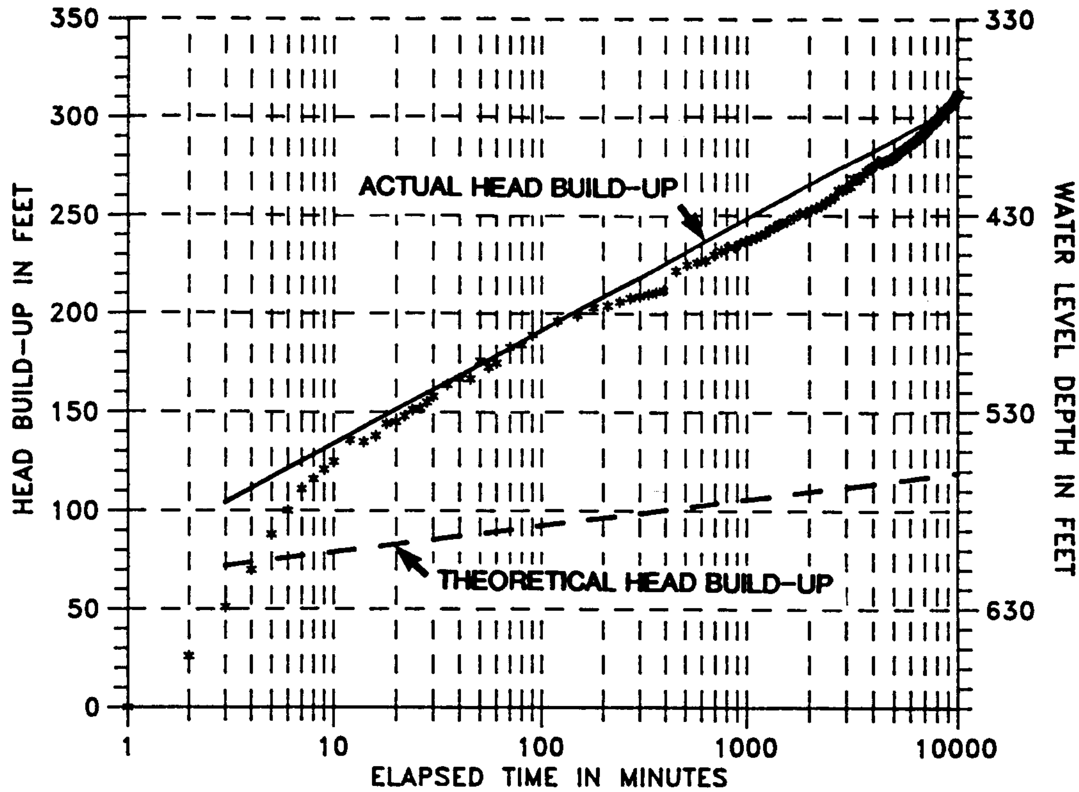

Fig. 3–Comparison of Theoretical to Actual Head Buildup

As part of this project, a monitoring well was constructed approximately 100 feet from the injection well to monitor head buildup at a remote location and to monitor water quality in the aquifer. Observed head buildups at the monitoring well (M-1), compared to head buildups in the injection well, are shown in Table 1.

TABLE 1
HEAD BUILDUP DATA

Injection Run	Head Buildup (ft) at A-6A	M-1	Length of Run (days)
IR-1	164.	34.	7.
IR-2	212.	37.	14.
IR-3	180.	---	7.
IR-4	172.	---	7.
IR-5	162.	28.	21.
IR-6	314.	40.	7.
IR-7	307.	47.	7.
IR-8	365.	49.	14.

Water level response at well M-1 is quite rapid, indicative of confined aquifer conditions. Typically, water level changes are observed at M-1 within 3 minutes of the initiation of injection (Table 1).

Regardless of the head buildup in the injection well, or the duration of the injection run, the subsequent pump cycles appear to be relatively insensitive to these factors. Typically, the pump cycles have been of approximately the same duration under varying injection and head buildup conditions (approximately 3 hours). In addition, discharge from the injection well during the pump cycles typically clears in less than 30 minutes.

Since injection is similar to the development of a well, the injection process may mobilize fines within the aquifer matrix that could create subsequent problems during pumping of the production well. This potential is measured in terms of sand production at the injection well during each pump cycle. During this project sand production during pumping has been monitored with the use of Rossum meters and information to date indicates that no appreciable sand is being produced as a result of the injection process.

From a hydraulic standpoint, the Arapahoe aquifer is capable of receiving large volumes of injected water and no unanticipated problems have been encountered during the injection/pump cycles conducted to date. Injection rates are expected to be increased to 1,000 gpm (approximately 2/3 of the well's current production rate) during the latter years of the study.

Water Quality

During each of the injection runs, weekly water quality samples are obtained from the source water to evaluate the quality of the injection water. Additionally, between each injection run and pump cycle, water quality samples are obtained from monitoring well M-1 to assess potential water quality changes in the aquifer matrix at a remote point from the injection well. Water quality samples are also obtained from the injection well during each of the pump cycles.

The major areas of concern related to water quality are (a) shifts in major ion concentrations, which may indicate precipitation and subsequent clogging, (b) specific metal ions that may oxidize due to the presence of chlorine and/or dissolved oxygen and precipitate, causing clogging, (c) biologic parameters related to potential growth in the well due to the introduction of highly oxygenated surface water that could plug the well screens and (d) total trihalomethanes (THMs) which may be formed during the chlorination process at the treatment plant and be introduced to the Arapahoe aquifer through injection. The parameters tested to evaluate these issues are shown in Table 2.

TABLE 2
SELECT WATER QUALITY PARAMETER LIST

Calcium	Carbonate	Total Dissolved Solids
Magnesium	Bicarbonate	Total Suspended Solids
Sodium	Sulfate	Turbidity
Potassium	Chloride	Total Coliforms
Iron[1)]	Fluoride	Heterotrophic Plate Count
Manganese[1)]	Silica	Total Trihalomethanes
	Sulfide	
	Nitrate+Nitrite	
	Ortho-Phosphate	

1) Analyzed for both dissolved and total concentrations.

On a quarterly basis, a more complete water quality analysis is conducted of the source water, the monitoring well discharge and the injection well discharge. These analyses include a complete inorganic parameter list, as well as volatile organics.

Field water quality parameters (pH, Eh, specific conductance, dissolved oxygen and temperature) are monitored on a continuous basis during both the injection runs and the pump cycles by the use of a Martek 15 flow cell.

Water quality analyses to date indicate no significant shifts in major ion concentrations that would indicate that the chemical equilibrium had been disturbed. Additionally, the introduction of chlorinated water into the injection well has not resulted in any appreciable introduction of total trihalomethanes (THMs) into the aquifer matrix. However, the introduction of chlorinated water into the injection well may be resulting in limiting biological activity in the well, as no appreciable increases in biological activity have been noted to date as a result of the injection process.

The one water quality change that has been observed as part of this process is an increase in total iron concentrations in the injection well after some injection runs. Figure 4 shows the total and dissolved iron concentrations that have been observed with time in the injection well. It is not known at this time if these increases in total iron concentrations are related to oxidation of the well casing itself, whether there is some oxidation of iron compounds in the aquifer matrix, or whether there is bottle contamination or lab error. It should be noted that the dissolved and total iron concentration at the injection well prior to all injection was near the drinking water standard for iron (0.24 mg/L versus a standard of 0.3 mg/L dissolved iron). With the exception of one injection run (IR-6), iron concentrations remained below the drinking water standard.

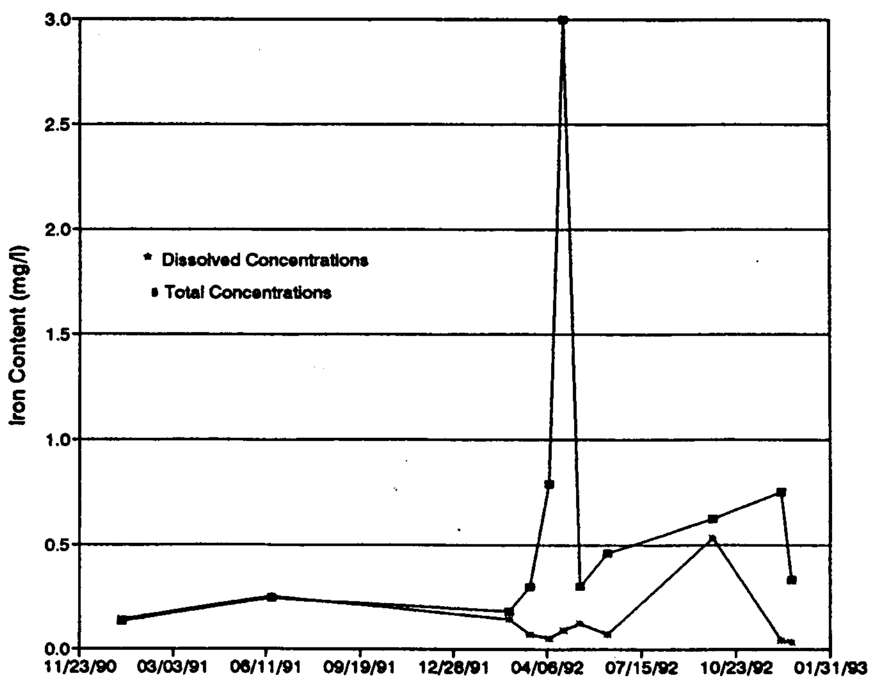

Fig. 4–Iron Concentration at A-6A versus Time

There do not appear to be significant water quality changes occurring as a result of the injection process and it is not currently believed that water quality considerations will be a factor in determining the long-term success of an injection and recovery process.

EVALUATION OF LEGAL ISSUES

The principal issue related to injection storage with subsequent recovery will most likely not be related to technical issues, but will focus on the legal issues under Colorado Water Law. There currently are no statutes related specifically to artificial recharge and its subsequent recovery and use.

The Colorado Division of Water Resources is a participant in this 5-year research and development project and preliminary discussions have been held with Division staff on how to evaluate the legal issues.

The principal issues that need to be resolved include:

(a) how credit will be determined for water stored in the aquifer, i.e will losses be assessed;

(b) how long can water be stored before subsequent recovery and beneficial use;

(c) what pumping, volumetric and spacing limitations need to be placed on injection recovery wells;

(d) can water be injected at one location and extracted at another location without injuring intervening water rights; and

(e) how will the above issues change based on whether the receiving aquifer is confined, semi-confined or unconfined.

The project participants are currently in the process of developing a model to evaluate these points, and it is envisioned that the results of this model would be used as the basis for preparing rules and regulations related to injection storage in the bedrock aquifers of the Denver Ground Water Basin with subsequent recovery and beneficial use of these waters.

The ultimate goals of the conjunctive use concept for injecting surface waters into deep bedrock ground water aquifers is that excess surface water supplies would be injected in these aquifers during wet years, stored until a dry year cycle occurred where surface water supplies would be limited, and then extracted for beneficial use to supplement limited surface water supplies. Since there are no losses from storing water in the aquifer, the amount of water that could be recovered should be related to the net injected volume.

Storage of water in the Denver Ground Water Basin aquifers provides for efficient storage, while also making surface water and ground water facilities more efficient by increasing their usage during off-peak times. Efficient use of surface water supplies through a conjunctive use program also slows the depletive effect on the Denver Basin aquifers. The results of this 5-year study will hopefully provide answers as to whether this concept can become reality on a full-scale, operational basis.

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1) Senior Project Engineer and Associate, John C. Halepaska and Associates, Inc.
2) District Manager, Willows Water District
3) President, John C. Halepaska and Associates, Inc.

GROUND WATER MANAGEMENT IN COLORADO THROUGH WELLHEAD PROTECTION

Gordon McCurry, Hydrogeologist
Camp Dresser & McKee Inc.
1331 17th Street, Suite 1200
Denver CO 80202

Kathleen Reilly, Director
Wellhead Protection Program
Colorado Department of Health
4300 Cherry Creek South Drive
Denver, CO 80222

Abstract

Ground water is the principal source of municipal water in over 550 public supply systems throughout Colorado. A key to successfully managing ground water supplies is to minimize the potential for aquifer contamination. This can be accomplished by developing and implementing a wellhead protection program, which focuses on protecting water quality in the recharge area surrounding a supply well. Wellhead protection programs were formally developed as part of the 1986 Safe Drinking Water Act Amendments, wherein States were required to develop EPA-approved plans to protect their municipal ground water supplies. Wellhead protection programs include seven components: identifying all entities with a role in carrying out the plan and designating a lead entity, mapping out the recharge area of a well or wellfield, identifying potential contaminant sources within the delineated recharge area, developing management approaches for the potential contamination sources, formulating contingency plans, involving the public, and applying these concepts to siting new wells. Colorado has decided to take a non-regulatory approach toward implementing wellhead protection programs. The State anticipates EPA approval of its plan in early 1993, making it one of the few Western states with an approved wellhead protection program plan. The rationale behind and details of the State's wellhead protection program guidance are discussed. Approaches taken by several municipalities in implementing wellhead protection programs in Colorado are reviewed.

Introduction

Ground water is used as a source of municipal drinking water throughout Colorado. As of 1992, approximately 428,000 of the State's 3.5 million residents are served by one of the public ground-water supply systems that exist in the State; another 100,000 or so use private wells (Colorado Department of Health, 1992). When used carefully ground water is a high-quality, consistent source of long-term municipal supply. Although most of Colorado's 557 public supply systems are quite small, serving fewer than 3,300 people, the economic stability of the communities which utilize ground water are closely tied to the minimal treatment costs that they currently enjoy. As has become readily apparent in the last decade, once ground water supplies become contaminated they have proven to be very difficult, if not impossible, to clean up (EPA, 1989b). Protecting aquifers from contamination is therefore becoming an increasingly important aspect of managing municipal ground water supplies.

The federal Environmental Protection Agency (EPA) has also recognized the importance of protecting and preserving ground water quality. As part of the Safe Drinking Water Act (SDWA) Amendments of 1986, the EPA formulated a preventative concept aimed at protecting public ground water supplies from contamination. This concept, termed wellhead protection, focuses on protecting water quality in the recharge area surrounding a supply well. Under Section 1428 of the SDWA Amendments, each State is required to develop a plan for wellhead protection that contains seven components prescribed by EPA. The EPA has oversight and approval authority for the development of State wellhead protection plans, but has given individual States reasonable latitude in developing their plans due to the unique combinations of ground water use, types of aquifers and hydrogeologic settings that exist from State to State. Individual municipalities or other public suppliers are to develop their plans based on their respective State plan, and will receive approval from the State agency that is in charge of administering the wellhead protection program. Given the small size of most of the public ground water supplies and in keeping with the State's traditional individualism, Colorado responded with a voluntary, non-regulatory approach to wellhead protection. Many other Western States have taken a similar approach, including Nebraska, Montana, North Dakota and South Dakota.

Components of a Wellhead Protection Plan

The EPA guidelines specify seven basic elements that are to be included in a State wellhead protection plan. These are described below, including the approach Colorado has taken to satisfy each of the requirements.

1. Define Individual Roles. The EPA requested that all entities with a role in carrying out the State wellhead protection program be identified, that a lead agency be appointed, and that the duties of all other entities be defined. Colorado has divided its responsibilities between water quantity and water quality. The primary agency responsible for administering ground water supply is the State Engineer's Office of the Department of Natural Resources, Division of Water Resources. The primary agency that administers aspects relating to ground water quality is the Ground Water Unit of Department of Health, Water Quality Control Division. This latter division is the lead agency for the wellhead protection program and is responsible for developing and implementing the State plan. Numerous other State, local and private agencies have some involvement in ground water within Colorado. Their role will be to exercise their authorities to protect public ground water sources of drinking water.

2. Delineate Wellhead Protection Areas. Wellhead protection areas were defined by the EPA as "the surface and subsurface area surrounding a water well or wellfield, supplying a public water supply system, through which contaminants are reasonably likely to move toward and reach such water well or wellfield" (SDWA, 1986). The EPA provided many options for delineating the wellhead protection areas, including using criteria based on distance, aquifer drawdown, time of travel, flow boundaries or assimilative capacity of the aquifer (EPA, 1987).

Colorado approached this task by evaluating the types of aquifers present in the State. The distinct types of aquifers that were identified are unconfined, confined, and fractured. The State determined that for unconfined and confined aquifers, a delineation method based on the time of travel would yield wellhead protection areas that incorporate the most important aspects of ground water flow and aquifer hydraulics in the different regions of the State. The State wellhead protection plan recommends that a minimum five year time of travel criteria be utilized for unconfined and confined aquifers, assuming that the contaminants will migrate at the same rate as the ground water. This means that aquifer contaminants located at the periphery of a wellhead protection area will take five years, under continuous pumping at the maximum rate, to reach the supply well. Delineation criteria for fractured aquifers will be decided on an individual basis, often using surface water drainage basin boundaries and fracture mapping concepts to establish the wellhead protection areas.

3. Identify Potential Contaminant Sources. This element calls for the public water supplier to inventory the actual and potential contaminant sources located within or close to the wellhead protection area. The EPA has provided lists of business and facility operations that could lead to ground water contamination. The potential contaminant sources could range from agricultural operations to Superfund sites, so the specific operations and land uses within a given town and its wellhead protection areas should determine the types of operations that need to be inventoried. The inventory is often undertaken by conducting a door-to-door survey within the delineated wellhead protection areas, often using community service and/or school groups. The surveys are augmented by obtaining listings of underground storage tanks, CERCLA sites and accidental spill reports from the County or State Health Departments. The results are plotted on maps which show the delineated wellhead protection areas to allow for further evaluation.

Common business operations in Colorado that pose a threat to ground water quality include underground storage tanks at corner gas stations or industrial facilities, auto repair shops, dry cleaners, town landfills, fertilized and irrigated farmland, and household septic systems. The State has developed a generalized listing of potential contaminant sources and a sample questionnaire that could be used.

4. Develop Management Approaches. The information obtained through the contaminant source inventory is used along with existing management programs to develop new approaches to protecting the water supply within the wellhead protection areas. The EPA offers many suggestions for controlling pollution sources, including having the water supplier implement a household hazardous waste collection program, develop zoning and subdivision ordinances to restrict or prohibit certain land uses, work with industrial facilities to upgrade and enforce operating standards and develop waste minimization programs, and to purchase property or development rights to key parcels of land (EPA, 1989a). The public water supplier can and should make full use of existing Federal, State and County antidegradation regulations and ordinances in developing a wellhead protection management strategy. Management approaches should also include ground water monitoring within the wellhead protection area, and a concerted public education program.

Colorado's approach to managing and controlling contaminant sources recognizes the differences and limitations among the ground water suppliers, and advocates simple, cost-effective approaches that build upon existing methods and programs at all levels of government. Applicable regulations in Colorado include zoning and land use restrictions; set back requirements around public supply wells; the 1990 Farm Bill (SB 90-126), which promotes the proper and correct use of pesticides and commercial fertilizers; and Federal/State regulations on CERCLA, RCRA, UST; and State Sewage Sludge Application and Ground Water Quality regulations. Non-regulatory approaches which the State plan recommends include public education, land acquisition environmental easements, intergovernmental agreements, and ground water monitoring.

5. Formulate Contingency Plans. The EPA stresses the importance of this activity, since it can help avoid or minimize interruptions in water service in the event of an emergency. Aspects recommended by the EPA are that the public water supplier define the major water supplies, routing mechanisms, and weak links in the distribution system, develop emergency response plans for both water supply and water quality disruption, establish criteria for implementing the emergency response plans, and

clearly identify the parties responsible for implementing the plans. The level of effort expended in developing contingency plans is related to the size of the public supply system, the vulnerability of the system to disruption, and the existence of backup supplies. Water suppliers should prepare for both short-term (emergency) disruptions, due to accidental spills or line breaks, and long-term disruptions due to insufficient supplies. Contingency plans should incorporate existing local emergency response plans and State contingency plans.

6. Site New Wells. The EPA requests that the wellhead protection concepts discussed above be applied to areas where new and/or replacement wells may be sited. The full benefits of wellhead protection can be realized in the relatively undeveloped portions of a town, where new supply wells might be installed to accommodate growth of the town. In Colorado it is recommended that the public water supplier delineate a wellhead protection area using a five year time of travel as the criteria, and conduct a contaminant source inventory of the proposed site. The State wellhead protection plan also advocates coordinating the planning for new wells along with other planning and development activities, and recommends incorporating public participation into the new well siting process.

7. Ensure Public Participation. This is the most important aspect of a successful wellhead protection program. If individuals become aware of where they obtain their water, of how vulnerable their ground water supplies are to contamination, and of how difficult and costly it would be to treat their contaminated supplies, they will be much more likely to modify their activities to minimize the chances of contaminating their water. The EPA requests that State plans outline measures for informing the public and soliciting their input about implementing wellhead protection plans. They recommend press releases, newsletters to local governments, school and community group presentations and developing informational brochures.

Colorado recognizes that the success of its voluntary plan will require a heavy emphasis on public education and participation. Toward this end, a citizen advisory group was formed to assist in developing the State plan. In addition, concerted efforts have been made to inform people through formal presentations, participation in a variety of meetings, and relevant promotional affairs. The concept of wellhead protection in Colorado has been presented in newspaper articles, community and professional group newsletters, in schools and through informational brochures. The benefits of long-term, protection oriented planning through wellhead protection programs is catching on through out the State.

Implementing Colorado's Wellhead Protection Plan

The State plan was developed starting in July 1990. The draft plan was submitted to local governmental agencies and is currently under final review by the EPA. An approved State plan is anticipated by summer 1993, making it one of the few Western States with an approved plan. Even though the State plan has not been finalized, the interest in wellhead protection has been so great the several towns in Colorado have begun developing plans for their public supply systems. The Town of Castle Rock started developing their wellhead protection program in 1992. Their water supply system taps a shallow unconfined aquifer through a series of wells located in downtown, residential and agricultural areas. They are currently finalizing the delineation of wellhead protection areas of each cluster of supply wells. The City has also conducted a comprehensive inventory of potential contaminant sources and is compiling this information on maps. The City was able to utilize graduate students working through the Environmental Policy and Management program of University of Denver and community groups for many of these activities. The town of Eads, in southeast Colorado, has completed a wellhead protection plan and submitted it to the State for approval. Many public ground water supply systems in the eastern plains of Colorado are also very interested in wellhead protection.

Conclusion

Wellhead protection is a valuable management strategy for municipal and public ground water supply systems. The benefits of a wellhead protection program are in reducing the potential for contaminating the ground water that supplies a public well or wellfield. This preventative program could yield substantial cost savings to the municipality or public supply system and to the community within its service area. The wellhead protection program in Colorado is in its early stages. Colorado's voluntary program is oriented toward being practical, low-cost, and site-specific. The Water Quality Control Division of the State Department of Health can provide information, guidance and support to public water suppliers who wish to consider developing a wellhead protection program for their ground water supplies.

REFERENCES

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